ICTP 2021

The 13th International Conference on the Technology of Plasticity

VIRTUAL EVENT

July 25-30, 2021

FINAL PROGRAM

Current as of July 14, 2021

SPONSORED BY: TMS

This conference is sponsored by the Materials Processing & Manufacturing Division and the Shaping and Forming Committee.

www.tms.org/ICTP2021

SCHEDULE

The schedule is in Eastern Daylight Time (UTC-4:00).
Use the Time Zone Converter to translate event times into your local time zone.

Keynote presentations will be live with a webinar-style Q&A. Contributed and invited presentations are pre-recorded. Please watch these presentations in advance of the Q&A sessions and come prepared with questions.

Wednesday, July 21, 2021		
Virtual platform access opens for registrants Contributed and invited oral and poster presentations available to view on-demand		On-demand
Sunday, July 25, 2021		
On your own	Virtual platform orientation	On-demand
Monday, July 26, 2021		
7:30 - 9:00 a.m. EDT	Introduction, awards ceremony, & keynote presentation	Live
9:00 - 9:15 a.m. EDT	Break	
9:15 - 10:15 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
10:15 - 10:20 a.m. EDT	Break	
10:20 - 11:20 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
Tuesday, July 27, 2021		
7:30 - 9:00 a.m. EDT	Keynote presentations	Live
9:00 - 9:15 a.m. EDT	Break	
9:15 - 10:15 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
10:15 - 10:20 a.m. EDT	Break	
10:20 - 11:20 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
Wednesday, July 28, 2021		
7:30 - 9:00 a.m. EDT	Keynote presentations	Live
9:00 - 9:15 a.m. EDT	Break	
9:15 - 10:15 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
10:15 - 10:20 a.m. EDT	Break	
10:20 - 11:20 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
Thursday, July 29, 2021		
7:30 - 9:00 a.m. EDT	Keynote presentations	Live
9:00 - 9:15 a.m. EDT	Break	
9:15 - 10:15 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
10:15 - 10:20 a.m. EDT	Break	
10:20 - 11:20 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
Friday, July 30, 2021		
7:30 - 9:00 a.m. EDT	Keynote presentation & closing ceremony	Live
9:00 - 9:15 a.m. EDT	Break	
9:15 - 10:15 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
10:15 - 10:20 a.m. EDT	Break	
10:20 - 11:20 a.m. EDT	Breakouts: Q&A sessions for oral presentations	Live
Friday, July 30, to Tuesday, August 31, 2021		
Virtual platform access remains open for registrants through August 31.		On-demand

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Welcome to the 13th International Conference on the Technology of Plasticity (ICTP 2021). For the first time, one of the world's largest and most prestigious manufacturing technology conferences convenes virtually. The COVID-19 pandemic, now in its second year, continues to restrict travel and in-person gatherings, but it does not deter the progress of scientists and engineers. Hundreds of international participants are coming together online for the "Olympics of Metal Forming," as ICTP has come to be known. Metal forming is among the earliest technologies of humankind, but its potential is still vast. The meeting is uniquely positioned in a place of carrying on traditions, sharing new knowledge, and collaborating to make exciting discoveries. The organizing committee, advisory committee, international scientific committee, and TMS would like to thank you for engaging in this important work. Your participation in ICTP 2021 is greatly appreciated.

TIPS FOR PARTICIPATING IN THE VIRTUAL EVENT

1) **Remove Distractions.** Notify others that you are at a conference. Set your out-of-office message in your e-mail client. Actively listen and take notes during the presentations, as if you were attending in person.
2) **Attend in Real Time.** Whenever possible, listen to keynote presentations at their scheduled time and watch other presentations prior to the Q&A session so that you are able to ask questions and engage in discussions.
3) **Relax, and Enjoy!** If you miss something, don't worry. One of the benefits of a virtual event is the ability to access recordings of the presentations. You have access to the recordings and the proceedings through the end of August 2021.

CONFERENCE ORGANIZERS

LEAD ORGANIZER

Glenn Daehn,
The Ohio State University, USA

LOCAL ORGANIZING COMMITTEE

Libby Culley, The Ohio State University, USA
Glenn Daehn, The Ohio State University, USA
Anupam Vivek, The Ohio State University, USA

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CONFERENCE DETAILS

GETTING STARTED

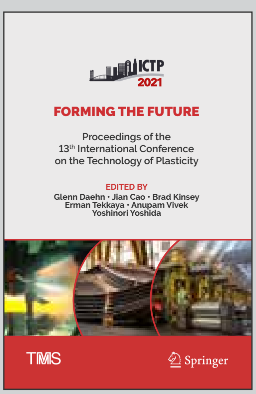
To participate in ICTP 2021, you will need to first log in to the conference platform. Click here to enter the conference or enter the following link into a browser: www.tms.org/ICTP2021/Connect

- Enter Login Name: This is the e-mail address you used for registration.
- Enter Password: This is your unique order number found on your registration confirmation.

TECHNICAL SUPPORT

ICTP 2021 is hosted on the Bravura virtual event platform. If you need assistance using the virtual platform, contact the Bravura support team by using the chat tool in the bottom right corner of the screen or by e-mailing support@bravuratechnologies.com.

DOWNLOAD ICTP 2021 PROCEEDINGS



All registrants receive free electronic access to the ICTP 2021 proceedings publication until August 31, 2021.

To download the proceedings, go to the proceedings publications login page at https://www.tms.org/ICTP2021Proceedings. Enter your order number, found at the top of your registration confirmation.

KEYNOTE SPEAKER PRESENTATIONS

Keynote speakers will give live presentations with webinar-style question-and-answer sessions. Refer to the schedule to participate.

CONTRIBUTED AND INVITED PRESENTATIONS

The contributed and invited presentations are pre-recorded and available on demand. Access begins on July 21, 2021 and ends on August 31, 2021. Live discussions are scheduled for breakout sessions. Refer to the schedule to participate.

AWARDS

Announcements for the following awards will take place during Monday's introduction:

- Japan Society for Technology of Plasticity (JSTP) International Prize for Research & Development in Precision Forging
- Japan Society for Technology of Plasticity ICTP Award for Young Researchers

VIRTUAL MEETING SETTINGS

The following practices are recommended for optimal participation:

- Google Chrome browser; use the latest version.
- Mute your audio settings before joining a session.
- Minimize distractions; consider an out-of-office response for e-mail.

For additional technical support, contact the Bravura support team by using the chat tool in the bottom right corner of the screen. For questions about programming, contact programming@tms.org.

CLOSED CAPTIONING

Access closed captioning by using Google Live Caption in the Chrome browser.
Open Settings >> Advanced >> Accessibility. Toggle Live Caption to **On**. Open a new tab with video content and play a video. Captions should appear once speaking begins.

To stop Live Caption, open Settings >> Advanced >> Accessibility and toggle Live Caption **Off**.

Sudarsanam Babu,
University of Tennessee, Knoxville, USA
"Vision 2030: A Vision for America's Science and Engineering Enterprise & Relevance to Advanced Manufacturing"
Friday | 7:30 a.m. | July 30, 2021

The NSB's Vision 2030 lays out actions to achieve the four goals. (1) Foster a Global Science and Engineering Community: Make sure that America is a reliable partner and is at the table to avoid being technologically surprised. (2) Expand the Geography of Innovation: Do more to create opportunities and jobs across the country. (3) Deliver Benefits from Research: Enhance the return to U.S. taxpayers from these investments and empower the nation's businesses and entrepreneurs to compete globally. Achieve this goal in a way to ensure a more inclusive enterprise and diverse S&E community. (4) Develop STEM Talent for America: Over the next decade, our nation must focus heavily on developing America's STEM talent, including researchers and a STEM-capable workforce at all educational levels, from skilled technical workers to Ph.D. researchers. In addition, the role of science and technology of plasticity with reference to advanced manufacturing will be outlined.

Irene Beyerlein,
University of California,
Santa Barbara, USA
"Using Plasticity for Making High-Performance Nanostructured Composites"
Wednesday | 7:30 a.m. | July 28, 2021

Superior structural properties of materials are generally desired in harsh environments, such as elevated temperatures, the high strain rates of impact, and irradiation. Composite nanolaminates, built with alternating stacks of metal layers, each with nanoscale individual thickness, are proving to exhibit many of these target properties. In principle, the nanolaminate concept can be applied to any bimetallic system; however, they have not been widely applied to materials with a hexagonal close-packed (hcp) crystal structure. The roadblock lies in their complex, anisotropic deformation behavior. In this presentation, we discuss recently developed methods to manufacture nanostructured composites containing hcp metals. These techniques exploit plastic deformation as part of the synthesis process and have the potential to manufacture product in forms and sizes suitable for high-performance structural applications. We further highlight in this presentation modeling and experimental efforts to understand linkages between the processed nanostructure, local deformation mechanisms, and mechanical performance.

Pierre-Olivier Bouchard,
Mines ParisTech, France
"Numerical Modeling of Ductile Damage during Metal Forming: State of the Art and Future Challenges"
Tuesday | 7:30 a.m. | July 27, 2021

Despite numerous studies, the prediction of ductile damage and failure during metal forming processes still needs further investigations in particular for complex loading paths. Ductile damage analysis is usually addressed through uncoupled failure criteria or coupled damage models. Both approaches rely either on micromechanical bases or on phenomenological considerations. After a short review of these different approaches, the talk will focus on the main complexities related to damage analysis during metal forming processes. Strain rate and temperature effects, complex multiaxial stress states, non-proportional and cyclic loading conditions will be addressed with examples given at the process scale, whereas a micro-scale finite element framework will also be presented to get a better understanding of some of the physical mechanisms arising in such complex loading conditions.

Oana Cazacu,
University of Florida-REEF, USA
"Recent Advances on Modeling Plastic Deformation of Textured Metals with Applications to Metal Forming"
Tuesday | 8:15 a.m. | July 27, 2021

An accurate description of the yield surface defining the onset of plastic deformation is essential for high-fidelity numerical predictions of forming processes. Due to the ease in calibration from simple tests, generally von Mises isotropic criterion and Hill orthotropic criterion are used in industry. While more advanced 3-D yield criteria have been developed, generally such criteria are written in terms of eigenvalues of transformed stress tensors and as such the anisotropy coefficients are not directly expressible in terms of mechanical properties.
Using general representation theorems, generalizations of the isotropic invariants J2 and J3 such as to account for plastic anisotropy have been developed. Using these anisotropic invariants, the anisotropic form of any isotropic yield function can be obtained simply by replacing J2 and J3 with their respective anisotropic generalizations. This framework ensures that the minimum number of anisotropy coefficients is specified. Illustrative examples of full three-dimensional yield criteria expressed in terms of generalized invariants and their application to the prediction of formability of single crystals and polycrystalline FCC, BCC and HCP materials are presented.

Jun Chen,
Shanghai Jiao Tong University, Shanghai, China
"Recent Investigations on Incremental Sheet Forming: From Fundamentals to Industrial Application Technologies"
Thursday | 7:30 a.m. | July 29, 2021

Incremental sheet forming (ISF) is a promising flexible forming process in fabricating low-batch or customized sheet metal parts and has potential in reduced process lead time and cost, and increased formability. In the plenary talk, recent investigations on ISF fundamentals and the technologies for ISF industrial application will be presented, which cover loading path algorithms, forming tool development, surface roughness and forming load predictions, new variants of ISF, deformation mechanism of different ISF variants and several industrial application cases. Finally, an outlook about ISF will be made as well.

Matthias Kleiner,
Leibniz Association, Germany
"Innovations Through Collaborative Research"
Monday | 7:30 a.m. | July 26, 2021

In the context of global challenges, such as pandemics, climate change, or digitization urgent and highly complex questions arise that require excellent, innovative research at the highest level to answer them. But what are the prerequisites for creative, excellent top-level research that finds urgently needed innovative solutions to acute problems?
Innovation processes are not one-way streets but occur in constant interaction between knowledge and application and hence rarely happen at one time in one place: Innovation frequently relies on collaborations between disciplines, across sectors and even beyond different regions. And sometimes it is based on chances of serendipity.
Dealing with global challenges requires more and more concentration and mutual inspiration of our knowledge, our powers and our methods as scientists. Productive interaction networks of diverse transfer relationships between different participants are needed for this. Quite often innovation is driven by the demands of exploration and happens in the development of a technique through application in the field. This kind of innovation includes new organizational forms of joint research, business models or social practices.

Takashi Kuboki, University of Electro-Communications, Japan
"Tube Forming and Fabricating Technologies for Contributing Society by Tackling Problems of Environment and Aging Population"
Thursday | 8:15 a.m. | July 29, 2021

Technologies for forming and fabricating tubes have been contributing to the development of society and should evolve and have great roles in the future, considering the problems related to the environment and aging population. Tubes have advantages of high rigidity for a unit weight and could manufacture light-weight components for transport equipment. Miniature tubes would be useful at the medical front in the aging society. The technologies on tubes have the potential to contribute to solving these problems and realizing sustainable societies.

This paper introduces the authors' technologies and reviews others' recent technologies on tubes. The technologies include hydro and air forming, rotary forming, bending, micro forming and so on. These technologies are qualitatively evaluated in terms of conflicting characteristics, such as formability, strength, productivity, flexibility and miniaturization. Some technologies are emerging to improve some of the conflicting characteristics at the same time for realizing excellent performances of the formed products.

Christopher Schuh, Massachusetts Institute of Technology, USA
"The Fundamentals of Microparticle Impact Bonding in Metals, Alloys, and Advanced Materials"
Wednesday | 8:15 a.m. | July 28, 2021

There are a variety of materials manufacturing technologies that rely on kinetic impacts to achieve additive material build-up, including, notably, cold spray and laser-induced forward transfer. The unit processes of these manufacturing paradigms involve small quantities of material (micrometer scale particles) and extremely high velocities (~ km/s), so the impact events involve a number of fundamental physical mysteries at the extremes of materials mechanics. This talk will overview our efforts at developing quantitative in-situ methods to study such impacts, involving strain rates up to about 108 s-1. Using an all-optical test platform to launch and observe the impacts, we are able to provide insight on the mechanics of shock and spall, bond formation, and erosive wear. By systematically exploring a range of materials with different properties, we develop a picture of the controlling physics of bonding, which includes mechanical properties (elastic and plastic), thermal properties (related to adiabatic heat), and surface films. The talk will review our work on a variety of pure metals and engineering alloys and will also provide a view on new issues that arise in advanced materials like metallic glasses.

HONORARY SYMPOSIA

Taylan Altan, The Ohio State University, USA
Key Organizer: Eren Billur, Billur Metal Form, Turkey

Niels Bay, Technical University of Denmark, Denmark
Key Organizer: Paulo Martins, University of Lisbon, Portugal

Xue Yu Ruan, Shanghai Jiao Tong University, China
Key Organizer: Jun Chen, Shanghai Jiao Tong University, China

Yasuhisa Tozawa, Nagoya University, Japan
Key Organizers: Takashi Ishikawa, Chubu University, Japan
Yoshinori Yoshida, Gifu University, Japan

Rob Wagoner, The Ohio State University, USA
Key Organizer: Hojun Lim, Sandia National Laboratories, USA

Zhongren Wang, Harbin Institute of Technology, China
Key Organizers: Shijian Yuan, Harbin Institute of Technology, China
Gang Liu, Harbin Institute of Technology, China

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MEETING POLICIES

By registering for this meeting, attendees accept the terms of the TMS Privacy Policy and agree to abide by TMS policies, including the Meetings Code of Conduct and the TMS Anti-Harassment Policy. For additional information on policies related to TMS events, visit the TMS Meetings Policies page and the Code of Conduct portal. A complete listing of Society policies can be accessed through the Society Bylaws & Policies section of the TMS website.

REFUNDS

The deadline for all refunds was June 17, 2021. No refunds will be issued at the congress. Fees and tickets are nonrefundable.

TIME ZONES

Unless otherwise noted, all times for this conference and related events will take place in the local time zone, EDT (UTC/GMT -4 hours). Use a tool like the Time Zone Converter to translate event times into your local time zone.

LANGUAGE

The meeting and all presentations and program materials will be in English.

CURRENCY

All meeting fees are expressed in U.S. dollars (USD).

ACCESS TO RECORDED PRESENTATIONS AND PROCEEDINGS AFTER THE CONFERENCE

Please note that registrants will have access to all recorded presentations from ICTP 2021 through August 31, 2021. Log in to the conference platform at any time after the conference has ended to view content. The proceedings publication will also be available for registrants to download through August 31, 2021. After that time, standard pricing will take effect.

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TECHNICAL PROGRAM

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Monday Introduction and Keynote

Monday AM | July 26, 2021

Session Chair: E. Tekkaya, TU Dortmund

7:30 AM Introductory Comments and Awards Ceremony

8:15 AM Keynote
Innovations through Collaborative Research: *M. Kleiner*[1]; [1]Leibniz Association
In the context of global challenges, such as pandemics, climate change or digitization, urgent and highly complex questions arise that require excellent, innovative research at the highest level to answer them. But what are the prerequisites for creative, excellent top-level research that finds urgently needed innovative solutions to acute problems? Innovation processes are not one-way streets but occur in constant interaction between knowledge and application and hence rarely happen at one time in one place: Innovation frequently relies on collaborations between disciplines, across sectors and even beyond different regions. And sometimes it is based on chances of serendipity. Dealing with global challenges requires more and more concentration and mutual inspiration of our knowledge, our powers and our methods as scientists. Productive interaction networks of diverse transfer relationships between different participants are needed for this. Quite often innovation is driven by the demands of exploration and happens in the development of a technique through application in the field. This kind of innovation includes new organizational forms of joint research, business models or social practices.

Agile MF I

Monday AM | July 26, 2021 | 9:15 - 10:15 AM

Session Chair: G. Hirt, RWTH Aachen University

Roll Forming of Cup with Curved Rotary Profile: *B. Zhang*[1]; B. Hu[1]; C. Wei[1]; X. Zhao[1]; [1]North University of China
In order to improve the production efficiency and material utilization of cup with curved rotary profile, a new method of roll forming is proposed. That is, a roll forming equipment with a set of preforming rolls and a set of shaping rolls is mounted on the drawing hydraulic press to form curved rotary profile of cup. Influence of roller number on the roll forming was studied by numerical simulation. The results show that the mouth of the workpiece is extremely uneven after performing with two-rolls, and part of metal flows into the gap of rolls, which forms a thin flash edge and folds during shaping. The mouth of the workpiece is relatively even after preforming with three-rolls or four-rolls, and folding is not found after shaping. The accuracy of numerical simulation is verified by the experiment, cups with curved rotary profile that meet the requirements were formed.

Flexible Manufacturing of Concave-convex Parts by Incremental Sheet Forming with Active Medium: *S. Thiery*[1]; N. Ben Khalifa[1]; [1]Leuphana University of Lüneburg
Incremental sheet forming with active medium (IFAM) is a flexible manufacturing process that creates concave-convex sheet metal parts in one clamping without needing a counter tool or a die. In the first study of this new process [1], a conventional hemispherical tool has been used in interaction with pressurised air to manufacture concave-convex parts. Thereby the geometric accuracy was not satisfying, so that within the present study, a conical tool with dedicated angle is introduced to IFAM. The idea behind this tool concept is to restrict the inclined part wall to a target angle. At first, results from numerical investigation show an improvement of the accuracy when a conical tool is used to manufacture a truncated convex pyramid. Subsequently, experiments validate the numerical model and reveal an increased process reliability. Experimental investigations of truncated convex cones and concave-convex parts close the paper and underline the feasibility of the tool concept.

Manufacturing of Tailored Blanks with Pre-shaped Involute Gearings by Using a Flexible Rolling Process and Its Application in a Sheet-bulk Metal Forming Process: *M. Vogel*[1]; R. Schulte[1]; O. Kaya[1]; M. Merklein[1]; [1]Institute of Manufacturing Technology
Nowadays, the efficient production of complex functional components in short process chains is important due to the goal of a further reduction of greenhouse gases. Therefore, the new process class of sheet-bulk-metal forming was developed, which combines the advantages of sheet- and bulk forming operations. One approach is the application of a flexible rolling process for manufacturing tailored blanks to improve the components properties.Heretofore, only geometries with a homogenous local material thickening were manufactured, to ensure a proper die filling of functional elements. In order to increase the intricacy, a new design that contains involute gearing cavities is introduced. In this paper the mild deep drawing steel DC04 with an initial sheet thickness of t0 = 2.0 mm is used to present new manufacturing approaches. Furthermore, the subsequent application of the tailored blanks in a calibration process is shown, with a characterization of the geometrical and mechanical properties.

The Dieless Drawing Process for the Elongation of Ultrafine Copper and Brass Wire: *A. Milenin*[1]; P. Kustra[1]; M. Wróbel[1]; M. Packo[1]; V. Pidvysots'kyy[2]; [1]AGH University of Science and Technology; [2]Institute for Ferrous Metallurgy
In the study a new process for the production of ultrafine copper and brass wires is proposes. The proposed process is based on the dieless drawing. The workpeace for dieless drawing is a thin wire (100 microns) obtained by a conventional drawing method. The proposed technology is based on the implementation of a multi-pass incremental deformation. Moreover, in each pass, strain and strain rate sensitivity of flow stress should be positive and significant. The deformation parameters in each pass are determined on the basis of an analysis of the dependence of the flow stress on the strain, strain rate and temperature. For this purpose, plastometric tests of copper and CuZn37 alloy were performed. For estimation of technological plasticity and wire surface roughness physical and numerical modeling of dieless drawing were performed. The obtained data were used in the practical implementation of the incremental dieless drawing technology.

Deformation Analysis in Ultrasonic-assisted Multi-stage Incremental Sheet Forming: Z. Cheng[1]; *Y. Li*[1]; F. Li[1]; J. Li[1]; [1]Shandong University
Multi-stage incremental sheet forming (MISF) is a novel manufacturing process in which complex 3D shapes can be formed through a series of forming processes using generic forming tools. This study aims to explore effects of ultrasonic vibration on the MISF process and reveal the deformation mechanism based on the microstructure analysis. First, the initial, intermediate and final shapes were designed for the MISF in which the wall angle and depth deviation of the adjacent stage should be decreased. Then, a series of experiments for ultrasonic-assisted ISF was performed during which the strain evolution was recorded by the digital image correlation system. Furthermore, the microstructure evolution (e.g. grain size, misorientation and texture) of the formed parts under different forming conditions and forming stages was examined through the optical microscope (OM) and the electron back-scatter diffraction (EBSD). Through this study, further insight into the deformation mechanism during the ultrasonic-assisted MISF was provided.

Robotic Roller Forming Process and Strategies to Eliminate Geometrical Defect of Edge Waves: *Y. Liu*[1]; J. Min[1]; J. Lin[1]; [1]Tongji University

Robot-based roller forming (RRF) is a new dieless and flexible forming process using a roller mounted on an industrial robot to form sheet metal products by a number of passes with predefined tool paths. In this study, DP590 (dual-phase) steel sheets were initially formed to bent specimens having a right angle by RRF with 3 passes, and edge wave defects were observed at the flange of the DP590 specimens. Finite element analysis was utilized to reproduce the edge waves. According to finite element simulation, longitudinal plastic strains are generated at the flange edges due to excessive tensile and compressive stresses, which results in severe edge waves. Two strategies are introduced to reduce edge waves. One is to optimize forming parameters, and the effects of forming angle increment and moving direction of the roller on longitudinal peak strains at the flange edges were evaluated. Another strategy to reduce edge waves is to apply laser heating in RRF, where the heating spot is always in front of the roller. Experiments demonstrate that laser heating reduces forming forces and edge waves with fewer forming passes.

Open-die Forging of Copper Cone: *A. Shirizly*[1]; G. Harpaz[1]; A. Shmuel[1]; [1]Rafael

The open-die forging/upsetting of bulk material to cone shape involves high plastic deformation. The plastic strain caused major changes in the mechanical and metallurgical characteristics. Aim to gain better understanding of those characteristics change, experimental plane followed by analytical and numerical models were developed and established. The material properties and the friction condition (with several lubricants) were measured prior the process modeling. A analytical models (upper bound and Lower bound) were simulate the forging forces and compere to finite element model. The models support and compere to the experimental work using C101 copper. The preform samples were surface etched by grid pattern and strain caused by the Forming Operations measured due the grid changes, while, the flow pattern inspected and compered using a resemble material and numerical model. Good comparison were found between experimental results and the theoretical models.

Penetrating Tool Friction Stir Incremental Forming Using Alternating Tool Path Direction: *W. Jiang*[1]; T. Miura[1]; R. Matsumoto[2]; M. Okada[1]; M. Otsu[1]; [1]University of Fukui; [2]Osaka University

In order to improve limit of forming height in penetrating tool friction stir incremental forming, alternating tool path direction was proposed. In this method, a forming tool was rotated at a clockwise direction and tool was moved along a tool path in a clockwise direction and counter-clockwise direction, alternatively. Pure aluminum sheets which size is 200 mm x 200 mm x 2 mm were formed into a truncated conical shape. Forming limit in height and distributions of volume change obtained in alternating tool path direction and solo tool path direction were compared. Repeatability, formable working conditions and forming accuracy were also investigated. From the results, forming limit in height was dramatically improved than that by the conventional tool path. The forming accuracy of the formed parts by penetrating tool friction stir incremental with the proposed tool path was better than that by the conventional single point incremental forming.

Big Data

Monday AM | July 26, 2021 | 9:15 - 10:15 AM

Session Chair: M. Gorji, Massachusetts Institute of Technology

Development of Mechanical Cards for Finite Element Analysis of Mild Steels by Parameter Optimization: *E. Tamer*[1]; E. Kiziltas[1]; C. Seyalioglu[1]; [1]Borcelik Steel Industry Trade Inc.

Material card generation has a significant role for characterizing the mechanical behavior to estimate accurate deformation in finite element analysis. Regarding to this, the most commonly used characterization test for sheet metals is the uniaxial tension test due to its simplicity and well-defined testing standards. The mechanical properties such as ultimate tensile strength can be determined by tensile tests. However, the strain level can reach to a specific value which is low as compared to strain levels reached in cold forming operations. In this paper, the experimental data is optimized with finite element analysis and a good consistence between experimental and simulation results is achieved. Parameter optimization is used as a guiding tool to extend strain levels according to 3 mechanical equations: Swift, Hockett-Sherby, Combined material model. The user interface is designed with the detailed graphs and optimized parameters with the help of MATLAB tool.

On the Potential of Machine Learning Algorithms to Predict the Plasticity of Sheet Metal: *M. Gorji*[1]; D. Mohr[2]; [1]MIT; [2]ETH

Neural networks provide a potentially viable alternative to differential equation based constitutive models. Here, a neural network model is developed to describe the large deformation response of the non-quadratic Yld2000-2d yield criterion along HAH (homogeneous anisotropic hardening) model in sheet material. Using conventional return-mapping scheme, virtual experiments are performed to generate stress-strain data for random reversal and monotonic biaxial loading paths. Subsequently, a basic feed-forward and recurrent neural network model is trained and validated using the results from the virtual experiments. The results for a "shallow network" show remarkably good agreement with all experimental data. The identified neural network model is implemented into a user material subroutine und used in basic structural simulations such as notched tension and in-plane shear experiments. In addition to demonstrating the potential of neural networks for modeling the rate-independent plasticity of metals, their application to more complex problems involving strain-rate and temperature effects is discussed.

Investigation of Machine Learning Models for a Time Series Classification Task in Radial-axial Ring Rolling: *S. Fahle*[1]; T. Glaser[1]; B. Kuhlenkötter[1]; [1]Lehrstuhl für Produktionssysteme Ruhr-Universität Bochum

The great potential of machine learning models in different domains has been shown in recent years. Based upon initial research regarding preprocessing methods for time series classification in the hot forming technology of radial-axial ring rolling, this paper takes the next step to further investigate the suitability of different machine learning models for a classification task regarding the ovality of a formed ring. This is done by implementing several models of the time series classification domain in machine learning and training them on actual production data of thyssenkrupp rothe erde Germany. The data set consists of different production days and ring geometries. Different experiments will be performed, the results will be analyzed regarding performance, interpretability and usability in the production environment. Thus a suitable model for the underlying task will be investigated, which is essential for a future model deployment.

Comparison of Linear Regression and Neural Networks as Surrogates for Sensor Modeling on a Deep Drawn Part: *M. Ryser*[1]; M. Bambach[1]; [1]ETH Zurich
Several developments in deep drawing aim at systematically determining modifications during tool tryout. Recent work deals with a simulation based method to discover the current state parameters based on characteristic measurement quantities and infer a tryout proposal by comparison with the simulated robust optimum. Whereas the simulation provides an accurate model of the drawing process, a low-fidelity surrogate model is required to predict the influence of process parameters on the targets in a computationally efficient manner. In this work, training data is generated by a stochastic finite element simulation in AutoForm. The datapoints are used to fit and evaluate linear models as well as neural networks for regression. These models use process parameters as predictors to estimate the target parameters draw-in and local blank holder forces. Results show that simple models outperform complex models. No evidence was found that the model accuracy increases by using neural networks.

Neural Network Surrogates Model for Metals Undergoing Yield Point Phenomena within Finite Element Analysis: *J. Allen*[1]; J. Cheng[1]; X. Hu[1]; X. Sun[1]; [1]Oak Ridge National Laboratory
Finite element analysis (FEA) has yielded results in excellent agreement with experiments for a wide range of mechanical simulations and material constitutive models. However, it is often the case that simple material models are unable to capture the wide range of behavior found in real materials without increasing the complexity of the model and simulation time. For example, a mathematical constitutive model for BCC metals that show upper and lower yield points (i.e., the yield point phenomenon) is not available. In this work, a neural network is trained using the constitutive response for the tungsten-tantalum alloy system for various temperatures and strain rates. The neural network is then used as a surrogate model within FEA simulations with the calculated stress-strain response compared to the experimentally measured data. It will be shown that the trained neural network surrogate model captures the material behavior remarkably well.

Characterization of Plasticity and Ductile Fracture of Metals under Proportional and Non-proportional Loading I

Monday AM | July 26, 2021 | 9:15 - 10:15 AM

Session Chair: Y. Lou, Xi'an Jiaotong University

Experimental Study on Uniaxial Strain Cyclic Behavior of GS-20Mn5: *Z. Zou*[1]; S. Han[1]; H. Wang[1]; Q. Li[1]; B. Guo[1]; S. Zhao[1]; [1]Yanshan University
Due to the common discontinuity of the structure and non-uniform load, local high stress phenomenon tends to be appeared in the mechanical structure under repeated loading, and even local small plastic deformation maybe occur. In this case, the cyclic elastic-plastic mechanical properties of the structural steel are the key elements for the reasonable and accurate assessment of structural safety. In order to study the cyclic mechanical properties of GS-20Mn5, which is a commonly used steel in load bearing mechanical equipment, corresponding strain cyclic loading tests were performed. The cyclic elastoplastic deformation characteristics under strain-controlled cyclic loading with different strain ratios (R=-1,0.5) are studied, and the cyclic hardening/softening and mean stress relaxation features are revealed. The results show that the cyclic hardening/softening features are affected by the strain amplitude and cycles. This test material tends to show cyclic hardening at higher strain amplitudes. The cyclic stress-strain curve is obtained by the incremental step test, and the corresponding yield strength is about 4.8% larger than that under uniaxial tension. When R=0.5, the test material exhibits obvious mean stress relaxation. When the strain amplitude is 0.16%, 0.30% and 0.40%, the mean stress decreases then stabilizes at about 25 MPa, -3 MPa and -6 MPa, respectively. For the mechanical equipment made of GS-20Mn5 with local small plastic deformation under cyclic loading, the obtained cyclic mechanical performance of GS-20Mn5 can provide reference for the analysis and evaluation of the structural safety.

Experimental Study on the In-plane Torsion Test for Sheet Metal: *C. Zhang*[1]; Y. Lou[1]; [1]Xi'an Jiaotong University
In-plane torsion tests attract a lot of attention recently since it can avoid unwanted reaction torque compared with the traditional in-plane shear test. In this study, the in-plane torsion tests are used to strain different types of specimens to characterize plastic behaviors of sheet metals. For specimens with slits, strain hardening is calibrated up to large deformation by the finite element model updating (FEMU) technology with the experimental torque-torsion angle curves. Fracture strain is measured under shear by the in-plane torsion test. Cyclic shear loading tests are also carried out for multiple in-plane torsion test specimens to characterize the kinematic hardening behavior of sheet metals. This study shows that the in-plane torsion tests are a proper testing method to experimentally study the fracture in pure shear, the strain hardening at large deformation, and the kinematic hardening behavior under cyclic loading.

Strain Hardening of AA5182-O Considering Strain Rate and Temperature Effect: *H. Shang*[1]; P. Wu[1]; Y. Lou[1]; [1]Xi'an Jiaotong University
Strain hardening properties of AA5182-O metal sheet are experimentally studied and analytically modelled in this research. A notched specimen is used to characterize the strain hardening properties of the alloy at different strain rate and temperature up to large strain until fracture. The strain hardening behaviors are then modeled by popular analytical models to consider the strain rate and thermal effects. The high nonlinear strain hardening with the effect of strain rate and temperature is also illustrated by artificial neural network. The results show that the strain hardening with strain rate and thermal effect can be accurately modelled by the neural network compared with the conventional models, but its computation efficiency is much lower than the analytical models.

Plastic and Fracture Characteristics of WE43 Mg Alloy Under Complex Stress States: *P. Wu*[1]; C. Zhang[1]; Y. Lou[1]; Q. Chen[2]; H. Ning[2]; [1]Xi'an Jiaotong University; [2]Southwest Technology and Engineering Research Institute
This paper investigates the deformation behavior and fracture characteristics of WE43 Mg alloy under complex stress states, including uniaxial tension, plane strain tension, uniaxial compression, shear, etc. With the digital image correlation technique and a hybrid experimental-numerical method, experimental data are obtained for the stress-strain curves and fracture strain for different tests. The results indicate the effect of loading conditions on both yielding and fracture. The effect of loading condition on yielding and fracture is modeled by popular yield functions and fracture criteria. The predicted yield surfaces and fracture envelopes are predicted by experimental results to evaluate their accuracy on the modeling of plasticity and fracture for the WE43 Mg alloy.

Evaluation of isotropic and anisotropic constitutive models on plasticity prediction of AA7075 extruded tube under Tension-Tension and Tension-Compression: *S. Nazari Tiji*[1]; A. Asgharzadeh[1]; T. Park[1]; M. Athale[1]; F. Pourboghrat[1]; [1]The Ohio State University
Plasticity of AA7075-O extruded tube under tension-tension (T-T) and tension-compression (T-C) was characterized using multiaxial tube expansion test method. Three different yield functions, von-Mises, Hill's 1948, and Yld2004 were considered to model the anisotropic plasticity of the AA7075-O tubes under T-T and T-C. The anisotropic models were calibrated based on the measured biaxial stresses and the conjugate plastic strain rates as strain-rate potential based on plastic work equivalency. As shown, this calibration method is an accurate and more flexible way of calibrating the advanced yield functions with no necessity for having proportional loading paths. It was also shown that the three yield functions predict the strain paths under T-C conditions almost similarly, however, the strain paths under T-T conditions are predicted better as the number of anisotropy parameters in the yield functions increases.

On Edge Crack Initiation of an Aluminum Sheet Metal: J. Sheng[1]; *S. Yang*[2]; M. Alharbi[1]; W. Tong[1]; [1]Southern Methodist University; [2]Korea University of Technology and Education
Edge crack initiation and growth in an aluminum sheet metal were investigated experimentally under overall uniaxial tension, plane strain tension and shearing loading conditions along its RD, DD and TD directions. A simple edge crack initiation criterion was formulated from the local strain measurement results. Nonlinear finite element analysis was carried out to analyze the deformation of the same aluminum sheet metal in a hole expansion operation using a quartic polynomial quartic yield function with the associate flow rule. The calibrated anisotropic plasticity model and edge crack initiation criteria were evaluated in terms of the predicted locations of necking and potential crack initiation in the hole expansion of the aluminum sheet metal.

Estimation and Prevention of Strain Localization in Shear Tests: *H. Traphöner*[1]; T. Clausmeyer[1]; A. Tekkaya[1]; [1]TU Dortmund University
The localization of strain in conventional shear tests and in-plane torsion tests is analysed for three different materials, namely CP1000, DP1000, and DC04. The influence of material properties, such as strength, strain hardening, and strain gauge length on the measurement of shear strains is investigated experimentally and by a new analytical approach. The weakly hardening high-strength complex-phase steel CP1000 shows experimental and analytical deviations up to 25% of the determined strain depending on the evaluation strategy. Such devia-tions will lead to crucial errors for the calibration of fracture curves and damage models. By a new grooved in-plane torsion test specimen shear tests can be performed without the influence of the localization of strain. Strain measurements can thus be performed more exactly nearly regardless of the strain gauge length and hard-ening behavior. In first experimental results the deviation is below 4.6% for CP1000 and below 0.5% for DC04.

Heterogeneous Deformation in (a+ß) Titanium Alloys: Iin-situ Explorations of Strain Localization and Its Governing Deformation Micro-events: *S. Wei*[1]; C. Tasan[1]; [1]Massachusetts Institute of Technology
The diverse microstructural combinations in two-phase titanium alloys have enabled a profuse platform in tailoring the corresponding mechanical performances. The plastic deformation coordination between a and ß phases is of fundamental significance in affecting the macroscopic load-bearing responses, yet, the underlying deformation micro-events especially their contribution to strain localization and partition still remain elusive and deem detailed considerations. In this presentation, by studying a Ti-Al-V-Fe (a+ß) alloy via integrated in-situ digital image correlation (DIC), in-situ synchrotron X-ray diffraction, and crystallographic calculation, we aim to showcase the exploration of the following three fundamental topics: (1) what are the deformation micro-events that governing strain localization inception? (2) how do strain localization and/or its partition evolve with respect to plastic straining? (3) how do the foregoing deformation micro-events affect damage nucleation and thereby macroscopic failure? Broader indications for mechanistically-guided microstructural design will also be included.

A New Criterion for Triclinic-asymmetric Yielding: Implicitly Describing Anisotropy and Distortional Asymmetry: *Z. Brunson*[1]; A. Stebner[2]; M. Wakin[1]; [1]Colorado School of Mines; [2]Georgia Institute of Technology
With every industry striving to reduce the weight of components and structures from aerospace and automotive to wind and solar power, structural materials with anisotropic and asymmetric behavior are becoming more popular. Since an accurate and efficient description of the elastic limit is necessary to describe both the deformation during manufacturing and the final component strength, we propose a new yield criterion for pressure-insensitive anisotropic and anisotropically asymmetric solids. Previous orthotropic yield criteria were extended using a fully implicit description for the anisotropy in both the strengths and strength differential effects (asymmetry). This provides for the modeling of asymmetry in shear for orthotropic materials and applications to lower symmetry materials such as triclinic. This presentation will explore the world of implicit and explicit models of anisotropic and asymmetric yielding, introduce our proposed yield criterion, and provide experimental case studies for various applications.

Constitutive Behavior I

Monday AM | July 26, 2021 | 9:15 - 10:15 AM

Session Chair: H. Huh, KAIST

Analysis of the Thermomechanical Flow Behavior of Carburized Sheet Metal in Hot Stamping: *A. Horn*[1]; M. Merklein[1]; [1]Friedrich-Alexander Universität Erlangen-Nürnberg
The reduction of fuel consumption due to restrictions regarding CO2 emissions is one of the major driving forces for lightweight design in the automotive industry. In this context, hot stamping of ultra-high strength steels has developed to a state of the art process for manufacturing safety-relevant components. With regard to passenger safety and weight reduction, further potential lies in the functional optimization of the parts. Prior local carburization followed by hot stamping is a new process variant for tailored properties, which overcomes the limitations of established processes. Due to the varying carbon content after carburization, the sheets have graded mechanical properties. Within this contribution, the influence of temperature, time and carburization parameters on the flow behavior will be investigated. For this purpose, tensile tests at elevated temperatures will be carried out in a physical simulator of type Gleeble and the flow curves will be modeled with a suitable hardening law.

Dynamic Recrystallization Behaviors of 5083 Aluminum Alloys with Different Initial Microstructures under Hot Compression: *S. Ding*[1]; J. Yanagimoto[1]; [1]The University of Tokyo
To study the dynamic softening behaviors of 5083 aluminum alloys under hot compression, hot compression tests of 5083 aluminum alloys with extruded and homogenized initial microstructures were conducted at strain rate ranging from 0.1 to 10/s and deformation temperatures ranging from 350 to 450°C. The obtained flow curves under a homogenized initial microstructure were lower than those under an extruded initial microstructure, suggesting that different initial microstructures lead to different microstructure evolution processes. Electron backscatter diffraction (EBSD) was used to observe the microstructure evolution process. The characteristics of continuous dynamic recrystallization, particle-stimulated recrystallization and conventional dynamic recrystallization were confirmed. The experiments deformed at the same temperature and strain rate but with different strains showed the transition from continuous to conventional recrystallization. The recrystallization mechanism of 5083 aluminum alloys with different initial microstructures is thus finally illustrated.

Simulation of Cold Forging Processes Using a Mixed Isotropic-Kinematik Hardening Model: *L. Galdos*[1]; J. Agirre[1]; N. Otegi[1]; J. Mendiguren[1]; E. de Argandoña[1]; [1]Mondragon Unibertsitatea

Cold forging is a manufacturing process where a bar stock is inserted into a die and squeezed with a second closed die. It is one of the most widely used chipless forming processes, often requiring no machining or additional operations to get tight tolerances. Because materials to be formed are increasingly harder and the geometrical complexity is greater, the finite element simulation is becoming an essential tool for process design. This study proposes the use of the Chaboche hardening model for the cold forging simulation of a 42CrMoS4Al material industrial automotive ball pin. The material model has been fitted with experimental data obtained from cyclic torsion tests at different reversal plastic strains as well as monotonic torsion tests at different strain rates. Comparison between the classical isotropic hardening and the new mixed hardening model are presented for the different forging steps.

Influence of the Quenching Rate and Natural Ageing Duration on the Formability and Mechanical Properties of EN AW-7075: B. Behrens[1]; S. Hübner[1]; *H. Vogt*[1]; O. Golovko[2]; S. Behrens[2]; F. Nürnberger[2]; [1]Institute of Forming Technology and Machines, Leibniz University Hannover; [2]Institute of Materials Science, Leibniz University Hannover

In recent years, 7xxx-aluminum alloys have been the subject of numerous investigations in the field of warm and hot forming and suited heat treatments to fully utilize its potential for applications in automotive bodies. Alternatively, forming blanks of these alloys at room temperature in the W temper state is favorable since conventional tools can be used. However, this condition is unstable. As the ageing duration after quenching increases, the formability decreases due to natural ageing. Hence, the objective of the investigations was to determine the formability of EN AW-7075 as a function of the ageing time. Furthermore, since the quenching rate after solution heat treatment influences the resulting mechanical properties, an adapted process route to manufacture components with tailored properties was explored. For this purpose, samples were partially quenched and then artificially aged. To determine the influence of the quenching rate, hardness tests and microstructure analysis were carried out.

Evaluationg of Press Forming Technique for Bent Automotive Body Parts Using In-plane Shear Deformation: *Y. Fujii*[1]; M. Urabe[1]; Y. Yamasaki[1]; Y. Tamai[1]; [1]JFE steel

Press forming of automotive frame parts which bent in the height direction with high strength steel sheet suffers from fracture and wrinkle caused by bending deformation.We has succeeded in developing new cold press forming technique with a process of two steps: first step for inducing in-plane shear deformation and second step for shaping into the bent part. The shear deformation in the first step was obtained by draw forming in unconventional press direction and had effect of suppressing the bending deformation. Relationship between the bent angle of the part and the shear deformation was clarified by experiments of small simplified model. When induced in-plane shear deformation increased, the part which had higher bent angle could be formed. The efficacy of the developed technique was confirmed by experimental trials using a real-size model of a front side member rear with 1180 MPa grade ultra-high strength steel sheet.

Calibration and Verification of Stress-strain Curve in High Strain Region of Mild Steel Sheet: *H. Tsutamori*[1]; H. Oonishi[1]; T. Nishiwaki[1]; [1]Daido University

Stress-strain curve in high strain region is one of the most important models that must be taken into consideration for high-precision sheet forming simulation. In this study, using mild steel sheets, tensile tests were conducted with a necked shape specimen at the center in order to generate non-uniform elongation. Using image analysis, strain-load relationships were obtained using multiple gauge lengths, and stress-strain relationships were obtained by inverse analysis using FE simulation. With sufficiently small gauge length it is possible to obtain stress-strain relationships in high strain region. The advantage of this method is that it can be implemented with a uniaxial tensile test machine only as experimental apparatus. For validation, original hole expansion test model is proposed, that is not affected by friction. The thickness strain distribution along the hole with large plastic strain is compared with experimental and numerical results to indicate validity of this method.

Towards an Efficient Industrial Implementation of W-temper Forming for 7xxx Series Al Alloys: *R. Tran*[1]; L. Kertsch[2]; S. Marx[1]; S. Hebbar[2]; V. Psyk[1]; A. Butz[2]; [1]Fraunhofer Institute for Machine Tools and Forming Technology IWU; [2]Fraunhofer Institute for Mechanics of Materials IWM

Manufacturing technologies for parts made from ultra-high strength 7xxx series aluminum sheet material have been a focus of research in recent years. A promising approach is W-temper forming, where sheet material is cold formed after a heat treatment. Conventional heat treatment routes are very time consuming and inefficient. In this study a new more efficient and industry-orientated transfer tool concept has been developed. Heating and cooling of the sheets takes place in separate contact tempering stages, which allow superior heating and cooling rates in comparison to conventional methods. To analyze the influences of temperature rates and deformation on microstructure and mechanical behavior, thermo-mechanical experiments in a Gleeble simulator were carried out. The results prove the great potential of the transfer tool concept with an inline heat treatment for series production. The process dependent mechanical properties determine a suitable process window for the industrial application of the W-temper forming of the analyzed alloys.

Taylan Altan Honorary Symposium

Monday AM | July 26, 2021 | 9:15 - 10:15 AM

Session Chair: E. Billur, Billur

Invited

Enhancing Tool Life by Manipulating the Punch & Die Elastic Strain Field during Forging: *G. Ngaile*[1]; [1]North Carolina State University

Tool life is a major factor in the cost of forgings, productivity, and part integrity. This paper will discuss a new methodology for enhancing the tool life of forging dies by manipulating the elastic strain field induced in the die and punches during forging, such that the retained contact stresses at the tool-workpiece interface are minimized or eliminated during punch ejection and release of the forging from the dies. The retained contact stress is attributed to the spring-back of the dies/punches. Finite element simulations of the proposed tooling architectures which facilitate the relaxation of elastic strain field in the die at the end of the forging stoke will be presented. To assess the viability of this technique, a number of forging geometries have been simulated including, CV joint, pinion shaft, hub spindle, and gearbox main shaft. The researchers are currently developing a laboratory scale tooling setup for experimental validation.

Investigation of Effects of Part Features in Single Point Incremental Forming of Narrow Channels: *S. Jirathearanat*[1]; D. Kumar[1]; K. Fong[1]; A. Danno[1]; A. Kumar[2]; [1]Singapore Institute of Manufacturing Technology; [2]National University of Singapore
Narrow channels or ribs can be commonly found in sheet metal products. These narrow with high length-to-width aspect ratio channels are often integrated into sheet metal panels for functional features such as stiffeners or guide rails of various topographies, i.e. straight line or composite of curves. This work focused on development of Single Point Incremental Forming (SPIF) as a cost-efficient forming alternative to stamping or embossing of these features in short-series production. These channels present unique forming challenges, i.e. effects of channel spline geometry, varying cross section, end geometries on part formability and geometrical accuracy. SPIF of SS316L 0.5mm-thick narrow channels of three different geometries with maximum width of 20mm and its length-to-width aspect ratio lager than 5, i.e. 1) straight channel, 2) taper channel, and 3) curvature channel, was investigated. Based on the experimental results, 5mm dia. carbide tool and 0.1mm step-down size was recommended to optimize SPIF of these narrow channels. The effects of the different part features and their interactions with SPIF forming parameters on part formability and deviations are presented and analyzed for further development of die-less narrow channel forming for sheet metal industry.

Self-optimized, Intelligent Open Loop Controlled Steel Strip Straightening Machine for Advanced Formability: *F. Bader*[1]; E. Djakow[1]; L. Bathelt[2]; W. Homberg[1]; C. Henke[2]; A. Trächtler[2]; [1]Paderborn University; [2]IEM-Fraunhofer
Innovative self-correcting process control techniques which adapt to the initial geometric characteristics of the strip are a promising approach to fix the local varying distortion of coiled strips by optimizing the leveling process. This paper presents an innovative strategy to improve straightening of ahss materials (1.4310). This implies optimized leveling, adding minimal plastic deformation and, thus, strain hardening. Therefore, an "intelligent straightening machine" was developed which will be presented. To operate an intelligent straightening machine a reliable online measurement of the surface defects is fundamentally essential. This paper describes an approach towards the measurement of a bent steel strip for an automatic straightening process. Therefore, various ways of measuring the bending curvature are investigated. Optical, tactile and the MagnaTest are compared with each other. The bending measurement is linked to open/closed loop control and therefore providing an optimal straightening result in regards of formability, leveling and reduced strain hardening.

Finite Element Analysis of Die Quenching 22MnB5 Steel Sheets: *H. Livatyali*[1]; [1]Yildiz Technical University
Mathematical modeling of heat treatment processes necessitates dealing with inherent complexities such as large material property variations, phase transformations, complex inter-parameter couplings and boundary conditions. A mathematical framework based on a finite element model capable of predicting temperature history and thus, evolution of phases during heat treatment of the boron steel 22MnB5 through the inverse use of CCT diagram was developed. This novel model named the "gridding model" was integrated into the commercial FEA software MSC.Marc® by the user subroutine PlotV. Accuracy of the model was verified by simulating some die quenching experiments in the literature as well as those that were conducted in the laboratory. Simulation results show that if thermo-mechanical-metallurgical couplings are modeled correctly, the novel model can predict the temperature history and evolution of phases with an acceptable accuracy.

A Vision of Numerically Controlled, Autonomous Manufacturing and Metal Forming: *G. Daehn*[1]; [1]The Ohio State University
Here I lay out a vision for Hybrid Autonomous Manufacturing. Imagine you have a robot-automaton machinist who really likes and knows deformation. What would this enable? What's needed to get there? Use cases and brief research agenda are presented.

Joining by Forming and Deformation I

Monday AM | July 26, 2021 | 10:20 - 11:20 AM

Session Chair: P. Groche, Institute for Production Engineering and Forming Machines

Development of Criteria for Strain Induced Oxide Layer Fracture during Cold Rolling of Aluminum: *M. Navidirad*[1]; J. Plumeri[1]; W. Stepniowski[1]; T. Christ[1]; M. Watanabe[1]; W. Misiolek[1]; [1]Lehigh University
A combination of physical experimentation as well as numerical simulation of bond rolling of aluminum sheets has been investigated in this study. The surfaces of the sheets were anodized in sulfuric acid with addition of indigo carmine in order to provide the oxide layer coloration as well as two specified oxide thicknesses. A progressive reduction per pass has been implemented in consecutive experiments at constant rolling speeds to develop different degree of oxide surface expansion leading to its fracture. A numerical model of the rolling process has been constructed utilizing DEFORM-3D software, wherein strain, strain rate, and stress fields were calculated. The calculated localized strain distribution reinforces with experimental data to determine the critical localized deformation criteria leading to different stages of the oxide layer fracturing. Classical metallography as well as electron microscopy techniques were used to evaluate the evolution of the oxide fracture as a function of deformation.

Fretting Damage and Fatigue Property Analysis of Self-piercing Riveted Joints of AA5052 Aluminium Alloy: *Z. Huang*[1]; Y. Zhang[1]; J. Lai[2]; [1]East China Jiaotong University; [2]Nanchang University
The fatigue tests of self-piercing riveted joints of AA5052 aluminium alloy were carried out by axial tension-tension loading mode. The micro fracture characteristics of specimen with different parameters was analyzed by scanning electron microscopy and X-ray spectrometer, and the fatigue property as well as fretting damage failure mechanism of SPR joint were studied. The results show that the fatigue cracks occur in the fretting damage area where stress concentration exist. The form and the distribution of the fretting crumbs are important factors which affect the fatigue property of joint. Within the value range, the fatigue life prolongs with the increase of stress ratio, however decrease with the increase of loading level adopted. The fatigue property differs between different riveting direction, and better strength property could be obtained when the rivet direction reverse.

Fatigue Characteristics and Failure Mechanism of Self-piercing Riveting DP590 and AA6061 Plates: *Z. Huang*[1]; Y. Jia[1]; J. Lai[2]; [1]East China Jiaotong University; [2]Nanchang University
Duplex steel, aluminium alloy, carbon fiber reinforced composites and other materials have become the preferred lightweight materials for automobiles. The self-piercing riveted joints of dual phase steel DP590 and aluminium alloy AA6061 were selected for fatigue tests, and the fatigue properties of the joints were analyzed. The typical fatigue failure fractures were observed by scanning electron microscopy(SEM), and the micro failure mechanism of the joints was analyzed. The results show that the fatigue properties of self-piercing riveted joints are different with different upper substrates. The failure modes of the joints are all fracture of the lower substrates. When the upper substrate is DP590 plate under high fatigue load, the cracks are easy to initiate in the rivet area. The cracks of the other self-piercing riveted joints originate on the side of the lower plate and extend along the rivet area to the width of the substrate.

From Bridge to Bumper – Utilization of Pre-stressing during Manufacturing of Hybrid Sheet Metal Structures: *H. Husmann*[1]; P. Groche[1]; [1]Institute for Production Engineering and Forming Machines
Pre-stressing is often used in civil engineering to increase the load bearing capacity of bridges and buildings. In order to exploit this potential in sheet metal structures as well, efficient processes for joining and pre-stressing of tendons are required. Therefore, an approach to join and pre-stress fiber reinforced plastic (FRP) straps and sheet metals during a forming process is proposed. The FRP strap is placed around two collars drawn into the sheet. A punch plastically expands the collar, while the FRP strap is elastically elongated, resulting in beneficial pre-stresses after unloading due to the different spring-back. In this paper, the predominant mechanism is verified and parameters influencing the pre-stress are identified by experimental and numerical investigations. The hypothesis is investigated, that a customized pre-stress and thus a higher strength during the structure's usage can be controlled by varying the collar's expansion. Possible applications include bumpers and side impact beams.

Computer Aided Modeling of the Hot Forming Staking Process Based on Experimental Data: *S. Härtel*[1]; E. Brückner[1]; B. Awiszus[1]; M. Gehde[1]; [1]Chemnitz University of Technology
As a non-detachable and point-acting joint, thermoplastic staking is primary used for the production of electronic and sensor elements as well as for the joining of components in the automotive interior and exterior. Commonly, the advantages of staking processes are its cost-efficient and seemingly simple process control. Regarding the industrial application, staking is principally a well-established forming process. However, despite of the high number of applications, the joint design and the process settings are mainly based on extensive empirical tests. At present, the FE-simulation of these thermoplastic staking processes are not state-of-the-art. Due to these facts, within the frame of the paper, these gaps are to be closed by the computer aided modeling of the hot forming staking to map the heating and forming behavior of this process close to reality. This procedure demands the associated experimental validation of the simulation. In summary, the numerical model shows a high conformity to the experimental data and allows a simulative mapping of the morphological characteristics of the riveted joint as well as indicative statements to the process parameters, which means in particular the minimal heating time for forming and the optimized post-heating time for a morphological homogenization.

Metal Forming Process I

Monday AM | July 26, 2021 | 10:20 - 11:20 AM

Session Chair: E. Massoni, CEMEF MINES ParisTech

Innovative Simulation Strategy for the Mastering of Tribological Surface Transformations: *M. Dubar*[1]; L. Dubar[1]; H. Boungomba[1]; P. Moreau[1]; C. Hubert[1]; [1]LAMIH UMR CNRS 8201
Reducing energy consumption and improving vehicle comfort has pushed car manufacturers to develop components that combine high mechanical performance and optimum lightness. Concerning the specific case of suspensions parts manufacturing, the materials involved require high mechanical characteristics coupled to a good ability to plastic deformation. These specifications imply severe conditions during forming, leading to tribological surface transformations in the case of springs. The aim of this work is to master these transformations by FEM modeling and refined material investigations (SEM, residual stresses and hardness). The 3D FEM model is made with ABAQUS, considering kinematic hardening effect on the one hand, and on the other hand tribological data. The interfacial characteristics have been obtained by means of a specific testing bench, able to reproduce industrial contact conditions. The mechanical variables of the model are coupled with a specific damage model in order to correlate to the metallurgical surface transformations.

Methods for Increasing the Durability of Forging Tools - Comprehension Review and Outlook: Z. Gronostajski[1]; *P. Widomski*[1]; M. Kaszuba[1]; [1]Wroclaw University of Science and Technology
The problem of the low durability of hot forging tools is widely known and undergoes many particular research actions. Most often these studies have a narrow range of case studies instead of a universal approach. It was found that there is no single multifunctional method for increasing durability, but general directions for improving durability should be considered.Currently, the main directions of durability improvement are surface engineering technologies, especially layers and coatings increasing wear resistance. Among them, hybrid solutions predominate, involving the use of several techniques on one tool in order to synergistically interact and obtain higher wear resistance. In this work, the results of many studies from the last several decades are gathered to present the possibilities of increasing the tool life in forging processes. The available methodologies, systems and approaches for selecting methods of durability improvement were also analyzed and their effectiveness evaluated.

Effect of Blanking on Magnetic and Mechanical Properties of Non-oriented Electrical Steel: *R. Cui*[1]; S. Li[1]; J. He[1]; [1]Shanghai Jiao Tong University
World-wide blanking is the most popular technique for producing the non-oriented electrical steel lamination. However, blanking has a great effect on magnetic property and mechanical property, such as the introduction of uneven residual stress, the deterioration of magnetic properties and the increase of micro-hardness. In this research, non-oriented electrical steel sheets are investigated via blanking test by 3 kinds of punches. The blanking edges are examined by the optical microscopy and micro-hardness test to visualize the distribution of micro-hardness. The magnetic properties are also measured. The results show that the blanking clearance has a great influence on magnetic properties and mechanical properties of the blanked material.

Impact of the Temperature Field of a C38 Steel Slug on its Thixoforging: Experiments and Simulations: *E. Becker*[1]; [1]Arts et Métiers Institue of Technology
The thixoforging forming process for steels makes it possible to produce complex shaped parts near netshape, or very close, in one step with a very low forging force compared to the conventional forging process. To obtain an optimal thixoforged product, it is necessary to have a mastery of the process parameters. The heating stage of the steel slug is a major phase in this process. It makes it possible to obtain a partially semi-solid billet allowing the thixoforging of the latter but also its prehension for transfer to the press. The article presents the temperature field in the volume of the semi-solid C38 steel billet obtained by experimental measurements and simulations. Under these conditions of heating the billets, it also shows the characteristics of the parts obtained, fibering and micrographs, and shaping, the necessary thixoforging force.

Influence of Precoating on the Decarburization of the Surface Layer of Forged Parts during the Hot Die Forging Process: Z. Gronostajski[1]; *P. Widomski*[1]; M. Kaszuba[1]; M. Zwierzchowski[1]; [1]Wroclaw University of Science and Technology
This research evaluates the effect of pre-coating of forged parts on decarburization. First, the effect of different coatings on the rods decarburization during the induction heating process was tested. Coatings were deposited before forging. Once completed testing, the measurements and observations of the decarbonized layer were made. The next stage involved analysis of the decarburization of the forged parts after forging. The forged parts were made using precoating of pre-forging elements; pieces cut off a metal rod. Based on tests results, the possibility of using this solution in the technique of industrial hot forging was evaluated. The results of laboratory tests have confirmed that lubrication of metal pieces is sufficient, as well as proved it to be effective in reducing decarburization of the surface layer. Results indicate that decarburization may be reduced to a minimum when we use Bonderite product in a concentration of 66% and 50%.

Experimental Study of Asymmetric Rolling of Aluminum Alloys: *G. Vincze*[1]; M. Butuc[1]; A. Lopes[1]; [1]University of Aveiro

In this work, the effect of asymmetric rolling parameters on the mechanical properties of two aluminum alloys was investigated. The asymmetric rolling (ASR) process is known as a process capable to improve the properties of the material through microstructure refinement and development of a shear component of texture that leads to an improvement of strength and plastic anisotropy. An asymmetric mill equipped with two identical rolls commanded by independent motors was used to analyze the effect of reduction per pass, asymmetry factor and the rolling route. The two materials, AA6022 and AA6061, modified by ASR, were analyzed by uniaxial tensile test, hardness test and Electron Backscatter Diffraction technics. It was observed a strong increase of yield stress and ultimate tensile strength in detriment of formability, being more accentuated for AA6061 compared to AA6022. Regarding the texture evolution, shear texture components are linked to a higher reduction per pass.

Microstructure and Damage Development I

Monday AM | July 26, 2021 | 10:20 - 11:20 AM

Session Chair: T. Clausmeyer, TU Dortmund University

Hardening/Softening Characteristics of a TRIP-assisted Duplex Stainless Steel under Cyclic Deformation: M. Jin[1]; L. Chen[1]; *Z. Zou*[1]; S. Hao[1]; H. Wang[1]; Q. Li[1]; S. Zhao[1]; [1]Yanshan University

Recently, a series of economical duplex stainless steel (DSS) with transformation induced plasticity(TRIP) effect which improves the mechanical properties have been developed by replacing Ni-Mo with Mn-N. The mechanical properties of the above TRIP-assisted DSS under cyclic loading condition were studied and the microstructural mechanism was characterized by TEM. The results show that it's cyclic hardening/softening characteristics are sensitive to strain amplitude and the number of cycles(N). With a relatively small strain amplitude, cyclic hardening occurs firstly (N < 5), then cyclic softening starts and trends to stabilization gradually. With a relatively large strain amplitude, after a rapidly cyclic hardening (N<5), it is softening continuously until failure. The dislocation walls formed in ferrite during cyclic deformation which are responsible for the overall cyclic softening; While austenite undergoes cyclic induced e martensite transformation at relatively large strain amplitude whereby the cyclic softening is suppressed.

Relaxation Characteristics of Creasing Process of Scored Paperboard for Liquid Container: *S. Nagasawa*[1]; T. Nagumo[1]; A. Sakamoto[1]; K. Umemoto[1]; [1]Nagaoka University of Technology

A knowledge of dynamic bending moment resistance acting on a hinge, which is folded on a creased line, is important in order to adjust mechanical conditions for boxing a paperboard. In this work, dynamic creasing characteristics of liquid-container-purpose paperboard of basis weight 313 g/m^2 were investigated, when the holding time of a position of creasing knife was varied with the specified indentation depth. In the scoring process, the time-dependent behaviors of reaction force and the permanent scored depth were experimentally investigated for the elapsed time of 100 seconds. When using the paperboard scored with the specified indentation depth and varying the holding time, the bending moment response at a 90 degree folding test was investigated. In this folding and unfolding process, the effect of holding time at the scoring process on the bending moment resistance was analyzed, especially for characterizing the initial gradient of stiffness.

Temperature Dependent Fracture Loci Of AZ31 Magnesium Alloy Sheets: *R. Bertolini*[1]; Q. Wang[1]; A. Ghiotti[1]; S. Bruschi[1]; [1]University of Padua

Magnesium alloys have been used in the automotive and aereospace industry for several years, thanks to their high strength-to-density ratio. Their mechanical characteristics at room and even at elevated temperature have been well-studied, whereas, when it comes to temperatures lower than the room one, only a few studies are available in literature. To this aim, the present paper investigates the mechanical behaviour of AZ31 magnesium alloy sheets deformed at different temperature regimes. Tensile tests till fracture were carried out at room temperature, -100 °C, -50°C, 100°C and 300°C using different specimen geometries in order to vary the stress triaxiality. The fracture strain values were identified making use of a combined numerical-experimental approach, whereas the fracture surfaces were qualitatively characterized by means of stereoscopy and scanning electron microscopy. Finally, the AZ31 fracture locus as a function of the stress state and temperature was constructed.

Application of the Nondestructive Evaluation (NDE) Method to Evaluate the Sheared Edge Quality and Edge Cracking: *C. Gu*[1]; N. Pathak[1]; S. Freed[1]; H. Kim[1]; [1]EWI

Evaluating the shear edge quality and edge cracking is important in forming the advanced high-strength steel for automotive structural parts. This paper introduces the eddy-current based NDE method to evaluate the sheared edge quality. Using different shear clearances from 5 to 25% of the sheet thickness, different work hardening magnitudes were applied on the sheared edges which varied the local formability. The NDE sensor scanned the sheared DP780 blanks to obtain the NDE data. To compare the NDE data to the work hardening level of the sheared edge, the microhardness was measured. The edge formability was evaluated using half specimen dome test (HSDT) with digital image correlation (DIC) to correlate the failure strain with the NDE data. The NDE result shows good correlation with edge formability and microhardness. With additional development effort, the eddy-current based NDE method can be implemented as a real-time monitoring tool for rapid edge quality evaluation.

Study of Hydrogen Embrittlement Behavior of Hot-stamped Ultra-high Strength Steel: H. Zhang[1]; X. Zhang[1]; J. Tang[1]; *X. Han*[1]; [1]Shanghai Jiao Tong University

The hydrogen embrittlement (HE) behavior of hot-stamped ultra-high strength boron steel B1500HS was studied. A series of tensile tests and microstructure observations for B1500HS samples after electrochemical hydrogen charging were performed and analyzed. Based on the experimental results, some interesting phenomena were studied. Firstly, the relationship between the mechanical properties of hot stamped B1500HS and the hydrogen concentration and charging time were presented; Secondly, both reversible HE and irreversible HE were revealed and the conditions leading to them were discussed; Thirdly, the effects of tensile rate on B1500HS after hydrogen charging were also studied. Besides, the mechanism of the above phenomena were further involved in this work.

Technologies to Speed Innovation

Monday AM | July 26, 2021 | 10:20 - 11:20 AM

Session Chair: G. Ngaile, North Carolina State University

Experimental Investigation of Different WAAM (Wire-Arc Additive Manufacturing) Processes and Their Influence on the Component Properties and Formability: *P. Colditz*[1]; M. Graf[1]; A. Hälsig[2]; S. Härtel[1]; K. Prajadhiana[3]; Y. Manurung[3]; B. Awiszus[1]; [1]Technische Universität Chemnitz, Professur Virtuelle Fertigungstechnik; [2]Technische Universität Chemnitz, Professur Schweißtechnik; [3]Universiti Teknologi MARA, Faculty of Mechanical Engineering
With the wire-arc additive manufacturing (WAAM) complex components can be built up layer by layer from metallic construction materials. In this investigation two different WAAM processes with high built-up rates (CMT and pulsed GMAW) were compared in terms of geometry formation and component properties. The reference is a rectangular thin-walled geometry made of the austenitic stainless steel 316LSi (1.4430). During the welding process, the temperature development in the base plate as well as in the weld layer were measured. The experimental comparison of CMT (R_m=630MPa) and pulsed GMAW (R_m=605MPa) is completed by the determination of the mechanical properties using micro tensile tests. Furthermore, the additive manufactured walls were cold rolled with a subsequent heat treatment or hot rolled to provide proof of formability and forming induced property improvement.

Validation of Automatically Generated Forging Sequences Using FE Simulations: *Y. Hedicke-Claus*[1]; M. Kriwall[1]; J. Langner[1]; M. Stonis[1]; B. Behrens[1]; [1]IPH-Institut für Integrierte Produktion Hannover gGmbH
In this study an analytical method is developed to automatically design a multi-staged forging sequence based on the CAD file of the forged part. The method uses artificial neural networks to analyse the geometry of the forging and to classify it into a shape class. A slicer algorithm divides the forging into cutting planes and calculates the mass distribution around its centre of gravity line. An algorithm shifts the points of the polygon courses of the cross-sectional contours and approximates the mass distribution step by step from the forging to the semi-finished product. Each preform is exported as CAD file. The generated sequences are simulated and evaluated by form filling, folds and cracks. The conducted FE simulations showed, that the automatically generated forging sequences allow the production of different forgings. By help of the FE results, the algorithm is now refined, and the method subsequently validated by experimental forgings.

Pre-forging Shape Design Using Conformal Mapping Method: *C. Liu*[1]; W. Xu[1]; M. Liu[1]; [1]Chongqing University
In this paper, a novel method of using conformal mapping to design the pre-forging shape is proposed to achieve a reasonable three-dimensional (3D) shape of the pre-forging. Firstly, the 3D final forging was two-dimensional (2D) sliced to simplify the design problem. The new profile of each slice was calculated based on the conformal mapping method. Then, the discrete points on all new profiles were combined into a 3D point cloud for surface reconstruction to obtain 3D model of the pre-forging. Next, four parameters (conformal factor and triaxle scaling factors) were applied to describe the pre-forging shape. Finite element analysis was used to simulate the forging process of the designed pre-forging. Finally, this method was applied to design the pre-forging shapes of different forgings. Through reasonable parameter values, satisfactory pre-forging shapes can be obtained. This method is effective, easy to implement, and has universal adaptation.

Multi-objective Optimization of Elbow-bar Transmission Mechanism Based on Virtual Prototyping: *X. Dong*[1]; [1]Xuanwu District
The kinematics and dynamics characteristics of transmission mechanism will directly affect the processing quality and efficiency of multi-link die forging press. Based on the structural parameters of a certain type of die forging press, the dynamic optimal model of elbow-bar transmission mechanism is established. Several performance indexes in the respect of kinematics and dynamics were put forward which were took as the objective functions and constraint functions. Based on virtual prototyping, this paper proposed an improved genetic algorithm method for an elbow-bar transmission mechanism, which can also be applied to optimal synthesis of multi-link mechanisms where there it is possible to obtain the analytically solution of the kinematic position. And with this, we find an optimized dimensions of elbow-bar transmission mechanism. Theoretical and simulation results examine the performance of the optimized mechanism, and demonstrate that its performance parameters are improved obviously.

Zhongren Wang Honorary Symposium

Monday AM | July 26, 2021 | 10:20 - 11:20 AM

Session Chair: S. Yuan, Harbin Institute of Technology

Invited
Professor Z.R. Wang's Contributions to Metal Forming Theory, Technology and Education: *G. Liu*[1]; S. Yuan[1]; K. Zhang[1]; [1]Harbin Institute of Technology
Prof. Wang once served as the president of the China Society for Technology of Plasticity (CSTP) and hosted the 4th ICTP in Beijing 1993 as Chairman. During 60 years' academic life on metal forming. He has published 17 books and more than 300 academic papers, has won international and national Awards 5 times, including invention award and science & technology progress award, etc. His main contributions include: developing the engineering plasticity theory and promoting its applications; inventing the die-less hydroforming method for large scale spherical shells; solving the technological problems of several major national projects in China; leading internationalization of Chinese community of plasticity engineering; educating a group of talents on metal forming.

A Study of the Forming Quality of Magnesium Alloy Cylindrical Parts with Inner Ribs by Induction-heating Assisted Spinning: *Q. Xia*[1]; J. Long[1]; G. Huang[1]; S. Yuan[1]; Y. Qin[2]; [1]South China University of Technology; [2]University of Strathclyde
Magnesium alloy cylindrical parts with inner ribs (MACPIR) are attractive as lightweight components for improving the performance of high-end equipment in various industrial sectors. Induction-heating assisted spinning (IHAS), an effective way to manufacture cylindrical parts made of difficult-to-deform materials, was used to form the MACPIR. However, when using this process for MACPIR, nonuniform deformation and other forming defects can easily occur between the cylindrical wall and inner ribs. An FEM model of MACPIR during IHAS was developed via ABAQUS, and experimental verification was conducted. Forming defects that occurred during the spinning process of MACPIR were analyzed, and evaluation indexes of forming quality were proposed. The results show that the concavity of rib back, and nonuniform distribution of rib height along tangential and axial directions are the main forming defects. Additionally, the influence of process parameters on the forming quality was discussed. The results indicate that the forming quality of MACPIR can be improved under a forming temperature of T=300~350, roller feed rate f=0.4~0.6mm/r and thinning ratio of wall thickness t=65~75%. The simulation results confirm well with experimental ones.

TECHNICAL PROGRAM

Friction Law in Cold Metal Forming: *Z. Wang*[1]; Y. Yoshikawa[2]; W. Dong[1]; [1]Gifu University; [2]Meijo Univeristy

In cold forming, liquid lubricants and lubrication coatings are generally employed. As the basis for understanding of friction behavior under lubricated conditions, the friction law under dry condition is determined based on experimental results in compression of metal sheets by a DLC coated tool. Then the friction law of lubrication coatings is investigated. Finally, the friction law under lubricated conditions is proposed based on the friction law under dry condition and experimental results by the testing method with side stretching and the high pressure friction test.

Adding Value by Advancing Metal Forming: *L. Wang*[1]; T. Dean[2]; [1]Imperial College London; [2]University of Birmingham

The metal forming industry is responding to the changing technical and commercial demands of customers and increasingly stringent legislative restrictions. In addition, lead times are contracting. Also OEMs are demanding deliveries just-in-time on changeable schedules and for many products batch quantities have become smaller than a few years ago. To meet these challenges, in the metal forming industry, the rate at which new and existing process technologies and production practices are being developed is increasing. Computer-aided design and manufacturing systems have been allied to computer process simulation, to form powerful cloud based knowledge-based tools for producing parts right-first-time through identifying the customers' needs. The purpose of this paper is to illustrate some advances made in metal forming industry by the authors, through advancing the base of scientific process knowledge, to meet the demands for added value products.

Recent Advances in Sheet and Tube Hydroforming: *S. Zhang*[1]; D. Chen[1]; Y. Xu[1]; Y. Ma[1]; [1]Institute of Metal Research, Chinese Academy of Sciences

Pulsating hydroforming and impact hydroforming are two advanced technologies to increase the formability of material compared with other traditional forming technologies. They were systematically investigated from aspects of technical principle, forming mechanism, equipment and applications. Pulsating hydroforming can improve the forming ability by altering the friction condition of sheet/tube parts or by utilizing the effect of transformation induced plasticity of stainless steels under the pulsated loading. As for impact hydroforming, the strain rate can reach 10^3~10^4/s and the instantaneous pressure can be GPa level, which can obviously increase the elongation of hard-to-form material by 20%~60%. The effect of flexible liquid and impact impulse was investigated by both experiment and simulation, while the mechanisms are related to the compatible deformation of second phase, strain decentralization and defect stabilization. The technologies have been used on the manufacturing of complex, thin walled components for the fields of aeronautics and aerospace, automobile, nuclear power.

Rim Thickening of Disk-like Parts Using Spinning: *W. Xinyun*[1]; J. Junsong[1]; D. Lei[1]; G. Pan[1]; Z. Mao[1]; [1]Huazhong University of Science & Technology

In this study, a multistage spinning process was employed to thicken the rim of a disc-like sheet blank with a uniform thickness. In this process, the workpiece is clamped between the upper spindle and lower spindle, while all of them rotating together. A set of rollers with external grooves, which passively rotate under the drive of friction between the roller and workpiece, feed along the radial direction of the workpiece to compress and thicken the rim in sequence. Based on FEA and experiments, the influences of defects and process parameters on the forming behavior were investigated. Moreover, the effect of preformed shape on the workpiece deformation in the successive stage was also considered. Process parameters were optimized based on flow line distribution.

Poster Session

Monday AM | July 26, 2021

Deforming Behavior in Magnetic Pressure Parallel Seam Welding: *T. Ichimura*[1]; Y. Ito[1]; M. Miyazaki[1]; A. Hatta[2]; [1]National Institute of Technology, Nagano College; [2]DMG MORI CO., LTD.

Magnetic pressure welding (MPW) has attracted attention as a new joining method for aluminum thin plates. MPW is a collision welding process for producing metallic bonds of similar and dissimilar materials, utilizing electromagnetic force as the acceleration mechanism. MPW is a method of abruptly adding a high density magnetic flux around a metal material and utilizing the generated electromagnetic force to deform the thin plate at high speed and pressure welding. This paper deal with the deformation behavior of aluminum sheet with parallel coils. The sample used for this analysis is assumed to be a thin plate made of aluminum and composed of quadrilateral elements of plane strain.As the result, the collision point velocity is very high-speed at the initial collision point, but it decreases continuously during the welding. Even if the thickness was changed, the tendency of the collision point velocity and the collision angle did not changed.

Dependence of Mesoscale Structure of Drawn High Carbon Steel Wire on Wire Diameter: *S. Gondo*[1]; R. Tanemura[2]; R. Mitsui[2]; S. Kajino[1]; M. Asakawa[2]; K. Takemoto[3]; K. Tashima[3]; S. Suzuki[2]; [1]National Institute of Advanced Industrial Science and Technology (AIST); [2]Waseda University; [3]Factory Automation Electronics Inc.

For high carbon steel wire with 0.444 mm in initial diameter, our previous work clarified that mesoscale structure composed of its fiber textures is formed during wire drawing process. The mesoscale structure transitions into primary fiber texture, primary and secondary fiber textures, subprimary and secondary fiber textures with increasing drawing strain. The objectives of this study are clarifying the mesoscale structure in higher drawing strain and the dependence of mesoscale structures on the wire diameters. High carbon steel wires of 0.276, 0.444 and 0.936 mm in diameter were drawn to be as fine as possible. Crystal orientation analysis by electron backscatter diffraction pattern showed that the mesoscale structure transitioned in order as mentioned above, then the structure with only subprimary fiber texture was formed regardless of initial wire diameters. The thickness of secondary fiber texture decreased logarithmically with decreasing the drawn wire diameter at more than 1.4 of drawing strain.

Development of Antiloosening Bolts Based on Innovative Double Thread Mechanism: *T. Takemasu*[1]; [1]Happy Science University

We developed new double-thread bolted joints based on an innovative mechanism composed of single and multiple coarse threads. The number of coarse threads of the multiple-thread was set to 3 (denoted as 3DTB-II), and its thread structure was fundamentally modified to improve rolling formability and strength as follows: (i) one of the three multiple-thread grooves was removed for 3DTB-II specimens and one of the two remaining grooves shifted downwards by a half pitch (denoted 3-1DTB-IIB) and (ii) the depth of the multiple-thread grooves was reduced by up to 50% of the thread height (denoted 3-1DTB-IIC). FEM thread rolling simulations were performed using a dedicated die. The two kinds of modified DTB-II specimens were rolled precisely and the thread heights reached the target value at all cross sections. The forming states in the thread rolling experiments well matched the FEM simulation states.

High-temperature Properties of Hot-work Tool Steel (AISI H13) Deposited via Direct Energy Deposition: *J. Son*[1]; G. Shin[1]; K. Lee[1]; C. Choi[2]; D. Shim[3]; [1]Korea Institute of Industrial Technology; [2]Stevens Institute of Technology; [3]Korea Maritime and Ocean University
Conventionally, tool steels are repaired by welding; however, that of repairing is expensive, time consuming, and does not guarantee homogeneous quality. Hence, this study focused on developing an alternative repairing technique using direct energy deposition (DED) to minimize thermal effects. To simulate a repair using DED, AISI H13 powder was deposited onto heat-treated JIS SKD61. The deposited material was observed through scanning electron microscopy and its hardness and tensile properties were determined at 25, 200, 400, 600, and 800. The deposited material showed different hardness distributions in its cross section, revealing four representative features. The deposited region and dilution showed a hardness of 620 Hv with a dendrite structure. The hardness decreased to 490 Hv in the heat-affected zone, revealing a tempered martensite structure; however, it increased to 550 Hv in the substrate, and revealed a typical martensite structure. At all temperatures, the deposited material showed higher hardness than heat-treated SKD61. Moreover, it showed higher ultimate tensile strength and lower elongation in deposited region. Therefore, this study indicated that without heat treatment, a part repaired using DED can have better mechanical properties than heat-treated SKD61.

Strain-rate-sensitivity Calibration of Aluminum Alloy Sheet by Electromagnetic Flanging of Circular Hole: *W. Liu*[1]; Y. Lin[1]; H. Zhou[1]; Z. Meng[1]; S. Huang[1]; [1]Wuhan University of Technology
The strain rate of aluminum alloy sheet reaches up to thousands per second in electromagnetic forming, and it is difficult to obtain the flow stress curve at such high speed. For the hardening law at high strain rate, the strain-hardening term was initially determined by the quasi-static uniaxial tensile test to simplify the parameter identification. Due to the delayed deformation at the central zone of circular workpiece in the electromagnetic bulge test by planar spiral coil, an inverse method of strain-rate-sensitivity calibration has been proposed by electromagnetic flanging of circular hole. The initial size of circular hole was determined as a half diameter of planar spiral coil, and the discharged energy was defined to induce reasonable deformation. A numerical model was established for electromagnetic flanging of circular hole. The experimental and simulated deformation distributions on the cross-sectional profile of workpiece were compared to calibrate the strain-rate-hardening term of Johnson-Cook model.

The Effect of Interface Cohesion on Layer Stability during Accumulative Roll Bonding of Cu/Ta Multilayers: *L. Semenchenko*[1]; U. Asim[1]; R. Mier[2]; N. Senabulya[3]; M. Demkowicz[1]; [1]Texas A&M University; [2]Los Alamos National Lab; [3]University of Michigan
We present a combined experimental and modeling investigation of composite morphology in Cu/Ta laminates processed by accumulative roll bonding. Using x-ray computed tomography, we examine numerous instances where Ta layers necked and pinched off during rolling. Maintaining layer continuity is important in the mechanical performance of multilayered metals. To understand the origin of layer instabilities, we carried out finite element simulations using an isotropic elastoplastic material model to model Cu and Ta layers in a representative volume element with different interaction properties between them. We demonstrate the plastic flow stability during rolling depends on interface cohesion and indicates that laminates with more uniform layer thickness may be processed by controlling the interface properties.

FEM Analysis on Multi-pass Wiredrawing Process of Ultra-fine Steel Wire: Investigation on Stress, Strain and Hardness: *T. Saito*[1]; K. Saitoh[1]; [1]Kansai University
Recently, there occurs an increasing demand for high precision extra fine steel wires. In order to manufacture ultrafine wires with high accuracy, it is necessary to clarify processing behavior inside the wire. The purpose is to investigate change of mechanical state inside the wire that has been drawn multiple times. However, since it is insufficient to observe experimentally, elastic-plastic finite element simulation is applied to understand the properties. Some three-dimensional models to be machined continuously multiple times are prepared and analyzed. We compare multiple models with different die shapes and discuss mainly the effects of die shapes on wire's properties. In particular, it is successful that hardness is evaluated by our newly proposed methodology using materials mechanics. It is found that the smaller the die angle per pass, the smaller the difference in strain distribution inside the wire. The same tendency is obtained as the number of processes is increased.

Tuesday Keynote

Tuesday AM | July 27, 2021

Session Chairs: J. Cao, Northwestern University; F. Barlat, Pohang University of Science and Technology

7:30 AM Keynote
Numerical Modeling of Ductile Damage during Metal Forming: State of the Art and Future Challenges: *P. Bouchard*[1]; [1]Mines ParisTech
Despite numerous studies, the prediction of ductile damage and failure during metal forming processes still needs further investigations in particular for complex loading paths. Ductile damage analysis is usually addressed through uncoupled failure criteria or coupled damage models. Both approaches rely either on micromechanical bases or on phenomenological considerations. After a short review of these different approaches, the talk will focus on the main complexities related to damage analysis during metal forming processes. Strain rate and temperature effects, complex multiaxial stress states, non-proportional and cyclic loading conditions will be addressed with examples given at the process scale, whereas a micro-scale finite element framework will also be presented to get a better understanding of some of the physical mechanisms arising in such complex loading conditions.

8:15 AM Keynote
Recent Advances on Modeling Plastic Deformation of Textured Metals with Applications to Metal Forming: *O. Cazacu*[1]; [1]University of Florida
An accurate description of the yield surface defining the onset of plastic deformation is essential for high-fidelity numerical predictions of forming processes. Due to the ease in calibration from simple tests, generally von Mises isotropic criterion and Hill orthotropic criterion are used in industry. While more advanced 3-D yield criteria have been developed, generally such criteria are written in terms of eigenvalues of transformed stress tensors and as such the anisotropy coefficients are not directly expressible in terms of mechanical properties. Using general representation theorems, generalizations of the isotropic invariants J2 and J3 such as to account for plastic anisotropy have been developed. Using these anisotropic invariants, the anisotropic form of any isotropic yield function can be obtained simply by replacing J2 and J3 with their respective anisotropic generalizations. This framework ensures that the minimum number of anisotropy coefficients is specified. Illustrative examples of full three-dimensional yield criteria expressed in terms of generalized invariants and their application to the prediction of formability of single crystals and polycrystalline FCC, BCC and HCP materials are presented.

Agile MF II

Tuesday AM | July 27, 2021 | 9:15 - 10:15 AM

Session Chair: J. Cao, Northwestern University

Numerical Modelling and Deformation Mechanics of the English Wheel Process: *D. Bowen*[1]; A. Erdinç[2]; A. Shokrani[1]; O. Music[2]; E. Loukaides[1]; [1]University of Bath; [2]TED University

The mechanisation of traditional craft processes can serve as a starting point for novel process development in the increasingly topical field of flexible metal forming. This approach presents several challenges including understanding the underlying mechanics, mechanization and providing suitable control methods for such processes. Here, we focus on the underlying mechanics of the process known as the English wheel. In this work, the process is studied through numerical modelling techniques. The process boundary conditions present a particular modelling challenge not often encountered when modelling conventional industrial processes. Different modelling methods to capture these boundary conditions are explored and results are compared with physical trials performed in the lab. A parametric study identifies geometrical capabilities and limits of the process, when varying the machine configuration.

A New Test Method for Sheet Metal Deformation Subjected to Tension under Cyclic Bending and Compression (TCBC): *H. Long*[1]; S. Ai[1]; F. Tian[1]; B. Lu[1]; J. Chen[2]; H. Ou[3]; [1]The University of Sheffield; [2]Shanghai Jiao Tong University; [3]The University of Nottingham

A new test method for sheet metal deformation, Tension under Cyclic Bending and Compression (TCBC), is developed in this study. The TCBC method is capable of testing material deformation under tension, bending and compression with cyclic loading. The effect of each deformation mode can be independently controlled by adjusting corresponding parameters. A TCBC test rig is designed and manufactured and an aluminium alloy is tested under four deformation modes: simple tension, tension under cyclic bending, tension under cyclic compression, and tension under cyclic bending and compression. The maximum elongation and fracture occurrence of the tested specimen under different deformation modes are compared. It has been found that the maximum elongation increases significantly under TCBC condition due to strengthened localised plastic deformation which delays the fracture. The new TCBC method can be used for testing material formability in incremental sheet forming processes, such as single point and double side incremental forming.

Incremental Collar Forming Process for the Manufacturing of Branched Tubes and Pipes: *A. Leonhardt*[1]; P. de Witt[1]; M. Rehm[1]; V. Kräusel[1]; [1]Chemnitz University of Technology

Beside the manufacturing of finished parts by Incremental Sheet Forming (ISF) final operations within the process chain can also be realized with this technology. The technological capabilities of performing incremental (hole-)flanging operations for sheet metal parts has been investigated in research context. The current topic focusses on the transfer of the incremental forming technology to manufacture tubular parts. An incremental collaring process was developed where all motions are executed by the forming tool. Due to the fixed position of the workpiece, tubes as well as pipes can be branched. Stainless steel tubes made of 1.4404 (316L) with an outer diameter of 54 mm and a wall thickness of 1.5 mm were used for numerical simulation with FE-software Abaqus/Explicit and comparative forming experiments. The influence of varying process parameters (e.g., pre-hole geometry, step size) on the properties of the tube collar (e.g., geometric accuracy, wall thickness) was investigated.

Tube Roll Forming Flower Design and Flexible Roll Adjustment with CAE Simulation: *J. Sheu*[1]; B. Wang[1]; C. Yu[1]; [1]National Kaohsiung University of Science and Technology

The roundness and the angle of the edges on the cross-sectional profile at the exit of fin pass are crucial for the welding quality of the ERW tube. In this paper, the adjustment of the bending angles of break down rolls, the top and the side caging positions, and the fin pass gap were proposed to control the cross-sectional geometry and dimension accuracy of the roll formed blank at the exit of fin pass station. The roll forming machine layout is capable of making tube with diameter range from 5 to 13 inches. The CAE simulations were carried out to verify the proposed roll flower designs and the roll adjustment strategies. The CAE predictions showed the same flower design should have different roll adjustments for different tube size. The sound roll formed blank were obtained with proper roll adjustment and roll flower design.

On the Geometrical Accuracy in Incremental Sheet Forming: *G. Hirt*[1]; R. Kordtomeikel[1]; T. Bremen[1]; M. Laugwitz[1]; D. Bailly[1]; [1]Institute of Metal Forming - RWTH Aachen University

The industrial application of incremental sheet forming (ISF) still stays behind the expectations due to the low geometrical accuracy of the produced parts as well as the insufficient predictability of the forming result. This is due to the fact that some mechanisms which cause the geometrical deviations are not fully understood. Many investigations have already been carried out to determine, which types of stresses induced by ISF influence the forming result. This paper tries to systematically categorize selected typical geometric deviations and to review their underlying mechanisms based on current literature as well as own experience. The intention is to provide a structured basis for future scientific discussion and to stimulate an exchange of experience, with the goal, that a better understanding may help to improve the geometrical accuracy of parts manufactured by incremental sheet forming.

Investigation of an Integrated Process for Bending and Cross Section Forming of Tubular Lightweight Parts Based on a Working Media Made of Materials with High Plasticity: *M. Hermes*[1]; V. Holstein[1]; [1]University of Applied Science South Westphalia

Thin-walled steel profiles are the key to cost efficient lightweight structures. Structure parts and design elements in cars and trucks are often based on curved and hydroformed profiles. The possible production chains for steel profiles are often long and complex and the machines and tools are expensive and the flexibility is bad. For smaller production lots e.g. for applications in aircraft industry these processes are not efficient. This paper shows a solution for smaller and middle sized production lots realized by an integrated process for bending and cross section forming of tubular lightweight parts by a forming operation based on a working media made of plastic materials. The paper shows the process idea, the mechanism, the process analysis and the process limits.

Numerical Modelling of the Flow Forming Process: Computation Time Optimization and Accuracy Analysis: A. Roula[1]; *K. Mocellin*[1]; P. Bouchard[1]; [1]CEMEF Mines ParisTech

Flow forming is an incremental forming process during which a roller tool deforms a rotating sheet metal by applying a force which is local and evolving during the entire process. The finite element software FORGE® is used in order to model this process. The local tool-workpiece contact conditions and the high rotation speed make the modelling of this process difficult with high computation time. It is therefore necessary to develop optimization strategies aiming to reduce the computation time whilst maintaining a sufficient level of results accuracy. A first configuration optimization method consists in reducing the geometry of the initial blank and using symmetry planes. The final reduced geometry obtainable is 36° wide. This method is then associated with a second one which consists in reducing the number of calculation time steps during the entire process. The calculation time steps removed are those occurring when the roller tool is not in contact with the deformable sheet metal anymore. The two combined methods give the ability to drastically reduce the computation time compared to the reference case. In addition, the global and local results of the reference case are mostly conserved when applying the configuration optimization methods.

The Effect of Ultrasonic Vibration on Material Movement in Incremental Sheet Forming: *R. Cheng*[1]; A. Bansal[1]; J. Kang[2]; X. Liu[2]; A. Taub[1]; [1]University of Michigan; [2]The Ohio State University

Applied mechanical vibration in various manufacturing processes, usually at ultrasonic frequencies of 20kHz, has been shown to influence the forming and friction forces. The material softening behavior under superimposed ultrasonic vibrations is known as acoustoplasticity. This paper investigates the effect of acoustoplastic softening phenomenon on material movement in incremental forming of AA7075 sheets. A 45° cone is formed using a two-point incremental forming strategy (TPIF). Added ultrasonic vibration shows higher amount of material movement, which is supported through quantitative measurements including greater bulge height, surface profilometry, and thickness distribution around the tool contact area. Surface roughness measurements, relative to the depth of the geometry, increases with progressive forming. This coincides with the notion of greater material movement, accumulation, and surface deformation.

Constitutive Behavior II

Tuesday AM | July 27, 2021 | 9:15 - 10:15 AM

Session Chair: T. Kuwabara, Tokyo University of Agriculture and Technology

Experimental Study and Modelling of Stress Relaxation Ageing Behaviour and Post-form Mechanical Properties in Creep Age Forming of Al-Zn-Mg Alloy: *Y. Li*[1]; F. Lyu[2]; Z. Shi[1]; Y. Zeng[2]; X. Huang[2]; J. Lin[1]; [1]Imperial College London; [2]AVIC Manufacturing Technology Institute

The stress relaxation ageing behaviour and post-form mechanical properties of an Al-Zn-Mg alloy, AA7B04, have been experimentally investigated and modelled. Stress relaxation ageing tests were carried out under different initial stress levels and durations at 165 °C and subsequent tensile tests were performed at room temperature. The detailed effects of stress and time on stress relaxation and main post-form mechanical properties (yield strength, ultimate tensile strength and uniform elongation) have been analysed and discussed. Based on the results and analysis, a set of unified constitutive equations has been developed for the first time to simultaneously predict stress relaxation ageing behaviour of the aluminium alloy during creep age forming (CAF) process and the main mechanical properties of the products after CAF. The model is comprised of three sub-models, including microstructure, stress relaxation ageing and post-form mechanical properties, and has successfully predicted corresponding behaviour. The developed model provides an effective tool to not only predict the forming process, but also support possible industrial applications for CAF products.

Accurate Modelling of Flow Stress of AISI1025 at Room Temperature and Its Application to Precision Forging Simulation: M. Joun[1]; *M. Razali*[1]; J. Byun[1]; K. Lee[2]; [1]Gyeongsang National University; [2]Pungkang, HoaSeong

This paper evaluates and criticizes the Swift model of expressing strain hardening behaviours of metals at room temperature using an experimental tensile test and its FE prediction. A concept of reference flow stress curve composed of two ranges of strain divided by the true strain at the necking point is proposed, which predicts tensile test exactly from the standpoint of engineering and is thus employed to evaluate the Swift model. It has been shown that it has a weak point in describing the flow stress of typical strain hardening material with emphasis on necking. An improved Swift model is applied to obtain accurate flow stress of a commercial steel AISI1025 and it is employed to simulate a sequence of cold forging processes by precision complete analysis for process and die optimal design in terms of die life, which should be conducted under an accurate analysis model.

Stress-relaxation Age Forming of A Component with Complex and Large Curvatures: Simulation and Manufacturing: Q. Rong[1]; *Z. Shi*[1]; Y. Li[2]; J. Lin[1]; [1]Imperial College London; [2]Beihang University

Stress-relaxation age forming (SRAF) of a panel component (820*300*3 mm) with complex and large curvatures has been simulated and corresponding SRAF test of an Al-Mg-Si alloy, AA6082-T6, has been carried out in this study. An FE model is established to simulate the stress-relaxation ageing (SRA) behaviour of AA6082 during SRAF at various stress levels, for the first time, ranging from elastic to plastic regions and a unified constitutive model for SRA of the material has been implemented into finite element (FE) software ABAQUS via the user-defined subroutine CREEP. An optimised tool surface was determined from FE simulation through springback predication and compensation and was used for manufacturing test. A good agreement of the formed shape has been achieved between the FE simulation and the SRAF test, with a maximum shape error below 4 mm, satisfying the industrial requirement. Hardness results from the formed plate show insignificant change of strength during SRAF, in good agreement with the simulation. The effects of the initial plastic strain and creep strain generated during loading and stress-relaxation stages on the formed shape have also been analysed.

CANCELLED: Rate Dependent Hardening Behavior of Autobody Sheet Metals in Tension and Compression: *H. Huh*[1]; [1]KAIST

This paper is concerned with evaluation of rate-dependent hardening behaviors of auto-body sheets with novel tension and compression testing devices. Hardening behaviors in tension and compression are indispensable for accurate numerical simulation of sheet metal forming and subsequent spring-back as well as crashworthiness. Novel in-plane tension and compression testing devices are developed with a servo-hydraulic testing machine to obtain tension-compression hardening curves of auto-body steel sheets at intermediate strain rates ranging from 0.001 s-1 up to 100 s-1. With the testing devices specially developed, hardening behaviors are evaluated in tension-compression for mild steel sheets, TRIP980, TWIP980 steel sheets and magnesium alloy at various strain rates ranging from 0.001 s-1 to 100 s-1 in terms of the flow stress considering the Bauschinger effect and the permanent softening. It is observed that the stress offset is dependent on the inherent characteristics of steel sheets as well as the strain rates.

Flow Behavior and Processing Map of a Nickel-based Superalloy during Hot Plastic Deformation Process: *B. Zhang*[1]; S. Huang[2]; W. Zhang[2]; B. Zhang[2]; Y. Ning[1]; [1]Northwestern Polytechnical University; [2]Central Iron and Steel Research Institute

Nickel-based superalloys have been widely used to produce high performance components in advanced engine. In present research, isothermal compression tests of GH4065A Nickel-based superalloy were conducted at deformation temperatures of 1020-1140°C and strain rates of 0.001-1.0s^{-1}. The deformation temperature and strain rate have a significant effect on the true stress-strain curves, from which the intrinsic connection between the flow stress and deformation behavior can be systematically studied. The apparent activation energy of deformation was calculated to be 454.5kJ/mol at the strain of 0.65 when the flow stress was steady. Meanwhile, the constitutive equation was constructed for modeling the hot plastic deformation of this superalloy. Based on the microstructure observation, the influence of hot processing parameters on microstructure has been deeply explored. Moreover, the microstructural mechanism during hot plastic deformation was revealed, which can provide the optimization of hot forging process for manufacturing high performance components in advanced engine.

Hot Deformation Behavior and Constitutive Modeling of a Novel Ni-based Superalloy: *H. Yu*[1]; Q. Liu[1]; H. Yang[1]; B. Zhang[1]; B. Xie[1]; Y. Ning[1]; [1]Northwestern Polytechnical University

Ni-based superalloys are widely used to manufacture the key components in gas turbine engine,since their superior mechanical properties at elevated temperature.In present work, hot deformation behavior of a novel Ni-based superalloy was investigated by compression test at temperatures of 1020-1140°C and strain rates of 0.001-10s-1.At low temperature and high strain rates, the flow stress rapidly increased to a peak value due to work hardening. However, at high temperature and low strain rates, the flow curves exhibited typical dynamic softening stage. The hot deformation activation energy of the studied superalloy is determined to be 735.5KJ/mol, and a strain compensated Arrhenius type constitutive equation is obtained.Comparison of the predicted and experimental values, the developed constitutive equation can accurately describe the deformation mechanism and the flow behavior.Meanwhile, the influence of hot processing parameters on microstructure has been deeply explored, which can optimize the process parameters for manufacturing key components in gas turbine engine.

Constitutive Model and Plate Forging Ability of 5052 Aluminum Alloy under Different Temperatures: L. Qiquan[1]; *Y. Li*[1]; D. Wenzheng[1]; W. Zhigang[2]; [1]Xiangtan University; [2]Gifu University

The paper was concerned with plate forging of Al5052. Biaxial tensile tests were conducted to obtain the rheological behavior and stress-strain curve of Al 5052 under warm temperature. An FEM model utilizing the data mentioned above was proposed to simulate the solid boss process of Al5052 by sheet-bulk forming. It was interesting to find out that boss height and forming defects vary with the combination of process parameters. Thus five factors and four level orthogonal experiment table was designed to study the effect of counter-punch force, boss diameter, boss radius, initial sheet thickness and friction coefficient on boss height and dimple defect. The results indicated that boss diameter and counter-punch force play the most important role on the boss height and defect, respectively. Finally, the corresponding experiments were consistent with the numerical prediction results.

Analysis of Creep Behavior of Magnesium Alloy Sheet (AZ31B) in Warm Forming: *J. Yu*[1]; C. Lee[1]; [1]Seoul National University of Science and Technology

In this study, spring-back of magnesium alloy sheet in V-bending was observed according to holding time in the die set and plastic deformation at warm forming conditions. Also, the creep behavior of the magnesium alloy sheet was investigated in the numerical simulation to analyze the spring-back. At room temperature, the spring-back is 28.11° and 24.99° at holding time of 0 and 1000sec respectively. Also, at 250°, the spring-back is 11.46° and 1.12° at holding time of 0 and 1000sec respectively. The results indicate that creep recovery occurs by increasing holding time in the die set during the warm forming. The experiment was conducted at different punch radius R(1, 2, 4, 5mm) to analyze the effect of creep recovery velocity on the spring-back during V-bending operation. Furthermore, Microstructure observations were conducted for detail insight into the results.

Effect of Short Pulsed-current on Stress Relaxation in Uniaxial Tensile Test: *I. Indhiarto*[1]; Q. Zheng[2]; T. Shimizu[1]; T. Furushima[2]; M. Yang[1]; [1]Tokyo Metropolitan University; [2]University of Tokyo

Electricity assisted metal forming, especially using pulsed-current, was demonstrated to promote drop in flow stress and improving formability. To investigate the effect of pulsed-current on stress relaxation, an uniaxial tensile test was conducted with different pulsed-current parameters by changing its pulse-width and frequency. Employed short pulse width was in range of microsecond, while the frequency was arranged under 1 kHz. Different level of temperature was employed to consider effect from joule heating. Stress relaxation in tensile test was repeated at constant strain interval at 3% strain. This research present analysis of stress relaxation influenced by time-dependent parameter of short pulsed-current

Metal Forming Process II

Tuesday AM | July 27, 2021 | 9:15 - 10:15 AM

Session Chair: H. Utsunomiya, Osaka University

Forming of PMMA Sheets by Lap Incremental Forming with Local Friction Heating: *M. Otsu*[1]; K. Tanaka[1]; T. Miura[1]; M. Okada[1]; [1]University of Fukui

A new forming method for PMMA sheets using friction stir incremental forming was proposed. In this method, A5052 sheets, A1050 sheets and PMMA sheets are overlapped and formed simultaneously. PMMA sheets which size was 185 mm x 185 mm and thickness were 0.5, 0.2 and 2 mm were employed for specimens. A hemispherical tool with a diameter of 6 mm was used. The tool was rotated at 6000 - 12000 rpm and moved at 1000 - 4000 mm/min. Sheets were formed into a frustum of conical shape with the height of 40 mm and wall angles of 45° - 65°. Shape of formed sample was measured and compared with the objective shape. From the experimental results, formed sheet surface roughness was Ra = 4.45 μm and Rz = 25.89 μm. The limit of formable wall angle was 60°.

Research of Press Forming of CFRTP under the Control of a Distribution of Temperature and Blank Holder Force: *M. Hoshino*[1]; Y. Nagai[2]; [1]Nihon University; [2]Tamagawa University

In recent years, industry field has an increasing demand for high strength and lightweight carbon fiber reinforced plastics (CFRP). Furthermore, next request is reduction of forming time. But carbon fiber reinforced thermosetting resin (CFRTS) that is commonly used can not shortening molding time any more. For the purpose of shortening molding time and reducing production cost, carbon fiber reinforced thermoplastics (CFRTP) has been researched. CFRTP does not require chemical reactions to molding. So it is possible for CFRTP to shorten molding time. In this study, the purpose is reduction of molding time by application press forming for CFRTP. By fundamental experimental results, it is clear that non-uniform temperature is distributed over blank in hot press forming and there is porosity in some forming condition. By optimizing a distribution of temperature and blank holder force, formability of CFRTP could be improved.

Research Progress on Advanced Forming and Performance Strengthening of Complex Thin-walled Aluminum Alloy Components: *Y. Song*[1]; L. Hua[1]; J. Lu[1]; P. Zhou[1]; W. Wu[1]; [1]Wuhan Universtiy of Technology

Aluminum alloy is the most potential lightweight material, which has been widely used in aviation, aerospace, automobile, high-speed rail and so on. Advanced forming and performance strengthening methods of complex thin-walled Aluminum alloy components have been the focus of international research. In this paper, the latest research progress in the field of forming and performance strengthening of aluminum alloy sheets and components is reviewed, including isothermal tensile deformation behavior, constitutive equations, processing mapping, friction and wear behavior at high temperature, dynamic strain aging and electromagnetic shocking treatment(EST).Then the technical difficulties and development trend of aluminum alloy forming manufacturing are discussed.

Friction Based Solid State Recycling: An Industry-ready Technology?: *A. Latif*[1]; G. Buffa[1]; G. Ingarao[1]; L. Fratini[1]; [1]University of Palermo

Conventional recycling routes for aluminum alloys, based on remelting, are not efficient in terms of energy demand and, what is more, permanent material losses occur because of oxidation. In order to overcome such issues, researches have turned to Solid State Recycling (SSR) strategies, directly turning aluminum scraps into semi-finished products by avoiding the remelting step. Within this process category the authors have focused on friction based SSR methods. In these processes, the work of the friction forces between the die and the material being processed decays into heat causing material softening, thus allowing solid bonding activation. In the proposed presentation the authors will discuss strengths and weaknesses of two process variants: Friction Stir Extrusion and Friction Stir Consolidation. Process mechanics, process engineering (both experimental and numerical) and potential environmental savings will be presented along with the knowledge gap to be still covered to get these processes suitable for industrial applications.

Microstructure and Damage Development II

Tuesday AM | July 27, 2021 | 9:15 - 10:15 AM

Session Chair: I. Beyerlein, University of California, Santa Barbara

Analysis of Cross-hardening by High Resolution Orientation Imaging: *T. Clausmeyer*[1]; G. Gerstein[2]; F. Gutknecht[3]; F. Nürnberger[2]; [1]Instiute of Forming Technology and Lightweight Components (IUL), TU Dortmund; [2]Leibniz Universität Hannover; [3]Instiute of Forming Technology and Lightweight Components (IUL), TU Dortmund University

Sheet metals undergo several loading path changes in sheet-bulk metal forming (SMBF). Ferritic steels an other materials exhibit cross-hardening after orthogonal loading path changes. Cross-hardening is induced by the interaction of currently active dislocations with persistent dislocation structures which have formed during previous loading. The analysis of persistent microstructures requires transmission electron microscopy (TEM) or electron contrast channelling imaging (ECCI). An alternative approach is to apply high-resolution electron backscatter diffraction (EBSD) to detect inter- and intragranular misorientations. These provide information of the substructure in sequences of uniaxial pre-straining followed by simple shear. Such methods are used to detect orthogonal strain path changes in components manufactured by sheet-bulk metal forming. The microstructural evidence is compared with macroscopic stress strain data for the steel DC04.

Assessment of Calibration Strategies and Model Predictions for Damage in Formed Components: *A. Schowtjak*[1]; O. Hering[1]; R. Meya[1]; A. Tekkaya[1]; T. Clausmeyer[1]; [1]Institute of Forming Technology and Lightweight Components (IUL), TU Dortmund University

The existence and evolution of voids affect component properties such as mass density, strength and elastic stiffness. Material models for the prediction of such properties need to be calibrated. In this work, an efficient and robust methodology for the parameter identification that enables an accurate prediction of the void area fraction is presented. A parameter identification scheme based on macroscopic quantities is applied to a Lemaitre damage model. This model is used to predict the void evolution in the process chain of calibre rolling with subsequent forward rod extrusion. Additionally, a parameter identification strategy based on experimental void analysis is performed for a Gurson-Tvergaard-Needleman model and applied to air bending. Both strategies are analysed with regard to their prediction qualities in terms of void evolution based on high-resolution scanning electron microscopy measurements. The predicted mass density and strength are compared to experimental data to assess the quality of prediction.

Influence of Specimen Preparation Methods on the Mechanical Properties and Superplastic Behavior of AA5083 Sheets: *M. Dastgiri*[1]; L. Kiawi[1]; I. Sari Sarraf[1]; D. Green[1]; [1]University of Windsor

Edge quality has a considerable effect on characterization of sheet materials. In this study, AA5083 sheet specimens were prepared using 4 different methods: shear, wire-EDM, waterjet cutting and conventional milling. Mechanical properties were determined from tensile tests carried out at 450˚C and quasi-static strain rates. Optical microscopy and scanning electron microscopy were used prior and after tension tests to analyze the relation between the quality of the edge and mechanical properties. It was found that milled specimens resulted in considerably greater values of total and uniform elongation. Moreover, milling by removing material in smaller increments also leads to slightly greater elongation values. The microscopic investigation revealed that specimens whose edges have lower arithmetic mean roughness (Ra) have greater values of elongation. The SEM investigation also revealed that micro-cracks are more prevalent at the edges of specimens that have a greater surface roughness.

An Extended GTN Ductile Fracture Model for a Broad Range of Stress States: H. Wu[1]; *X. Zhuang*[1]; Z. Zhao[1]; [1]Shanghai Jiao Tong University

This contribution provides an extended GTN model for predicting damage and fracture of metallic materials under high, low and negative stress triaxiality loadings. In this proposition, two internal damage variables are introduced into GTN model in order to affect the hydrostatic stress and deviatoric stress contributions. The first damage variable is void volumetric damage due to the nucleation, growth, inner-necking of primary voids and nucleation of secondary voids. The void shear damage is proposed as the second damage variable taking the void rotation, distortion and secondary nucleation into account. A novel effective damage is constructed to combine these two damage contributions during the deformation. The extended GTN model has been implemented into ABAQUS/ Explicit and the parameters are calibrated through the inverse analysis under different stress states. The validity of the new model is assessed by comparing numerical prediction with experimental measurements.

The Local Strain Evolution for Structured Sheet Metals during Uniaxial Deformation: *E. Ermilova*[1]; A. Nikitin[1]; S. Weiss[1]; [1]Technical University of Brandenburg at Cottbus-Senftenberg

Structured materials can be progressive alternatives to commonly used flat sheets because of their higher bending stiffness and stability compared to flat sheet metals, made of the same alloy. The application of sheet metals requires accurate information regarding their strength and deformation behavior. Such data are not commonly available and have to be measured by specific test set ups and implementation of tests. The aim of this work is to obtain new knowledge about deformation mechanisms of structured sheet metals. Structured sheet metals (SSM) made of conventional deep-drawing steel DC04 were investigated by means of tensile tests. The influence of the structure type arrangement on the deformation behaviour was analyzed. The evolution of local strains was analyzed by means of strain gauge measurements as well as 3D-displacement measurements with an ARAMIS high resolution camera-system. Local orientation changes in different structural elements were measured using the electron backscatter diffraction technique.

Rob Wagoner Honorary Symposium I

Tuesday AM | July 27, 2021 | 9:15 - 10:15 AM

Session Chair: H. Lim, Sandia National Laboratories

Forming Limit Results Comparing the Bragard Technique with a Statistical, Deformation-history Analysis: *M. Stout*[1]; J. Signorelli[1]; A. Roatta[1]; [1]Instituto de Física Rosario, CONICET, Universidad Nacional Rosario

We designed a laboratory scale, Marciniak and Kuczynski, testing device to record the deformation history from limit-strain experiments and used this equipment to test a commercially designated Zn20 sheet and a drawing-quality steel. Reference limit strains were calculated with the Bragard analysis, norm ISO 12004-2, and we compared these results to a time-history approach based on Pearson's correlation coefficient. The Bragard analysis uses the deformations outside of the necking instability to calculate the strain limits, while the time-history approach studies the deformation history within the plastic instability. For the highly rate-sensitive Zn20 the Bragard standard is conservative for all strain states. For the moderately strain-rate sensitive steel, results from the two techniques were nearly identical in balanced-biaxial tension. However, the Bragard analysis is again conservative for plane-strain and uniaxial-tension deformations. Our results indicate that the Bragard and temporal analysis should be combined to obtain the optimal forming-limit diagram.

Constitutive Hardening Model Development for Materials with Evolving Microstructural Phase Constituents: *K. Raghavan*[1]; J. Hu[1]; E. Pavlina[1]; X. Hu[2]; J. Cheng[2]; X. Sun[2]; [1]AK Steel; [2]Oak Ridge National Laboratory

Next generation advanced high strength steels and metastable austenitic stainless grades show considerable evolution in their microstructural phase constituents due to transformation of austenite into martensite during deformation. The austenite to martensite transformation depends on strain rate, temperature, deformation mode and intrinsic composition dependent austenite stability. In this study, we examine stress strain behavior at different strain rates (0.001/s – 1000/s) for representative advanced high strength third generation austenite containing Q&P steels and metastable austenitic stainless steels. Applicability of several constitutive hardening models, both phenomenological and based on transformation modeling, are explored to describe the experimental stress-strain data.

Investigating Plastic Anisotropy of Al7079 Using Crystal Plasticity Simulations: *H. Lim*[1]; S. Kramer[1]; E. Corona[1]; A. Jones[1]; B. Reedlunn[1]; T. Park[2]; F. Pourboghrat[2]; [1]Sandia National Laboratories; [2]The Ohio State University

Processing techniques used to produce polycrystalline metal alloys often result in preferred crystal orientations with associated plastic anisotropy. While various anisotropic plasticity models are used to predict final shapes and prevent catastrophic failure, more predictive models require multiple mechanical tests at various orientations and stress states to fit many model parameters. In order to efficiently characterize and predict plastic anisotropy without extensive mechanical tests, crystal plasticity finite element method (CPFEM) simulations using initial microstructural data from EBSD and XRD measurements are performed and compared with experiments. Tensile tests of Al7079 at various directions are performed to obtain stress-strain response and r-values. It is shown that CPFEM model incorporating the texture and grain morphology of Al7079 captures anisotropic mechanical behavior and r-values reasonably well. In addition, various factors that may influence the accuracy of the anisotropy prediction are investigated.

Simulated Microstructure Effects on Macroscopic Mechanical Properties Based on Multiscale Crystal Plasticity: *Y. Aoyagi*[1]; R. Kobayashi[1]; D. McDowell[2]; [1]Tohoku University; [2]Georgia Institute of Technology

Multiaxial stress state causes complex deformation in sheet metal forming. Sheet metals produced by severely rolling show mechanical anisotropy depending on the strong rolling texture. While crystal plasticity simulations considering actual microstructure information has attracted attention with developing of microscopic observation of metals using the electron backscattered diffraction pattern (EBSD) method. However, a uniaxial tensile test generally determines mechanical properties used for the crystal plasticity simulation by neglecting the mechanical anisotropy. In this study, crystal plasticity simulation on severely rolled metals is carried out to investigate the effects of microstructures of metals on mechanical properties. Yield surfaces are predicted by crystal plasticity analyses based on the microstructure observed using EBSD method and stress-strain curves obtained by uniaxial and biaxial tensile tests. Extreme value distributions of mechanical properties estimate the effects of the microstructures.

Relating Microstructure to Deformation in Al Alloys via Multiscale Electron Microscopy: *J. Kacher*[1]; Y. Yoo[1]; [1]Georgia Institute of Technology

Ductile fracture is an inherently multiscale processes, ranging from nanoscale crack nucleation mechanisms to collective dislocation interactions ranging across hundreds of microns. Understanding these processes requires multiscale characterization approaches that reflect the nature of the processes. A key factor in these multiscale approaches is the ability to quantify data in such a way that information can be passed between the length scales. In this talk, I will discuss the application of multiscale electron microscopy techniques to understanding fracture in Al 6xxx alloys under different loading conditions. Heat treatable Al alloys provide an especially interesting case study as they are composed of a range of secondary particles, including distributed intermetallic particles, dispersoids on the order of single microns, and precipitates, as well as heterogeneities inherent to polycrystalline materials. Results will be discussed in terms of ductile fracture processes and the general applicability of multiscale electron microscopy to understanding deformation and failure.

Descriptions of Several Cyclic Plasticity Phenomena Based on Y-U Model: Elastic-plastic Transition, Closure of Stress-strain Loop and Ratcheting: *F. Yoshida*[1]; [1]CEM Institute Corporation

For numerical simulation of springback, an accurate description of stress-strain response in the elastic-plastic transition region, specifically unloading process, is of vital importance. This paper describes its constitutive modeling based on the Yoshida-Uemori (Y-U) kinematic hardening law, along with the description of nonlinear unloading-reloading stress-strain behavior. For modeling of nonlinear unloading, it is treated as the nonlinear elasticity, which is directly associated with the plastic-strain dependent chord modulus. Cyclic plasticity modeling for the subsequent small-scale plastic region is discussed. Furthermore, the descriptions of closure of a cyclic stress-strain hysteresis loop and ratcheting are presented. For the above modeling, no additional material parameters are needed. The model was validated by comparing the numerical simulation of stress-strain responses with the corresponding experimental observations in advanced high-strength steel sheets.

Advancing the Accuracy of Computational Models for Double-sided Incremental Forming: *N. Moser*[1]; D. Leem[2]; S. Liao[2]; K. Ehmann[2]; J. Cao[2]; [1]National Institute of Standards and Technology; [2]Northwestern University

Double-Sided Incremental Forming (DSIF) is a rapid-prototyping manufacturing process for metal forming that, for low-volume production, is competitively energy-efficient. However, controlling DSIF for arbitrary designs with respect to accuracy and formability is an ongoing challenge. These challenges arise due to a lack of understanding (and control) of the underlying deformation mechanisms in DSIF. And so, there is a need for high-fidelity simulations of DSIF that unravel these underlying complexities. Moreover, DSIF pushes the limits of today's finite element formulations due to true strains that approach one, finite rotations, nonlinear contact, and triaxial stress states that range across multiple length scales. To confidently develop a finite element model of DSIF, an extensive verification and validation process must be considered, which is the objective of this study. Differing finite element types, boundary conditions, and amounts of artificial acceleration are compared, and recommendations based on efficiency and accuracy are summarized.

New Generation Press Hardening Steels with Tensile Strength of 1.7-2.0GPa and Enhanced Bendability: *J. Wang*[1]; Q. Lu[1]; X. Xiong[1]; H. Yi[1]; [1]General Motors China

Press hardened components are widely used in a vehicle's body structure to increase safety and reduce mass for improved fuel economy. The commercial steel grade is the boron-containing 22MnB5 with 0.22-0.24 in wt% carbon, which can achieve a tensile strength of 1.5GPa. As vehicle lightweighting increasingly becomes a design imperative for automotive industry, it is desired to utilize press hardened components with strength exceeding 1.5Gpa by increasing carbon to 0.30-0.35 in wt%. However, increased carbon content often reduces fracture resistance under bending. This paper investigates bendability of two new press hardening steels. The first steel, with a tensile strength of 2.0Gpa, is coated with aluminum silicon to avoid oxidation and scaling during the hot stamping process. The second steel, with a tensile strength of 1.7Gpa, does not have any pre-coating and yet it is oxidation resistant at hot stamping temperature. Mechanisms of achieving enhanced bendability are also discussed.

A Critical Review on the CPFEM Models Accounting for Gain Boundary Hardening Effect and Some Developments toward Simplification of the Wagoner Super-Dislocations (SD) Model: *Y. Shen*[1]; R. Chen[1]; G. Liu[1]; [1]Shanghai Jiao Tong University

Grain boundary hardening effect is an important but difficult topic in crystal plasticity finite element method (CPFEM). CPFEM Models accounting for grain boundary effect are critically reviewed from 3 aspects: 1) The key gradients in the model, 2) Comparison to the simple two-phase composite model, 3) Comparison to the "real or ideal" slip profile evolution. Based on these critical reviews, the Wagoner super-dislocations (SD) model for grain boundar hardening is developed with an emphasis on its simplification. Performance of the simplified model is evaluated.

Characterization of Plasticity and Ductile Fracture of Metals under Proportional and Non-proportional Loading II

Tuesday AM | July 27, 2021 | 10:20 - 11:20 AM

Session Chair: F. Yoshida, CEM Institute Corporation

Work Hardening and Fracture Strain Measurement of Hardened SKD11 Steel Using Shear Punching Test: *T. Matsuno*[1]; K. Nakagiri[1]; H. Shouji[2]; M. Ohata[2]; [1]Tottori University; [2]Osaka University

This study identified the work-hardening parameters and fracture strain of a hardened die-steel (SKD11). Due to the brittle behavior of SKD11 in tensile tests, a shear punching test was used as the low stress-triaxiality suppresses material fracture. Furthermore, a minute punch-die clearance was used to increase the compression stress due to material deformation. SKD11 steel sheets of 1.0 mm thickness were successfully deformed, and the punching force and stroke were recorded for inverse analysis using the finite element analysis (FEA). Subsequently, FEA of the shear punching test was repeated to optimize the parameters of Swift's work-hardening law. Consequently, the Swift parameters were derived to ensure that the measured values of the punching force and stroke correspond with the numerically simulated curve. The fracture strain was identified as the maximum equivalent plastic strain at the punch stroke of specimen rupture.

Invited

Anisotropic Plasticity and Ductile Fracture of Titanium Alloy Sheet at Elevated Temperature: Characterization and Modeling: *H. Li*[1]; H. Yang[1]; [1]Northwestern Polytechnical University

Heat assistant approach is promising to promote the formability of hard-to-form materials such as titanium alloy sheets. However, under thermal-mechanical coupling effects, the non-uniform deformation related anisotropic plasticity, damage and fracture of the material may be complicated and urgently need to be fully understood and accurately described. Thus, the experiments along different loading directions under various temperatures are conducted, and a yield-fracture locus in the stress plane is attempted to be plotted, revealing the distinct anisotropic yield and fracture evolution of the alloy during various thermal-mechanical loading conditions. Then, considering the effects of temperature on anisotropy plasticity and damage, a heat related discontinuous plasticity-fracture model is established and numerically implemented into FE simulation to smoothly present the evolution of plasticity and fracture behaviors. The comparison between the experimental results and numerical ones verifies the proposed model for describing the anisotropy in plasticity and ductile fracture under various thermal-mechanical loading conditions.

Invited

Effect of Anisotropy Evolution on Several Sheet Metal Forming Processes: *F. Yoshida*[1]; [1]CEM Institute Corporation

Most of sheet-metal forming simulations assume that the anisotropy of a sheet is fixed constant throughout the forming process. However, some materials show apparent anisotropy evolution with increasing plastic deformation. This paper presents a framework of description of anisotropy evolution, where an anisotropic yield function, which varies continuously varies with plastic strain, is defined as an interpolation between two yield functions at two discrete levels of plastic strain. The effect of anisotropy evolution was examined for several types of sheet metal forming processes, such as hydraulic bulging, conical-cup drawing, and cruciform-shaped drawing, by performing these experiments on a mild steel and type-5000 aluminum sheets together with the corresponding finite element (FE) simulations. From the comparison of FE simulations with the experimental results, it was concluded that the description of anisotropy evolution is essential for accurate simulation.

New Methods for Fracture Detection of Automotive Steels: *J. Noder*[1]; C. Butcher[1]; [1]University of Waterloo

The VDA 238-100 tight-radius bend test has received significant attention from industry over the past decade because it provides a proportional plane strain – plane stress state until fracture. It will be demonstrated that the adoption of the vertical punch force as the unique metric for failure detection can lead to false positives. The punch force will reduce at large bend angles due to the mechanics of the test even in the absence of material failure. Two novel detection methods based on the nominal principal stress and the plastic work were evaluated on six different steel grades with a nominal ultimate tensile strength of approximately 590 MPa. For performance ranking of materials with the same strength level, the plastic work metric is found to be sufficiently sensitive to distinguish between various 590 MPa steel grades since the material hardening rate is directly embedded.

Joining by Forming and Deformation II

Tuesday AM | July 27, 2021 | 10:20 - 11:20 AM

Session Chair: Z. Huang, East China Jiaotong University

Mechanical Properties of Aluminum-stainless Steel Bimetal Composite Fabricated by Extrusion Process: *K. Fong*[1]; A. Danno[1]; D. Kumar[1]; S. Jirathearanat[1]; W. Ong[1]; [1]Singapore Institute of Manufacturing Technology

In this work, an indirect extrusion process was designed to manufacture a stainless steel reinforced aluminium composite. The design utilized a feeding mandrel to prevent the deformation of the stainless steel wire and to facilitate the embedding of the wire within the aluminium alloy during extrusion. By using this method, a 12 mm diameter 6061 aluminium alloy embedded with a 2 mm diameter 304 stainless steel wire was successfully fabricated. Energy-dispersive X-ray spectroscopy revealed that aluminium and iron elements had diffused into the interfacial layer between the aluminium-stainless steel to induce some degree of metallurgical bonding. The yield strength, tensile strength and elongation to failure of the extruded composite after solution and aging heat treatment were 343.8±5.5MPa, 405.3±5.1MPa and 18.0±1.3%, respectively. As compared to extruded aluminium, yield strength, ultimate tensile strength and elongation to failure were improved by 41.8%, 31.6% and 6.3%, respectively. This result suggests that the composite material has better strength and toughness as compared to aluminium alone.

Spot Butt Friction Stir Welding of Thin Stainless Steel Sheets: *H. Yoshimura*[1]; T. Muraoka[1]; T. Miura[2]; M. Okada[2]; Y. Takahashi[3]; M. Otsu[2]; [1]Kagawa University; [2]University of Fukui; [3]National Institute of Technology, Kagawa College

Spot butt friction stir welding of thin stainless steel sheets is proposed. The used material was 18%Cr-8%Ni stainless steel and thickness of the sheet was 0.1mm. In case of the thin metal sheet of such thickness, especially not overlap but butt joining, there are few previous researches. The difficulties are sheet rigidity, tool shape and tool position control. Because it is difficult to form the probe having complicated shape accurately, the semispherical shaped tool was used. The tool was rotated and moved to the position decided by the prescribed static pushing load. To avoid adhesion between sheets and a backing plate, a ceramic backing plate was selected. Effects of the tool rotation speed and the prescribed pushing load on weldability were examined. Only when the joining was successful, the characteristic load change by metallic adhesion between the tool and sheets was observed.

Temperature and Deformation Modeling for the Friction Stir Welding Process in AZ31 Magnesium Alloy: *R. Giorjao*[1]; J. Avila[2]; E. Monlevade[3]; A. Ramirez[1]; A. Tschiptschin[3]; [1]The Ohio State University; [2]UNESP; [3]USP

Friction stir welding (FSW) is a solid state joining process that uses frictional heat generated by a rotating tool to join materials. Yet, the tool role in the material processing, due to complex material flow and its difficult modeling, is still not entirely understood. In this matter, a computational solid mechanics numerical model aimed to simulate the FSW process in an AZ31 alloy is proposed. This model uses an Arbitrary Lagrangian-Eulerian code in two different pin profile tools, with threaded and unthread pins. Point tracking technique was applied in the model to provide deformation, velocity and temperature data both conditions. It was noticed that velocity and strain rate have higher values in the threaded condition. Finally, the point tracking data was applied in a grain size model and compare to the real microstructure, showing good consistency of the predicted temperature and deformation behavior calculated by the model.

Friction Stir Welding Applied in Joining of Armor Steel: A. Ramirez[1]; W. Evans[2]; *R. Giorjao*[1]; M. Eff[3]; M. McDonnell[4]; [1]The Ohio State University; [2]NASA; [3]EWI; [4]Combat Capability Development Center - Ground Vehicle Systems Center

Friction Stir Welding (FSW) is a solid-state joining technique that utilizes non-consumable tool to stir two materials into a joint. In this study FSW parameters were developed and used to weld Wrought Homogeneous Armor steel. Metallography, micro hardness indention, and thermal modeling was also employed to predict the joint's properties. Through this work parameters were down-selected to make defect free weld. Examining the micrographs and SEM images, the microstructure appeared to be fully martensitic. The martensite found in the stir zone (SZ) and heat affected zone has undergone auto-tempering as well. When examining the micro hardness profile of the weld, it appears that the SZ hardness is close to that of the base metal. This would indicate that some level of tempering is occurring during the welding process, leaving a tempered martensitic microstructure.

Elastoplastic Finite Element Analysis of Multi-body Processes for Joining Mechanical Parts: M. Joun[1]; J. Yoo[1]; *S. Chung*[2]; R. Sekar[2]; [1]Gyeongsang National University; [2]MFRC

Fabricating lightweight assembly of auto-parts is of great importance and joining technology using plastic deformation is very attractive because of high strength and structural reliability. In developing such assembling processes, prediction technology with high accuracy is essential to optimize the structural system and minimize the manufacturing cost. However, the related technologies are not still sufficiently developed for the sake of application because of complexity of the problem. Joining and other assembly processes highlight the requirement of a multibody metal forming simulation. In this paper, an improved methodology of conducting elastoplastic finite element analysis of multi-body processes is given and several examples are solved in terms of interfacial stresses or residual stresses and solution accuracy. A multi body simulation of an assembly process of the first-generation hub bearing unit is carried out and validated to illustrate the applicability of this methodology.

Microstructure Development by Forming I

Tuesday AM | July 27, 2021 | 10:20 - 11:20 AM

Session Chair: D. Hughes, Sandia National Laboratories

Microstructure Evolution during Isothermal Forging of 7A85 Aluminum Aviation Component: *H. Jianliang*[1]; Y. Yi[2]; M. Jin[1]; H. Bo[1]; [1]Yanshan University; [2]Central South University
A 7085 aluminum aviation component with high ribs and thin webs was successfully formed by the isothermal forging process, and its microstructure was investigated by optical microscope (OM), transmission electron microscope (TEM) and cellular automaton simulation. The cellular automaton model of 7A85 aluminum alloy, including dislocation density model, nucleation rate equation as well as grain growth model was established, and the parameters of the cellular automaton models were determined by the hot compression experiment on the thermal-mechanical simulator Gleeble-1500. The cellular automaton simulation results agree well with the optical micrographs of the aviation forging, showing good homogeneity in both the size and the distribution of grain structure. The TEM images show that a homogeneous distributed dislocations and precipitates of the forging formed by the isothermal forging process can be attained, which can inhibit the migration of the grain boundaries, resulting in the small and uniform grains of the aviation forging.

Forming of Parts with Locally Defined Mechanical and Ferromagnetic Properties by Flow-forming: E. Wiens[1]; W. Homberg[1]; *B. Arian*[1]; [1]Paderborn University
To generate a highly efficient use of material resources for formed parts a locally adoption of required strength and integrated functions is advised. By using austenitic steel, the volume fraction of deformation-induced alpha martensite, which has an influence on the strength and the magnetic permeability of the material, is highly dependent on the degree of deformation and the workpiece temperature in the deformation zone. By selective adjustment of the process parameters wall thickness reduction Δs and deformation temperature Td it was possible to produce local restricted areas with an alpha martensite volume from almost negligible to 80 % at the same deformation stage, using a spinning or flow forming process. This way axially graded and locally varying mechanical and sensory properties, e.g. for a magnetic displacement sensor, can be produced. The aim of this ongoing work is a closed loop control of properties by using micromagnetic sensors during spinning processes.

CANCELLED: Microstructure and Thermomechanical Properties of AA7075 Sheet Metal Processed by ECAP: *M. Gruber*[1]; C. Illgen[2]; P. Frint[2]; M. Wagner[2]; W. Volk[1]; [1]Chair of Metal Forming and Casting; [2]Institute of Materials Science and Engineering
Equal-channel angular pressing (ECAP) is an established method for the improvement of mechanical properties by grain refinement. While there is a profound knowledge about ECAP of bulk materials, there is only little information on the effect of ECAP on sheet metals. In this contribution the effect of ECAP at different temperatures (20, 75, 150 and 225 °C) and processing routes (A, C and D) on the microstructure and mechanical properties of AA7075 aluminum sheets is investigated. The microstructure is examined using Electron Backscatter Diffraction (EBSD). The results show that microstructural changes and precipitation kinetics could be affected using different configurations. Furthermore, the mechanical properties of the ECAP material is characterized by tensile tests at different temperatures. It was found that the materials strength is controlled by ECAP and the corresponding processing conditions. Due to the specific microstructural features the thermomechanical properties could be considerably improved for future practical applications.

Data Preparation in the Digital Material Representation Based 3D Cellular Automata Model of Static Recrystallization: L. Madej[1]; *M. Sitko*[1]; M. Mojzeszko[1]; L. Rychlowski[1]; D. Zych[1]; K. Perzynski[1]; G. Cios[1]; [1]AGH University of Science and Technology
Development of the complex three dimensional cellular automata model of recrystallization is the overall goal of the research. To properly capture local heterogeneities, in grain morphology, crystallographic orientation as well as distribution of stored energy after deformation, the digital material representation concept and finite element modelling are used. Two different approaches for generation of digital microstructure model subjected to numerical simulation of deformation conditions and subsequent heat treatment were developed and are presented. In the first case, results from electron backscattered diffraction based serial sectioning method are used to provide input data on 3D microstructure state. In the second case, numerical Monte Carlo grain growth model to generate representative volume element was developed. Examples of obtained microstructural data and their influence on cellular automata static recrystallization simulation results are also presented.

Study of the Influence of the Mixed-grain Structure on the Microscopic Deformation Behavior of 316LN Steel: *Y. Li*[1]; H. Zhang[1]; M. Liu[1]; Z. Cui[1]; [1]Shanghai Jiao Tong University
Mixed-grains are common microstructures for heavy forgings. Taking 316LN austenitic stainless steel as an investigated material, two kinds of grain structures were tested for observation of microscopic deformation heterogeneity: uniform fine grains and mixed structures with millimeter-grade coarse grains (MCGs). Tensile tests and EBSD as well as OM observations were performed. Results showed that the deformation of the MCGs exhibited single slip if they were with soft orientation, and cross slip if they were with hard orientation. Obvious slip bands were observed in the MCGs. The fine grains were seen easily rotated in the deformation, forming distinguished bumpy grain boundaries, while the MCGs displayed smooth grain morphologies. The interior MCGs undertook severer deformation than the fine grains, which showed the strain partitioning ability of MCGs were limited. This deformation behavior is capable to lead the crack initiation in the interface of MCGs and fine grains.

Thermomechanical Analysis and Experimental Validation of ECAP for Aluminum Sheet Metal: *M. Gruber*[1]; Y. Yang[1]; C. Illgen[2]; P. Frint[2]; M. Wagner[2]; W. Volk[1]; [1]Chair of Metal Forming and Casting, TU Munich; [2]Institute of Materials Science and Engineering, TU Chemnitz
Equal-channel angular pressing is an established method for the improvement of mechanical properties by grain refinement through shear strains. While there is a profound knowledge about ECAP of bulk materials, there is only little information on the effect of ECAP on sheet metals. Therefore a tool was developed which is able to perform ECAP-tests for metals with a thickness of 1.8 mm. In this contribution a thermomechanical simulation model is used to examine the novel process. The simulation is performed to investigate the dissipated forming heat and the heat due to friction. To validate the numerical results, experiments are performed. By drilling holes in the material the forming temperature can be measured with thermocouples and the friction can be calibrated inversely. In this way, fundamental correlations between the heat development in the ECAP process for Aluminum sheet metal and the shear strain implied in the material can be obtained.

Novel Processes I

Tuesday AM | July 27, 2021 | 10:20 - 11:20 AM

Session Chair: B. Kinsey, University of New Hampshire

Transcription of Mirror-finished Surface onto A5083 Aluminum Alloy Plate by Friction Stir Forming: *T. Ohashi*[1]; K. Okuda[1]; H. Mofidi Tabatabaei[1]; T. Nishihara[1]; [1]School of Science and Engineering, Kokushikan University

In this study, the surface smoothing effect was investigated with friction stir forming on JIS A5083 aluminum alloy plate with a mirror-finished nickel electroformed die. In the experiment, a material plate was placed on the die while friction stirring was conducted on its back surface. Furthermore, the high pressure and heat caused by the friction-stir process lead to material deformation, and the die surface profile was transferred to the material. The average of the arithmetical mean height (Ra) and maximum height of profile (Rz) of the material plate surface were improved from 2 and 17 micrometers to 1 and 9 micrometers, respectively. This improvement was achieved through a process that uses a die, whose surface roughness Ra and Rz were 1 and 8 micrometers, respectively. Moreover, the finished surface details were investigated, including its surface profile and microstructure, and discussion of the transcript mechanism by spectrum analysis using maximum entropy method (MEM) was presented.

Numerical Simulation of Pipe Bending Supported by Hydraulic Pressure for Manufacturing Butt-welding Fittings: *J. Domitner*[1]; P. Auer[1]; C. Sommitsch[1]; [1]Graz University of Technology

An innovative pipe bending process supported by hydrostatic pressure was patented in 1995. This process was designed for producing butt-welding fittings which particularly fulfil the dimensional specifications of the ASME B16.9, MSS SP-75 and MSS SP-43 standards. Since the patent has meanwhile expired, the bending process is now available for common use. This work presents a finite element (FE) model build in the software package LS-DYNA for determining the suitable process window to bend defect-free butt-welding fittings. The model was exemplarily applied for investigating bending of a 90° stainless steel elbow based on a straight pipe of nominal pipe size (NPS) 6. Comparing the calculated geometry of the elbow with the geometry of an industrially produced elbow revealed very good dimensional agreement. This confirms that the presented model can be utilized for determining suitable process conditions which allow for producing defect-free components.

Using Local Heat Treatment for Producing Uniform Profile Hollow Components by Radial Rotation Profile-forming: *R. Laue*[1]; S. Härtel[1]; B. Awiszus[1]; [1]Chemnitz University of Technology

The two principal process steps of Radial Rotation Profile-Forming are the production of the preform and the subsequent radial profile forming of the hollow part. During the preform production wrinkles occur and these wrinkles can be formed directly in the indentation of the mandrel. In the second process step, the wrinkles are used to form the finish profile of the component. However, there is no wrinkle formed in every indentation. In this case, high sheet thinning and inhomogeneous properties occurs due to forming of the final profile. To avoid this disadvantage, a local laser heat treatment is carried out to control the wrinkling for the first time. The laser treatment leads to local hardening areas and wrinkling occurs in the area with the lower strength basic material in every indentation. The experimental and numerical investigation of the laser heat treatment and the influence on the two forming steps are shown.

Combined Computed Tomography and Numerical Modeling for the Analysis of Bending of Additively Manufactured Cellular Sheets: *S. Rosenthal*[1]; E. Jost[2]; C. Saldana[2]; T. Clausmeyer[1]; M. Hahn[1]; A. Tekkaya[1]; [1]Institute of Forming Technology and Lightweight Components (IUL), TU Dortmund University; [2]Woodruff School of Mechanical Engineering, Georgia Institute of Technology

Additively manufactured (AM) metallic sheets with internal cellular structures are formed in a bending operation. This enables a higher degree of lightweighting potential due to design freedom and strain hardening. Computer tomography (CT) of those structures with wall thicknesses of 0.3 mm reveal manufacturing inaccuracies of the AM-process between the CAD and actual geometry of up to 30%. The CT-data shows that the geometric deviation of the unit cells is periodic. A surface model based on CT-data is used to evaluate volume-meshing strategies in a finite element model, benefiting from the periodicity of the core structure. With the CT-based numerical model, the accuracy in predicting force-displacement response can be increased, when compared to the ideal CAD-based model. It is demonstrated that accurate representation of the actual geometry in the numerical model is critical for a correct prediction of the bending behavior and the investigation of localization phenomena during deformation.

Analysis of Tube Spinning: *E. Sariyarlioglu*[1]; O. Music[2]; M. Bakkal[3]; [1]Istanbul Technical University and Repkon Machinery; [2]TED University; [3]Istanbul Technical University

Tube spinning is a continuous bulk forming technique to produce seamless, conical and contoured tubes. Over the last six decades, tube spinning process has been applied in a wide range of engineering applications; especially in automotive, aerospace, nuclear and defense industry. However, the process has seen little or no change, and more importantly, despite a large volume of literature investigating the process, understanding of the process mechanics is limited and the key references are papers published about 50 years ago in the U.S.A. and Japan. This paper investigates the process mechanics, looking into mechanism of deformation, failure modes and process operating window. The process is investigated using a numerical model with implicit time integration and Arbitrary Lagrangian-Eulerian method (ALE). The model has been developed and validated with physical trials using a commercial FE software package and used to provide insight into key aspects of process mechanics.

Fluidity of the Wood Composite Combined with Natural Binder on Injection Molding: *S. Kajikawa*[1]; M. Horikoshi[1]; T. Kuboki[1]; S. Tanaka[2]; K. Umemura[2]; K. Kanayama[2]; [1]The University of Electro-Communications; [2]Kyoto University

Research and development for processing technology of naturally-derived material have been demanded for preventing mass disposal of petroleum-derived plastics. Authors have proposed injection molding of new wood composite with natural binder, which is composed of sucrose and citric acid. The wood composite is plasticized to be deformable when heated, and then molding is possible. In this study, effect of the natural binder content and mixture ratio of the sucrose and the citric acid on fluidity of the wood composite on injection molding was investigated. At first, optimum temperature for plasticizing the wood composite was investigated by thermal analysis and extrusion test. Based on these results, injection molding was carried out. Product was obtained successfully when the fluidity of the wood composite was high. The fluidity was improved with an increase of the binder content, and optimum mixture ratio of the sucrose and the citric acid was 75:25.

Development of a New Printing Method Using Soft Material Tools: *Y. Yoshikawa*[1]; Y. Masegi[1]; [1]Meijo University

Coining and nanoimprint are forming processes for surface micro geometry of metal or plastic. Pattern on the tools of these process is usually produced using precision cutting, photo lithography, ion beam milling and so on. However, these forming methods of pattern need long processing time and high cost. A new printing method for metal using soft material tools is developed. This method uses paper or plastic film with fine pattern produced by laser printer as printing tool. Aluminum disc is compressed with soft material tool between upper and lower flat dies. In order to print in high accuracy and uniformed pattern to metal surface, effects of process conditions to printing are investigated. Experimental results using soft material tools showed that the good condition for high accuracy is changed by combination of average pressure and work piece shape.

Cutting Blades for Food Processing Applications Manufactured Using Innovative Spin Forming: *T. Rostek*[1]; H. Makeieva[1]; W. Homberg[1]; [1]Paderborn University

Cutting blades for various food processing applications are primarily manufactured using standardized grinding processes at present. This results, on the one hand, in time-consuming and hence expensive production and, on the other hand, means that the surface roughness is not optimized in a microbiological manner, leading to high healthcare costs for foodborne infection. The strength of the cutting blades is additionally less-than-ideal, which causes a high expenditure on wear. Current research work at the Department for Metal Forming Technologies (LUF) is focused on innovative spin forming processes which have high potential for manufacturing parts with an excellent surface roughness in short process times. Along with the process-integrated thermal treatment, this is fundamental for the research and development of improved manufacturing technologies for high-performance cutting blades. This paper looks into innovative process strategies for manufacturing parts with locally graded characteristics, improved surface roughness characteristics and greater strength of the cutting edge.

Rob Wagoner Honorary Symposium II

Tuesday AM | July 27, 2021 | 10:20 - 11:20 AM

Session Chair: G. Daehn, Ohio State University

Experimental Study on Texture Evolution of Mg-Y Magnesium Alloy in Extrusion: *D. Li*[1]; W. Tang[1]; D. Tang[1]; Y. Peng[1]; [1]Shanghai Jiao Tong University

Addition of rare earth (RE) elements, such as Y, Ce, Gd, etc., has been used as texture modifiers to improve the formability of Mg alloys. In hot extrusion, the non-RE alloys generally exhibit a {10-10} or {10-10}-{11-20} fiber texture, depending on the recrystallized fraction, whereas the yttrium containing alloys develop weaker texture and a {11-21} fiber component. Recent experiments showed that formation of the {11-20} and {11-21} fiber textures are closely related to continuous dynamic recrystallization (CDRX) of Mg alloys. In this work, a CDRX model is implemented into the visco-plastic self-consistent (VPSC) framework by quantifying the transformation of low angle boundaries into high angle boundaries inside each grain. Furthermore, a phenomenological multiple slip model is integrated into the polycrystal model for better predictions of the recrystallization texture in the extrusion. The effective multiple slip modes that operate during the dynamic recrystallization are determined through simulation.

Nonlinearity of the Crystal Yield Function in the Rate-independent Crystal Plasticity and Its Effect on the Evolution of Anisotropy: *T. Park*[1]; J. Kim[2]; H. Lim[3]; S. Nazari Tiji[1]; A. Asgharzadeh[1]; F. Pourboghrat[1]; [1]The Ohio State University; [2]Pusan National University; [3]Sandia National Laboratories

In typical crystal plasticity framework, the constitutive functions for the slip rate is commonly described by the rate-dependent formulation to avoid the non-uniqueness of the active slip systems due to the interdependency of the slip systems. These rate-dependent models are computationally expensive as these models impose numerically stiff, highly non-linear equations that need to be solved at every integration point. Alternatively, the rate-independent crystal plasticity model uses the crystal yield function to describe the slip deformation and plastic spin by the active slip systems without the non-uniqueness problem. In this study, the effect of nonlinearity between resolved shear stress and slip rate on the shape of the crystal yield function in the formulation of the rate-independent crystal plasticity was rigorously investigated. In addition to the effects of the crystal plasticity model, the influence of the nonlinearity of the single crystal yield function on the evolution of anisotropy for various polycrystalline materials was evaluated.

Predictive Model for the Strength of Self-piercing Riveted Joints: C. Kim[1]; *W. Noh*[2]; M. Lee[1]; [1]Seoul National University; [2]Korea Institute of Industrial Technology

An analytical model for assessing the joint strengths of self-piercing riveted (SPR) sheets was newly proposed in this study. The strength prediction model has parameters associated to the complex geometrical relationship between a rivet and jointed workpieces, and the mechanical properties of both rivet and surrounding materials. The parameters introduced in the model were referred to the results of finite element simulations of the SPR process. The proposed analytical model was validated by comparing the strengths of the SPR jointed tensile-shear (or lap shear) and cross-tension samples with experimental results. The calculated strengths were in good agreements with measured values for various combinations of sheet metals.

A Predictive Strain-gradient Treatment with No Undetermined Constants or Length Scales: G. Zhou[1]; W. Chung[2]; E. Homer[3]; D. Fullwood[3]; M. Lee[4]; J. Kim[5]; H. Lim[6]; H. Zbib[7]; *R. Wagoner*[1]; [1]Ohio State University; [2]Korea University; [3]Brigham Young University; [4]Seoul National University; [5]Pusan National University; [6]Sandia National Laboratories; [7]Washington State University

A crystal-plasticity FE material model ("SD" model) was previously shown to predict, quantitatively and without arbitrary fit constants, the mechanical behavior of metal polycrystals. Confirmed quantitative predictions were achieved for the Hall-Petch Effect, the Bauschinger Effect, and Pre-Yield Nonlinear stress-strain behavior. The last of these was predicted inherently by the SD model before its existence was known experimentally, thus emphasizing its predictive nature. The SD model incorporated two simplifying fundamental assumptions: 1) only edge dislocations were assumed to be active, and 2) only like-dislocation interactions were considered within a single slip system and grain. Separately, two approximate treatments were adopted to achieve numerical stability: 1) column element-sampling (i.e. only elements along a slip direction to integrate the internal back stress), and 2) implementation of the back stress as a friction stress (opposite in sign and not exceeding the applied local stress).The resulting new General Mesoscale ("GM") model eliminaes both of the fundamental SD assumptions and both of the approximate SD treatment without invoking any arbitrary parameters. The new GM model retains the predictive nature of SD while permitting solutions for much more general problems and materials. Results for the two methods are compared and a series of numerical tests presented.

On the Newly Proposed Shear Constraint for Orthotropic Plasticity Modeling of Sheet Metals: J. Sheng[1]; M. Alharbi[1]; *W. Tong*[1]; [1]Southern Methodist University
A new shear constraint has appeared recently in the literature as an general restriction on the anisotropic yield criteria of sheet metals. An evaluation of such a shear constraint was carried out in terms of Hill's 1948 quadratic and Gotoh's 1977 quartic yield functions in plane stress. It was shown that the so-call non-physical numerical artifacts of their non-equivalence in pure shear in stress and strain are in fact the intrinsic features of an anisotropic material. The shear constraint itself should be regarded instead as merely a simplifying but overly restrictive assumption of reduced anisotropy without a general physical basis.

Wednesday Keynote

Wednesday AM | July 28, 2021

Session Chairs: A. Vivek, The Ohio State University; G. Hirt, RWTH Aachen University

7:30 AM Keynote
Using Plasticity for Making High-performance Nanostructured Composites: *I. Beyerlein*[1]; [1]University of California, Santa Barbara
Superior structural properties of materials are generally desired in harsh environments, such as elevated temperatures, the high strain rates of impact, and irradiation. Composite nanolaminates, built with alternating stacks of metal layers, each with nanoscale individual thickness, are proving to exhibit many of these target properties. In principle, the nanolaminate concept can be applied to any bimetallic system; however, they have not been widely applied to materials with a hexagonal close-packed (hcp) crystal structure. The roadblock lies in their complex, anisotropic deformation behavior. In this presentation, we discuss recently developed methods to manufacture nanostructured composites containing hcp metals. These techniques exploit plastic deformation as part of the synthesis process and have the potential to manufacture product in forms and sizes suitable for high-performance structural applications. We further highlight in this presentation modeling and experimental efforts to understand linkages between the processed nanostructure, local deformation mechanisms, and mechanical performance.

8:15 AM Keynote
The Fundamentals of Microparticle Impact Bonding in Metals, Alloys, and Advanced Materials: *C. Schuh*[1]; [1]Massachusetts Institute of Technology
There are a variety of materials manufacturing technologies that rely on kinetic impacts to achieve additive material build-up, including, notably, cold spray and laser-induced forward transfer. The unit processes of these manufacturing paradigms involve small quantities of material (micrometer scale particles) and extremely high velocities (~ km/s), so the impact events involve a number of fundamental physical mysteries at the extremes of materials mechanics. This talk will overview our efforts at developing quantitative in-situ methods to study such impacts, involving strain rates up to about 108 s-1. Using an all-optical test platform to launch and observe the impacts, we are able to provide insight on the mechanics of shock and spall, bond formation, and erosive wear. By systematically exploring a range of materials with different properties, we develop a picture of the controlling physics of bonding, which includes mechanical properties (elastic and plastic), thermal properties (related to adiabatic heat), and surface films. The talk will review our work on a variety of pure metals and engineering alloys and will also provide a view on new issues that arise in advanced materials like metallic glasses.

Forging

Wednesday AM | July 28, 2021 | 9:15 - 10:15 AM

Session Chair: W. Zhuang, Wuhan University of Technology

Optimization of Open-die Forging Using Fast Models for Strain, Temperature and Grain Size in the Context of an Assistance System: *F. Rudolph*[1]; M. Wolfgarten[1]; V. Keray[1]; G. Hirt[1]; [1]IBF - Institute of Metal Forming, RWTH Aachen University
Besides achieving the intended final shape, one main aim of open-die forging is the adjustment of the mechanical properties by transforming the cast structure into a fine-grained microstructure. To achieve this the process needs to be designed in a way that ensures achieving all required part properties, such as grain size, which up to now often requires a lot of operator experience. This paper presents the concept of a forging assistance system, since during forging small deviations from the previously designed pass-schedule might add up to unacceptable errors.Such an assistance system requires the evolution of part geometry and surface temperature as input, which are captured with a thermographic camera. The assistance system then uses fast models for equivalent strain, temperature and microstructure which allow calculation of these properties for the core fibre within seconds on the basis of semi-empirical and physical formulae. However, in the context of an assistance system, which gives real-time advice in case of process deviations, these calculation times are still fairy long, if the hundreds of iteration necessary for process optimization are taken into account. Therefore, three scenarios of deviations, which have to be solved within different time frames, are examined to explore the limits of the chosen classical optimization algorithm.

Galling-free Micro-forging of Titanium Wire with High Reduction in Thickness by Beta-SiC Dies: *T. Aizawa*[1]; K. Ito[2]; T. Fukuda[2]; [1]Nano Coat Film, LLC.; [2]Tokai ENgineering Service, Co., Ltd.
Pure titanium as well as beta-type titanium alloys are difficult to be shaped into parts and tools by the stamping and forging. In particular, this chemical galling prevented titanium and titanium alloys from net shaping for medical parts and fine tools. In the present study, beta-type SiC coated SiC punch and die was developed to demonstrate that upsetting with the reduction in thickness by 60 % becomes free from metallic titanium transfer to die and punch surfaces. A pure titanium wire with the diameter of 0.98 mm was prepared for upsetting experiments by the CNC (Computer Numerically Control) micro-forging system. The relationship between measured torque and stroke reveals that pure titanium circular wire plastically deformed to a triangular pin by 60 % in reduction. SEM-EDX proved that no metallic titanium transferred onto the die and punch surface.

Development of Automatic Design System for Closed Die Forging Process of Disk-shaped Products: *Y. Kobayashi*[1]; E. Sakamoto[1]; T. Yagami[1]; [1]Hitachi, Ltd.
In the process design of closed die forging, various design conditions such as the number of stage and the die-surface shape for each stage are determined by a designer considering the process requirements; load restriction, forged shape accuracy, and so on. During the process design, it is a problem that these design conditions have a lot of combinations. For this reason, a forging process has usually considered by trial and error using CAE or real machine. In particular, there are numerous patterns for the combination of the number of stage and the die-surface shape for each stage, which is called process layout. Researches for improving design-operations efficiency have been performed. Nevertheless, the process-layout design is still dependent on trial-and-error approach. In this study, to improve the efficiency about process-layout design, automatic design system using CAE was developed for closed die forging of disk-shaped products.

TECHNICAL PROGRAM

General Step Reduction and Enlargement Method for Knowledge-based Process Planning of Totally Non-axisymmetric Forged Products with Blanking and Punching: *M. Umeda*[1]; Y. Mure[2]; K. Katamine[1]; K. Matsunaga[1]; [1]Kyushu Institute of Technology; [2]Kagoshima Prefectural Institute of Industrial Technology

A forging process planning method, including blanking and punching, termed General Step Reduction and Enlargement (GeneSteR+E), is discussed for cold- and warm-forged products. It is applicable to non-axisymmetric forged products that consist totally of non-axisymmetric shape elements, and can generate multiple process plans without relying on design cases. The shape of a forged product is split into outer and inner shapes, which are then split into axisymmetric and non-axisymmetric shape representation units termed basic elements (BEs) according to shape separation rules. Process plans are generated in a reverse order from a final forged product by applying shape transformation rules that reduce the number of steps between BEs until a billet (or a blank) is obtained. The shape transformation rules are defined not only for forging, but also blanking and punching. An experimental knowledge base was implemented and applied to several non-axisymmetric forged products, such as an electrical connector. The results show that the GeneSteR+E method is applicable to the design of forging process including blanking and punching of totally non-axisymmetric products, and can generate satisfactory process plans comparable to those developed by anexperienced engineer.

Investigation of Failure Mechanisms of Cemented Carbide Fine Blanking Punches by Means of Process Forces and Acoustic Emission: *H. Voigts*[1]; R. Hild[1]; A. Feuerhack[1]; T. Bergs[1]; [1]Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University

Due to the processing of materials with ever greater strength in fine blanking, the lifetime of conventional high-speed steel punches decrease rapidly. Materials with a higher wear resistance and compressive strength, such as cemented carbide, are investigated for the use in fine blanking processes. However, cemented carbide punches of-ten fracture during the stripping off phase due to the combined tensile and flexural stress collective. The under-standing of fracture mechanisms and subsequent fracture prevention supports the application of cemented car-bides. The fracture mechanisms during stripping off are mostly unknown. The objective is to identify fracture mechanisms of cemented carbide punches. The fracture of cemented carbide punches was metrologically moni-tored by means of acoustic emission (AE) and process forces. The fracture pattern was analyzed related to the measured signals. In order to interpret the AE-signal, basic process analyses were performed. Subsequently, a punch fracture of cemented carbide was provoked with the high-strength material S700MC. Cemented carbide punches tend to fracture during stripping off as a cause of tensile and flexural loads due to asymmetrical interactions with the scrap web.

A FE Billet Model and A Spring-mass-damper Press Model for the Simulation of Dynamic Forging Process: Application to a Screw Press: J. Mull[1]; C. Durand[1]; C. Baudouin[1]; R. Bigot[1]; *M. Song*[1]; [1]Université de Lorraine, Arts et Métiers ParisTech

In forging processes, the determination of blow efficiency is very important, as it quantifies the part of the stroke energy actually transmitted to the billet. Thus, forging processes should be deeply analyzed in order to better understand the stroke energy conversion, accurately estimate blows efficiency and thus better predict process parameters. In this paper, a spring-mass-damping vibration model is proposed to describe the behavior of a screw press. A simulation of the upsetting of copper specimen is performed with a FE software with no consideration of the press behavior. Then, forging load from the FE simulation is used to perform simulation of the whole forging process with the press model. Results show that the model is relevant to simulate forging load and ram displacement. Moreover, simulation can predict the distribution of the energy during the simulation and the blow efficiency can be calculated. This new way to obtain blow efficiency might improve productivity in process development and provide a better understanding of energy driven machine.

Compression of C/Thermoplastic Printed Composite; Shaping Parameters and Material Health: *V. Haguenauer*[1]; E. Becker[1]; L. Freund[1]; D. Felix[2]; R. Bigot[1]; [1]Arts et Métiers Institue of Technology; [2]Setforge Engineering

The EPITHER process is an innovative way of shaping C/ Thermoplastic composite materials to produce massive structural parts that combine the strength of CRFT composite materials with the high production rates of forging. Composite structural parts contribute to the reduction of CO2 emissions by reducing weight, especially those in motion for power transmission. This process has a preforming step necessary for the placement and orientation of continuous carbon fiber composites necessary to increase their characteristics. In this study, this preforming step is performed by 3D printing. In order to obtain finished products with good dimensional and material characteristics, this study provides elements for optimizing certain process parameters and the associated results, particularly at different steps in the forming process.

High Speed and Impulse Forming I

Wednesday AM | July 28, 2021 | 9:15 - 10:15 AM

Session Chair: A. Vivek, The Ohio State University

Mathematical Model and Quantitative Analysis of Residual Stress Hole during Laser Shock Peening: *X. Cheng*[1]; J. Zhang[2]; S. Cheng[1]; C. Yan[2]; Q. Xia[2]; [1]Guangzhou Civil Aviation College; [2]South China University of Technology

Laser shock peening (LSP) can induce residual compressive stress on the component surface, thus improving the fatigue performance of the component. Therefore, LSP has been widely used in aerospace, vehicle engineering and other industrial fields. To research the phenomenon of residual stress hole (RSH) caused by LSP, the “volcano” mathematical model for analyzing the influence factor of RSH was conduct. Quantitative analysis indexes for describing RSH such as relative crater depth, relative crater width, and stress loss ratio were proposed. Based on the reference’s data, a preliminary analysis was performed. The results showed that the main influence factor was the relative crater depth. In order to obtain the best uniform residual stress distribution, overlapping LSP should be used when the relative crater depth is greater than 10%, and the distance between the centers of adjacent spots should be equal to the “crater” radius of the residual stress hole.

The Effects of the Shearing Speed on the Sheared Edge Quality and Edge Cracking: *C. Gu*[1]; D. Schoch[2]; H. Kim[1]; F. Alamos[1]; J. Bornhorst-Home[2]; [1]EWI; [2]Airam Press Co. LTD

High-speed shearing was studied to potentially improve sheared-edge quality for steel. The AIRAM pneumatic press can provide significantly higher speed than a conventional press at low energy cost. The maximum speed can reach over 1.5 meters per second depending on equipment setup. The study evaluated the pneumatic press that could increase the slide speed up to 1.5 meters per second. Various grades of steel, BH340, DP780 and Gen-3 980, were sheared using the pneumatic press with two different pressure levels as well as using a conventional press with 0.2 meters per second with the same tooling. The edge quality of the sheared blanks was evaluated using half specimen dome test (HSDT) and micro-hardness. The effects of the high-speed shearing are discussed in this paper.

High-speed Material Characterization Using an Instrumented Forging Hammer: *L. Galdos*[1]; J. Agirre[1]; N. Otegi[1]; D. Abedul[1]; A. Oruna[1]; [1]Mondragon Unibertsitatea

Dynamic testing of materials is needed to model high speed forming processes (i.e. hammer forging) and crash/impact behaviour of structures among others. The most common machines to perform medium to high speed tests are the servo-hydraulic high speed tensile machines and the Hopkinson bars. The paper analyses the possibility to use a laboratory forging hammer for the characterization of materials at medium and high strain rates. For this, a forging hammer has been constructed which is accelerated with a pneumatic cylinder and is able to speed up the anvil up to 6 m/s. Cylindrical specimens have been deformed at different speeds and a high speed camera and an accelerometer have been used to monitor the real specimen strain using DIC and the anvil acceleration respectively. The differences when using both sensors information or only the accelerometer are shown and discussed.

Computational Modeling of Magnetic Pulse Dissimilar Alloys Welding: Aluminum Alloy 6082-T6 and HC420LA Steel: N. Rodríguez[1]; *E. Iriondo*[1]; D. Jouaffre[2]; F. Girot[3]; [1]University of the Basque Country; [2]Plateforme INNOVALTECH; [3]IKERBASQUE, Basque Foundation for Science

The use of lightweight materials such as high strength steels, aluminum alloys and composites is increasing. The joints of dissimilar alloys as the Aluminum Alloy 6082-T6 and the HC420LA steel are studied in this work. The selected joining process is the Magnetic Pulse Welding (MPW) which enables to weld these two alloys, being non-joinable by other traditional welding technologies. The technology involves a strong electromagnetic-mechanical-thermal interaction. The investigation will be developed mostly on computational modeling by means of the use of LS-DYNA software, taking into account the key process parameters and their influence. The work will finish presenting experimental results of the cases modelled by finite elements in order to validate the predictive feasibility of the numerical analysis. All the analized cases reached the welding of both blanks and this was confirmed by metallographic characterization. The results show that the simulations developed follow the same geometrical behavior as experimental results.

Shaping of Sharp-edged Design Elements by Electromagnetic Forming: *V. Psyk*[1]; C. Scheffler[1]; A. Stalmann[1]; M. Goede[2]; [1]Fraunhofer Institute for Machine Tools and Forming Technology; [2]Volkswagen Aktiengesellschaft

Modern car body design includes parts with sharp-edged elements, which are challenging for conventional sheet metal forming technologies. Applying high strain rates allows increasing formability for numerous materials including typical aluminium alloys used in the automotive industry. Therefore, integrating high-speed forming into a conventional process can help to extend forming limits. The feasibility of locally sharpening a deep-drawn radius by integrated electromagnetic forming was proved in literature, but up to now only target radii one magnitude bigger compared to the sheet thickness were regarded. The presented paper shows that also target radii in and below the size of the sheet thickness are possible by this process combination. Based on a simplified 2D-component geometry, complementary experimental and numerical investigations served for developing different variants of a modular test tool and analyzing the influence of important process and tool parameters on the forming result.

Advancements in the Simulation of Magnetic Pulse Forming Processes with FORGE(R): *J. Alves*[1]; F. Bay[2]; U. Ripert[1]; J. Barlier[1]; N. Poulain[3]; [1]Transvalor S.A.; [2]MINES ParisTech; [3]Transvalor Americas

In this work we present the latest developments on the electromagnetic (EM) module of FORGE(R) and the derived improvements for simulating the magnetic pulse forming process. We will cover the following aspects: advanced material description for high intensity magnetic fields; improved meshing/remeshing for large displacements in the fully immersed multi-objects approach and, advanced 2nd order time-stepping integration for accurate computation of the EM fields

Microstructure and Damage Development III

Wednesday AM | July 28, 2021 | 9:15 - 10:15 AM

Session Chair: T. Balan, Arts et Metiers Institute of Technology

Optimization of Lattice Structures for Additively Manufactured Interpenetrating Composites: *J. Allen*[1]; A. Moustafa[2]; J. Cheng[1]; X. Hu[1]; D. Splitter[1]; A. Shyam[1]; Z. Cordero[2]; [1]Oak Ridge National Laboratory; [2]Rice University

Additively manufactured (AM) metal-metal composites consisting of PrintCasted 316L austenitic stainless-steel lattice structures infiltrated with A356 casting alloy, have recently been developed for use in high energy absorption systems. The ability to intricately form the composite and control the phase distribution give engineers a greater latitude over material property design with proposed applications ranging from static load bearing to dynamic blast containment structures. In this work, new lattice structures are examined within finite element models in order to determine optimized structures for use in energy absorption systems. 316L austenitic stainless-steel lattice structures taking on face center cubic and diamond cubic structures are examined with varying volume fractions (20-60% by volume; the deficit being A356 casting alloy). Particular attention is given to the analysis of localized/non-localized damage initiation and propagation and the role this plays in energy absorption systems.

Full-field strain measurement in multi-stage shear cutting: High-speed camera setup and variational motion estimation: *C. Hartmann*[1]; W. Volk[1]; [1]Technical University of Munich

Shear cutting process simulation alone already represents a challenging task, but the numerical analysis of multi-stage shear cutting process is even more challenging. Despite the numerical challenges, also the experimental validation of simulation models represents a major challenge, especially regarding the development of the shear affected zone. Therefore, in this work we address the experimental analysis of multi-stage shear cutting as a basis for validation and, moreover, for data-based modelling approaches. We present an in situ test design and measurement setup that preserves the process boundary conditions of shear cutting. An enhanced high-speed optical full-field evaluation method enables local and time-resolved measurement of strain fields and strain rate fields for each shear cutting stage. A mapping of these state variables between the individual cuts enables us to analyze consistently the shear affected zone throughout the entire multi-stage process and thus to characterize the final state of the shear zone experimentally.

Finite Element Simulation of Edge Fracture by Mapping the Shear-induced Ductile Damage into Hole-expansion Simulation: *L. Mu*[1]; Z. Jia[2]; B. Guan[2]; Y. Zang[2]; [1]New Mexico State University; [2]University of Science and Technology Beijing

A ductile fracture (DF) model (uncoupled type, originally presented at ICTP2017), which is endowed with both stress triaxiality and Lode parameter dependence, is selected to define the ductile damage accumulation from hole-blanking to the subsequent hole-expansion for a DP780 sheet. The calibrated DF model yields an asymmetric 3D fracture surface, which can well describe the material's ductility within a wide range of stress state from simple shear to balanced biaxial tension. The hole-blanking process is simulated using the DF model for different blanking clearances. With the help of a fully integrated simulation framework, the ductile damage induced by hole-blanking is completely mapped into hole-expansion simulation to incorporate the pre-damage field for the sheared edge. We find that after considering the pre-damage field, the accuracy of edge fracture simulation is significantly improved in terms of both hole-expansion ratio and fracture propagation path.

An Extended Ductile Fracture Prediction Model Considering Hydrostatic Stress and Maximum Shear Stress: *Z. Jia*[1]; L. Mu[2]; B. Guan[1]; Y. Zang[1]; [1]University of Science and Technology Beijing; [2]New Mexico State University

To consider the effect of the second principle stress on the ductile fracture prediction, the Mu-Zang model (uncoupled type), which was originally proposed at ICTP2017, is extended by incorporating with a hydrostatic stress term. An aluminum alloy material (Al 6016-T6) is selected with a series of static ductile fracture tests performed on five different specimen geometries, which can cover a wide range of stress state. A robust simulation-experiment approach is adopted to characterize the correlation between the material's ductility and distinct stress states. The extended model is then calibrated using least squares optimization. The resulting 3D fracture surface demonstrates acceptable deviations from the tested data, manifesting a promising capability of the extended model to describe the ductility of the considered material within a wide stress state range. In addition, the comparison against other representative ductile fracture models further confirms a good prediction performance of the model proposed.

Pushing Forward the Limit of Transformation-induced Plasticity (TRIP) Effect: Nnew Strategies in Mechanically Metastable Alloy Design: *S. Wei*[1]; J. Cann[1]; C. Tasan[1]; [1]Massachusetts Institute of Technology

Decades of effort in high-strength alloy investigations has well documented the significant role of strain-induced martensitic transformation in mechanical performance advancement (namely, the transformation-induced plasticity effect, TRIP). Albeit TRIP-assisted alloys benefit from stress delocalization and thereby deformation homogenization resulting from the transformation, the resultant product, martensite, is yet problematic: its extensive defects density and hardenability discrepancy with the adjacent austenite can lead to local embrittlement and hence fracture. In this presentation, we aim to propose three new mechanistic strategies that can potentially overcome this dilemma: first, triggering a plastic strain-induced FCC-HCP-FCC sequential martensitic transformation pathway; second, mitigating blocky HCP-martensite formation via the nucleation of extensive stacking faults; and third, designing superelastic nano-precipitates that reduce martensite retention in cyclic loading conditions. More detailed discussion about the deformation micro-mechanisms and the resultant plastic strain accommodation characteristics will also be provided.

Niels Bay Honorary Symposium

Wednesday AM | July 28, 2021 | 9:15 - 10:15 AM

Session Chair: P. Martins, IDMEC, Universidade de Lisboa

Invited

On the Characterization of Fracture Loci in Thin-walled Tube Forming: J. Magrinho[1]; *M. Silva*[1]; P. Martins[1]; [1]IDMEC, Universidade de Lisboa

This paper is focused on the formability limits by fracture of thin-walled tubes and provides for the first time ever the fracture forming limit lines associated to crack opening by tension (mode I), by in-plane shear (mode II) and by mixed-mode consisting of crack opening by modes I and II of fracture mechanics. This is accomplished by experimentation that combines digital image correlation and determination of gauge length strains in double notched tensile test (DNTT), staggered DNTT and shear test specimens. Results are plot in principal strain space and the crack opening modes are confirmed by fractography analysis performed with a scanning electron microscope. DNTT specimens are also used to determine fracture toughness in mode I. The utilization of DNTT, staggered DNTT and shear tests allow obtaining the strain loading paths and fracture loci across a wide range of forming conditions ranging from plane strain to pure shear.

Invited

50 Year's Research and Development on Metal Forming and Joining: *N. Bay*[1]; [1]Technical University of Denmark

My first subject of research was cold pressure welding. Microscopic studies of the weld formation led to establishment of a theoretical model for bond formation based on continuum mechanics, and a new surface preparation method introducing brittle surface layers by chemical Ni-plating. In parallel to this work, I studied fundamentals of friction in metal forming. Together with Wanheim a theoretical model for friction was proposed based on slipline analysis of the flattening of surface asperities. The model was later improved including subsurface deformation using finite element analysis. The increasing focus on environmental aspects of lubrication in sheet metal forming tribologically difficult materials such as stainless steel motivated research on development and testing of environmental friendly lubricants and tribo-systems preventing galling. A universal sheet tribo-tester was developed, which can carry out consecutive tests at controlled sliding length, sliding speed and idle time between tests in order to emulate production conditions. The work resulted in the introduction of new, environmentally benign lubricants, new tool coatings diminishing the risk of galling and tailored tool surfaces facilitating micro-plasto-hydrodynamic lubrication, which prevents galling. The work on strategic surface coatings promoting bond formation in cold pressure welding was continued in work on resistance projection welding of dissimilar metals. Development of an FEM program for resistance welding was initiated in the 1990-ies resulting in the formation of a Danish spin-off company SWANTEC commercializing and further developing the program, which today is state-of-the art and applied by a large part of automotive industry and steel mills in the world.

Friction and Thermal Insulation: Influence of Oxide Scale on Hot Forging Sequences: *L. Dubar*[1]; [1]LAMIH UMR CNRS 8201

In the field of hot forging processes, oxide scales are produced on steel billets by oxidation at high temperature. During forming, the oxide layer at the billet/tool interface affects not only friction but also the heat exchange. A global approach is first proposed with the determination of friction coefficients at high temperature with the presence of oxides. The tests are performed on the Warm and Hot Upsetting and Sliding Test. An investigation is conducted at microscale with pin on disk test at high temperature in a controlled atmosphere, in order to understand the phenomena involved during the substrate/oxide/soap/tool contact. The analysis of the results is conducted by integrating local material data. Finally, a thermomechanical finite element modeling of the forging process is developed considering the mechanical and thermal effects of the oxide layers. The impact on the forging sequence is investigated, by quantifying global and local improvements of the model.

Welding of Aluminum in Chip Extrusion: *A. Schulze*[1]; O. Hering[1]; A. Tekkaya[1]; [1]Institute of Forming Technology and Lightweight Components (IUL), TU Dortmund University

The reduction of energy consumption and CO2 emissions in the aluminum profile production can be achieved by solid state recycling. By direct hot extrusion, aluminum chips can be directly processed into semi-finished or near-netshape products requiring relatively low energy and having a high material yield. Since the mechanical properties of the extruded profiles highly depend on the welding of the individual chips, the main focus is to achieve a sufficient bonding between the chips. For this, the oxide layer covering the aluminum surface has to be broken. In order to predict the welding of the individual chips and estimate the process success a weld prediction model is developed. The influence of process parameters such as extrusion ratio, temperature and speed is analysed. The weld model is applied to further profiles and validated by experimental tryouts.

Testing Method of Anti-galling Ability of Lubrication Coatings in Multi-stage Cold Forging: *Z. Wang*[1]; S. Komiyama[2]; [1]Gifu University; [2]Nihon Parkerizing Co. Ltd.
An upsetting-ball ironing test has been developed to investigate the lubricating performance of coatings in multi-stage cold forging. By using this test, the lubricating performance of a zinc phosphate free coating called "dry in-place coating" has been evaluated and improved, and now the dry in-place coating is used worldwide due to its high anti-galling ability and low environmental impact. In the present paper, the feature of the testing method, galling process and the performance of lubricaiton coatings are discussed.

In Search of the Perfect Sheet Metal Forming Tribometer: L. Schell[1]; *P. Groche*[1]; [1]Institute for Production Engineering and Forming Machines
Due to increasing variant diversity and mass customization, time and cost-efficient process design has gained importance for several years. Tribological investigations are playing a key role as part of the process design. In particular, the desires for extended process limits, reduction of lubricant amount and reliable determination of friction coefficients for FE simulations place high requirements on tribometers in sheet metal forming.For quite some time, the strip drawing test with several variations has been considered as an efficient and meaningful method for tribological investigations. This paper summarizes the development of the strip drawing test to date. In particular, design principles for experimental modelling of tribological conditions of deep drawing processes and approaches for friction measurement are described. Moreover, the current state and future requirements for the development of the "perfect" tribometer are discussed in this paper.

Deformation Mechanisms in Tool-workpiece Asperity Contact in Metal Forming: *C. Nielsen*[1]; X. Zhang[1]; M. Moghadam[1]; N. Hansen[1]; N. Bay[1]; [1]Technical University of Denmark
The contribution to friction stemming from dissipation of plastic energy is studied by numerical simulations and experiments. The geometrical setup consists of a single model asperity, which is first flattened against a tool with grooves on a smaller length scale. Relative, tangential sliding between the model asperity and the tool is induced subsequently until a steady state is reached. The flank angle of the grooves on the tool is varied. Comparison between the simulations and the experiments leads to validation of the simulations at low tool flank angles, while the current numerical implementation cannot handle the complicated flow around the tool grooves with a large flank angle. At low flank angles, the simulated tangential tool force is in agreement with experiments when keeping one determined friction factor. This proves that the change in tangential force, corresponding to a change in apparent friction factor, is only due to the dissipated energy from the plastic waves. The validated numerical model can be used to determine a wider range of apparent friction factors for strain hardening materials.

Tribological Conditions in Hot Bending of 22MnB5 Tubes: *E. Simonetto*[1]; A. Ghiotti[1]; S. Bruschi[1]; [1]University of Padua
Thanks to the high stiffness-to-weight ratio given by the closed-section geometry, tubular components are particularly suitable for automotive applications that require extreme lightness to reduce the energy consumption and increase the crashworthiness. Tube bending processes are traditionally performed in cold conditions, but to overcome the dramatic problems of accuracy and formability that the new high strength steels present, a novel draw bending set at high temperature has been proposed. The paper presents the results of the investigations carried out on the tribological conditions of the hot draw bending of 22MnB5 tubes to obtain tubular parts with tailored mechanical properties. Investigations about the process thermal cycle has been performed with focus on the influence of the contact pressure on the heat transfer. The results show the practicability of the new process chain to obtain hot stamped tubular parts.

Effect of Production Rate on Lubrication Performance in Combined Forward-Can and Backward-Can Cold Extrusion Test: *K. Hayakawa*[1]; I. Takahashi[1]; Y. Kubota[1]; I. Ishibashi[2]; T. Nakamura[1]; [1]Shizuoka University; [2]ILUB Co., Ltd.
Effect of production rate on the lubrication performance of environmentally friendly lubricant was investigated using the tribological test of Forward Can – Backward Can Extrusion. In this test, the lubrication performance is examined from both finite element analysis and experiment. For the lubricant, double-layer-type lubricant was used. The calibration diagram on the relationship between the extruded geometry and the punch stroke was prepared at the forming rate of 20 spm (strokes per minute) and 1 spm using FE analysis. As workpiece materials, annealed steel SCM420 and aluminum alloy A4032 with three different surface treatment conditions was used. As a result, the friction coefficient value estimated was higher when the production rate was smaller. The dependency of the friction coefficient on the production rate was able to be reasonably evaluated by the present method.

Exploring the Fragmentation of Surface Films during Solid State Welding: *D. Cooper*[1]; G. Oberhausen[1]; [1]University of Michigan
Aluminum solid state welding occurs when intimate contact is achieved between substrates on the two sides of the interface. This contact requires the fragmentation of any intervening surface films. The fragmentation determines the threshold deformation needed to initiate welding and the final exposed area of the substrate, which determines the strength of the weld. Previous work has tended to focus on plane strain conditions but solid state welds may form under more complex stress conditions as found between billets in extrusion. In this talk, we explore the fragmentation and subsequent weld strength of aluminum bonded samples under varying surface conditions (e.g., roughness and lubricity) and deformation conditions. Experiments are conducted using accumulative asymmetric rolling of novel plate geometries to induce combinations of shear and in-plane compressive stress at the interface. Shear tests then determine the weld strengths and identical experiments on anodized samples are used to explore the oxide fragmentation.

Oscillation-free Determination of Material Properties at High Strain Rate: *X. Fang*[1]; [1]Inistitute of Automotive Light Weight Design
The determination of plastic deformation properties of materials under high speed loading is a challenge. The system ringing in a conventional servo-hydraulic tensile machine deteriorates the quality of force measurement. A precise determination of the plasticity and damage is thus difficult. In this work, the system ringing effect of the entire test system incl. machine, sample etc. were analyzed. We found out that the system ringing is location and geometry dependent. Inspired by the principle of the SHPB a new type of tensile sample has been developed. In a certain restricted area of this new sample, the tensile forces can be measured without any ringing effect. The plastic deformation and damage behavior can be determined using this type of specimen for a wide range of strain rate of 0.0001 - 1000 /s. To explain the functionality of the sample and the sample design, a physical model has been developed.

Influence of Forming Conditions on Metal Flow and Lubrication in Cold Backward-cup Extrusion: *K. Kitamura*[1]; K. Asai[2]; T. Mizuno[1]; [1]Nagoya Institute of Technology; [2]National Institute of Technology, Toyota College
Backward-cup extrusion has hard lubrication conditions such as high pressure, elevating temperature, and large surface expansion. This study focuses on the relationship between the surface expansions and forming conditions is experimentally measured. According to the main results, the minimum surface expansion ratio appears at the extrusion ratio of 3 to 4, and the punch nose without sharpness and roundness helps to inhibit the increase in the surface expansion. These evidences will be valuable to design the process conditions and the punch shape.

A Contact and Friction Model for Forming of Galvanized Steel Sheet Based on Fractal Theory: Y. Huang[1]; L. Wang[1]; M. Shi[2]; *X. Ma*[3]; [1]Jiangsu University; [2]Jiangsu University of Science and Technology; [3]SINTEF Industry

Galvanized steel sheets are increasingly used in automotive industry due to excellent corrosion resistance, sufficient weldability and formability. During sheet forming of galvanized metals, material failures such as exfoliation and cracking can be found in the zinc coated layers of the sheet under severe friction. Thus, the evaluation of the influences of surface topography, pressure and lubrication on friction could provide valuable guidance in forming of galvanized metals. A hot-dip galvannealed sheet and a hot-dip galvanized sheet are chosen in this tribology study. The surface topographies of the materials are measured using profile meter and the fractal parameters are calculated using the fractal theory. The contact model between the sheet and the die is established using the real contact area. The friction model concerning the surface topography of galvanized sheet and the pressure is thus formulated. The friction coefficients of the theoretical values are in reasonable agreement with the experimental.

Characterization of Plasticity and Ductile Fracture of Metals under Proportional and Non-proportional Loading III

Wednesday AM | July 28, 2021 | 10:20 - 11:20 AM

Session Chair: J. Yoon, KAIST

Invited

In-plane Stretch-bending Test for Determination of Large-strain Workhardening and Fracture of Sheet Metals: *R. Hino*[1]; G. Capilla[2]; H. Hamasaki[1]; K. Watanabe[3]; F. Yoshida[4]; [1]Hiroshima University; [2]University of Guanajuato; [3]Graduate School of Hiroshima University; [4]CEM Inst Co.

In-plane stretch-bending tests have been conducted to determine workhardening behavior at large strain and edge fracture limit of several high-strength steel (HSS) sheets. In this test a metal strip is bent in its width direction under longitudinal tensile force, and the outer edge of the bent strip undergoes a large uniaxial stretching which is much larger than the uniform elongation in conventional tensile test. Then a stress-strain curve at large strain can be determined through an inverse approach based on the experimental result and the corresponding FE analysis. In addition, localized necking and fracture limit strain at the outer edge of the bent strips are investigated by using the digital image correlation technique to discuss edge fracture limit (stretch flangeability) of the HSS sheets. Significance of a large-strain workhardening model and an anisotropic yield function is demonstrated by FE simulation of strain-localization in in-plane stretch bending.

Microstructure Informed Deformation and Fracture Model for High-strength Steels: *J. Lian*[1]; W. Liu[2]; Z. Li[1]; F. Shen[2]; S. Muenstermann[2]; [1]Aalto University; [2]RWTH Aachen University

In the integrated computational materials engineering (ICME) roadmap, quantitative correlation of the material microstructure and its mechanical deformation properties by using a multiscale modeling approach is of high interest for material production and component forming industry. In this study, we present a multiscale characterization and modeling approach to incorporate the influences of the microstructural features on the mechanical properties including plasticity, damage, and ductile fracture behavior. Both micro and macro scale experiments and simulation are conducted to describe and interpret the deformation and failure behavior. The anisotropic flow behavior under various strain rates is correlated with the microstructure features and their evolution during deformation, while the macroscopic damage/fracture behavior is also interpreted by the microstructural-level mechanisms in the mesoscale simulation. After validation of the model, we show the potential of the approach for the microstructure design toward a high-strength and damage-tolerant steel development.

Invited

Grain Size Effect on the Ductile Fracture of Steel in Hot Deformation: *Z. Cui*[1]; X. Shang[1]; H. Zhang[1]; Y. Li[1]; [1]Shanghai Jiao Tong University

Grain size undoubtedly has strong influence to the microscopic deformation inhomogeneity of steel, leading to a different fracture behavior. However, the grain size effect on the ductile fracture was not deeply investigated in the literature. Taking the 316LN stainless steel as an investigated material, this presentation will introduce our research work in the fracture behavior and criterion by considering the inhomogeneity of microscopic deformation caused by the difference of grain size and orientations. The investigation showed that the void evolution in matrix with large and small grain size has different influence to the fracture behavior of the steel. The voids growth model was established by considering the grain size effect. In hot deformation process, the dynamic recrystallization yields fine grains and releases the stress concentration resulted from dislocation pile-up. A fracture criterion was proposed to predict the ductile fracture of the steel undergoing hot deformation.

CANCELLED: New Methods for Fracture Detection of Automotive Alloys in the VDA238-100 V-Bend Bend Test: *J. Noder*[1]; C. Butcher[1]; [1]University of Waterloo

The VDA 238-100 tight-radius bend test has received significant attention from industry because it provides a proportional plane-strain-plane-stress state until fracture. A custom inverted V-Bend test frame has been developed to facilitate DIC strain measurement on the convex surface where fracture initiates. It will be demonstrated that the adoption of the vertical punch force as the unique metric for failure detection is fundamentally flawed. The force will reduce at large bend angles due to the mechanics of the test even in the absence of material failure. Three alternative methodologies for fracture detection are proposed based upon: the bending moment, nominal principal stress, and the strain rate for a range of representative automotive steels Finally, the VDA requirement to pre-strain high ductility materials that can form a complete fold without fracture is critically evaluated and shown to incorporate a non-linear strain path that affects the material response of each alloy differently.

An Application of Homogeneous Anisotropic Hardening Model to the Prestrained Hole-expansion Experiment: *J. Ha*[1]; Y. P. Korkolis[1]; [1]The Ohio State University

In this work, the plastic anisotropy of AA6022-T4 in hole-expansion is investigated focusing on prestraining effect, and its numerical solution is predicted by Homogeneous Anisotropic Hardening (HAH) model combined with an anisotropic yield function. For the prestraining, the material is subjected to 8 % of uniaxial tension in the RD in advance. Then, hole-expansion is conducted in a fully-instrumented hydraulic press with a flat-headed punch. In both experiments, digital image correlation (DIC) is used, to confirm the prevalence of uniaxial loading in the prestraining step and to measure thickness strain in the hole-expansion. The results show that the plastic anisotropy is manifested as a non-axisymmetric strain distribution around the hole. The prestraining, leading to non-proportional loading, changes the location of failure from ~45o to RD. The simulation shows the current version of HAH model is limited in capturing the thickness contours and the failure location.

Joining by Forming and Deformation III

Wednesday AM | July 28, 2021 | 10:20 - 11:20 AM

Session Chair: T. Kuboki, The University of Electro-Communications

Ultrasonic Forming - Alternative to Orbital Riveting for Small Bimetallic Components: *W. Presz*[1]; [1]Warsaw University of Technology
The development of electrical equipment has resulted in an increase in the demand for electrical switches, whose key element is contact. The orbital riveting technology has been successfully applied in assembling silver contacts. With the increase of the production, attention has been paid to the possibility of obtaining significant savings by replacing part of the rivet with copper. As a result, bimetallic contacts have been created. It has also proved that the direct transfer of orbital riveting technology from monometallic to bimetallic contacts narrows so much technological window that the cost-effectiveness of the whole process is debatable. One of the factors behind the use of orbital forming is the decisive reduction in friction. A similar effect gives the ultrasonic assistance in microforming processes. Within this work, based on the laboratory experiments results, it was suggested to replace the orbital riveting with ultrasonic riveting in relation to the miniature bimetallic contacts.

Self-piercing Riveting Using Rivets Made of Stainless Steel with High Strain Hardening: *B. Uhe*[1]; C. Kuball[2]; M. Merklein[2]; G. Meschut[1]; [1]Paderborn University; [2]Friedrich-Alexander-Universität Erlangen-Nürnberg
Rivets for self-piercing riveting differ in geometry, the material used, the condition of the material and the surface condition. To shorten the manufacturing process, the use of stainless steel with high strain hardening as rivet material is a promising approach. The authors have developed a rivet made of high nitrogen steel 1.3815, which is usable for the self-piercing riveting of challenging material combinations. The focus of the presented investigation is on the deformation behaviour of the rivet during the joining process. The analysis is being made for two material combinations by means of experimental joining tests and numerical simulation. The influences of the rivet geometry and the rivet material on the deformation behaviour are identified and evaluated for conventional rivets of types P and HD2, a rivet with an improved geometry made of treatable steel 38B2 and rivets made of the stainless steels 1.3815 and 1.4541.

Numerical and Experimental Investigations on Riveting Assembly Processing Parameters of Hub Bearing Unit: *Y. Wang*[1]; W. Xiong[1]; J. Zhou[2]; P. Ren[2]; [1]Hubei University of Arts and Science; [2]Hubei New Torch Technology Co., Ltd
Applying the rotary forging process (RFP) to the shaft-end riveting assembly of hub bearing units (HBU) is an important technological innovation with promising application prospect. Due to its advantages of stable pre-tightening, low cost and high integration, shaft-end riveting assembly have become a vital process in assembling the third generation HBU. However, due to the lack of systematic application research on RFP, there are still gaps between the domestic hub bearings and the imported products especially in terms of accuracy and consistency of performance. In the study, a numerical simulation platform (NSP) was adopted to simulate the assembling processes of HBU, in which the interference assembly, loading and unloading of RFP were simulated with ABAQUS / Standard, ABAQUS / Explicit and ABAQUS / Standard, respectively. The influence of processing parameters on product quality has been carried out by investigating several levels of feed displacement and feed rate, and relevant experimental research has also been conducted. It is found that the experimental results are in consistence with the numerical simulation results, demonstrating that the NSP adopted could be an alternative in determining and optimizing the processing parameters of RFP.

Fabrication of NiAl/TiAl-based Gradient Alloys by Additive Sintering: D. Wang[1]; *H. Ning*[1]; G. Liu[1]; [1]Harbin Institute of Technology
In this work, aiming at near-net forming and joining of complex shapes for difficult-to-deform alloys, a novel additive sintering route combined with hot pressing sintering (HPS) and powder compact joining for NiAl/TiAl based gradient alloys has been offered, which can break the technical bottleneck of difficult-to-deform alloys and their gradient alloys. The proposed additive sintering can be realized by reheating and holding the powders on the sintered compact samples under pressure,then the complex-shape components can be prepared by repeating the process. The results show that the samples prepared by additive sintering have well-bonded interfaces and the properties at room and high temperatures of the joining region are almost the same as the non-joined samples. Due to the improvement of plasticity for the previous compact sample during additive sintering, the high temperature tensile plasticity in the direction parallel to the interface of the final product has also been improved.

A New Non-destructive Testing Method Applied to Clinching: *R. Lafarge*[1]; A. Wolf[1]; C. Guilleaume[1]; A. Brosius[2]; [1]TU Dresden; [2]Institute of Forming Technology and Lightweight Construction Institute
To pursue better quality, there is a strong need for efficient and robust non-destructive testing methods for joining processes. Wolf et al. [*Production Engineering*, 2019] have proposed a new approach to detect loose bolted joints using acoustic waves. This method measures the dissipation of energy by recording the propagated waves on the surfaces of the joining partners next to the joint. The authors showed a link between the torque moments applied to the bolt and the ability of the joint to transfer acoustic energy using both simulations and experiments.In this article, we numerically investigate the ability to detect variation of some process parameters of the clinching process. To this extent, results of FEM calculation of the joining process are then used to simulate the control method. By varying parameters of the clinching model, their influence on the transmission of energy within the joint is studied.

Microstructure Development by Forming II

Wednesday AM | July 28, 2021 | 10:20 - 11:20 AM

Session Chair: W. Misiolek, Lehigh University

Metal Foils for Bipolar Plates – Correlation of Initial Grain Size and Forming Behavior of 316L: *A. Bauer*[1]; T. Mehner[1]; B. Awiszus[1]; T. Lampke[1]; [1]University of Technology Chemnitz
As the forming of metallic bipolar plates is mostly still state of research, the underlying forming mechanisms are not fully understood. This study deals with the topic of different grain sizes in the initial metal sheets and their influence on the forming results. Therefore, a work hardened 316L-foil (0.1 mm) was processed with different heat-treatment strategies resulting in three different grain sizes with average grain diameters of 47.4 µm, 19.3 µm and 7.9 µm. Afterwards, all heat-treated blanks were cut and deep drawn between two rigid dies to form a bipolar plate flow field. Besides force and geometrical factors like thinning and springback, the microstructure was analyzed by XRD and EBSD. Using these characterization methods, the mechanisms of twinning and preferred deformation of specific grain orientations during the forming process can be identified. Therefore, the impact of size effects on the forming behavior of metallic bipolar plates was shown.

Analysis of the Microstructural Forming Behavior of 316L Metal Foils with Different Initial Grain Sizes for the Production of Metallic Bipolar Plates: *A. Bauer*[1]; T. Mehner[1]; B. Awiszus[1]; T. Lampke[1]; [1]University of Technology Chemnitz

As the forming of metallic bipolar plates is mostly still state of research, the underlying forming mechanisms are not fully understood. This study deals with the topic of different grain sizes in the initial metal sheets and their influence on the forming results. Therefore, a work hardened 316L-foil (0.1 mm) was processed with different heat-treatment strategies resulting in three different grain sizes with average grain diameters of 47.4 µm, 19.3 µm and 7.9 µm. Afterwards, all heat-treated blanks were cut and deep drawn between two rigid dies to form a bipolar plate flow field. Besides force and geometrical factors like thinning and springback, the microstructure was analyzed by XRD and EBSD. Using these characterization methods, the mechanisms of twinning and preferred deformation of specific grain orientations during the forming process can be identified. Therefore, the impact of size effects on the forming behavior of metallic bipolar plates was shown.

T8 Heat Treatment Effect on Wear Behavior and Microstructure of Cryo and RT Ecaped Al 6063: A. Sreenivasulu[1]; *S. Gurugubelli*[1]; [1]J N T U K University College of Engineering

The effect of T8 heat treatment on wear behaviour of AA6063 were studied and precipitation kinetics was evaluated by SEM and XRD studies. AA6063 square rods of 9.5 mm X 9.5 mm X 100mm were solution treated at 5200C for 2hrs and quenched in water. One set of samples were processed by ECAP at room temperature and the other set were processed by Cryogenic ECAP after soaking in liquid nitrogen for 20 minutes. A die of 1080 channel intersection angle and 360 outer curvature angle was used and each sample was given four passes in route A and aged at 1800C. Hardness measurements were obtained at regular intervals and wear tests were conducted on pin-on-disc wear testing machine. SEM images were obtained and the wear behaviour of the alloy was correlated with the microstructures. Much improvement in wear resistance was observed in the alloy processed by cryo-ECAP.

Development and Implementation of Static Recrystallization Model of 6XXX Aluminum Alloy Using Industrial Experiments: *A. Alimov*[1]; I. Kniazkin[2]; N. Biba[3]; [1]Brandenburg University of Technology Cottbus-Senftenberg; [2]Bauman Moscow State Technical University; [3]Micas Simulations Limited

The paper focuses on the development of a static recrystallization model of 6XXX aluminum alloy based on industrial profiles extrusion analysis. 6XXX aluminum alloys are widely used for complex shapes with smooth surfaces suitable for visible architectural applications. Mechanical properties and surface defects, for example, streaking lines, are dependent on the microstructure. Static recrystallization occurs in alloys such as 6XXX due to high stacking fault energy. At the moment, there is no reliable static recrystallization model of 6XXX aluminum alloys found in the literature. In the presented paper a new approach has been proposed to determine the parameters of Johnson-Mehl-Avrami-Kolmogorov equation. It is based on using of strain and temperature history during extrusion of industrial profiles and examining the microstructure in their cross-sections and implementing of the inverse analysis approach. The developed model has been verified and used for simulation of the microstructure evolution in industrial extrusion cases and has shown sufficient accuracy.

Non-isothermal modeling of static recrystallization in hydroformed steel tube using a coupled Cellular Automata and Finite Element model: *A. Asgharzadeh*[1]; S. Nazari Tiji[1]; T. Park[1]; F. Pourboghrat[1]; [1]The Ohio State University

An accurate thermo-microstructural modeling setup was developed to model the kinetic of static recrystallization during annealing of hydroformed steel tube under non-isothermal condition. In this model, a coupled Cellular Automata and Finite Element thermal model was implemented to predict the kinetic of static recrystallization, which also accounts for the impact of multiaxial deformation and annealing temperature regime. First, an exact analytical solution was developed to calculate the flow behavior of steel tube during hydroforming experiment based on the data extracted from digital image correlation measurements. Second, the actual microstructure and orientation of the as-deformed material was obtained with EBSD test. Third, the calculated deformation characteristics as well as the obtained crystallographic and microstructural data were imported to the developed Finite Element-Cellular Automata model to predict the progress of static recrystallization and temperature changes during annealing. The results show that there is a reasonable agreement between the experimental data and predictions, confirming the accuracy of developed modeling setup in prediction of the progress of static recrystallization within hydroformed steel tubes.

Residual Stresses in Metal Forming I

Wednesday AM | July 28, 2021 | 10:20 - 11:20 AM

Session Chair: W. Volk, Technical University of Munich

Influence of Material Delivery Condition on Residual Stresses and Part Properties during Forward Rod Extrusion: *A. Jobst*[1]; M. Merklein[1]; [1]Friedrich-Alexander-University, Institute of Manufacturing Technology

During the manufacturing of semi-finished products the material is subjected to various forming steps. It is annealed before component manufacturing in order to reduce hardening and to ensure a good formability. Inhomogeneous pre-strengthening of the material influences the stress distribution during full forward extrusion. This affects the part's residual stress state and therefore its operating and failure behaviour. For prediction of the residual stress state, influences of the material delivery condition must be known. The aim of this paper is to derive dependencies between material properties and resulting residual stresses in the component. For this purpose, stainless steel in different delivery conditions is used. Residual stresses, microstructure and microhardness distribution of the materials are compared regarding the rods and extruded parts. The influences of the delivery condition are evaluated by comparing process and component properties.

Analysis of Cylindrically and Spherically Embossed Flux Barriers in Non-oriented Electrical Steel: *I. Gilch*[1]; S. Vogt[1]; T. Neuwirth[2]; B. Schauerte[3]; K. Hameyer[3]; M. Schulz[2]; W. Volk[1]; A. Gustschin[1]; H. Weiss[1]; [1]Technical University of Munich; [2]Technical University of Munich - Heinz Maier-Leibnitz Zentrum; [3]RWTH Aachen University - Institute of Electrical Machines

In reluctance and permanent magnet synchronous machines, flux barriers are crucial for magnetic flux guidance. Designed as cutouts, flux barriers reduce the mechanical strength of the rotor construction. To operate these electric drives at higher rotational speed, an alternative flux barrier design is required. Since residual stress influences the magnetic properties of soft magnetic materials, this paper deals with embossing induced residual stress as flux barriers in non-oriented electrical steel with 2.4 wt% silicon and a sheet thickness of 0.35 mm. The investigated flux barriers were fabricated with a cylindrical or spherical punch at two different penetration depths and were compared to a flux barrier fabricated as cutout. A residual stress analysis using Finite Element Analysis helps understanding the mechanism of embossed flux barriers. Additionally, the influence of induced residual stress on the magnetic material behavior is measured using standardized single sheet tests and neutron grating interferometry measurements. This investigation aimed at a better understanding of the flux barrier design by local induction of residual stress.

Residual Stresses in Hot Bulk Formed Parts – A Phenomenological Approach for the Austenite-to-Martensite Phase Transformation: *S. Uebing*[1]; D. Brands[1]; L. Scheunemann[1]; C. Kock[2]; H. Wester[2]; B. Behrens[2]; J. Schröder[1]; [1]Institute of Mechanics, Department of Civil Engineering, University Duisburg-Essen; [2]Institute of Forming Technology and Machines
In production engineering, current research focuses on the induction of targeted residual stress states in components in order to improve their properties rather than following the usual path of minimizing residual stresses to prevent failure. In this contribution, a focus is laid on the investigation of the subsequent cooling process of hot bulk formed parts. Such cooling of a component leads to a microscopic phase transformation, which has to be considered in order to compute residual stresses inside the material. A numerical approach based on a phenomenological macroscopic material model is presented to depict the related stress evolution.

Adjusting Product Properties by Deliberate Induction of Residual Stresses in Single Point Incremental Forming: *M. Dobecki*[1]; F. Maaß[2]; M. Hahn[2]; A. Tekkaya[2]; W. Reimers[1]; [1]Institute for Materials Science and Technology - Metallic Materials, TU Berlin; [2]Institute of Forming Technology and Lightweight Components (IUL), TU Dortmund
Single point incremental forming (SPIF) is a flexible manufacturing process for the production of customized hollow parts. The mechanical properties of the manufactured components are highly affected by the prevailing residual stress state. The objective of this research is the improvement of the product properties by selective induction of residual stresses. The residual stress state is influenced by the forming mechanisms bending, shearing and membrane stretching. These mechanisms are triggered by adjusting the ratio of step-down increment and tool radius. Numerical and experimental analysis of groove and cone geometries shows that higher step-down increments increase bending and smaller step-down increments increase shearing. Shearing leads to higher residual stress amplitudes. The resulting targeted residual stress state can improve the fatigue strength of a component up to 42%. Through superposed tensile and compression stresses, the residual stress amplitudes can be further increased or may even be inverted.

Formation of Residual Stresses in Austenitic Stainless Steels by Infeed and Recess Rotary Swaging: H. Hoche[1]; *F. Jaeger*[1]; A. Franceschi[2]; M. Oechsner[1]; P. Groche[2]; [1]Center for Engineering Materials (MPA-IfW), TU-Darmstadt; [2]Institute for Production Engineering and Forming Machines (PtU), TU-Darmstadt
The austenitic steels 1.4307 and 1.4404 significantly benefit from cold forming, due to their high work hardening ability. Optimizing the forming process chain could improve the component's fatigue properties in order to induce specific residual stresses in critical component areas. In this work, an analysis of the effects of the process parameters during rotary swaging on the resulting residual stresses is carried out. Through this incremental forming process, high strain hardening and a complex material flow history are induced in the workpieces. Therefore, measuring strategies for the residual stress measurement by XRD were developed. Here, especially the 1.4307 is a challenging material due to cold forming induced martensite. Despite phase change, both cold formed materials exhibit anisotropic microstructures as well as grain coarsening. Moreover, particular notched geometries are produced on the workpieces by rotary swaging. Measuring techniques are further developed for these complex geometries and the residual stresses are investigated.

Complementary Methods for Assessment of Residual Stress Fields Induced by Rotary Swaging of Steel Bars: *D. Charni*[1]; S. Ishkina[2]; J. Epp[1]; M. Herrmann[2]; C. Schenck[2]; B. Kuhfuss[2]; [1]Leibniz Institute for Materials Engineering - IWT; [2]Bremen Institute for Mechanical Engineering - bime
The process investigated in this paper consists of cold rotary swaging of steel bars. In recent work, surface residual stresses were found to be sensitive to process parameters and their fluctuations, leading to variations of residual stresses at different length scales. To properly evaluate the residual stress states in rotary swaged bars, several complementary measurement techniques were applied. Complementary to surface X-ray diffraction measurements, the applicability of micromagnetic methods was evaluated for fast mapping of local residual stress distribution at the surface with a spatial resolution down to 20 µm. Additionally, an evaluation of the full residual stress profile over the cross section was achieved by neutron diffraction. The combination of the different methods thus allowed a complete characterization of the generated residual stresses at different length scales. Furthermore, a 3D FE-model was developed and process simulation using Chaboche material model was carried out to investigate the residual stress generation and compare the results with the experimental data. The results show an overall good agreement of the experimental data with the simulation results.

Analysis of Influencing Factors on the Achievability of Bistable Fully Closed Shells by Semi-analytical Modelling: *P. Pavliuchenko*[1]; M. Teller[1]; G. Hirt[1]; [1]Institute of Metal Forming, RWTH Aachen University
Bistable fully closed shells can serve as long supporting structures that can be folded into a compact transport geometry and unfolded at the construction place and can be produced by incremental die-bending. In order to find a suitable bending radii a semi-analytical model was developed and experimentally validated in previous research. Nevertheless, minor deviations have occurred in the prediction of the stable geometries curvatures and the degree to which other parameters influence the achievability of bistable shells is still unclear. Therefore, an enhancement of the existing model is described and used for an analysis of the influence of different parameters on bistability and final shell geometries. To verify the results, experiments with two different materials (AISI 1095 and AISI 301) and different bending radii are presented. Finally, the paper shows the influence on the residual stress distribution and based on this, production limits for bistable fully closed shells are derived.

Sheet Forming I

Wednesday AM | July 28, 2021 | 10:20 - 11:20 AM

Session Chair: E. Iriondo, University of the Basque Country

Analysis of Material Work Hardening and Fracture Strains for Sheet Metal Stamping Processes: S. Golovashchenko[1]; S. Zdravkovic[1]; *N. Reinberg*[1]; S. Nasheralahkami[1]; W. Zhou[1]; [1]Oakland University
Experimental study of sheet material flow curves was performed using combined methods of cold rolling for prestraining material to targeted strain and then tensile testing. Experimental studies revealed that aluminum alloys show tendency for flow curves saturation which substantially lowers sheet work hardening. Performed numerical simulations of cup drawing illustrated that this effect leads to earlier material wrinkling compared to power law approximation of the flow curve. Examples of numerical simulation with Autoform software comparing various cases of flow curve approximation will be provided.Analysis of fracture strains was performed by combined gridding and paint spraying on the sheet surface. This approach enabled measurements of local strains in the area closely adjacent to fracture without having continuous access to this area by video camera. This approach was used for sheet hole expansion, sheared edge stretchability along straight cut, hemming, and self-piercing riveting for ultra high strength steels and aluminum alloys.

Finite Element Simulation and Punch Design for Tube Hydro-piercing: *Y. Hwang*[1]; W. Dai[1]; P. Lin[1]; [1]National Sun Yat-sen University
This study is focused on punch shape design in tube hydro-piercing processes of aluminum alloy A6005 tubes. The flow stresses of the aluminum alloy tubes obtained by tensile tests are used in the finite element simulations of tube hydro-piercing process with software "DEFORM 3D". The ductile fracture criterion of normalized Cockcroft and Latham is used during the FE simulations. The critical damage values for the criterion are obtained by comparing simulation results and tensile test data. The effects of various parameters such as the stroke, internal pressure, etc. on hydro-piercing processes and deformation mechanism are discussed. Experiments are conducted and the experimental shearing surface heights are compared with the simulation results to verify the validity of the analytical models. The effects of various parameters on shearing surface heights are also discussed by hydro-piercing experiments.

Formability of Functional Corrugated Cup: *Y. Harada*[1]; Y. Nishikubo[1]; [1]University of Hyogo
The formability of the corrugated clad cup was investigated to enhance the functionality of the cup. The drawn cup with a corrugated structure on the side wall was formed by deep drawing. Since the side wall of the cup had a wave shape, the wave shape was reproduced by using a unique die in which steel balls were arranged without the gaps in the shoulder of the die. In the experiment, the materials were low carbon steel SPCC, stainless steel SUS304, and pure titanium JIS-TP340. In the deep drawing process, the round blanks were employed and the flat sheet blanks were formed into a circle by a punch. The laminated sheets were successfully drawn without the cracks. It was found that the corrugated clad cups were successfully formed by using the roller die.

Fine-piercing of Electrical Steel Sheets by Edge-sharpened Diamond-punch: *T. Shiratori*[1]; T. Aizawa[2]; [1]Komatsu Seiki Kosakusho, Co., Ltd.; [2]Nano Coat Film, llc.
EV-motors required for much reduction of iron loss in the motor cores. Distortion of magnetic zones by piercing each electro-magnetic steel sheets of motor cores, is notices as one of the largest issues toward this reduction of iron loss. In the present paper, the edge-sharpened diamond punch was developed to significantly reduce the plastic strained area as well as the elastic recovery of pierced sheets. First, the femtosecond-laser trimming method was employed to reduce the edge curvature of diamond coating as well as the surface roughness. Micro-piecing experiments with use of EBSD analysis on the microstructure were utilized to demonstrate that plastic zones were narrowed along the shearing line.

Experimental Analysis on Granular Media Based Tube Forming with Active Axial Feed: E. Hoffmann[1]; C. Löbbe[1]; A. Tekkaya[1]; *S. Upadhya*[1]; [1]Institute for Forming Technology and Lightweight Components (IUL), TU Dortmund
Production of high strength, high stiffness and safety-relevant profile parts is feasible through the sequence of media based forming and in-die quenching. As forming media, solid granular media have been recently introduced (Chen, 2016). In this work, the granular media tube press hardening process with additional axial feeding is investigated in order to enhance the tube thickness distribution and to enlarge the process window. The experiments show that, compared to the process with frictional feed, the limits for insufficient forming and wrinkling are unaffected by the change of the feeding system, while the area for intolerable thinning is reduced. Additionally, through the new feeding system a higher degree of design freedom could be achieved, e.g. shoulder angles of 90° are possible. Furthermore, for the design of the process an advanced FEM simulation has been developed, which is based on the Drucker Prager cap model and covers also the thermal interactions.

Effects of Servo Press Forming on Various Strain Path Failures: *L. Zoller*[1]; T. Feister[1]; H. Kim[1]; [1]EWI
Utilizing a servo press for sheet metal forming provides benefits for users such as a fully adjustable slide motion and blank holder force control during the stroke. These allow users to program unique profiles based on position and velocity. This paper will discuss how unique servo press profiles can improve various strain path failures that may occur in final formed parts. Standard crank motion, variable blank holder force, and attach-detach slide motion were used to evaluate biaxial, plane strain, and uniaxial failure paths of three variations of bake hardened steel and three variations of GEN-3 steel. It was determined that different strain failure paths require different servo press programs to improve the overall part quality.

Formability Analysis of a Local Heat-treated Aluminium Alloy Thin-walled Tube: *A. Piccininni*[1]; J. Magrinho[2]; B. Silva[3]; G. Palumbo[1]; [1]Politecnico di Bari; [2]Istituto Superior Tecnico, Universitade de Lisboa; [3]Istituto Superior Tecnico, Universitade de Lisboa
The environmental concerns to save energy are driving the attention toward alternative ways to match light alloys with innovative manufacturing processes. Moreover, the need to increase the material formability has led the adoption of local heat treatment to gain relevance over the last years. The present work is focused on the evaluation of the room temperature formability of thin walled Aluminium alloy tube locally annealed by laser. The formability limits were preliminarily determined in the "as-received" conditions (tube expansion with elastomer). Numerical analyses were performed to define the experimental conditions to obtain different strain paths. Tube expansion tests were assisted by the Digital Image Correlation (DIC). Subsequently, the local laser treatment was investigated and Locally Annealed Tubes (LATs) were subjected to tube expansion tests. LATs strain paths and failure strains were compared to those in the "as-received" condition, allowing to evaluate the effect of the local modification on the formability.

Novel Roll Bonded Stainless Steel / Boron-steel Multilayer under Hot Stamping Conditions: M. Kamaliev[1]; M. Teller[2]; C. Löbbe[1]; G. Hirt[2]; A. Tekkaya[1]; *M. Stennei*[1]; [1]Institute of Forming Technology and Lightweight Components (IUL), TU Dortmund University; [2]Institute of Metal Forming (IBF), RWTH Aachen University
Aluminium-silicon coated boron-steels are regarded as standard material in direct hot stamping processes. Nevertheless, the material brings along some disadvantages such as the requirement of a long dwell time in the furnace for the generation of a resistant diffusion layer. In this paper a multilayer steel sheet, with a boron-steel core and stainless steel outer layers, is introduced and the manufacturing process by hot roll bonding is described. Due to the stainless steel surfaces, a coating for hot stamping is no longer necessary. The multilayer is characterized by hot tensile tests and compared with the monolithic multilayer-partners. Hot stamping experiments are conducted on a laboratory scale. Corresponding hardness measurements show that the core is hardened while the outer layers remain ductile. The new multilayer sheets offer the potential to deliver components with higher formability due to tailored properties along the sheet thickness and the use of rapid heating methods.

Experimental and Numerical Investigations into the Influence of the Process Parameters during the Deep Drawing of Fiber Metal Laminates: T. Heggemann[1]; W. Homberg[1]; *H. Sapli*[1]; [1]Universität Paderborn
Reducing fuel consumption and climate-damaging CO2 emissions are important current challenges for the automotive industry. These goals can be achieved by reducing the weight of the car. Extremely lightweight car bodies can be achieved by using exclusively composite materials, which have the major disadvantage of high costs and unsuitability for large scale production. A promising approach to the automated, large-scale production of lightweight automotive structures with a high stiffness to weight ratio is the combination of high strength steel alloys and CFRP prepregs in a hybrid material – fiber metal laminate (FML) – which can be processed by specially adapted forming technologies such as deep drawing. The paper presents recent results of the combined curing and forming process. The influence of the process parameters, the process limits, the necessary tool systems and the process strategies are similarly covered by the paper.

TECHNICAL PROGRAM

Hydro-mechanical Deep Drawing of Locally Solution Treated Aluminum Alloy Sheets: *T. Nishiwaki*[1]; R. Sako[1]; H. Tsutamori[1]; [1]Daido University

Improvement of formability of aluminum alloy sheets is desired because of their lower drawability than mild steel. Therefore, the special sheet forming methods such as a hydro-mechanical forming and a tailor heat treated blank have been developed for aluminum alloy sheets. In this study, we combined the both methods and investigated the limit of drawing ratio of tailor heat treated blanks in a hydro-mechanical forming process. Tailor heat treated blanks of A6061-T6 sheets were produced by the locally solution treatment which was conducted by heat transfer from metal plates heated to a high temperature. Hydro-mechanical deep drawing tests were performed using a cylindrical punch. The limit of drawing ratio of tailor heat treated blanks in a hydro-mechanical forming process was higher than that of simple hydro-mechanical forming and that of simple tailor heat treated blanks.

Development of Warm Press Forming Process Method of Ti-6Al-4V Alloy Sheet: *Y. Okude*[1]; T. Iwaoka[1]; I. Nakamura[1]; T. Katagiri[1]; [1]Tokyo Metropolitan Industrial Technology Research Institute

Because of the low ductility of Ti-6Al-4V alloy at the temperatures between room temperature and 600°C, fracture easily occurs during press forming. Hence, a method of press forming of Ti-6Al-4V alloy sheets at 300°C was developed. In this method, the punch motion and blank holding force were applied separately to prevent fracture at the punch radius until the maximum punch load was reached, and the deep-drawing process was demonstrated from the maximum punch load until finish forming to prevent the fracture at end of the flange. In addition, by applying the developed method, we were able to prevent the decrease in wall thickness at the punch shoulder, compared with that in press forming. As a result, warm press forming of Ti-6Al-4V alloy sheets at 300°C was achieved without fracture of the formed cup or local decrease in the wall thickness by applying the developed method.

Thursday Keynote

Thursday AM | July 29, 2021

Session Chairs: J. Cao, Northwestern University; Y. Yoshida, Gifu University

7:30 AM Keynote

Recent Investigations on Incremental Sheet Forming: From Fundamentals to Industrial Application Technologies: *J. Chen*[1]; Z. Chang[1]; [1]Shanghai Jiaotong University

Incremental sheet forming (ISF) is a promising flexible forming process in fabricating low-batch or customized sheet metal parts, and has potentials in reduced process lead time & cost, and increased formability. In the plenary talk, recent investigations on ISF fundamentals and the technologies for ISF industrial application will be presented, which cover loading path algorithms, forming tool development, surface roughness and forming load predictions, new variants of ISF, deformation mechanism of different ISF variants and several industrial application cases. Finally, an outlook about ISF will be made as well.

8:15 AM Keynote

Tube Forming and Fabricating Technologies for Contributing Society by Tackling Problems of Environment and Aging Population: *T. Kuboki*[1]; A. Shirayori[2]; M. Mizumura[3]; N. Utsumi[4]; Y. Hwang[5]; [1]The University of Electro-Communications; [2]Utsunomiya University; [3]Nippon Steel Corporation; [4]Saitama University; [5]National Sun Yat-sen University

Technologies for forming and fabricating tubes have been contributing to the development of society, and should evolve and have great roles in the future societies, considering the environmental problems. Global warming is a critical problem and the average temperature in the world is still increasing. Tubes have advantages of high rigidity for a unit weight and could manufacture light-weight components for transport equipment. The technologies on tubes should contribute for solving these problems and realizing sustainable societies.This paper introduces the author's technologies and reviews others' recent technologies on tubes. The technologies include hydro and air forming, rotary forming, bending, micro forming and so on. These technologies are qualitatively evaluated in terms of conflicting characteristics, such as formability, strength, productivity, flexibility and miniaturization. Some technologies are emerging to improve some of the conflicting characteristics at the same time for realizing excellent performances of the formed products.

9:00 AM Break

High Speed and Impulse Forming II

Thursday AM | July 29, 2021 | 9:15 - 10:15 AM

Session Chair: L. Galdos, Mondragon University

Local Microscopic and Integral Macroscopic Analysis of Magnetic Pulse Welds and Deformations for Dissimilar Metal Joints: *F. Huberth*[1]; B. Ragupathi[1]; C. Scheffler[2]; V. Psyk[2]; J. Preußner[1]; [1]Fraunhofer IWM; [2]Fraunhofer IWU

Magnetic pulse welding (MPW) technique combines high speed forming, impact and results in a partial weld at the collision zone of the accelerated flyer and the impacted target. Flyer, target and the acting coil can be positioned in different configurations resulting in different deformations of target and flyer accelerated by the magnetic pulse in the coil and thus different welds. The local effects for dissimilar metal joints of aluminum EN-AW-1050 and copper Cu-DHP are investigated for different configurations and impact energies by local micro tensile tests in thickness direction of the welded two metal sheets leading to the local weld strength distribution. For micro sample preparation, thin cross-sectional stripes (0.5 mm) are extracted from the contact parts of the sheets. The micro experiments are accompanied by micro structural analysis. These local microscopic testing and analysis results are correlated to integral macroscopic lap shear tests on the welds supported by simulations.

Grain Size Effect on Formability in Electromagnetically-assisted Micro-bulging of Pure Titanium Sheet: *C. Zhu*[1]; J. Xu[1]; H. Yu[1]; D. Shan[1]; B. Guo[1]; [1]Harbin Institute of Technology

It has been revealed that geometry and grain size effects have great effect on the formability of metal foils during quasi-static forming processes. However, there is little research on how these size effects influence formability of metal foils during high speed forming process e.g. electromagnetic forming. To characterize these size effects in electromagnetic bulging, miniaturized Nakazima test and numerical investigation were conducted. Pure titanium foils with different thickness and different grain sizes were utilized in the experiment. In addition, to clarify how forming speed influence the formability of metal foils, different forming voltages were adopted. Finite element method then was used to analyze the electromagnetic bulging process. To analyze how the size effects affect the ductile fracture in electromagnetic micro-forming, M-K failure criterion was modified to model the forming limit in micro-scaled deformation,and is found to be able to model the decrease of forming limit caused by size effects.

Influence of Ultrasonic-assistance on the Forming Limits of Steel: *M. Jäckisch*[1]; M. Merklein[1]; [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Institute of Manufacturing Technology (LFT)
Since Blaha discovered the beneficial effect of superimposing high-frequency oscillations to the metal forming process, the occurring force and stress reduction are well-known phenomena. Leading to an immediate flow stress reduction, the so-called ultrasonic-assistance is a promising approach to enable forming with reduced process forces. While the feasible force reduction has been investigated intensively, only a few analyses have been conducted in the context of the impact of ultrasonic-superposition on the forming limits. Latest investigations state earlier material failure due to localized forming with high strain rates. Within this paper, the influence of superimposed vibrations on the forming limits of C35E is investigated with regard to distinct oscillation amplitudes. For this purpose, ultrasonic-assisted shear tests are carried out and compared to high-speed shear tests with similar strain rates. This way, effects only caused by the high strain rates and those resulting from the recurring cyclic loading are separated.

Recent Developments of Vaporizing Foil Actuator Technique for Manufacturing Applications: K. Prasad[1]; J. Li[1]; B. Barnett[1]; Y. Mao[1]; G. Daehn[1]; *A. Vivek*[1]; [1]The Ohio State University
Vaporizing Foil Actuator (VFA) is an impulse or high-speed manufacturing technology using electrically driven rapid vaporization of thin conductors to produce short-duration pressure pulses of high magnitude. This impulse technique has been implemented for varied applications such as high strain rate forming, shearing, collision welding, and springback calibration. VFA technology for manufacturing processes potentially offers improved accuracy, reliability, and environmental safety and creates opportunities to design new products by joining similar and dissimilar material combinations. The paper includes the results of industrially relevant "work-in-progress" research with the VFA tool. The process's applications, mainly regarding advanced manufacturing such as metal-matrix composite (MMC) welding, axisymmetric welding, and impact-mediated additive manufacturing processes, are presented and discussed. The applications of the method characterize adequate responses to support the manufacturing process.

Augmentation of Plasma-based Impulse Generation with Rapid Chemical Reactions: *B. Thurston*[1]; Y. Mao[1]; T. Lewis[1]; A. Vivek[1]; G. Daehn[1]; [1]The Ohio State University
The use of a chemical explosive mixture to augment the Vaporizing Foil Actuator (VFA) and Laser Impact Welding (LIW) processes is introduced in this study. A liquid explosive known as Picatinny Liquid Explosive (PLX) was used to augment the capabilities of both the VFA and LIW processes. 304 stainless steel flyers 3mm thick driven by PLX augmented VFA and unaugmented VFA are compared. Similarly, 0.442mm thick Al3003 flyers driven by laser impact and PLX augmented laser impact are compared. In all cases a Photon Doppler Velocimetry (PDV) system was used to collect the velocity time profiles of the flyers. All PLX augmented experiments showed increases in both flyer acceleration and peak velocity over the same time scales as the unaugmented experiments. This indicates that the PLX provided impulse occurs at the same time as the VFA/laser impulse. The augmented VFA experiments showed a 28% velocity increase over the unaugmented experiments at 10kJ input energy. The augmented laser impact process exhibited peak flyer velocities 236% higher than laser impact using only the laser. Here we demonstrate that chemical augmentation is capable of significantly increasing flyer velocities for both VFA and LIW at the same input energies and under similar conditions. This development should expand the repertoire of flyer materials and thicknesses that can be impact welded by VFA and LIW.

Microstructure and Damage Development IV

Thursday AM | July 29, 2021 | 9:15 - 10:15 AM

Session Chair: P. Bouchard, CEMEF-Mines Paris Tech PSL

The Influence of Temperature and Strain Rate on the Superplastic Deformation Behavior and Microstructure Evolution of TNW700 Alloy: *L. Ma*[1]; M. Wan[1]; W. Li[1]; J. Shao[2]; X. Bai[2]; [1]Beihang University; [2]AVIC Manufacturing Technology Institute
TNW700 titanium, as a near-\945 high temperature titanium alloy, is designed to work at 700˚C for a short term service. Superplastic deformation behaviour of TNW700 alloy was investigated in a temperature range of 900-975˚C and a strain rate range of 0.0005-0.01s^{-1} to identify the optimum deformation temperature and strain rate. The microstructure evolution after high temperature tensile was investigated using scanning electron microscope. The research found that TNW700 alloy has an excellent superplasticity. The elongation exceeds 200% at various deformation conditions except 975˚C with higher strain rate of 0.005 and 0.01s^{-1}, and the maximum elongation of 613% was obtained at temperature of 925˚C and strain rate of 0.001s^{-1}. The flow stress is sensitive to temperature and strain rate, and it increases with decreasing temperature and increasing strain rate. In addition, the flow stress exhibits strongly work hardening with increasing of true strain, and the instantaneous work hardening exponent *n* and the critical hardening strain is accelerated as the strain rate decreases. The strain rate sensitivity exponent (*m*) is higher than 0.4 when the temperature is lower than 975˚C, which corresponds to dynamic recrystallization and grain boundary sliding. The *m* is 0.229 at temperature of 975˚C, corresponding to dynamic grains growth mechanism. The deformed microstructure of TNW700 alloy consists of \946 grains and equiaxed \945 grains. Increasing the temperature is beneficial to the transformation of \945 phase into the \946 phase, which resulted in an increase in the volume fraction of the \946 phase. The \946 grains growth rapidly at higher temperatures and lower strain rates due to higher diffusion coefficient.

The Study of Energy Absorption of Dual-material Tailored Plane Strain Sheet: *Y. Pengfei*[1]; G. Yulong[1]; X. Yong[1]; [1]School of Vehicle and Mobility, Tsinghua University
The combination of high strength and good ductility are very desirable for functional structures. Laser ridgeline quenching, as a relatively new technology to reinforce steels, gives a flexible to balance the rigidity and toughness of the tubular structures like A-pillar and sill. However, the deformation incompatibility, which is caused by partial quenching, could lead to a structural fracture under impact conditions.In this study, we suppose to investigate the plastic deformation and fracture behavior of partial quenched hot forming steel HR1500. First, quasi-static and dynamic tensile tests are conducted on the original and laser-quenched steels. Second, tensile tests are conducted on the partial quenched steels with three different boundary directions. Finally, the scanning electron microscopy-based electron backscatter diffraction is used to characterize the micro-structure evaluation and the feature of fracture of materials.

Hot Cutting of Press-hardened Parts in Different Heat Treatment Regimes: R. Schmidt[1]; A. Rautenstrauch[1]; *V. Kräusel*[1]; [1]Technische Universität Chemnitz

Parts made of press-hardened steels are cut in general by laser cutting. Shear cutting at room temperature of materials with a tensile strength above 1,500 MPa is not an alternative due to insufficient tool life quantity. The presented investigation relates to the hot cutting of press hardenable materials such as 22MnB5 and 34MnB5 and includes the determination of the cutting parameters (measuring rate of 100,000 Hz), the temperature and the formation of the microstructure and the dimensional accuracy of the cut parts during different heat treatments. The results of this investigation show that, when comparing two process routes, the maximum cutting force was reduced to approx. 70 % when cutting in the austenitic range, the acceleration during the cutting impact was close to zero and the deviations from the target geometry were very small. With regard to the measurement results, hot cutting can be an alternative to laser cutting.

Microstructural Influences on Grain Boundary Sliding in High Purity Aluminum: *M. Linne*[1]; T. Bieler[2]; S. Daly[3]; [1]Lawrence Livermore National Laboratory; [2]Michigan State University; [3]University of California at Santa Barbara

The presented work investigates grain boundary sliding (GBS), a grain boundary-enabled deformation mechanism, and its relationship with local plasticity and microstructural neighborhood. GBS is characterized experimentally at grain boundaries in 99.99% aluminum with a through-thickness, coarse-grained microstructure deformed in tension at 190 °C. High-resolution strain fields and microstructural information were measured to examine the influence of microstructural neighborhoods on interactions between GBS and slip transmission and strain localization. The findings include (1) direct transmission and GBS were anti-compatible and facilitated by opposing boundary types (low misorientation and high energy grain boundaries respectively); (2) increased GBS activity was correlated with decreased indirect transmission behavior and (3) GBS accommodation at triple junctions was enabled by intragranular plasticity. This work provides insight into the nature of GBS activity and can be used to identify strain transfer criteria that can lead to improved GBS-sensitive crystal plasticity models.

Statistical Analysis of Microscopic Strain Localization and Its Strain Level Dependence: *H. Oh*[1]; K. Biggs[1]; O. Guvenc[1]; S. Wei[1]; J. Kang[1]; C. Tasan[1]; [1]Massachusetts Institute of Technology

Deformation-induced microstructural strain localization is a key process determining various mechanical properties of metallic materials, including formability. However, due to the complexity of the strain localization patterns, most studies investigate this phenomena qualitatively. Recently it was shown that the statistical distribution of local strain in various steels follow a universal law, i.e., a lognormal distribution. To understand this behavior further, we performed a statistic study of strain localization in various single phase and multi-phase alloys. Based on these observations, we propose a parameter to describe the statistical distribution of localized strain. Furthermore, as the loss of viable facets at high deformation levels handicaps this approach, we propose a "stitching" method, that enables the investigation of strain localization at later stages of deformation, even up to fracture.

Microstructure Development by Forming III

Thursday AM | July 29, 2021 | 9:15 - 10:15 AM

Session Chair: J. Lohmar, RWTH Aachen University

Formability Improvements at Room Temperature of AA5754-H32 via Continuous Bending under Tension (CBT) and Pre-forming Heat Treatment: *J. Ha*[1]; A. Piccininni[2]; Y. Korkolis[1]; G. Palumbo[2]; M. Knezevic[3]; B. Kinsey[3]; [1]Ohio State University; [2]Politecnico di Bari; [3]University of New Hampshire

Aluminium (Al) alloys play a critical role for the transportation applications where weight reduction is a key aspect; however, the poor formability at room temperature limits their application for complex components. An innovative methodology to overcome this limitation is based on subjecting the material to a local, short-term heat treatment before the stamping to obtain a tailored distribution of properties. In addition, Continuous Bending under Tension uses the action of three rollers to remarkably increase the total elongation to failure. In the present work, the combination of the two approaches is investigated to improve the formability at room temperature of a strain hardenable 5xxx Al alloy, AA5754-H32. Specimens were subjected to both CBT and pre-forming heat treatments. Specimens were then subjected to hardness measurements and tensile tests at room temperature in order to assess the plastic behaviour and evaluate the effect on the material formability.

On Sampling Discrete Orientations for Texture Representation in Aggregates with Varying Grain Size: A. Vuppala[1]; A. Krämer[1]; *J. Lohmar*[1]; [1]Institute of Metal Forming

The amount of orientation difference of crystallites i.e. the texture in a metallic polycrystal governs, plastic anisotropy, electrical and magnetic properties of the material. While the grain size and morphology of polycrystals is often determined via light-optical microscopy, their texture is conventionally analyzed by X-ray diffraction measurements. However, these measurements cannot be correlated. Thus when modeling the texture evolution by means of the CP-FEM method, a sampling of orientations onto grains is required. Here a concept of sampling is introduced that first assigns only the highest weighted orientations generated via an ODF to the few grains of the RVE. This gives an overly sharp texture, especially for inhomogeneous aggregates. Now orientations within the aggregate are rotated in Euler space to match the experimental ODF through an optimization procedure. This enables a re-creation of the measured texture in aggregates with only a few grains and varying grain size.

The Effect of Temperature on Strain-induced Austenite to Martensite Phase Transformation in SS 316L during Uniaxial Tension: *E. Mamros*[1]; M. Kuijer[2]; M. Davarpanah[1]; I. Baker[2]; B. Kinsey[1]; [1]University of New Hampshire; [2]Dartmouth College

Controlling the microstructure of components is of interest to achieve optimal final part properties, i.e., materials by design. The manufacturing process itself can affect a material's characteristics by changing the microstructure. For example, past research has shown that an austenite to martensite phase transformation in stainless steel occurs during deformation. Temperature is known to have a significant influence on this phenomenon. In this paper, the effect of temperature on the austenitic to martensite phase transformation in SS 316L under uniaxial tension is investigated. Both a cooling system and a heat exchanger were employed in a uniaxial tension experimental setup to control the temperature. Tensile specimens were strained to fracture at four temperatures of -15°C, 0°C, 10°C, and 20°C. Digital imaging correlation (DIC) and a thermal imaging camera were used for tests at 0°C and above to capture strain and temperature data, respectively. Strain data could not be obtained at -15°C due to the DIC paint flaking during testing. X-ray diffraction was used to measure the weight percent of martensite in both the as-received and the tensile-tested materials.

Energy-dependent Surface Integrity of Stainless Steel AISI 304 after Robot-based Machine Hammer Peening: *R. Mannens*[1]; L. Uhlmann[1]; A. Feuerhack[1]; T. Bergs[1]; [1]Laboratory for Machine Tools and Production Engineering
Machine hammer peening (MHP) is a high-frequency, incremental surface treatment with a spherical plunger which enables reproducible local plastic forming of metallic surface layers. The elasto-plastic deformation leads to a targeted smoothing or structuring of the surface as well as to the induction of compressive residual stresses and strain hardening. However, since MHP is still a relatively new process, there are still considerably knowledge deficits with regard to the cause-effect relationships of the energy inputs set by the MHP process parameters and the resulting surface integrity of technically relevant alloys. Therefore, the objective of this work is to investigate the peening strategie's influence on the surface roughness, the macro and micro hardness, the residual stresses and the microstructure of AISI 304. The results show that MHP leads to smoother and harder surfaces resulting from deformation-induced martensite formation accompanied by high compressive residual stresses, grain refinement and higher dislocation densities.

A Novel Approach to Predicting Surface Properties Generated during Metal Forming Processes: *S. Alexandrov*[1]; [1]Samara National Research University
Thin fine grain layers are often generated in the vicinity of frictional interfaces in manufacturing processes as a result of severe shear deformation. These layers change surface properties of machine parts. The latter affects the performance of structures and machine parts under service conditions. The strain rate intensity factor is the coefficient of the leading singular term in a series expansion of the equivalent strain rate in the vicinity of maximum friction surfaces. The objective of the present paper is to develop a general approach to use the strain rate intensity factor for predicting the evolution of fine grain layers. The paper includes a conceptual approach, experimental results on upsetting and drawing, and a special numerical method for calculating the strain rate intensity factor. The latter is necessary since the strain rate intensity factor appears in singular solutions, and conventional finite element methods are not capable of calculating this factor.

The Evolution of Deformation Microstructures and Strain Hardening during Constrained Sliding with Implications for Metal Forming and Cutting Processes: *D. Hughes*[1]; [1]Sandia National Laboratories (ret.)
A novel apparatus to constrain and extremely deform the subsurface of a metal work piece during sliding was utilized to create an unprecedented average size (crystallite) scale of five nanometers with a high dislocation density near the surface. The depth and degree of subsurface deformation was quantitatively measured and statistically analyzed using high resolution transmission and scanning electron microscopy. Scaling and the principal of grain subdivision enabled a direct link between the deformation microstructure that was graded in size scale with increasing depth below the surface and the decreasing stress and strain. Dislocation mechanisms were demonstrated to dominate the deformation. These observations and analyses indicate that metals and alloys under constrained conditions may continuously refine their size scale and strain-harden. As a result the degree and depth of the deformation, which extends in depth twenty to eighty times the ridge height, far exceeds existing models and wedge experiments.

Xue Yu Ruan Honorary Symposium

Thursday AM | July 29, 2021 | 9:15 - 10:15 AM

Session Chair: J. Chen, Shanghai Jiaotong University

Invited
Professor Ruan and the International Cold Forging Group (ICFG): *E. Tekkaya*[1]; [1]TU Dortmund
This presentation is dedicated to Professor Ruan's (Shanghai) contributions to the international cold forging community. As a member and chair of the International Cold Forging Group (ICFG), I could follow the immense work Professor Ruan performed under complicated political boundary conditions in the field of metal forming research with focus on cold forging. Professor Ruan hosted several times the ICFG in Shanghai and established strong links between the Chinese experts and the international community both in academia and industry. Many important research projects have been conducted jointly with European industrial companies and universities and the Shanghai Jia Tong University. With his reliable and trustful personality, Professor Ruan left a whole community of successful young Chinese researchers and several manufacturing plants in China of international enterprises in the field of cold forging.

Possibility of Shear Forging as the Third Basic Process of Cold Forging: *Z. Wang*[1]; T. Hakoyama[1]; [1]Gifu University
Cold forging has been used widely to produce small parts with high precision. Upsetting and extrusion are the two basic methods of cold forging and parts with complicated shape are forged by combinations of upsetting and extrusion. The most important technical issue in cold forging is the extremely high tool pressure and thus materials with high strength are still difficult to be forged at room temperature due to the strength limitation of the tool materials. This paper proposes a new forging method called shear forging to reduce the forging load drastically. The possibility of shear forging as the third basic method of cold forging is discussed. Shear forging can provide a forging method of impossible shapes, materials with high strength and large size parts by cold forging at a low cost.

Machine Learning Based Prediction and Compensation of Springback for Tube Bending: J. Ma[1]; *H. Li*[2]; G. Chen[2]; T. Welo[1]; G. Li[3]; [1]Norwegian University of Science and Technology; [2]Northwestern Polytechnical University; [3]Chengdu Aircraft Industry (Group) Co., Ltd.
Bent tubes are extensively used in the manufacturing industry to meet demands on lightweight and high performance. As one of the most significant phenomena affecting the dimensional accuracy in tube bending, springback causes problems in tube assembly and service, making the manufacturing process complex, time-consuming and difficult to control. This paper attempts to present an accurate, efficient and flexible strategy to control springback based on Machine Learning (ML) modeling. An enhanced PSO-BP network-based ML model is firstly established, providing a strong ability to account for the influences of material, geometry and process parameters on springback. For the supervised learning, training sample data can be collected from the historical production process or, alternatively, finite element simulation and laboratory type experiments. Using cold bending of aluminum tubes as the application case, the ML model is evaluated with high reliability and efficiency in springback prediction and compensation strategy of springback.

Understanding the Microscale Plastic Behavior and Deformation Mechanism of Magnesium Alloy via Ex-situ Experiments and Full-field Crystal Plasticity Modeling: *H. Zhang*[1]; S. Xu[1]; X. Shang[1]; Z. Cui[1]; [1]Shanghai Jiao Tong University
Magnesium alloys have been of growing interest for their low density and high specific strength, but their applications are impeded by their poor formability at room temperature. This work employs the state-of-art experimental and modeling techniques to understand the jointly effect of thickness and grain size on the plastic behavior and deformation mechanism of wrought Mg alloy. Equal channel angle pressing were applied to AZ31 Mg alloy to fabricate billets with various grain sizes but the same basal texture. Interrupted micro-tensile tests combined with ex-situ EBSD characterizations were carried on the fine-polished specimens with different grain size and thickness. It shows that mechanical twinning is significantly affected by both grain size and thickness. In particular, the volume fraction of extension twins decreases with the number of grains in the thickness. Full-field crystal plasticity simulations demonstrate that both the contributions of basal slip and twinning are rather sensitive to grain size.

Applicability of ALE Based FEM Methods in the Numerical Modeling of 3D Fine Blanking Processes: *P. Hora*[1]; [1]ETHZ - Inst. of Virt. Manufacturing
FEM simulations of 3D-fineblanking processes are challenging in respects to a) the handling of a strong FE mesh distortion b) constitutive models with strain, strain rate and temperature dependency and c) adequate failure criterion for the prediction of cracks. In the presentation those three mentioned aspects will be discussed. For solution to the FEM modeling problem, a new ALE-based method will be presented. The material properties will be specifically validated for large strain values based on tension-torsion tests. As a failure criterion the modified Mohr-Coulomb and the GISSMO damage accumulation method will be used. For the validation of the numerical results a special testing equipment was developed, which allows the experimental check of the micro-geometry of the cutting edge on the cutting and especially crack behavior. The numerical results are compared with those experimental tests.

Extrusion Technology of High-performance Aluminum Alloy Profiles with Large Complex Section: *G. Zhao*[1]; C. Zhang[1]; [1]Shandong University
Focused on the extrusion technology of high-performance aluminum alloy profiles with large complex sections, a series of work has been carried out. The hot deformation behavior of aluminum alloy was studied, the constitutive equations and processing maps were derived for several kinds of alloys. The effects of process parameters and die structures on deformation of extruded profiles were researched. The optimization methods for designing large and complex extrusion die structures were put forward. The welding behavior and microstructure evolution on welding interface in porthole die extrusion process were revealed, and a new no-dimensional prediction model for solid-state welding was proposed, in which the stress triaxiality, equivalent strain rate, temperature and contact time were coupled. Moreover, the isothermal extrusion, on-line quenching and stretching straightening technique were studied. A series of extrusion dies and profile products were developed and applied in the high-speed train, light weight vehicles and large-scale engineering structures.

Bulk Microforming From Sheet Metal - A Promising Approach for the Mass Production of Cold Formed Metallic Micro Parts: *M. Kraus*[1]; M. Merklein[1]; [1]Institute of Manufacturing Technology (LFT)
Within this paper, multi-stage bulk microforming from sheet metal is investigated for the fabrication of metallic micro parts in laboratory scale with the material Cu-OFE. In a first step, the process-influencing variable of the blank holder pressure is analysed in the first forming stage in order to derive measures for the highest possible material utilization. The two-stage forming of the pin with cup is compared with a single-stage process to assess the part quality and material utilization depending on the process strategy. Using the correct geometric scaling, size effects are identified and their effects on the forming process are evaluated. The experimental results reveal that it is possible to fabricate micro parts with a diameter of 470 μm and a minimum wall thickness of 36 μm reproducible by using the presented cold bulk microforming process strategy.

Manufacturing Processes of Non-metallic Materials: *J. Cao*[1]; [1]Northwestern University
In honor of Prof. Ruan's broad program portfolio, I am presenting a summary of our non-metallic manufacturing processes work conducted at our Advanced Manufacturing Processes Laboratory of Northwestern University. The topics mainly include forming of woven composites prepreg materials and electrospinning.

On the Convexity Bound of the Generalized Drucker's Yield Function CB2001 for Orthotropic Sheets: W. Tong[1]; *S. Yang*[2]; [1]Southern Methodist University; [2]Korea University of Technology and Education
Drucker's sixth-order polynomial yield function for isotropic materials was generalized in the literature for modeling orthotropic sheet metals via a generalization of the two invariants of the deviatoric stress using the theory of representation. The constant c in the original Drucker's isotropic yield function is found to be bound between -27/8 and 9/4 per the convexity requirement. In many subsequent modeling applications of orthotropic sheets, the same bound is also tactically assumed for the constant c in the generalized Drucker's yield function. In this study, the validity on assuming such a convexity bound on the adjustable constant c for orthotropic sheets is examined closely. It isfound that a single convexity bound between -27/8 and 9/4 on the constant c does not hold at all for any of those yield functions formulated from the theory of representation approach.

Professor Ruan-An Extaodinary Pioneer within the Global Scientific Network Metal Forming: *R. Kopp*[1]; [1]RWTH Aachen University
Within the speech the outstanding scientific activities, the particularly successful cooperation with industrial companies all over the world and the deep relations to numerous colleagues in many countries are recognized.

Characterization of Plasticity and Ductile Fracture of Metals under Proportional and Non-proportional Loading IV

Thursday AM | July 29, 2021 | 10:20 - 11:20 AM

Session Chair: J. Min, Tongji University

Strength Prediction Model for Line Pipe Steels Subject to Multiple Deformation Paths: *H. Choi*[1]; S. Kang[2]; J. Lee[3]; M. Lee[1]; [1]Seoul National University; [2]POSCO; [3]KIMS
Manufacturing a line pipe includes complex forming steps: decoiling, leveling, and roll forming. The mechanical properties of final formed pipe are evaluated from samples taken out of the pipe, which needs additional bending deformations for standard tensile tests. In this process, materials are subject to complex deformation paths, represented by cyclic bending superimposed with tensile deformation. The material under loading path changes exhibits anisotropic hardening like Bauschinger effect and transient response, and what's more they are orientation dependent. Therefore, understanding the evolution of mechanical properties of pipe steels during the forming process is important to design coil strength targeting the final pipe strength. In this study, a distortional anisotropic hardening model, which captures the Bauschinger and cross-hardening/softening effects, is applied to predict the mechanical responses under multiple deformation paths. Specifically, identification of model parameters, finite element modeling, and quantitative validations by predicting proof strength after pipe forming are presented.

Experimental Implementation of SS 316L Cruciform Testing to Achieve Various Deformation Paths: *E. Mamros*[1]; S. Mayer[1]; J. Ha[1]; B. Kinsey[1]; [1]University of New Hampshire

By following varying deformation paths, e.g., a linear path to a final equibiaxial strain value versus bilinear deformation with uniaxial loading followed by nonequal biaxial loading, the same final strain state can be achieved. However, the stress state that the material is subjected to is considerably different due to the varying deformation. This is of interest in a growing field of stress superposition to improve formability and final part properties in metal forming applications. For example, this work may be applicable to forming patient-specific, trauma fixation hardware with differing strength and weight reduction requirements in various regions. In this paper, equibiaxial experimental tests were performed on a custom fabricated cruciform machine with the goal of investigating martensitic phase transformations in stainless steel 316L subjected to varying deformation paths. A novel cruciform specimen geometry was designed in collaboration with the National Institute of Standards and Technology to achieve large strain values in the gauge region to promote martensitic transformations. Digital Image Correlation was utilized to measure surface strains in-situ. A scanning electron microscope was used to measure the amount of martensitic transformation in the samples.

Invited

Plasticity and Ductile Fracture of Ultra-high Strength Steel Sheets under Complex Stress State: Experiments and Modeling: *F. Han*[1]; [1]Baosteel

As one of the means of light-weight, more and more ultra-high strength steel has been applied to car body. The plasticity, damage and fracture behavior of UHSS under complex stress state is the key to accurate simulation of forming process and crash. The newly developed high elongation QP steel and press-hardening steel of Baosteel were tested under different loading conditions, including shear, uniaxial tension, plane strain tension and biaxial tension. With the help of digital image correlation technology, the development of plastic strain under various stress states was analyzed. Based on the testing results and numerical simulation, the parameters of plasticity and fracture model of UHSS were obtained. The validity of the model was verified by comparing the stamping and crash test results of component made by QP and PHS steel. The research results will provide guidance for parts design and structural design in the application of UHSS.

Design of a New Cruciform-like Specimen for Combined Tension and Shear of Metal Sheets: *M. Kim*[1]; J. Ha[1]; Y. Korkolis[1]; [1]The Ohio State University

This paper is concerned with design of a new cruciform-like specimen to measure plastic flow under combined tension and shear loading conditions for AA6013-T4 aluminum sheet. The specimen design borrows from the "smiley face", which is commonly used for the simple shear experiment, but has four arms, as a cruciform specimen: two arms are used to induce shearing, while the other two induce tension. The details of the geometry are optimized by FEA to promote deformation uniformity in the cross section. Experiments are performed using an in-plane biaxial testing machine, with 5 different force ratios between tension and shear, so that combined stress states in (σ_{11}, σ_{22}, σ_{12}) 3D-stress space are probed. Based on the results, the Yld2000-2D anisotropic yield function is calibrated by least-square optimization, and the influence of shear stress on the yield function parameter calibration is evaluated by comparing yield surfaces identified by different calibration approaches.

Invited

Stress-based Ductile Fracture Criterion for Nonlinear Strain Paths with Model Calibration: *J. Yoon*[1]; [1]KAIST

A shear specimen is optimized by minimizing the variation of stress triaxiality in the shear zone. In the optimization, Hill48 and Yld2000-2d (Barlat et al., 2003) criteria and Hill48 with non-associated flow rule are employed to model the anisotropic deformation. Isotropic fracture behavior is modeled by both linear model and nonlinear model considering different triaxiality conditions. It is observed that the mean stress model shows significant difference in the compression area compared to Mohr Coulomb-based normal stress model and a new isotropic model with the mean stress term shows a good correlation for AA 6k21. The criterion is applied for drawing, redrawing and expansion for a beverage can which has complex nonlinear strain paths. Effect of kinematic hardening on fracture is also investigated. It has been shown that the proposed stress-based fracture model predicts the failure stroke accurately.

Extrusion and Drawing

Thursday AM | July 29, 2021 | 10:20 - 11:20 AM

Session Chair: D. Cooper, University of Michigan

Introduction of a New Method for Continuous Aluminum Hot Extrusion: *J. Gebhard*[1]; P. Kotzyba[1]; O. Hering[1]; A. Tekkaya[1]; [1]Institute of Forming Technology and Lightweight Components, Technische Universität Dortmund

The new extrusion process combines the conventional methods of direct and indirect aluminum hot extrusion by an innovative container and die setup with a moving or stationary valve. The process enables the continuous extrusion of aluminum profiles without any interruptions. With both variants, moving or stationary valve, the usual dead cycle times can be used for a continuous extrusion process. Furthermore, due to the continued material flow, a stationary profile exit temperature can be achieved, which leads to constant material properties. As up to now, a continuous extrusion press for aluminum is not available. The new process concept is analyzed on the basis of scaled experimental models using the model material plasticine and numerical simulations. The similarity of the model material was validated by aluminum extrusion experiments. Various model material colors were investigated, and the resulting material flow and process forces of the new process were analyzed.

Investigation of Forward–Backward-Radial Extrusion Process of Aluminum Alloy Wheel Hub: *Q. Wang*[1]; M. Meng[1]; X. Li[1]; Z. Zhang[1]; [1]North University of China

As a kind of extrusion process, the Forward-Backward-Radial Extrusion (FBRE) process can be used to produce complex shaped parts with hoop protrusions or flanges. The control of metal flow is the key to affect forming, strain distribution and forming load of parts during FBRE process. On the basis of summarizing research of FBRE process, this paper presents the numerical and experimental results of aluminum alloy hub production using this method. Material flow behavior, strain distribution and strain heterogeneity within the final product was investigated by finite element methods. The parameters such as billet size, die corner radius and friction conditions are optimized and determined to control the material flow in different regions. While the uniformity of extrusion deformation is greatly improved, the extrusion forming load is reduced, and the aluminum alloy hub was manufactured by FBRE process. The comparison between the theoretical and the experimental results show good agreement.

Co-extrusion of Compound-cast AA7075/6060 Bilayer Billets at Various Temperatures: *H. Chen*[1]; D. Giannopoulou[2]; T. Greß[3]; T. Mittler[3]; J. Isakovic[2]; W. Volk[3]; N. Ben Khalifa[1]; [1]Leuphana University of Lüneburg; [2]Helmholtz-Zentrum Geesthacht; [3]Technical University of Munich

Combination of dissimilar AA7075/6060 aluminum alloys benefits the advantages of high strength and good corrosion resistant in one hybrid component. Static compound-casting using appropriate casting conditions can achieve intermetallic bonding at the interface of the core AA7075 and sleeve AA6060. The inhomogeneous bonding due to non-uniform thermal conditions during static compound-casting can be eliminated by the following co-extrusion procedure. Direction hot extrusion of compound-cast AA7075/6060 bilayer billets at temperature of 420°C, 450°C and 480°C are conducted to analysis the influence of extrusion temperature on the interfacial bonding. The evolution of the interfacial bonding properties at different extrusion temperatures comparing with as-cast billets are depicted by light optical metallography and mechanical push-out test.

Reducing Aluminum Extrusion Transverse Weld Process Scrap: *G. Oberhausen*[1]; A. Christopher[1]; D. Cooper[1]; [1]University of Michigan

Nearly 20% of the aluminum produced globally is extruded. Up to one-quarter of this aluminum is scrapped in the form of extrusion butts and segments of extruded profiles that contain weak solid-state "transverse" welds that are created between consecutively extruded billets in direct extrusion. In this article, extrusion of differently colored clay billets is used to conduct a parametric study on the effect of extrusion ratio, die angle, friction coefficient, profile shape, and dummy block profile on the transverse weld length. Shorter transverse weld lengths require smaller lengths of the extruded profile to be extracted and scrapped. The results show that the transverse weld length can be reduced by decreasing the extrusion ratio, die angle, or friction coefficient. The profile shape also has a strong influence; the transverse weld length was found to scale with the cross-sectional perimeter to area ratio of the extruded profile. Additionally, it is shown that the dummy block profile (a previously unexplored design variable) can be modified to decrease the weld length. A concave dummy block was designed using an estimated velocity field for axisymmetric extrusion of solid rods, decreasing the weld length by 44%. The industry implications of this work and the need for further research are discussed.

Study on Complex Extrusion of Multi Billets: Evaluation of Mechanical Properties of Butt-joined Products and Analysis of Joining State: *M. Hoshino*[1]; I. Otake[1]; [1]Nihon University

In recent years, an aluminum double skin panel, which has a complicated and wide cross- sectional shape and is manufactured by extrusion is used for railway vehicles. It is difficult to manufacture a double skin panel exceeding 600 mm width in the current forward extrusion process. However, from the viewpoint of weight saving, there is a demand to make double skin panel with larger width. So it is proposed to manufacture double skin panel with complex extrusion of multi billets. Complex extrusion of multi billets is suitable for producing complicated and wide extruded shape. And the joint part of the double skin panel is joined in a plate shape. In this study, industrial pure aluminum A1050 and representative extruded aluminum alloy A6063 were extruded into a plate shape, and the joining state was evaluated by tensile test, micro Vickers hardness test, microscopic observation and numerical analysis.

Effect of Expansion Ratio on Formability in Tube Drawing with Diameter Expansion: H. Kawaguchi[1]; *S. Kajikawa*[1]; T. Kuboki[1]; I. Akasaka[2]; Y. Terashita[2]; M. Akiyama[3]; [1]The University of Electro-Communications; [2]Miyazaki Machinery Systems Co., Ltd.; [3]Akiyama Mechanical Engineering Consulting

The conventional tube drawing has the disadvantages that thickness reduction in one pass is small. As a method to eliminate this disadvantage, tube drawing with diameter expansion was proposed in this study. At first, the tube is flared by pushing the plug into the tube end. After that, the plug is drawn with chucking the flared end, and the entire tube is expanded. Tensile circumferential and axial stress reduce the tube thickness effectively during the plug drawing. In this study, effect of expansion ratio on formability, such as thickness reduction and dimensional accuracy, was investigated by experiments and finite element analyses (FEA) for verifying effectiveness of the proposed method. As a result, the thickness reduction ratio increased with an increase in the expansion ratio, and the maximum thickness reduction ratio was 0.3 when an aluminum alloy of A1070 was used. Furthermore, deformation mechanism was considered by FEA.

General

Thursday AM | July 29, 2021 | 10:20 - 11:20 AM

Session Chair: A. Luo, Ohio State University

A Study on Developing Advanced Design Formula for Heat Form Quench (HFQ®) of Complex-shaped Aluminium Panels: *N. Li*[1]; [1]Imperial College London

Hot Form Quench (HFQ®) is a disruptive hot forming technology, recently developed, to produce cost-effective, complex-shaped, high-strength aluminium panels. The objective of this study is to develop an advanced methodology to guide optimal design for manufacturability using HFQ® Technology, through tackling a cutting-edge design challenge in the automotive industry for creating battery boxes with deep corners for EVs. In this study, a demonstrator model is first designed. Then, experimental and numerical tests are carried out, based on aluminium alloy 6082, to obtain the correlation between design variables, as well as their relationship with forming parameters. As last, optimisation algorithms are implemented to explore the optimal design with maximum drawing depth and minimum bottom corner radii. The advanced formula and the understanding of the design challenges developed through this study will enrich the design guides for HFQ®.

Towards Room-temperature Forming of Magnesium Sheet Alloys: R. Shi[1]; J. Miao[1]; *A. Luo*[1]; [1]Ohio State University

Magnesium (Mg) sheet alloys have been attractive to the automotive industry for structural and body panel applications. One major challenge for automotive applications of Mg sheet alloys is their limited formability at room temperature. Recently, a new Mg sheet alloy and a multi-stage homogenization process have been developed at OSU, using an integrated computational materials engineering (ICME) approach. The new alloy achieved a yield strength of 240 MPa, tensile elongation of 30% and Erichsen Index of 7.7 mm, promising room-temperature forming applications. This paper will provide an overview of this new alloy design and thermomechanical processing development based on computational thermodynamic and kinetic modeling followed by experimental validation. The paper will also discuss microstructure evolution, strengthening mechanisms and plasticity of this new alloy.

The Effect of Crystallographic Texture Gradients on the Mechanical Response of Aluminum Automotive Extrusions: *W. Poole*[1]; A. Zang[1]; Y. Wang[2]; M. Wells[2]; N. Parson[3]; M. Li[4]; [1]The University of British Columbia; [2]University of Waterloo; [3]Rio Tinto Aluminium; [4]Ford Motor Company
There is current interest is expanding the use of aluminum extrusions in automotive applications. A challenge for the use of aluminum extrusions is the gradients of mechanical properties found within extrusions which result from inhomogeneous deformation during extrusion. In this work, the effect of local variations of crystallographic texture has been characterized experimentally using electron back scatter diffraction (EBSD) maps. In particular, through thickness effects have been examined for AA3xxx extrusion alloys and the role of texture variations has been considered for idealized extrusions using a porthole die. This work has focused on alloys which are primarily unrecrystallized after extrusion. The deformation textures have been predicted using the velocity fields extracted from finite element method calculations as an input for crystal plasticity simulations using the visco-plastic self-consistent method. It is found that texture predictions and the resulting mechanical anisotropy can be modelled well for situations where the strain path is relatively simple, for example near the centre of the extrudate but it is more challenging to predict properties near the surface where the shear strains due to friction can be greater than a true strain of 10.

"Learning by Seeing": Estimating Metal Plasticity Parameters Using In Situ Observations of Cutting and Indentation: *H. Chawla*[1]; S. Yadav[1]; G. Feng[1]; D. Sagapuram[1]; [1]Department of Industrial and Systems Engineering, Texas A&M University
We present a novel and highly efficient approach to solve the inverse problem of estimating plastic constitutive parameters of metals using high-speed imaging and in situ measurements of deformation fields in plane-strain cutting and indentation. Point estimates of best constitutive parameters are computed purely using optimization-based algorithms by minimizing the error between internal plastic work and the corresponding external work, without the need for expensive finite element simulations. A Bayesian statistical approach is also demonstrated for obtaining the posterior distributions of the parameters. Data from standard compression tests are used to validate the feasibility of this approach for inferring plasticity parameters of ductile materials, including copper, brass and low melting-point eutectic alloys. The talk will also address the effect of imaging-related parameters (such as noise, spatial resolution, frame rate) on parameter estimation, as well as possible extension of this approach to high strain rates (> 10^3 per second).

Phase-field Modelling of Ductile Fracture to Describe Edge Conditions in Local Formability Studies: *F. Di Gioacchino*[1]; J. Speer[1]; K. Clarke[1]; [1]ASPPRC Colorado School of Mines
By introducing a diffuse crack representation that depends on the critical energy release rate and an intrinsic length scale, phase-field modeling of fracture provides the framework for the formulation of physically-based gradient damage models that can be efficiently implemented in finite element calculations. Recently, we used the open-source FEniCS finite element computing platform to implement a phase-field model of ductile fracture. Here, we simulate expansion tests of punched and machined holes in sheets of advanced high strength steels. The different hole-edge conditions are described using initial boundary conditions for phase fields of damage and accumulated plastic strain. The value of the intrinsic length scale thus controls the thickness of the shear affected zone. Predictive capabilities are assessed by comparison with experimental measurements of hole expansion ratios.

Deforming Nanometric Volumes at Large Shear Strains by AFM Scratching: *M. Efe*[1]; B. Gwalani[2]; J. Tao[2]; T. Kaspar[2]; A. Devaraj[2]; A. Rohatgi[1]; [1]Energy and Environment Directorate, Pacific Northwest National Laboratory; [2]Physical and Computational Sciences Directorate, Pacific Northwest National Laboratory
Shear deformation can cause significant changes in the microstructures and textures of the deforming materials such as during solid phase processing (e.g. extrusion, friction stir processing, etc.) and material removal (e.g. cutting, grinding, etc.) methods used for manufacturing of components. While the shear deformation and associated mechanisms of microstructural evolution at the bulk scale are well known, effects of shear deformation at nanoscale remain unexplored. In this study, we demonstrate nanoscratching with an atomic force microscope (AFM) tip as a tool to impose large shear strains in nanoscale material volumes. With the AFM process parameters and tip geometry used in our study, nanoscratching of a single-crystal copper substrate resulted in heavily deformed chips and the sub-surface. The nanoscratching process showed characteristics analogous to bulk-scale machining. Deformation analysis, using approaches developed for bulk machining, indicated that the shear strain in the chips and subsurface was ~ 3.9 and 4.6, respectively. TEM examination of the chips and subsurface showed dislocation substructures, geometrically necessary boundaries and other defects akin to those seen in highly deformed bulk materials. However, the level of microstructure refinement was somewhat lower when compared to the single- or polycrystal copper deformed to similar strains at the bulk scale, indicating possible role of the size effect of the nanoscale deformed volume in controlling the deformation behavior.

An Improved Hot Stamping Process for Titanium Alloys by Fast Heating: *K. Wang*[1]; G. Liu[1]; L. Wang[2]; X. Wang[1]; [1]Harbin Institute of Technology; [2]Imperial College London
Titanium alloys are increasingly used in aviation and aerospace industry, but the price of titanium alloys components is always very high, which confines the further applications greatly. Hot stamping of titanium alloys is a young technology but with great potential to reduce the forming cost and improve the forming efficiency for titanium alloys sheet components. In this paper, some progress on hot stamping with furnace heating of titanium alloys achieved in our lab including forming process, microstructure and property evolution and deformation mechanisms are presented firstly. Then both advantages and limitations of this technology are discussed. At the end, a novel hot stamping with fast heating technology is proposed to extend the processing windows.

Residual Stresses in Metal Forming II

Thursday AM | July 29, 2021 | 10:20 - 11:20 AM

Session Chair: E. Tekkaya, TU Dortmund

Analysis of the Influence of Joining Partners on the Residual Stress Distribution in Assembled Shafts: C. Guilleaume[1]; *A. Brosius*[2]; [1]TU Dresden; [2]Institute of Forming Technology and Lightweight Construction Institute
In this paper the influence of joining partners like gear wheels on the residual stress distribution of an assembled shaft is analyzed using numerical FE-analysis as well as experimental verification. The joint is formed by a cross rolling process that uses two sets of opposing work rolls to push shaft material towards the joining partner, thereby forming a force and form closure. Previous work has shown that the residual stress distribution in the notch that is formed by this rolling process has a significant influence on the fatigue life of the shaft (42CrMo4) when submitted to cycling loads. In the experimental investigations strain gauges applied to the joining partners will be used to measure the resulting forces in the joint section and numerical analysis will be used to analyze the resulting stress distribution in the entire part. Different material and geometric combinations will be tested and analyzed.

Experimental and Numerical Investigations on the Development and Stability of Residual Stresses Arising from Hot Forming Processes: B. Behrens[1]; J. Schröder[2]; H. Wester[1]; D. Brands[2]; S. Uebing[2]; *C. Koch*[1]; [1]Institue of Forming Technology and Machines; [2]Institut für Mechanik

Residual stresses are an important issue as they affect both the manufacturing process as well as the performance of the final parts. Taking into account the whole process chain of hot forming, the integrated heat treatment provided by a defined temperature profile during cooling of the parts offers a great potential for targeted adjustment of the desired residual stress state. The aim of this work is the investigation of technological reproducibility and stability of residual stresses arising from the thermomechanical forming process. For this purpose, a long-term study of residual stresses on hot formed components is conducted. In order to develop finite element models for hot forming, a comprehensive thermomechanical material characterisation with special focus on phase transformation effects is performed. The numerical model is validated by means of a comparison between residual stress states determined with X-ray diffraction on experimentally processed components and predicted residual stresses from the simulations.

Investigations and Improvements in 3D-DIC Optical Residual Stress Analysis – A New Temperature Compensation Method: *F. Dahms*[1]; W. Homberg[1]; [1]Paderborn University

With the follow-up objective of measuring and generating defined residual stress distributions in aluminium flanges formed by friction-spinning of tubes, this paper proposes residual stress measurement by linear guided translation of the specimen between hole-drilling and 3D-DIC image capturing process. The procedural benefit is the usage of an ideal camera calibration, respectively the angle between the cameras and the specimen, which leads to an optimal depth of field with a wide range measuring surface around the drill hole. Influences of the linear guided displacement of the specimen on the measuring accuracy were determined to be tolerably low. The measurement of heating curves in the illuminated measuring process proves a thermal induced systematically error. Therefore, a mathematical approach for subtraction of thermal induced strain is proposed. The obstruction of heat dissipation by the speckle pattern coating is also considered. Additionally, solutions for external influences like airflow and vibration are applied.

Influence of Shear Cutting Process Parameters on the Residual Stress State and the Fatigue Strength of Gears: *D. Mueller*[1]; J. Stahl[2]; I. Pätzold[2]; R. Golle[2]; T. Tobie[1]; W. Volk[2]; K. Stahl[1]; [1]Institute of Machine Elements (FZG), Technical University of Munich; [2]Chair of Metal Forming and Casting (utg), Technical University of Munich

Shear cutting is used for manufacturing parts ranging from e.g. washers to complex gears. The latter are typically subjected to cyclic loading and fail foremost due to fatigue damages. In this paper, the influence of the process parameters on the residual stress state and the resulting bending fatigue strength are addressed. To simulate the bending stress occurring in the tooth root, C-shaped specimens were manufactured by different blanking processes. The die-clearance and punch and die edge radii were varied with these blanking techniques. After measuring the cut-surface geometry, the hardness distribution and the surface roughness, the fatigue strength was determined in a pulsating test rig. By carrying out residual stress measurements using x-ray diffraction and simulating the material flow behavior using the Finite-Element-Method, basic mechanisms, which are influencing the residual stress state and the resulting bending fatigue strength, were identified and will be presented and discussed in the paper.

CANCELLED: Impulse-based Residual Stress Relief: *B. Nirudhoddi*[1]; A. Vivek[1]; G. Daehn[1]; [1]Ohio State University

Recent impulse calibration studies have provided some insight into the mechanism of shock induced springback relief. The driving hypothesis for this physical phenomenon is that modest shockwaves relieve elastic residual stresses and result in net shape conformance. Calibration experiments were performed using the Vaporizing Foil Actuator (VFA) method to further understand this mechanism. The VFA method was used to deliver 1-3 GPa pressure waves to change the curvature of pre-strained aluminum workpieces to a fully flat shape. It is speculated that the change in shape is a consequence of elastic stress relief caused by the propagation of planar shockwaves. A mechanics and shock physics based theory for shockwave interaction with residual stresses is proposed. Preliminary pressure estimates were performed using a Photon Doppler Velocimeter and the Profile Indentation Pressure Evaluation (PIPE) method.

Sheet Forming II

Thursday AM | July 29, 2021 | 10:20 - 11:20 AM

Session Chair: C. Karadogan, Institute for Metal Forming Technology - University of Stuttgart

Development of Adhesion Preventing Method during Deep-drawing of Titanium Alloy Sheets: *Y. Okude*[1]; T. Iwaoka[1]; I. Nakamura[1]; [1]Tokyo Metropolitan Industrial Technology Research Institute

To prevent the adhesion during press forming of titanium alloy sheets, it is necessary to prevent the surface oxide film peeling caused by sliding between workpiece and die material with high surface pressure. Hence, we have focused on the method to prevent the titanium surface oxide film peeling during press forming to prevent the adhesion. The workpieces with surface oxide film by atmospheric and anodic oxidation was utilized to demonstrate the effect of titanium surface oxide film on formability in deep-drawing process. Additionally, the method to prevent the adhesion during deep-drawing process was developed. In this study, the compressed air was applied into die and the blank holding force (BHF) with vibration technique was utilized during circular-cup deep-drawing of TP340 sheets. As the results, the occurrence of adhesion was prevented significantly by application of developed methods.

Localized Contact Pressure of Blankholder for Stamping Irregular Sheet Parts by Configuring the Height of the Supporting Elements: *K. Fann*[1]; M. Liewald[2]; K. Riedmueller[2]; [1]National Chung Hsing University; [2]University of Stuttgart

This paper presents an engineering procedure for stamping irregular sheet metal parts with an elastic blankholder providing a localized contact pressure to ensure stamped parts without failures of cracks and wrinkles. This is done by arranging the height of the blankholder supporting elements in a die set, which is made by standard manufacturing quality and implemented in a press line equipped with standard die cushion. However, the contact pressure is very sensitive to the height of supporting elements. To eliminate the inherent noise from the GD&T of the die set, a finite element model for optimization of the contact pressure must be created according to the actual die set geometry. In this study, the blankholder geometry for stamping a fender-like part was scanned by GOM-ATOS and the height of cylindrical supporting elements was realized by inserting feeler gauges between blankholder and them according to the outcomes of finite element analysis.

Size Effect on Cyclic Deformation Behavior and Springback Prediction of Ultrathin Superalloy Sheet: *W. He*[1]; B. Meng[1]; B. Song[1]; R. Zhao[1]; L. Zhang[1]; M. Wan[1]; [1]Beihang University
Springback is a challenging issue in the processing of superalloy ultrathin components, and its prediction is affected by the size effect. In this research, the cyclic shear tests of superalloy sheets with different grain sizes were performed to clarify the relation between size effect and cyclic deformation behavior. The experimental results indicated that the Bauschinger effect is affected by the geometrical and grain size effects. To explore how the size effect affects the springback of ultrathin superalloy sheet, U-bending tests were performed on specimens with different grain sizes and thicknesses. In addition, different hardening models were compared by multiscale U-bending tests. The results showed that the YU model can well describe the cyclic deformation of superalloy sheet at various scales.

On the Determination of the Forming Limits by Necking and Fracture of Polycarbonate Sheet: *A. Rosa-Sainz*[1]; G. Centeno[1]; M. Silva[2]; J. López-Fernádez[1]; A. Martínez-Donaire[1]; C. Vallellano[1]; [1]University of Seville; [2]University of Lisbon
This research evaluates experimental methodologies for determining forming limits by necking and fracture in polycarbonate (PC) sheet by proposing developments of recent methodologies usually used in sheet metal forming [1,2]. With this purpose, Nakajima tests with different blank geometries are performed on 1 mm thickness polycarbonate (PC) sheet. The experimentation included the use of Digital Image Correlation (DIC) for the evaluation of strains and thickness measurements for the determination of failure strains. The results provided accurate formability limits by necking and fracture, establishing a general framework for analysing specific forming processes (such as incremental forming) on polymeric sheet. Differences in the shaping of the FLC and FFL curves for PC compared to those obtained in metal sheet are also discussed. REFERENCES. [1] A.J. Martínez-Donaire, F.J García-Lomas, C. Vallellano (2014). Materials and Design 57:135-145.[2] P.A.F. Martins, N. Bay, A.E. Tekkaya, A.G. Atkins (2014). International Journal of Mechanical Sciences 83:112–23.

A New Approach for the Production of Burr-free Sheet Metal Components Having Significantly Increased Residual Formability: *S. Senn*[1]; M. Liewald[1]; [1]University of Stuttgart Institute for Metal Forming Technology
Shear cutting induces high strains and work hardening into the shear-affected zone, thus reducing the formability of the sheet metal material during subsequent forming operations. A common method for increasing the residual formability of shear-cut component edges is to shave the surfaces. The shaving process allows highly hardened areas to be removed from a pre-cut contour, resulting in a comparatively high residual formability of the cutting surface. However, as with normal cutting, a burr remains on the shear surface when shaving. For this reason, a new process has been developed which combines counter-cutting and shaving, enabling the production of burr-free shear surfaces having high percentages of clean-cut proportions and significantly higher hole expansion ratios (factor 1.7) than conventional cutting surfaces. The present paper deals with numerical and experimental investigations carried out in the course of the process development with the high strength sheet metal material DP600.

Effects of Press Ram Vibrations on the Production Quality: B. Behrens[1]; K. Brunotte[1]; R. Krimm[1]; *O. Commichau*[1]; [1]Institute of Forming Technology and Machines
An indicator for the quality of products that are formed in an embossing process is the product contour. Highest contour quality is achieved, if the shape of the forming tool is perfectly imprinted into the material. However, contact pressure and tribological effects, that occur during the forming process, produce tool wear and thus impair the shape setting progress. To improve product quality, an electromagnetic actuation unit is presented in this paper, which applies horizontal vibrations into the press ram during the forming process. The actuation unit consists of two strong linear solenoids, which generate oscillating force with variable levels and frequencies. The vibrations improve the shape setting during the embossing process. The concept, design and the functioning of the actuators are presented in this paper. Additionally, experimental studies on an embossing process in a production environment were performed to study the quality improvement by means of press ram vibrations.

Study on the Effect of Embossing on the Bending Properties of High Strength Sheet Metals: *D. Briesenick*[1]; S. Walzer[1]; M. Liewald[1]; [1]Institute for Metal Forming Technology
Selective embossing of sheet metal blanks, prior processing, offers the possibility of locally modifying material properties. Small indentations applied on the sheet metal surface by a punch lead to increased material strength due to the induced strain hardening. Moreover, such locally embossed sheet metals show an enhanced process window with regard to forming processes and an improved performance under different loading conditions. The experimental study presented in this paper investigates the bending properties of high-strength steel sheets em-bossed on the tension or the compression surface of the bent blank. The effect of embossing on the bending resistance of two different materials (DP500 and TRIP780) were analyzed by varying the embossing patterns by density and depth. As a result, bending forces required in the tests rise when increasing the proportion of em-bossed surface. Therefore, the paper reveals potentials of local embossing with regard to a specific modification of bending properties of sheet metal components, thus enabling their use in lightweight constructions.

Effect of Machining Induced Microstructure Changes on the Edge Formability of Titanium Alloys at Room Temperature: *J. Kwame*[1]; E. Yakushina[1]; P. Blackwell[1]; [1]University of Strathclyde
The difficulty of forming titanium alloys at room temperature is well researched and is mostly attributed to their ability to form a strong crystallographic texture during plastic deformation. Also, one major issue of concern linked to the forming of such alloys is their high sensitivity to surface inhomogeneity. Various machining processes are utilised in preparing sheet hole edges for edge flanging applications. However, the response of edge forming tendencies of titanium to different edge surface finishes is not well investigated. The hole expansion test was used in this project to elucidate the impact of selected cutting techniques and edge finish integrities on the edge formability of CP-Ti (Grade 2) and Ti-3Al-2.5V alloys at room temperature. The results show that, the quality of the cut edge surface finish has major effect on the edge formability of the material. The paper explores the reasons and consequences for this for industrial forming operations.

An Investigation on Formability of Ti6Al4V Alloy in the Three-layer Sheet Hot Stamping Process: X. *Yang*[1]; B. Wang[1]; C. Zhu[2]; [1]University of Science and Technology Beijing; [2]Shandong Zhongxing Auto Parts Ltd Company

In the hot stamping process, the sheet will lose a lot of heat which results in poor formability of the sheet. So, a novel hot stamping process for the three-layer sheet is proposed in this paper, which uses two steel sheets to clamp the titanium alloy sheet for transferring and stamping. In this paper, the hot stamping depth is studied by experiments and simulation under the single/three-layer sheet hot stamping condition. The results show that the temperature of the titanium alloy sheet can be controlled effectively by using the three-layer sheet hot stamping process, and the stamping depth can be improved. Compared with the single-layer sheet hot stamping process, the depth of the titanium alloy parts can be increased by 135.7% under the three-layer sheet hot stamping process at 900°C, and the thickness distribution of titanium alloy parts obtained by three-layer sheet hot stamping process is more uniform. The finite element analysis results show that the temperature and stress distribution of titanium alloy sheet by three-layer sheet stamping process is more uniform, and the temperature difference is small through the sheet. The distribution of thickness obtained by simulation has good consistency with the experimental results. Under the three-layer sheet hot stamping process, the titanium alloy sheet has good deep drawing.

Investigation on Springback Behavior of Multi-intersecting High Stiffened Structure in Die Forming: *Q. He*[1]; W. Li[1]; M. Wan[1]; C. Li[2]; C. Cui[2]; [1]School of Mechanical Engineering and Automation, Beihang University; [2]Beijing Space Craft, China Academy of Space Technology

Multi-intersecting high stiffened structures have potential application in aerospace components, which are the main load-bearing structure of manned space station. However, its springback behavior is very complicated due to the interaction of multi-intersected ribbons and intersecting patterns during die forming. For the typical spherical shaped multi-intersecting stiffened structures, a new approach is proposed to quantize the influence on flexural neutral layer of multi-intersected ribs. The strain distribution along thickness at different radial positions of ribs is derived in theoretically. Reverse loading method is used to calculate springback radius of each position. Consequently, the final profile of the panel after springback is calculated by numerical integration. To verify the effectiveness of this method in predicting springback, finite element simulations based on ABAQUS software and experiments are both implemented. Comparison shows that the results are of good agreement, proving the method is capable of predicting springback of multi-intersecting stiffened structures.

Evaluating the Reliability of a Nondestructive Evaluation (NDE) Tool to Measure the Incoming Sheet Mechanical Properties: *F. Alamos*[1]; C. Gu[1]; H. Kim[1]; [1]Edison Welding Institute

Today, the automotive OEMs and part suppliers are increasing their material suppliers globally. Therefore, the same grade steels are supplied by different steel mills and batch conditions to meet this requirement. However, the variation of the incoming material properties can significantly influence the stamping quality associated with necking, wrinkling, and cracking. This increases the overall manufacturing costs and lowers productivity. Nondestructive evaluation (NDE) tools have become useful to reduce this uncertainty by measuring incoming material properties. The measured data can be used during production in a feed-forward control to select the optimal process parameters or as forming process parameter optimization, using simulations. A detailed evaluation of a 3MA (micromagnetic, multiparametric microstructure, and stress analysis) Fraunhofer's device and its viability of implementations in a production environment is introduced. The 3MA device was incorporated into an industrial robot and a practical calibration procedure was developed and validated for advanced high-strength steels.

Friday Keynote

Friday AM | July 30, 2021

Session Chair: G. Daehn, Ohio State University

7:30 AM Keynote
Vision 2030: A Vision for America's Science and Engineering Enterprise & Relevance to Advanced Manufacturing: *S. Babu*[1]; [1]University of Tennessee, Knoxville

The NSB's Vision 2030 lays out actions to achieve the four goals. (1) Foster a Global Science and Engineering Community – Make sure that America is a reliable partner and is at the table to avoid being technologically surprised. (2) Expand the Geography of Innovation: Do more to create opportunities and jobs across the country. (3) Deliver Benefits from Research: Enhance the return to U.S. taxpayers from these investments and empower the nation's businesses and entrepreneurs to compete globally. Achieve this goal in a way to ensure a more inclusive enterprise and diverse S&E community. (4) Develop STEM Talent for America. Over the next decade, our nation must focus heavily on developing America's STEM talent, including researchers and a STEM-capable workforce at all educational levels, from skilled technical workers to PhD researchers. In addition, the role of science and technology of plasticity with reference to advanced manufacturing will be outlined.

8:15 AM Concluding Comments

Rolling

Friday AM | July 30, 2021 | 9:15 - 10:15 AM

Session Chair: W. Poole, University of British Columbia

Hot Ring Rolling and Cold Expanding Strengthening of Mn18Cr18N Thick-wall Hollow Ingots: *H. Chen*[1]; H. Wen[1]; J. Wang[1]; F. Li[1]; W. He[1]; [1]Taiyuan University of Science and Technology

A short route manufacturing process of retaining rings was put forward, which composed of hollow ingots manufacturing by ESR, hot ring rolling and cold expanding strengthening. And microstructure mechanisms, deformation characteristics and process parameters during both of hot ring rolling and cold hydraulic expanding strengthening were investigated. The results show that the multi-pass flow stresses decreased with increase of interval time. During multi-pass compression, grain refined at lower temperature of 1050°C by static recrystallization, then grain refined at higher temperature of 1150°C by both of dynamic and static recrystallization. Based on the influence of the contact arc length ratio on strain penetration in the wall deformation zone, the driving roller radius of 500mm and the pressure roller radius of 130mm were determined for the ring rolling process off 712mm/308mmx902mm thick-wall hollow ingot. The optimum rotate velocity of the driving roller should be 0.8rad/s. And the feeding velocity of the pressure roller should to be 1mm/s for matching. During cold deformation, planar slip and twinning predominated at small and large deformation respectively to increase strength. For the hydraulic expanding process of 937/672×1034mm hollow forging, the optimum matching of 60° punch angle and 5mm contact seal height can be adopted for obtaining well-shaped strengthened forgings.

Fundamentals of Continuous Helicoid Auger Flighting Rolling - Deformation Mechanics, Kinematics and Applications: *M. He*[1]; [1]The Timken Company

An auger flighting is a helical-shaped circular product to transfer bulk materials in broad applications. Continuous auger flightings are formed from straight steel strips by a specialty rolling mill. Because of the geometry and configuration of the auger flighting, the rolling is more complex than the ordinary longitudinal rolling while the publication describing the theoretical features of the auger flighting rolling was hardly seen. In this article, fundamental kinematics and mechanics of the auger flighting rolling are mathematically developed, from which the contact area, rolling force and torque are calculated and the affecting factors are evaluated. Slip characteristics between the strip and forming rolls and the effects of roll offset are studied. The design considerations, primarily of the main roll shafts and the required rolling mill power, are also given. The application results were compared to the actual rolling readings with satisfactory agreements.

Decoupling of Adverse Effect of Inter-roll Thrust Force on Steering Control during Strip Rolling: *K. Yamaguchi*[1]; A. Ishii[1]; [1]Nippon Steel Corporation

Inter-roll thrust force due to roll misalignment in 4-high strip rolling mill affects difference in roll forces measured by load cell on the work side and that on the drive side. Since the roll force difference is utilized for strip steering control, in which roll gap tilting control is done assuming the roll force difference reflects strip off-centering behavior, the inter-roll thrust force gives serious disturbance to the steering control, and may cause troubles like tail crash. In this paper, an inter-roll thrust force decoupling method for the steering control is proposed. The method utilizes measured thrust counter forces acting against work roll chocks to obtain effective roll force difference for the steering control. Validity of the decoupling method is confirmed using a laboratory 4-high mill which can control cross angles between rolls and measure the work roll thrust counter forces.

Effect of Delivery Angle on Longitudinal Buckling in Temper Rolling of Thin Steel Strips: *T. Okazaki*[1]; Y. Kimura[1]; H. Kijima[1]; M. Miyake[1]; [1]JFE Steel Corporation

In temper rolling of double reduced thin sheet strips, shape defect called "longitudinal buckling" appears. In previous study, the effect of several rolling conditions on the longitudinal buckling was investigated. However, effect of delivery angle over 4 degree has not been experimented. In this paper, effect of large delivery angle is investigated in laboratory rolling. Results show that by increasing delivery angle, the buckling appears clearly and the number of waves decreases, and by delivery angle over 24 degree the buckling disappears. Next we calculate the buckling characteristics of the sheet which twines around the work roll by the elementary theory. We find that the change of number of waves by delivery angle calculated from the analysis almost agrees with the experimental result when delivery angle is larger than 10 degree. It is estimated that the shape of sheet which twines around the work roll affects the longitudinal buckling phenomenon.

A Fast Computational Model for the Local Stress Distribution and Mechanical and Thermal Work Roll Deformations with Effects on Strip Profile and Flatness during Hot Rolling of Strip in Four-high Mills: *C. Overhagen*[1]; [1]University of Duisburg-Essen

A fast model is presented for the three-dimensional stress and roll force distribution along the strip width. This local data is used to calculate the 3D deformation of the work roll barrel by flattening and deflection using a combined analytical and finite element procedure. Detailed information about the work roll deformation can therefore be obtained because the model does not rely on a constant roll force. The local strip and work roll temperatures are calculated by numerical solution of the heat equation and the evolution of thermal roll crown is calculated for a given rolling campaign. The strip shape is found by intersection of the deformed roll with the initial strip. An upper-bound technique is applied for the resulting strip flatness. Typical methods of profile and flatness adjustment (roll crown, roll bending, zonal roll cooling, CVC) are discussed with effects on strip profile and flatness.

Study on the Transferability of Rolling with Ordered Texturing Roll: *Y. Fujii*[1]; [1]Kobe Steel/Mechanical Working Research Section

The texture rolling is to transfer the roughness on the strip from the textured roll surface. From our previous studies, it was confirmed that the relative velocity in the roll bite is an important factor in the prediction of transferability, and that these depends on the pseudo friction coefficient.In this paper, we investigated the relationship between the roll surface morphology and the friction coefficient using the ordered texturing roll. We carried out the experiments with the 3 kinds of rolls which have 1) RD and 2) TD and 3) 45 degree groove. From these experiments, we evaluated the pseudo friction coefficients of each conditions by using rolling load. As the result, we found that the roll with higher transferability has higher friction coefficient. These pseudo friction coefficients come from the geometrical shear stress.

A Computational Study on the Producible Rolling Thickness in Ultra-thin Strip Rolling: *X. Liu*[1]; H. Xiao[1]; C. Yu[1]; [1]Yanshan University

It is very difficult to continue the cold rolling process of a thin strip when the strip has been thinned to a certain thickness. The Stone formula is the most common approach for predicting this limit, but it was found that the results obtained from this formula are rather inaccurate when applied in experiments or the production of ultra-thin strip rolling. In this paper, the variation law of the contact profile and rolling pressure of ultra-thin strips with different conditions were obtained by FEM, which provide a new definition for the Stone minimum thickness. Furthermore, a theoretical computational model of producible rolling thickness for an ultra-thin strip based on the Fleck theory was established, providing theoretical guidance for practical production by defining the product specification ranges and rolling regulations for existing rolling mills and determining the roller diameters and force and energy parameters for the design of rolling mills.

Investigation of a Novel Constructive Hot Ring Rolling Process for Double Metal Composite Ring: *J. Deng*[1]; Z. Cheng[1]; D. Qian[1]; J. Liu[1]; R. Wu[1]; [1]Wuhan University of Technology

Double metal composite ring has the advantages of two materials, which is widely used in specific fields. The traditional manufacture method is welding. And some scholars try to use ring rolling process to produce a composite ring. However, the interface connection quality is not well. In this paper, a novel constructive hot ring rolling process to manufacture a seamless double metal composite ring is proposed. First, two separate rings with different metals are assembled together. And then the surface interface area on the upper and lower of the assembled ring are welded in oxygen-free environment, which can suppress the interfacial oxidation during heating process. After that, the surface welded ring is cleaned and heated. Finally, the target double metal composite ring is formed by hot ring rolling. An experiment of constructive hot ring rolling process for double metal composite ring was carried. The interface healing effect of the composite ring was detailed studied. The result indicated that the interface healing degree was significantly improved by this method.

Achieving an Interference Fit between Two Rings during Composite Ring Rolling: *C. Cleaver*[1]; J. Allwood[1]; [1]University of Cambridge
Composite ring rolling could bring substantial material, cost and energy savings and allow for lighter weight components, by joining concentric rings with different material properties. For there to be any possibility of achieving a material bond, an interference fit between the rings must be maintained. In this paper, a force equilibrium-based model is introduced to predict when such a fit is possible. This model, for radial composite rolling, predicts a limit to the flow stress of the inner ring relative to the outer ring; suggesting a maximum ratio of about 160%. It also shows that the inner tool's diameter must often be significantly smaller than the outer tool's. The model was successfully tested in four composite ring rolling experiments with two grades of Aluminium alloy, 1050 and 6063, and different tool sizes, suggesting it could be a valuable new guide to designing composite ring rolling processes.

Advanced Design of Work Roll Contours for Different Roll Mill Types: *X. Feng*[1]; X. Wang[1]; Q. Yang[1]; Z. Wu[1]; [1]University of Science and Technology Beijing
Modern steel producers are competing to roll Non Grain Oriented Silicon (NGOS) steel strip with 1.25 meter in width, 0.5 to 0.35 mm in thickness and a profile deviation that is less than 5 micron-meters. Mathematical models are indispensable tools to study the mechanism of work roll contours during rolling, but industrial try-outs are required to validate their effects on strip profile. Thus, this paper presents the effects of various work roll contours designed for: 1) the 6th and 7th stand of a 4-high hot tandem rolling mill; 2) single stand 6-high reversing cold mill; 3) 1st, 2nd and 3rd stand of a 6-high tandem cold mill; Results show that the NGOS strip profile hit rate of 5 micron-meters is increased by the implementations of advanced work roll contours.

A Novel Flexible Skew Rolling Process for Step Shafts: Feasibility Study: *L. Lin*[1]; B. Wang[1]; J. Shen[1]; [1]School of Mechanical Engineering, University of Science and Technology Beijing
This paper develops a novel flexible skew rolling (FSR) process to produce step shafts. The process includes four stages: radial rolling, rollers inclining, skew rolling and rollers levelling. Each roller has three freedoms (circle rotation, radial rotation and radial-feeding motion), which can manufacture different axles by programming different rollers' movements that can achieve flexible rolling with same tools. A flexible skew rolling mill with dual-rotatable-shafts (DRM-80) was invented and manufactured, and feasibility experiments were performed at this mill. A shaft (total length 605 mm, minimum diameter 50 mm) was formed, and has well dimensional accuracy. The main forming defects include knurled pockmarks, helical grooves, side cavity, and diameter tolerance. The experimental FSR part is free from internal cracks by observing the transverse and longitudinal section. The study results verified that the novel flexible skew rolling process is positive and the new type DRM-80 mill is reliable.

Value of, and Limits to, Simulation

Friday AM | July 30, 2021 | 9:15 - 10:15 AM

Session Chair: O. Cazacu, University of Florida

CANCELLED: FE Simulations of Piercing and Trimming of Al Alloys and AHSS: D. Diaz-Infante[1]; A. Narayanan[1]; A. Groseclose[2]; *T. Altan*[1]; [1]The Ohio State University; [2]General Motors
For a given sheet material and thickness, the piercing and trimming conditions (punch/die clearance, punch shape, tool corner radii, lubrication, cutting speed, tool wear, and elastic deflection of tool and press) affect the quality of the pierced/trimmed edge and the quality of the subsequent forming or flanging operations. The application of FE simulations to understand the fundamentals of cutting is quite challenging. This is mainly due to inaccuracies in a) determining material properties at high strains, b) effect of cutting speed, c) determining the so-called Critical Damage Value (CDV) that determines the fracture during cutting. The present study aims to illustrate how FE simulations can predict the significant variables in piercing/trimming of an Al alloy 5182-O and an AHSS CP-W 800 with different sheet thicknesses (1.2 mm and 4.0 mm). The results of this study illustrate the difficulties and limitations of FE analysis in predicting piercing/trimming variables.

Constitutive Law Parameter Identification for Hot Forging Using Compression Experiments on Forging Presses: G. Venet[1]; C. Baudouin[1]; *T. Balan*[1]; [1]Arts et Métiers ParisTech
Constitutive laws for hot forming typically consider the effects of strain, strain rate and temperature. Their parameter identification requires experiments performed on wide ranges of these three factors. Usually, specialized equipment is utilized to ensure uniform strain, strain rate and temperature. Alternatively, parameter databases provide parameter sets for various materials and constitutive laws at a low cost. This work explores the potential of using compression experiments on industrial presses for parameter identification of such constitutive models, in order to balance the cost and accuracy of these two existing alternatives. The results are compared to reference results produced on specialized large temperature / strain rate compression equipment. Two materials are used to prove the usefulness of the proposed methodology.

FE-based Investigation on the Influence of Inhomogeneously Heated Billets on Subsequent Forging Processes: *A. Jagodzinski*[1]; H. Gerland[1]; M. Kriwall[1]; J. Langner[1]; M. Stonis[1]; B. Behrens[1]; [1]IPH - Institut für Integrierte Produktion Hannover gGmbH
Inhomogeneously heated billets can shorten or simplify forging process chains. This shall be achieved by setting various temperature fields within a billet, resulting in different yield stresses. This study investigates the influence of inhomogeneously heated cylindrical billets on the forging process using FEA. For this, two inhomogeneously heated and three homogeneously heated reference process chains are developed and compared. Each process chain is optimized until form filling and no defects occur. They are evaluated based on the forming force, the necessary material and die abrasion wear.The results showed a small time window for a successful forming for inhomogeneously heated process chains. Forming forces and die wear increase for inhomogeneously heated billets. However, they show up to 12.5 % less flash than homogeneously heated billets. This shows a potential for inhomogeneous heating to make forging processes more efficient. Subsequently, experimental tests will be carried out to verify the simulation results.

Advances and Challenges in Computational Modeling of Impact Welding Process: *A. Nassiri*[1]; T. Lee[2]; B. Liu[3]; A. Vivek[1]; T. Abke[4]; G. Daehn[1]; [1]The Ohio State University; [2]Hyundai Motors; [3]Air Force Institute of Technology; [4]Honda R&D Americas
In impact welding, extremely high plastic strain regions develop. Thus, traditional finite element analysis methods are not able to accurately simulate the process due to excessive element distortion near the contact region. Despite the great successes in developing hybrid and adaptive remeshing techniques, mesh-based numerical methods suffer from difficulties in some aspects which limit their applications in high-strain-rate problems. Recently, with the progress in computational capabilities, the next generation of computational methods, so called meshfree methods, have received significant attention. Among all meshfree methods, smoothed particle hydrodynamics (SPH) has received major consideration. In this study, the high-speed impacts between AM-Steel/AM-Steel, Copper/Copper, and Al/Steel were simulated. Then, to study the effects of coating and diffused materials on weldability, different SPH platforms were developed. To experimentally validate the numerical efforts, vaporizing foil actuator welding (VFAW) was conducted. Good agreement between the simulations and experimental results provided confidence in the computational modeling.

Comparison on the Processing of Height Deviations of Disks from FEM and Real Rollings in Radial-Axial Ring Rolling: *T. Glaser*[1]; P. Schwarz[2]; S. Fahle[1]; K. Paffrath[3]; B. Kuhlenkötter[1]; [1]Ruhr-Universität Bochum; [2]Bergische Universität Wuppertal; [3]TKM GmbH
Transferring insights from simulations to an industrial application is a state-of-the-art procedure. The knowledge of how to design a manufacturing process, e.g. for radial-axial ring rolling, is mainly taken from two sources: the machine operator's experience and experiments, which are time- and cost-intensive. Therefore, creating results by using finite element method is a valuable alternative. This paper focusses on the shape deviations in the domain of radial-axial ring rolling. It is a hot forming process to produce e.g. steel rings, used as blanks for the manufacturing of huge bearings or gear rims. Real radial-axial rolled disc shaped rings will be compared to data of a FEM simulation (QForm 3D) with a focus on the deflection of the ring's height. Regarding disc-shaped rings, the production of a constant height is of high importance to save effort and costs of rework.

Simulations of Grain Growth with Arbitrary Grain Boundary Energy: *E. Eren*[1]; J. Mason[1]; [1]University of California, Davis
The Finite Element Method (FEM) is often used to simulate deformation, but high temperature processes can additionally involve grain boundary motion that is difficult within existing FEM simulations. The FEM simulations that do exist cannot generally be used for predictive purposes because they do not allow for anisotropic grain boundary properties, have unphysical anisotropy from the underlying numerical model, or allow only a restricted set of topological events that bias the grain boundary network evolution. Recent progress will be reported in developing a FEM simulation that (1) uses a volumetric mesh to eventually allow the inclusion of arbitrary material physics, (2) significantly expands the set of topological events to allow for general grain boundary network dynamics, and (3) proposes an energy dissipation criterion to identify the physically most plausible of these events. Moreover, the performance of three proposed equations of motion will be evaluated and compared to analytical results.

PID Controller Integrated with FEM Model to Generate Boundary Conditions for Free Tube Bulging for Tubular Material Characterization: *S. Nazari Tiji*[1]; T. Park[1]; H. Kim[1]; A. Asgharzadeh[1]; M. Athale[1]; J. Kim[2]; F. Pourboghrat[1]; [1]The Ohio State University; [2]Pusan National University
A PID controller was implemented in FEM platform as a user subroutine instead of a sophisticated and expensive control system implemented in a tube hydroforming machine to numerically generate the required boundary conditions, axial feed and pressure profiles, based on proportional strain path at the pole of the bulging tube in the FEM simulations. The generated boundary conditions can directly be used in free tube bulging experiments to generate different deformation modes for tubular material characterization based on accumulated plastic work equivalency. It was also shown that the numerical algorithm developed works accurately for isotropic and anisotropic yield functions. In this study von-Mises and Hill's 1948 were used as the material models.

Yasuhisa Tozawa Honorary Symposium

Friday AM | July 30, 2021 | 9:15 - 10:15 AM

Session Chairs: T. Ishikawa, Chubu University, Y. Yoshida, Gifu University

Invited
A Plasticity Framework for Forming Applications: *F. Barlat*[1]; T. Kuwabara[2]; [1]Pohang University of Science and Technology; [2]Tokyo University of Agriculture and Technology
This presentation reviews the key features of a plasticity framework developed by the author and his co-workers over the last two decades. The purpose is to define an accurate macroscopic plasticity theory applicable to numerical simulations of practical forming processes in industry. The constitutive relationships are developed for anisotropic materials with an anisotropic hardening assumption. The framework relies on mathematical concepts, physical understanding of deformation mechanisms and experimental results. Lower scale simulation results are essential for the introduction of relevant features in the macroscopic framework. The experimental investigations on plasticity conducted by Professor Tozawa in the 1960's and 70's is of fundamental importance for the development and validation of the theory. An application of the approach for numerical forming process simulations of a complex sheet product is described as an illustration.

Invited
Prof. Yasuhisa Tozawa's Achievements in the Field of Metal Forming: *T. Ishikawa*[1]; [1]Chubu University
Prof. Yasuhisa Tozawa's achievements in the field of metal forming is introduced and reviewed. He has consistently been involved in the study of metal forming. (1) Sheet metal forming, especially bending accuracy and bending fracture and deformation behavior of sheet materials under multiaxial stresses. (2) Strip rolling, especially its three-dimensional analysis. (3) Cold forging, especially evaluation of flow stress and fracture of forging materials. He has been active internationally as a member of CIRP and ICFG. As an excellent educator, he was also enthusiastic about teaching guidance for undergraduate and graduate students, or company engineers, and nurtured many leading researchers and engineers.

Surface Quality of Extruded Sidewall in Cold Backward Cup Extrusion with Low-frequency Torsional Oscillation: *R. Matsumoto*[1]; S. Takatsuka[1]; H. Utsunomiya[1]; [1]Osaka University
The surface quality of an extruded sidewall of a workpiece was investigated in cold backward cup extrusion with torsional oscillation. In this extrusion process, a cylindrical aluminum workpiece lubricated with a mineral oil was simultaneously extruded in the axial direction and twisted in the circumferential direction between extrusion and knockout punches with an axial speed of 0.1 mm/s, an alternating amplitude of 5deg, and a maximum angular speed of 0.5 rpm at room temperature. The sidewall of the workpiece was axially extruded and circumferentially rotated with approximately 25% lower contacting pressure with the container, so that the surface of the sidewall was uniformly smoothed. Furthermore, the circumferential profile of the sidewall height of the extruded workpiece was close to uniform because the workpiece was uniformly lubricated by the circumferential rotation of the workpiece.

Anisotropic Ductile Fracture Estimation of Diagonal Cracks in Flange-shaped Parts: *A. Watanabe*[1]; K. Hayakawa[2]; S. Fujikawa[3]; T. Takeshita[4]; M. Furutani[4]; [1]Nissan Motor Co., Ltd. and Graduate School of Science and Technology, Shizuoka University; [2]Graduate School of Science and Technology, Shizuoka University; [3]Nissan Motor Co., Ltd.; [4]Jatco Ltd.
Inclined rotary forming (IRF) is a combined process of bending and axial compression with rotation, which is used to forge flange shaft-structured parts from round rod billets. Although the forming load is less than that of conventional processes, cracks may develop during the IRF process. However, it is difficult to predict cracks by applying the conventional ductile fracture prediction equations. In this paper, an equation for predicting ductile fractures is proposed that considers anisotropic ductile fractures. The proposed equation was expressed as a second rank tensor resulting from the product of the stress tensor and strain increment tensor. The proposed equation was verified through a uniaxial tensile test conducted on a notched round bar and the compression test of cylindrical specimen referring to the past literature. The proposed equation was applied to the IRF process. Consequently, it was possible to estimate the lubrication conditions that make diagonal cracks smaller.

Prediction on Microstructure of Large Scale Hot Forged Ni-based Super Alloy: *N. Yukawa*[1]; T. Yamada[1]; C. Osawa[1]; E. Abe[1]; [1]Nagoya University

Recently, it has been more important to realize the higher combustion temperature of a gas turbine for air crafts. In order to attain that, it is necessary the material gets an excellent mechanical property like tensile strength. The grain size of the material has a large influence on the mechanical property. Therefore, it is imperative to predict recrystallization behavior under hot forging and heat treatment for controlling the grain size. In this study, we focused on Alloy 718 of a Ni-based superalloy and developed a prediction model for the fractions of dynamic recrystallization and the grain size under a large scale hot forging. The calculated results are good agreements with experimental results of the fractions of dynamic recrystallization and grain size.

Three-dimensional Analysis of Strip Rolling by Coupling Elastic Deformation of Rolls and Rolling Mills: *J. Yanagimoto*[1]; [1]The University of Tokyo

This paper will describe the characteristics of three-dimensional stress field of strip and plastic deformation which is affected by the elastic deformation of rolls and rolling mills. FE analysis results will be presented. Elementary three-dimensional numerical analysis of strip rolling will be presented to compare the results obtained by FEM.(This presentation is a part of session dedicated to Prof. Tozawa)

Characterisation of Anisotropic Material Behaviour: *E. Tekkaya*[1]; T. Clausmeyer[1]; F. Kolpak[1]; O. Hering[1]; F. Gutknecht[1]; H. Traphöner[1]; [1]TU Dortmund

During metal forming processes the workpiece material undergoes large plastic strains. The material develops anisotropic behavior as it is plastically deformed. This anisotropy effects not only the material flow during forming but also the properties of the formed part such as the residual stresses, the yield strength, the damage level etc. Pioneering studies on the determination of anisotropic hardening behavior has been conducted by Professor Tozawa in the seventies. This presentation focuses on the anisotropic hardening behavior of metals at very large strains and describes experimental techniques to quantify anisotropic hardening.

Analysis of Orientation Behavior of Plate-like Particles in Differential Speed Powder Rolling: *K. Shinagawa*[1]; K. Kudo[1]; [1]Kyushu University

Rolling of powder compacts has been used to develop grain-orientated microstructures, especially for anisotropic magnetic material, but can also be applied to piezoelectric ceramics. To obtain a thick ceramic green sheet, powder rolling may be an effective way to actualize higher productivity, compared with a conventional process consisting of slip casting and subsequent laminating of thin sheets. However, the rolling condition to reach high orientation of plate-like ceramic particles, in bodies plasticized with organic binders, has not been studied sufficiently, and should be clarified based on the theoretical consideration. In this study, the effects of differential speed powder rolling on the orientation behavior of plate-like particles are examined by using the Folgar-Tucker model. The change in orientation angle distribution is computed under assumption of a simple velocity field in rolling process. It is shown that the shear deformation in advance of compression is effective to obtain higher degree of orientation.

Control Theory for High End Press Brake: *Z. Wang*[1]; [1]Gifu University

This paper proposes a control theory of V-bending of sheet metals for high end press brake. The control theory consists of the basic relationship between the product angle and the punch stroke, inflexion point and bending load. The proposed control theory has been applied to the high end press brake and gives a great performance.

The Process Design to Control the Yield Ratio of Yield-Ratio-Control-Steel on Both Wire Production and Forging Process: *Y. Lee*[1]; [1]Korea Institute of Materials Science

Yield-ratio-control-steel(YRCS) is a steel which the yield strength can be controlled although the same tensile strength. The lower yield ratio steel is more effective for cold forging since the forging load is lower and tool life is enhanced. The yield ratio of YRCS metal is controlled by plastic deformation amount and cooling rate. So, the yield ratio is changed cooling rate after wire rolling as well as plastic deformation during cold wire drawing. Moreover, precision forged part can be used directly without post-heat-treatment(quenching/tempering) because the strength of forged part is increased by work hardening and grain refinement. Three major process variables are considered to get the proper yield ratio on cold forging of bolt which tensile strength is over 800 MPa. The cold drawing amount of wire is major variable to change the yield ratio, while cooling rate is the most important variable affected on their strength.

Surrogate Modelling of Search Range in Polyhedron Flow Stress Model Identification with Inverse Analysis and Cylindrical Compression Test: *Y. Yoshida*[1]; J. Samukawa[1]; T. Nishiwaki[2]; M. Murata[3]; [1]Gifu University; [2]Daido University; [3]Nagoya Municipal Industrial Research Institute

Identification of flow stress is conducted with inverse analysis based on finite element analysis. In this procedure, the search range space of equivalent strain and equivalent strain rate should be figured out. In this research, surrogate modeling of maximum value of the strain and strain rate is performed with compressed cylindrical specimen shape with machine learning.

Hole Expansion Simulation of Steel Sheet Considering Differential Hardening: *T. Kuwabara*[1]; S. Nomura[1]; [1]Tokyo University of Agriculture & Technology

The deformation behavior of a steel sheet in hole expansion forming (HEF) using a flat-bottomed cylindrical punch has been investigated both experimentally and analytically to investigate the effect of material modeling on the accuracy of the finite element analysis of HEF. The elastic-plastic deformation behavior of a test material is precisely measured using the biaxial tensile test with cruciform specimens and the multiaxial tube expansion test with tubular specimens. Many linear stress paths in the first quadrant of stress space are applied to the specimens to measure the contours of plastic work and the directions of plastic strain rates to determine appropriate material models assuming either isotropic hardening or differential hardening. The accuracy of HEF simulation is improved by using the differential hardening model.

Lubrication and Surface Effects

Friday AM | July 30, 2021 | 10:20 - 11:20 AM

Session Chair: W. Homberg, Paderborn University

Development of Oil-type Lubricants for Cold Forging Using Phase Transition Behavior Under High-pressure Conditions: *T. Okano*[1]; N. Tanino[1]; K. Kitamura[2]; [1]Idemitsu Kosan Co., Ltd.; [2]Nagoya Institute of Technology

In the process of cold forging, lubricant is one of the important elements because they contribute to prolong the die life and improve the surface quality of products. On the other hand, it is well known that lubricants are exposed to the very severe condition such as high contact pressure and high temperature induced by processing heat. So that, oil type cold forging lubricants cause oil film shortage and induce processing defect. In order to make a breakthrough in these situations, we find out the possibility of phase transition materials from liquid to solid under high-pressure conditions. In this research, we develop new oil type lubricants for cold forging using phase transition materials. Moreover, we find that these materials show higher lubricating performance for cold forging process compared with the conventional lubricants. These results indicate that phase transition behavior under high-pressure conditions support the lubrication for cold forging process.

Analysis of Work Hardening and Tribological Changes after a Gap Controlled Drawbead Passage: *H. Schmid*[1]; M. Merklein[1]; [1]FAU Erlangen-Nürnberg, Institute of Manufacturing Technology

In deep drawing processes, drawbeads are frequently used to control material flow while forming. It is well-known, that material parameters are changed significantly after a drawbead passage. Also, there are many references that the tribological system after a drawbead is changed and that this has influences on the ongoing forming process. In this study, the connection between work hardening and the tribological system after a drawbead is analyzed with respect to the initial state. Therefore, sheets are drawn through a gap controlled drawbead passage while parameters like the gap between blank holder and die or the materials are varied. Afterwards, hardness measurements will be carried out as well as 3D surface measurements to correlate them. For these investigations, three different sheet metals are used: a conventional deep drawing steel, an advanced high strength steel AHSS and an aluminum alloy, as they represent the variety of industrial used sheet metal.

Evaluation of Lubricant Performance for Thick Sheet Ironing Process by Ball Ironing Test: *N. Sae-eaw*[1]; Y. Aue-u-lan[1]; [1]King Mongkut's University of Technology North Bangkok

A thick sheet ironing process is normally used to control the uniform wall thickness of products. To evaluate the performance of lubricants by conventional tests, such as Ring Compression Test (RCT) is not suitable due to the limitation in the low level of normal contact pressure, surface expansion, and relative velocity. In this research, Ball Ironing Test (BIT) was proposed as a new simulative tribo-test. Finite Element Modeling (FEM) together with the statistical analysis was employed during the design and determine the frictional indicator of the BIT. According to the results, the maximum load is very sensitive to the friction and can be used as an indicator to evaluate and approximate the friction coefficient via Frictional Calibration Curve. Different types of lubricants were tested experimentally and demonstrated different performance during the BIT. In conclusion, the BIT is suitable for evaluating the ironing process.

Investigations on Dynamic Characteristics of a Mechanical Press Considering Both Translational Clearance Joint and Lubrication Effect: *X. Wu*[1]; Y. Sun[1]; [1]Nanjing University of Science and Technology

The existence of clearance in the motion joints of multi-body systems can significantly influence the dynamic responses. Distinguished from the previous studies, the inclination characteristics of the slider, which are crucial in the stamping forming process, are analyzed in this paper. To achieve a higher analysis accuracy, lubrication actions are introduced to the dynamic equations, and contact forces evaluated by the L-N dry contact model are also considered. Numerical simulations were carried out to investigate the influence of clearance size and crank speed. Then, Poincaré maps and spectrum graphs were adopted to indicate the regularity of the system responses. Furthermore, experimental validations were achieved based on the testing system for a mechanical press. It indicates that the translational clearance joint can play a vital role in the slider inclination issue, and will lead the system dynamics into chaos with a specific range of parameters.

Novel Processes II

Friday AM | July 30, 2021 | 10:20 - 11:20 AM

Session Chair: T. Lee, Incheon National University

Vacuum Hot-roll Bonding of Titanium and Carbon Steel Using Pure Iron Interlayer: *C. Yu*[1]; X. Liu[1]; H. Xiao[1]; Y. Zhao[1]; [1]Yanshan University

In this paper, the effect of a pure iron interlayer on properties of the multi-pass hot-roll bonding titanium/carbon steel plate was studied. The mechanical and microstructural properties of the composite plate were investigated by optical microscopy and scanning electron microscopy, as well as tensile-shear, bending and tensile tests. The results show that when the reduction ratio is below 18%, the shear strength of the interface is higher with the pure iron interlayer than without it. At 35% reduction, the shear strength is similar in both cases. At a reduction ratio of 68%, with the pure iron interlayer, fracture of the bonding interface occurs on the titanium matrix, whereas without the pure iron interlayer, fracture occurs on both the titanium matrix and the compound layer on the interface. Including the pure iron interlayer improves the bending and tensile properties of the titanium/carbon steel plate appreciably.

Accurate Mapping of Thermal Camera Measurements on Planar Deformations: *C. Karadogan*[1]; M. Liewald[1]; [1]Institute for Metal Forming Technology - University of Stuttgart

Synchronous measurement of temperature distribution with infrared cameras has been increasingly used in the thermomechanical analysis of sheet material behavior. Measured temperatures are used, however, only qualitatively due to absence of well-developed coordinate mapping methods applicable to thermographic measurements. The study introduces a primitive, easy to use, yet effective approach for accurate coordinate mapping from real to image coordinates, and inverse, applicable to even highly oblique thermographic and photographic measurements of planar deformations. The method is not limited to any camera model and precisely counteracts inhomogeneous image distortion. It can be used as a stand-alone optical measurement approach, but at the same time, it allows flawless correlation with commercial DIC systems by allowing accurate mapping between thermographic and photographic measurements of planar deformation in real and image coordinates.

Influence of Axial Feed-rate on Shape and Thickness Changes during Multi-pass Tube Spinning: Experiments and Modelling: *B. Roy*[1]; Y. Korkolis[2]; Y. Arai[1]; W. Araki[1]; T. Iijima[3]; J. Kouyama[3]; [1]Saitama University; [2]The Ohio State University; [3]Asahi Seisakusho Co., Ltd.,
The primary purpose of this research is to investigate the influence of axial feed-rate on shape and thickness changes in multi-pass, mandrel-free tube spinning for producing a hemispherical shape at room temperature. The target shape is formed experimentally by 7 spinning passes from annealed, pure aluminum AA1070-O tube. The experiments are conducted with three different axial feed-rates i.e. 2, 5 and 7.5 mm/rev., and interrupted after spinning passes 2, 4 and 7. In every experiment, the tube buckled at some point during the process, due to the high axial-feed. It was also found that decreasing the axial feed-rate generates higher elongation and lower thickness change. A 3D elastic-plastic finite element (FE) model of the multi-pass tube spinning process is described. The mechanisms of influence of the axial feed-rate on axial buckling, tube elongation and thickness change are discussed through the comparison between experimental and simulation results.

A Brief Review on Theoretical Aspects of Bar Straightening with Recent Developments in its Modelling, Simulation, Control System and Stabilisation: *S. Roy*[1]; A. Pal[1]; N. Das Talukder[2]; [1]Jadavpur University; [2]Former Professor Emeritus
This paper presents a brief review of various researches done on bar straightening. Bar straightening can be considered as a significant process in the value stream of bar production. The paper dealt briefly on various types of arrangements available in bar straightening process. The theoretical perspectives have been looked into in simplified manner. Residual stresses, curvature and bending moment thereof due to reverse kinematic bending have been discussed. A system approach has been taken as how development on bar straightening process emerged over the years. The recent developments in bar straightening using modelling / numerical modelling give an insight of reduction in curvature after reverse bending. Simulation / Numerical simulation approaches in bar straightening process have been looked into. Key aspects like positioning of rolls and minimisation of straightness errors have been considered. How control system is applied with Multi-Step Straightening Control System (MSSC) in reducing curvature has been discussed. The paper has been intended to present an overall view of bar straightening from inception till modern times.

Investigation on the Whole Forming Process of Super-large Flat Ring: *D. Xie*[1]; W. Xu[1]; Y. Wang[1]; R. Chen[1]; [1]Chongqing University
The main concerns of forming super-large rectangular ring are forming accuracy, rolling stability, uniformity of deformation and accordingly the distributed microstructure and related mechanical property of the rolled ring. In this paper, a rectangular ring with diameter of 9m is taken as an example, which is the bearing ring of a carrier rocket. To meet the requirements of formation and performance, the whole forming process, including multi-directional forging, punching, reaming and ring rolling is investigated step by step. Three multi-directional forging schemes are compared in order to improve the internal quality of ring billet. For the reaming process, four different reduction amounts per pass are designed to control the end surface quality of the reaming operation part. To refine grain and minimize the anisotropy of the rolled ring, the ring rolling process is divided into high temperature rolling and low temperature rolling, the feeding strategy of which are studied respectively.

Effect of Bending Intensity on Straightness in Spinner Straightener: K. Kawasaki[1]; *T. Kuboki*[1]; S. Kajikawa[1]; H. Matumura[2]; T. Ono[2]; H. Seimiya[2]; [1]University of Electro-Communications; [2]Shimomura Tokushu Seiko
This paper presents the optimum processing condition of spinner straightener. Spinner straightener straightens wire rod using several straightening tools by subjecting the rod to repetitive bending and unbending with rotational movement. This research investigated the effect of bending intensity on straightness of wire by changing the die positions which determine the bending intensity. Both the experiment and an analysis were carried out for the investigation. One of the unique points of this study is the usage of actual operation line for the experiment instead of laboratory equipment. Another unique point is the combination of the finite element analysis (FEA) and a purpose built fundamental analysis. The analysis and experiment were in good agreement, and showed the existence of the optimum condition. The straightness was improved with the increase of the bending intensity up to the optimum bending intensity. However, excessive bending intensity deteriorated the straightness.

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