SUPERALLOY 718 and Derivatives

625 · 725 · 718 · 625 Plus · 706 · René 220 · PWA 1472 · 718 Plus · Waspaloy · C263 · René 41 · 939 · 720 · 282

7th International Symposium on SUPERALLOY 718 and DERIVATIVES

October 10-13, 2010
Marriott Pittsburgh City Center
Pittsburgh, PA

FINAL PROGRAM

Sponsored by:

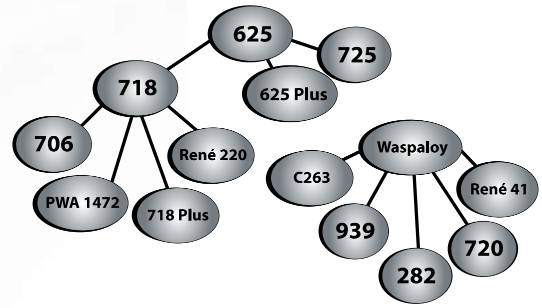
TMS
High Temperature
Alloys Committee

Co-sponsored by:

ASM INTERNATIONAL
The Materials Information Society

www.tms.org

SUPERALLOY 718 and Derivatives



Welcome to the 7th International Symposium on Superalloy 718 and Derivatives!

This is the seventh in a series of conferences focused on Superalloy 718 and Derivatives 625 and 706, which have occurred over the past 20 years, but with a scope that incorporates the energy industry and U720/Waspaloy alloy families.

ABOUT YOUR REGISTRATION

Full Conference Registration includes the welcoming reception, coffee breaks, conference luncheons, access to the technical sessions and sponsor showcase, and a copy of the post-conference proceedings.

Student Registration includes the welcoming reception, coffee breaks, conference luncheons, and access to the technical sessions and sponsor showcase.

Guests may purchase tickets for the welcoming reception and conference luncheons at the registration desk. Tickets are $40 for the welcoming reception and $45 per luncheon.

Badges must be worn to gain access to the technical sessions and social functions.

Conference Proceedings Publication

All papers presented at the 7th International Special Emphasis Symposium on Superalloy 718, 625, 706, and Derivatives will be published in the proceedings CD-ROM. A copy of the proceedings is included with the registration fee for full conference registrants. Additional copies of the conference proceedings may be purchased for $60 at the registration desk.

NOTE: The student registration fee does not include a copy of the proceedings.

TABLE OF CONTENTS

CALENDAR OF EVENTS

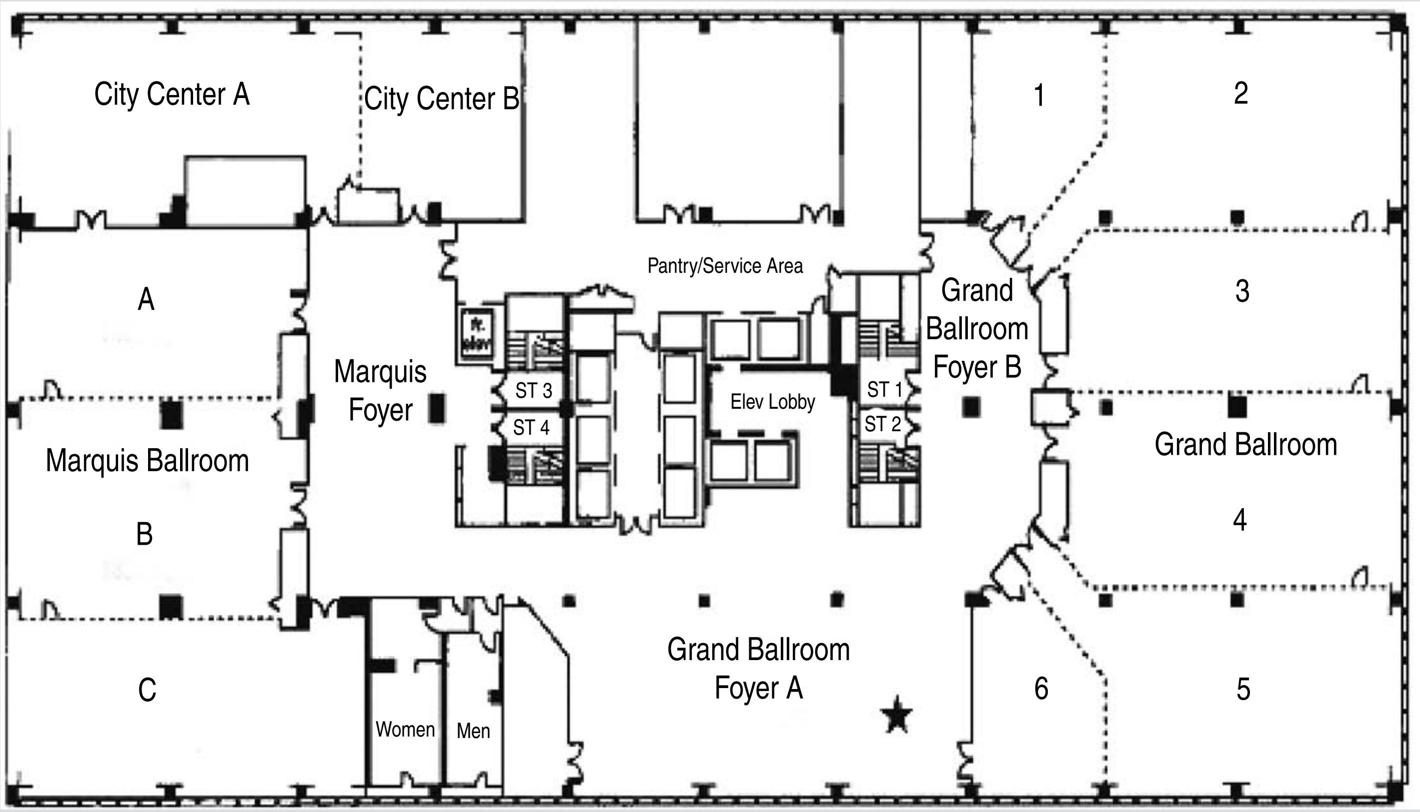
Sunday, October 10	Time	Location
Registration	4 to 8 p.m.	Grand Foyer
Keynote Presentations	6:30 to 7:45 p.m.	Salon 4
Welcoming Reception and Sponsor Showcase	7:45 to 9 p.m.	Salon 1, 2 & 3
Sponsored by Pratt & Whitney		

Monday, October 11	Time	Location
Registration	7 a.m. to 5 p.m.	Grand Foyer
Continental Breakfast	7:30 to 8 a.m.	Salon 1, 2 & 3
Technical Sessions	8 a.m. to 5:15 p.m.	Salon 4
A.M. Break and Interactive Poster Session	9:30 a.m. to 10 a.m.	Salon 1, 2 & 3
Sponsored by ATI Aerospace		
Sponsor Showcase	9:30 a.m. to 3 p.m.	Salon 1, 2 & 3
Luncheon	11:30 a.m. to 1 p.m.	Marquis A&B
Sponsored by Reference Metals Co.		
P.M. Break and Interactive Poster Session	2:30 to 2:50 p.m.	Salon 1, 2 & 3
Sponsored by ATI Aerospace		

Tuesday, October 12	Time	Location
Registration	7 a.m. to 5 p.m.	Grand Foyer
Continental Breakfast	7:30 to 8 a.m.	Salon 1, 2 & 3
Technical Sessions	8 a.m. to 5:20 p.m.	Salon 4
A.M. Break and Interactive Poster Session	9:30 to 10 a.m.	Salon 1, 2 & 3
Sponsored by MTS Systems, Inc.		
Sponsor Showcase	9:30 a.m. to 3 p.m.	Salon 1, 2 & 3
Luncheon	11:30 a.m. to 1 p.m.	Marquis A&B
P.M. Break and Interactive Poster Session	2:30 to 2:50 p.m.	Salon 1, 2 & 3

Wednesday, October 13	Time	Location
Registration	7 a.m. to noon	Grand Foyer
Continental Breakfast	7:30 to 8 a.m.	Salon 1, 2 & 3
Technical Sessions	8 a.m. to 4:45 p.m.	Salon 4
A.M. Break and Interactive Poster Session	9:30 to 10 a.m.	Salon 1, 2 & 3
Sponsored by Carpenter Technology		
Sponsor Showcase	9:30 a.m. to 3 p.m.	Salon 1, 2 & 3
Luncheon	11:30 a.m. to 1 p.m.	Marquis A&B
P.M. Break and Interactive Poster Session	2:30 to 2:50 p.m.	Salon 1, 2 & 3
Sponsored by Carpenter Technology		

Marriot Pittsburgh City Center Floor Plan



About the Conference Location

Computer/Network Facilities

The Marriott Pittsburgh City Center has complementary wireless internet in every guest room, as well as on the second floor and in the lobby of the hotel.

Accommodations

The Marriott Pittsburgh City Center is centrally located in downtown Pittsburgh, Pennsylvania steps away from the business district and directly across from the newly opened Consol Energy Center. The hotel staff is dedicated to attending to every detail to make your stay a truly personal experience. Each of the 402 rooms features dramatic views of the Pittsburgh skyline.

Programming Notes

Technical Sessions
The technical program will begin Sunday, October 10 and conclude Wednesday, October 13.

Keynote Speakers
Two distinguished speakers will kick off the conference on Sunday, October 10 in Salon 4 at 6:30 p.m. with in-depth insight on superalloy-related issues.

Bill Brindley, Chief Technologist, Rolls-Royce Fellow, Rolls-Royce Corporation, USA
"Introducing New Materials into Aero Engines – Risks and Rewards – A Users' Perspective"

Art Kracke, Vice President of business technology, Teledyne Allvac, USA
"Ni-Base Superalloys, the Most Successful Alloy System of Modern Times – Past, Present, and Future"

Luncheon Speaker
Monday • 11:30 a.m. to 1 p.m. • Marquis A&B

Sponsored by Reference Metals Co.

Mariana Perez de Oliveira, Metallurgical engineer, CBMM
"The Value of Nb in Super Alloys"

Since its foundation, CBMM has invested in the development of Nb related materials. The company's goals are not only to supply the Nb demand, but also to discover how this element can help overcome the challenges presently facing human kind: wise, sustainable growth that is energy and cost efficient, as well as environmentally sensitive. The search for new materials is necessary and the superalloys industry is called upon to overcome today's technological barriers. CBMM sees itself as a long-term partner committed to helping develop solutions to overcome challenges in the quest for a better future by contributing sustainable Nb
technological advances.

Policies

Audio/Video Recording Policy
TMS reserves the right to all audio and video reproductions of presentations at TMS sponsored meetings. Recording of sessions (audio, video, still photography, etc.) intended for personal use, distribution, publication or copyright without the express written consent of TMS and the individual authors is strictly prohibited.

Photography Notice
By registering for the conference, all attendees acknowledge that they may be photographed by TMS personnel while at events and that those photos may be used for promotional purposes.

Americans with Disabilities Act
TMS strongly supports the Federal Americans with Disabilities Act (ADA) that prohibits discrimination against, and promotes public accessibility for those with disabilities. In support of this act, we ask those attendees requiring specific equipment or services to contact the TMS Meeting Services Department to advise specific needs in advance.

Organizing Committee

Conference Chair: **Jon Groh**, *GE Aviation, USA*

Committee Members:
Anthony Banik, *ATI Allvac, USA*
Xingbo Liu, *West Virginia University, USA*
Randy Helmink, *Rolls-Royce, USA*
Alec Mitchell, *University of British Columbia, Canada*
Xishan Xie, *Science and Technology University of Beijing, China*
Tim Gabb, *NASA Glenn Research Center, USA*
Agnieszka Wusatowska-Sarnek, *Pratt & Whitney, USA*
Eric Ott, *GE Aviation, USA*
Göran P. Sjöberg, *VolvoAero Corp, Sweden*

Honorary Member: **Edward A. Loria**, (*1916-2010) In Memoriam*

THANKS TO OUR SPONSORS

TMS and the TMS High Temperature Alloy Committee acknowledge the generous support of the following sponsors:

REFERENCE METALS COMPANY
THE Niobium Supplier
CBMM
innovate respect compete
www.referencemetals.com | 412.221.7008

PRATT & WHITNEY DEPENDABLE ENGINES

ATI Aerospace

CARPENTER

MTS®

Thermo-Calc Software

JMatPro

Reception and Keynote Presentations

Sunday PM
October 10, 2010

Room: Salon 4
Location: Marriot Pittsburgh City Center

Session Chairs: Jon Groh, GE Aviation; Tony Banik, ATI Allvac

6:30 PM Introductory Comments

6:35 PM Keynote
Introducing New Materials into Aero Engines – Risks and Rewards – A Users Perspective: Malcolm Thomas[1]; *Bill Brindley*[1]; David Furrer[1]; [1]Rolls-Royce Corporation

Developing and certifying new aircraft engines is expensive. Once introduced, an engine will have a life measured in decades, and manufacturers and users are reluctant to introduce changes for a number of reasons, not least of which are safety, reliability and cost. Thus the opportunities for new material introduction are few and the consequences of an imperfect decision are high. It is therefore imperative that materials engineers utilize any opportunity to introduce material improvements that are presented. This presentation will discuss the risks and necessary actions to achieve successful material insertion and will give examples of successful and unsuccessful changes.

7:05 PM Introductory Comments

7:10 PM Keynote
Ni-Base Superalloys, the Most Successful Alloy System of Modern Times – Past, Present, and Future: *Art Kracke*[1]; [1]ATI Allvac

The deep roots of superalloys are said to go back the 1920's although the term 'super-alloy' is believed to have first been used in the early 1950's referring to cobalt-based alloys such as Vitallium and Waspaloy®. During the past 50 plus years much alloy, hot working, heat treating and process development has occurred facilitating many of the end use technologies we know today. This presentation will discuss some of the history of the superalloy industry related to the superalloys 718, Waspaloy and their derivatives' including ATI 718Plus® alloy. The presentation will then describe the wide range of manufacturing techniques used for the production of superalloys, available product forms and end-use applications. Concluding the presentation will be a discussion on what advancements we are likely to see in the future.

7:45 PM Welcoming Reception

Raw Materials and Casting Technology

Monday AM
October 11, 2010

Room: Salon 4
Location: Marriot Pittsburgh City Center

Session Chairs: Alec Mitchell, University of British Columbia; Randy Helmink, Rolls-Royce Corporation

8:00 AM Introductory Comments

8:05 AM Invited
An Overview of SMPC Research Programs to Improve Remelt Ingot Quality: *Rod Williamson*[1]; [1]Remelting Technologies Consulting

Research conducted by the Specialty Metals Processing Consortium (SMPC) has focused on developing tools to improve the quality of specialty alloy ingots produced by vacuum arc remelting (VAR) and electroslag remelting (ESR). Especially during the last ten years, the program has focused on developing model-based process monitors and controllers. These tools employ predictive, dynamic, low-order electrode melting and ingot solidification models to estimate important process variables. Process monitors log these estimated variables (some of which are not subject to measurement) to computer files and use them to evaluate the health of the processes. Monitors are capable of detecting and flagging various process upsets and sensor failures. Process controllers use the model-based variable estimates for feedback. Improved melt rate controllers have been developed using this method. Additionally, VAR pool power and pool depth controllers have also been demonstrated. Laboratory and industrial trials have shown the robustness and accuracy of these tools.

8:30 AM
Considering the Solidification Structure of VAR Ingots in the Numerical Simulation of the Cogging Process: *Jan Terhaar*[1]; Jörg Poppenhäger[1]; Dieter Bokelmann[1]; Hendrik Schafstall[2]; Kanchan Kelkar[3]; [1]Saarschmiede GmbH Freiformschmiede; [2]Simufact Engineering GmbH; [3]Innovative Research, Inc.

The main objective of Vacuum Arc Remelting is to control solidification conditions in order to obtain a columnar dendritic structure throughout the whole ingot. The change in primary dendrites' growth direction, determined by the pool shape, leads to non-isotropic material properties in terms of plastic flow. As the correct prediction of flow behavior is crucial for the further analysis of forming processes (as for example in the application of damage criteria), this specific feature of remelted material has to be accounted for in the modeling of ingot breakdown. Using Barlat's formulation for the plastic flow, the structural constitution of alloy 718 VAR ingots could be linked to the alloy's plastic flow behavior by modeling the inhomogeneity of properties determined by remelting experiments and simulations. Hence, the influence of different remelting process conditions on hot workability could be examined. Compared to the commonly used vonMises approach some differences could be revealed.

8:50 AM

Solidification Front Tilt Angle Effect on Potential Nucleation Sites for Freckling in the Remelt of Ni-Base Superalloys: *Jairo Valdes Ortiz*[1]; Xingbo Liu[1]; Paul King[2]; Christopher Cowen[2]; Paul Jablonski[2]; [1]West Virginia University; [2]National Energy Technology Laboratory

By considering the mushy layer as a porous media with variable permeability, a Rayleigh number based freckling criterion was developed from the Flemings ratio between the magnitude of the interdendritic flow velocity and the solidification rate. The proposed form includes the effect of the tilt angle by preserving the anisotropic nature of the permeability tensor throughout the derivation and uses Poirier's experimentally determined functional forms for the parallel and perpendicular components. The proposed form of Rayleigh number criterion was found to provide better resolution when evaluated against available experimental data in the literature. Especially, it showed that the nucleation of channels in the mushy layer leading to freckles is equally probable in the proximity of the tips of the dendrites or deeper in the mushy layer, for example at approximately 0.7 liquid fraction and 0.4 liquid fraction respectively, depending on the angle of tilt of the solidification front.

9:10 AM

Assessment of Test Methods for Freckle Formation in Ni-base Superalloy Ingot: *Koji Kajikawa*[1]; Masaru Tanaka[1]; Sigeru Suzuki[1]; Hitohisa Yamada[1]; [1]The Japan Steel Works, Ltd.

Ni-base superalloys are well-known as freckle prone materials. Various researchers have reported several types of test methods for investigating freckle formation condition in Ni-base superalloy ingots. Although varieties of test methods have been reported, there seem few articles about comparison among the test methods. In order to reveal the characteristic of the test methods, some of the test methods were compared. This study shows, which could be more suitable test method for freckling condition in a large size ingot. Also incompleteness of some of freckle formation theories is discussed. Using selected test method, the candidate Ni-base superalloys for advanced ultra super critical (A-USC) steam turbine that would be operated in 700-760C steam conditions were tested. The experiment revealed the freckling tendency of A-USC candidate alloys.

9:30 AM Break and Interactive Poster Session

10:00 AM Invited

Casting Superalloys for Structural Applications: *Göran Sjöberg*[1]; [1]Volvo Aero Corporation

Open air investment casting of superalloys for aerospace applications is a process that dates back about 80 years. The introduction of vacuum metallurgy 30 years later made the development and the use of higher strength and higher temperature resistant superalloys feasible since the very reactive alloying elements like aluminum, titanium and niobium that brought these features could be handled in the casting process without being oxidized. The development of the high strength Alloy 718 (INCONEL 718 patented by INCO) 50 years ago enabled large size complex geometry structural castings to be produced efficiently and thus replacing previous weld assembly part designs made of less potent stainless steel grade alloys. With the introduction of hot isostatic pressing as a post processing step the quality of the castings could be significantly improved opening for more critical aircraft engine applications.With increasing diameters there is a diminishing return in terms of capital investment, number of parts and capital amortization and today there is a reversed trend to build the very large diameter structures as assembly parts. In this context the welding is the ultimately critical process not least when more temperature capable alloys are considered at the same time.

10:30 AM

Castability of 718Plus® Alloy for Structural Gas Turbine Engine Components: *Benjamin Peterson*[1]; Venkatesh Krishnan[1]; David Brayshaw[2]; Randy Helmink[3]; Scott Oppenheimer[4]; Eric Ott[5]; Raymond Benn[6]; Michael Uchic[7]; [1]Honeywell Aerospace; [2]PCC Structurals Inc.; [3]Rolls-Royce Corporation; [4]ATI Allvac; [5]GE Aviation; [6]Pratt & Whitney; [7]Air Force Research Laboratory

Recent developments from the cast 718Plus® Metals Affordability Initiative (MAI) program will be presented and discussed. The objective of the program is to investigate and enable the use of 718Plus® in the form of investment castings by (1) increasing the allowable operating temperature by about 75°F as compared with conventional cast Alloy 718 and (2) achieve approximately 25 percent cost savings as compared with cast Waspaloy. This program builds on the successful MAI program for wrought 718Plus. This technology will be implemented for the manufacture of gas turbine structural components including: combustor plenums, stator cases, diffuser cases, turbine cases, turbine frames, and other various high-strength/high-temperature structural castings. An overview of the results from the castability, weldability, and initial mechanical property investigations will be discussed. A preliminary cost benefit to aerospace components after implementation is predicted to be substantial. This recent work has warranted further investigation through the MAI program.

10:50 AM

The Behaviour of Primary Carbides in As-Cast Alloy 718 during Long-Time High-Temperature Heat Treatment: *Alec Mitchell*[1]; A. Akhtar[1]; D. Breband[1]; [1]University of British Columbia

In this work we present the results of a study on the carbide composition/size changes which result from long-time heat treatments at 1200C carried out on a typical as-cast ingot structure. The results demonstrate that the carbide size can be significantly changed by this treatment, but that there is also a strong possibility that solutioning reaction of the Laves phase component of the eutectic can lead to incipient melting and microporosity. The times required for changes which would be of significance in modifying the LCF behaviour are extremely long approaching 100h and are probably not practical for industrial application.

11:10 AM

Fatigue Behavior of Cast Nickel Alloys for Use in Advanced USC Shells: *Jeffrey Hawk*[1]; Paul Jablonski[1]; [1]U.S. Department of Energy

In order to reduce greenhouse gas emissions the efficiency of pulverized coal steam power plants must be increased. Raising the temperature (primarily) and pressure (to a lesser extent) are ways to do this, but to significantly increase efficiency, temperatures in excess of 700C are needed. Above 700C, wrought nickel alloys are needed for component parts. However, high-strength, creep-resistant and weldable cast nickel is not available. In order to address this issue, cast analogues of selected wrought nickel, e.g., 263, 282 and 105, have been produced. Tensile and creep properties for the cast material have been good. Fatigue behavior has not been investigated. This work explores the LCF behavior of these alloys to see if their performance is acceptable. The microstructure of the cast alloys will be discussed with respect to the wrought material and microstructural features that affect fatigue behavior will be identified.

Wrought Processing and Alloy Development

Monday PM — Room: Salon 4
October 11, 2010 — Location: Marriot Pittsburgh City Center

Session Chairs: Tony Banik, ATI Allvac; Ian Dempster, PCC-Wyman Gordon Forging

1:00 PM Introductory Comments

1:05 PM Invited
Effect of Process Modeling on Product Quality of Superalloy Forgings: *Martin Stockinger*[1]; Martin Riedler[1]; Daniel Huber[1]; [1]Bohler Schmiedetechnik GmbH & Co KG

Even so effects of forming, heating and cooling properties of superalloys like 718 are well understood, the influence of complex thermomechanical processes can not be described analytically. Thus the usage of simulation tools is a necessity in order to secure properties and stable processes. With increasing computer power and the development of FEM it is today possible to simulate these processes with high accuracy in sufficient time periods. Typical advantages like optimization of input-weight, guaranteed die filling as well as prevention of folding or overheating will be part of the paper. In addition the benefits of recent developments on residual stress simulation as well as microstructure and nanostructure models and their influences on mechanical properties will be discussed. Finally some simulation examples including process variations and their effects on the quality of parts will be compared with results of microstructure evaluation and mechanical testing of forgings.

1:30 PM
Influence of Both γ Distribution and Grain Size on the Tensile Properties of Udimet 720Li At Room Temperature: Jean-Roch Vaunois[1]; *Jonathan Cormier*[2]; Patrick Villechaise[2]; Alexandre Devaux[3]; Benjamin Flageolet[4]; [1]Aubert & Duval, Site des Ancizes; ENSMA/LMPM UMR CNRS 6617; [2]ENSMA/LMPM UMR CNRS 6617; [3]Aubert & Duval, Site des Ancizes; [4]Aubert & Duval, Site de Pamiers

The dependence of a forged Udimet 720Li alloy tensile properties to thermal treatments has been investigated. Various heat treatments combining a first step of high temperature solutioning followed by a two steps aging has been applied. The following parameters were studied: solution temperature (either sub/super-solvus), its cooling rate, temperatures and lengths of the aging treatments. All the microstructures were analyzed by SEM-FEG. A special attention was paid to the different γ' populations that were quantified by image analyses. The correlation between tensile properties (both yield stress and rupture strength) and γ' distributions will be discussed considering both the fine/coarse multimodal γ' intragranular precipitation and the small amount of primary γ' at grain boundaries preventing pronounced grain growth during solution treatment. SEM in-situ tensile experiments have been performed at room temperature to evaluate the respective contribution of intragranular/intergranular slips to the macroscopic plastic deformation.

1:50 PM
Properties of New C&W Superalloys for High Temperature Disk Applications: *Alexandre Devaux*[1]; Eric Georges[1]; Philippe Heritier[1]; [1]Aubert & Duval

The enhancement of efficiency in gas turbine engines requires the development of new superalloys capable of withstanding higher temperatures. The development of novel industrial cast and wrought (C&W) disk alloys with required combination of strength, creep and fatigue resistances at 700°C is particularly desired due to the expensive cost of powder metallurgy. The new nickel base superalloys developed by Aubert & Duval were therefore designed to fulfill these requirements. This paper presents the mechanical properties and the microstructural stability of these superalloys. The good workability and the chemistry confer to the alloys an attractive cost. Tensile, creep, fatigue and FGR tests show that the new alloys have high mechanical properties up to 700°C. Based on these results, it should be possible to extend performance capabilities, in terms of cost and mechanical properties, of most current C&W superalloys for turbine disks.

2:10 PM
Grain Boundary Engineering of Allvac 718Plus® for Aerospace Engine Applications: *Peter Lin*[1]; Virgil Provenzano[1]; Gino Palumbo[1]; Tim Gabb[2]; Jack Telesman[2]; [1]Integran Technologies USA Inc.; [2]NASA Glenn Research Center

Grain Boundary Engineering (GBE™) and GBE surface treatments are (GBEST™) patent- and trademark-protected thermo-mechanical processing technologies that are applicable to a broad range of metals and alloys. In this study, the main objective of the research and development program was to extend the applicability of the GBE processing technology to a more advanced superalloy, Allvac®718Plus®, which is a new derivative of Alloy 718. The specific technical objectives of this study were to: (1) develop and optimize GBE processing strategies for the bulk microstructure of the 718Plus® and (2) develop a processing methodology for locally optimizing the GBE microstructural characteristics at the near-surface region of the alloy. Grain boundary engineered microstructures were successfully produced in the 718Plus® alloy and the effect of GBE processing on the alloy mechanical properties at elevated temperatures will be summarized.

2:30 PM Break and Interactive Poster Session

2:50 PM

An Advanced Cast/Wrought Technology for GH720Li Alloy Disk from Fine Grain Ingot: Yuxin Zhao[1]; *Shuhong Fu*[1]; Shaowei Zhang[1]; Xin Tang[1]; Na Liu[1]; Guoqing Zhang[1]; [1]Beijing Institute of Aeronautical Materials

GH720Li(Udimet 720Li) is a highly alloyed superalloy and available in powder or wrought products. Usually, Udimet 720Li alloy converted from ingot to billet and disk is processed by hot extrusion and isothermal forging. However both large extrusion and isothermal forging equipments are currently not available in China. This paper demonstrates recent development of fine gain ingot casting technology. It is possible directly to convert GH720Li alloy ingot for billet. The fine grain ingot is sound and crack-free without segregation, typically with uniform ASTM 2~3 grain size. Hot ductility of fine grain ingot and the effect of deformation parameters and post heat treatment on γ' phase precipitation behavior and grain growth have been systematically studied. Based on these results, by means of near isothermal forging technology, trial pancake with ASTM 7 fine grain structure has been achieved, which demonstrates the possibility of GH720Li alloy disk to meet component requirement.

3:10 PM

Research on Inconel 718 Type Alloys with Improvement of Temperature Capability: *Shuhong Fu*[1]; Jianxin Dong[1]; Maicang Zhang[1]; Ning Wang; Xishan Xie[1]; [1]University of Science and Technology Beijing

Rapid development of aero-engines has led to stringent requirements for Inconel 718 type alloy to be used at 680~700ºC. Currently, China is developing this kind of modified 718 alloy without Co for domestic aviation industry. This paper concentrates to investigate the precipitation behavior of different phases, long time microstructure stability and mechanical properties of new 718 type modified alloy by adjustment of chemical composition for improvement of temperature capability. A new stable globular phase mainly precipitated at grain boundaries(temporarily named δ'' phase), different to δ phase in conventional 718 alloy, has been observed in modified 718 alloy. Furthermore, compact morphology precipitation of γ' and γ'' phase has been observed. After long time aging δ'' phase and compact morphology precipitation of γ' and γ'' phase characterize with superior thermal stability. Mechanical properties test results show the new modifed alloy can provide better stress-rupture life and fatigue resistance than conventional 718 alloy.

3:30 PM

FE Simulation of Microstructure Evolution during Ring Rolling Process of INCONEL Alloy 783: *Jong-Taek Yeom*[1]; Eun-Jeoung Jung[1]; Jeoung-Han Kim[1]; Jae-Keun Hong[1]; Nho-Kwang Park[1]; Kook-Joo Kim[2]; Jin-Mo Lee[2]; Seung-Sik Choi[2]; [1]Korea Institute of Materials Science; [2]Taewoong Co.

Microstructure evolution during ring rolling process of INCONEL alloy 783 was investigated with the combined approaches of 3-D FEM(Finite Element Method) simulation and microstructure prediction model. A microstructure prediction models was considered by recrystallization and grain growth behaviors varying with process variables. The model was established by the analyzed results of hot compression and isothermal heat treatment tests. Microstructure evolution during ring rolling process of INCONEL alloy 783 was calculated by de-coupled approach between FEM analysis and microstructure prediction model. The prediction results were compared with the experimental ones. Our proposed microstructure simulation module was useful for designing hot forming process of INCONEL alloy 783.

3:50 PM

Effect of Temperature and Strain during Forging on Subsequent Delta Phase Precipitation during Solution Annealing in ATI 718Plus® Alloy: *Erin McDevitt*[1]; [1]ATI Allvac

ATI 718Plus® alloy relies upon grain boundary precipitation of the delta phase in order to achieve good resistance to notch failure. Delta phase precipitation can occur when forging at subsolvus temperatures or during solution annealing heat treatment. Precipitation of delta phase during solution anneal heat treatment can be affected by the interaction of forging temperature and strain during hot working whereby the combination of high forging temperature and low strain can result in unsatisfactory delta phase precipitation. Additionally, delta phase precipitation can be affected by exposure to supersolvus temperatures after forging is complete. This paper describes the effect of thermal mechanical processing history on delta phase precipitation in 718Plus and provides guidance on best practices to achieve optimum mechanical properties.

4:10 PM

Modeling the Hot Forging of Nickel-Based Superalloys: IN718 and Alloy IN718Plus: *Esteban Marin*[1]; Douglas J. Bammann[2]; Arthur Brown[3]; Haitham El Kadiri[2]; R. Daniel Costley[4]; Paul T. Wang[2]; Mark F. Horstemeyer[2]; [1]Mississippi State University; [2]Center for Advanced Vehicular Systems, Mississippi State University; [3]Sandia National Laboratories; [4]Miltec Research and Technology

The work presents the use of an internal state variable material model to describe the rate-- and temperature--dependent large deformation response of the nickel-based superalloys Inconel 718 and Inconel 718 Plus. The current version of the material model describes the elastic-plastic and thermal deformation of metals, having two internal state variables whose evolution equations account for dislocation hardening and static/dynamic recovery processes. Other microstructural features such as recrystallization and grain growth are currently being added to the model. Experimental data from mechanical characterization tests of cylindrical and double conecompression specimens are used to both calibrate the material model and validate its predictive capability. In general, the calibrated model predicts well the experimental stress/load levels as well as the rate and temperature dependence of the mechanical response of these superalloys.

4:30 PM
Microstructure and Properties of Fine Grain IN718 Alloy Bar Products Produced by Continuous Rolling: *Guosheng Chen*[1]; Qingzeng Wang[1]; Fengjun Liu[1]; Zixing Wang[1]; Jianxin Dong[2]; Xishan Xie[2]; [1]Special Steel Business Unit, Baoshan Iron and Steel Co. Ltd.; [2]University of Science and Technology Beijing

The newly imported high-alloy steel continuous rolling line in Baoshan Iron and Steel Co. Ltd, which is the first production line in China, was introduced in this paper. The 14 ~ 55mm diameter bar hot-rolling procedure has been refined after studying the influences of processing parameters such as micro-structure of continuous rolling billet, rolling start temperature, continuous rolling deformation ratio, rolling line rate, and control cooling parameters on microstructure and properties of IN718 bars. In comparison with traditional open-train mill, this continuous rolling technology provides fine grain bar products with uniform grain structure and reasonable distribution of d phase. Grain size of bar products can be controlled at ASTM 10 in the center and ASTM 11 ~ 11.5 near the surface by means of this technology. Now this technology is in a stable production condition and the bar products produced provide excellent mechanical properties.

4:50 PM
Premium Quality Nickel Base Alloys Bars and Billets Produced by the Largest Rotary Forging Machine: *Arnold Tatschl*[1]; Michael Walter[1]; Michael Lohner[1]; [1]Bohler Edelstahl GmbH & Co KG

Production with the world largest radial forging machine, the RF100 from GFM with its maximum forging force of 2000t, started at Bohler Edelstahl at the beginning of 2009. Forging with varying stroke frequencies and rotation angles open technical possibilities to adjust the forging parameters for a thermo-mechanical process in such a manner which results in a well-worked core structure as well as an improved surface quality.The paper describes the processing of nickel base alloys ingots on the radial forging machine RF100 of Bohler Edelstahl GmbH and Co KG/Austria. The target was to produce large round bars and billets of Inconel 718, 625 and Waspaloy for aerospace and oil and gas applications. The achieved results regarding micro structure, yield and cost-efficiency are reported. Improvements associated with the new process technology and equipment design are compared with conventional production results on hydraulic presses.

Fabrication and Novel Production Technology and Development

Tuesday AM Room: Salon 4
October 12, 2010 Location: Marriot Pittsburgh City Center

Session Chairs: Göran Sjöberg, Volvo Aero Corporation Engines; Eric Ott, GE Aviation

8:00 AM Introductory Comments

8:05 AM Invited
An Overview of Ni Base Additive Fabrication Technologies for Aerospace Applications: *Chris English*[1]; Sudhir K. Tewari[1]; David H. Abbott[1]; [1]GE Aviation

The cost of aerospace components is often significantly increased due to the amount of material over and above the finished geometry that must be removed during manufacturing. This results in a substantial conversion cost needed to generate the final component. It is not uncommon to machine away 90% or more of the initial input shape, thereby increasing cost, cycle time and other overhead costs. Additive manufacturing includes an umbrella of technologies that can be used to dramatically reduce the BTF ratio, resulting in lower cost and manufacturing cycle time. An overview of additive manufacturing technologies and their fit into aero engine manufacturing will be presented. Advantages and disadvantages of the technologies will be discussed. Development work will be presented with commonly used Ni-base and Ti base aerospace materials. Cursory mechanical property results and cost modeling will be presented. Near-term equipment and process development needs will be addressed.

8:30 AM
Linear Friction Welding of Allvac® 718 Plus Superalloy: Krutika Vishwakarma[1]; O. Ojo[1]; Priti Wanjara[1]; *Mahesh Chaturvedi*[1]; [1]University of Manitoba

The newly developed Allvac® 718 Plus Superalloy was successfully joined by linear friction welding (LFW). However, contrary to the widely held view, it was found that LFW of Allvac® 718 Plus Superalloy is not necessarily a completely solid state joining process. Grain boundary liquation, liquation due to dissolution of delta phase and constitutional liquation of second phase particles, such as MC type carbides and Ti rich carbonitride particles, were observed in the thermo-mechanically affected zone (TMAZ) in the as-welded condition. Post weld heat treatment analysis further confirmed the presence of liquation during LFW. The development of microstructure both, during welding and that after the post weld heat treatment was studied through microstructural characterization of the base metal, TMAZ and the interface region by optical and analytical electron microscopy techniques. In this presentation details of the microstructural analysis will be presented, and implications of liquation will be discussed.

8:50 AM

Transient Liquid Phase Bonding of Newly Developed HAYNES 282 Superalloy: Adam Ghoneim[1]; *Olanrewaju Ojo*[1]; [1]University of Manitoba

A new gamma prime strengthened nickel based superalloy, HAYNES 282, with properties surpassing that of Waspaloy, has been developed for elevated temperature structural applications. Transient liquid phase (TLP) bonding is an attractive manufacturing and repair process for joining superalloys. A factor that can limit the commercial appeal of the technique is possible elongation of processing time, tf, required to produce reliable joint free of deleterious eutectic at high bonding temperatures. Application of finite element simulation shows that this can be caused by solubility decrease in the base alloy. Comparison of the results of TLP bonding of HAYNES 282 with those of other Mo-lean nickel based superalloys, like IN 738, shows that the prohibitive elongation of time tf is less pronounced in HAYNES 282, which could be related to solubility-enhanced formation of interface Mo-rich borides. Both the numerical analysis and experimental results of this study will be presented and discussed.

9:10 AM

Investigation of Homogenization and Its Influence on the Repair Welding of Cast Allvac 718Plus: *Joel Andersson*[1]; Göran Sjöberg[1]; Josefin Larsson[2]; [1]Volvo Aero Corporation/Chalmers University of Technology; [2]Chalmers University of Technology

Heat treatment experiments have been carried out to bring understanding to the efficacy of different temperatures and dwell times on the degree of homogenization of the cast Allvac 718Plus alloy which is prone to segregation mainly due to its high content of niobium. The effect of homogenization on weld repair was also examined. The homogenization heat treatment temperatures ranged from 1050°C to 1200°C with 1hr, 5 hrs and 10 hrs dwell times. The degree of homogenization was measured as the reduction of the amount of Laves phase by manual point counting in an optical microscope at high magnification. Longer range, interdendritic, patterns were established through line scan EDS analysis in SEM. It was found that short time (1hr) does not significantly reduce the amount of Laves phase whereas 5 hrs and 10hrs are much more efficient. Interdendritic homogenization does not occur to any measurable extent even at the highest temperature and longest dwell time (1200°C-10hrs) which was also reflected in bulk macro Vickers hardness tests. In the weld repair tests, one of the most homogenized material conditions (1125°C-5hrs +1200°C-10hrs) turned out to be the most prone to cracking while the number of weld cracks after a moderate homogenization heat treatment (1125°C-5hrs) was much smaller.

9:30 AM Break and Interactive Poster Session

10:00 AM Invited

Additively Manufactured INCONEL® Alloy 718: *Raymond Benn*[1]; Randy Salva[1]; [1]Pratt & Whitney

Significant contributions have been made in recent years to the development of Additive Manufacturing (AM) technology. Improvements in laser and electron beam-based AM equipment using powder injection, powder bed or wire feed systems have benefited from advances in software programs to convert complex CAD models into Digitally Manufactured parts. Wider acceptance of AM technology use in, for example the aerospace industry, is driven by meeting stringent quality, schedule and cost requirements. These factors, in addition to the specific property requirements and level of part-family complexity, strongly influence the selection of the appropriate Additive Manufacturing process. This presentation will briefly review some of the factors and criteria that must be addressed to transition an “AM opportunity” into a viable business case.

10:30 AM

Simulations of Temperatures, Residual Stresses, and Porosity Measurements in Spray Formed Super Alloys Tubes: *Reinhard Ristau*[1]; Andreas Becker[1]; Volker Uhlenwinkel[1]; Reinhold Kienzler[1]; [1]University of Bremen

Spray Forming is a technology to produce near net shapes parts. To calculate residual stresses during the different process steps (spray forming, heat treatment) a simulation tool for the temperature distribution is developed which incorporates all necessary sub steps (metal deposition on the substrate, heat transfer across the surface by conduction and radiation). The resulting temperature distribution is used as load to calculate the stresses during all process stages. Mainly at the interface substrate/deposit a region with elevated porosity is observed. Correlations based on porosity measurements and temperature simulations in conjunction with temperature measurements (thermocouples, pyrometer) will be given for the porosity as a function of temperature at the moment of decomposition. The effect of rolling on the porosity will be shown.

10:50 AM

Flowforming of a Nickel Based Superalloy: Shawn Rhodes[1]; *Juan Valencia*[1]; John Ryan[1]; Steven Stawarz[1]; Christopher Humiston[2]; [1]Concurrent Technologies Corporation; [2]Benet Laboratories

Flowforming is a relatively new metalworking technology that has been applied to successfully cold form Inconel. This forming process is ideally suited to take the place of the current forging and machining processes for tubular components. The large plastic deformations during flowforming have the benefit of refining the materials microstructure. In the present work, computer simulation, mechanical testing and materials characterization have been conducted to develop a failure/damage model to support the cold forming behavior of an Inconel alloy. Results have enabled the prediction of the conditions for material failure during flowforming operations. In addition, the numerical model also provides information as to the optimum preform and roller geometry, feed rate, and setup parameters in accordance with the desired product end state. The numerical process model in conjunction with proper characterization of the mechanical properties have been useful to substantially reduce the trial and error methods used in flowforming operations.

11:10 AM

Evaluation of Metal Injection Molded Alloy 718 for Aerospace Applications: Michael W. Peretti[1]; *Eric A. Ott*[1]; [1]GE Aviation

Because of its versatility and high temperature properties, Alloy 718 is used extensively in gas turbine engines and aerospace systems. Components are typically fabricated by both wrought processes, such as forging, and as castings to make complex shapes. When high-volume production of small parts is required, however, these processes sometimes result in high manufacturing cost. Metal injection molding (MIM) offers a route for low-cost fabrication of these items in Alloy 718. Used extensively in the automotive industry, consumer products, and medical devices, MIM has not been widely adopted as a manufacturing process of choice in the aerospace industry. One reason for this is the general lack of availability of mechanical property data and industry standards for MIM 718 material.

Alloy Applications and Characterization

Tuesday PM — Room: Salon 4
October 12, 2010 — Location: Marriot Pittsburgh City Center

Session Chairs: Jon Groh, GE Aviation; Xishan Xie, Science and Technology University of Beijing

1:00 PM Introductory Comments

1:05 PM Invited
Additive Manufacturing for Superalloys – Producibility and Cost: *James Moor*[1]; Andrew Debiccari[1]; Benjamin Lagow[2]; Sudhir Tewari[3]; Mary Kinsella[4]; [1]Pratt & Whitney; [2]Rolls Royce Corporation Indianapolis; [3]GE Aviation; [4]Air Force Research Laboratory

The primary goal of the MAI - Additive Manufacturing for Superalloys, Producibility and Cost Evaluation project, was to demonstrate the ability to fabricate nickel components using additive processes and to demonstrate the potential for cost and/or lead-time reductions of up to 50% in high-temperature static turbine engine components such as diffuser and turbine cases.

1:30 PM
Hot Ductility Study of HAYNES® 282® Superalloy: *Joel Andersson*[1]; Göran Sjöberg[1]; Mahesh Chaturvedi[2]; [1]Volvo Aero Corporation/Chalmers University of Technology; [2]University of Manitoba

The hot ductility of the newly developed Haynes 282 alloys has been investigated in different solution heat treatments conditions using the Gleeble weld thermal simulation method. The ultimate purpose of this study is to assess the feasibility of using this new alloy for the large aircraft engine structures. The strengthening response on cooling down from the solution heat treatment at different temperatures between 1121 and 1135°C with cooling rates of ~0.3°C/s was considerable (~100 HV increase compared with the as-received condition of HV215) and which may jeopardize weldability, not unexpectedly, in γ' hardening alloys. Initial hardness had no or minor influence on hot ductility. Still, the coarse grains achieved by a solution heat treatment heating at 1135°C-2hrs, ASTM 1 compared to initial ASTM 5 did lower the hot ductility.

1:50 PM
Effect of Nickel Content on Delta Solvus Temperature and Mechanical Properties of Alloy 718: *Richard Frank*[1]; Christopher Roberts[1]; Jingxian Zhang[1]; [1]Carpenter Technology Corp.

Knowledge and control of the delta phase solvus temperature is critical to optimize processing and heat treatment of 718 alloy for best mechanical properties. This is the case in aerospace applications where delta phase is used to produce fine grain structures during forging, and in oil field applications where the delta phase is dissolved during solution treatment. Delta phase solvus is primarily controlled by niobium content; however, niobium content in 718 alloy is tightly controlled by industry specifications, either directly or indirectly by the mechanical properties required. The effect of nickel content on delta phase solvus is not well understood as thermodynamic models and previous experiments have produced conflicting results. The purpose of this study was to confirm the effect of nickel content on delta solvus temperature using experimental heats and to document tensile and stress rupture properties. Trends will be compared with the results of modeling simulations.

2:10 PM
Numerical Simulation of the Simultaneous Precipitation of δ and γ' Phases in the Ni-Base Superalloy ATI Allvac®718 Plus™: *Rene Radis*[1]; Gerald Zickler[2]; Martin Stockinger[3]; Christof Sommitsch[4]; Ernst Kozeschnik[1]; [1]Vienna University of Technology; [2]Montanuniversität Leoben; [3]Böhler Schmiedetechnik GmbH and Co KG; [4]Graz University of Technology

The precipitation of delta (Ni3(Nb,Al)) and gamma' (Ni3(Al,Ti,Nb)) in nickel-base superalloys is crucial for the achievement of superior mechanical properties. Important microstructure parameters such as grain size are controlled by the existence of coarse delta precipitates, while the gamma' nano-precipitates are mainly responsible for strengthening. In this paper, the precipitation behavior of delta and gamma' phases in the novel nickel-base alloy ATI Allvac® 718PlusTM, as well as their kinetic interactions will be discussed. The evolution of the volume fraction of both phases is calculated at several different temperature levels using the thermo-kinetic software MatCalc and is compared to experimental data. Below the super-solvus temperature of gamma', the precipitation kinetics of delta is influenced by the previous nucleation and growth of gamma'. This leads to a delay in the precipitation kinetics of delta and a discontinuity in the C-curves of the time-temperature-precipitation (TTP) diagram, which is finally presented.

2:30 PM Break and Interactive Poster Session

2:50 PM Invited
Alloy 718 for Oilfield Applications: *John deBarbadillo*[1]; Sarwan Mannan[1]; [1]Special Metals Corporation

Alloy 718 was developed for use in the aircraft turbine engine, but its unique combination of room temperature strength and aqueous corrosion resistance make it ideal for oilfield bolting, shafting and drill tooling. Its popularity stemmed in part from its availability in many bar sizes from stockists. As well environments became more severe; stress corrosion failures in production equipment were experienced. This led to the evolution of the chemistry and microstructure specifications that distinguish today's oilfield grade

718 from aerospace grades. This paper reviews the development of the grade and its applications and describes some of its unique characteristics, testing and manufacturing methods. Consumption of 718 in the oilfield has probably reached its peak. Ever increasing requirements for strength and corrosion resistance have led to the introduction of new alloys that will begin to erode 718's market share. The last section of the paper describes these new alloys.

3:20 PM

Characterization of Microstructures Containing Abnormal Grain Growth Zones in Alloy 718: *Benjamin Flageolet*[1]; Oussama Yousfi[2]; Yoann Dahan[1]; Patrick Villechaise[3]; Jonathan Cormier[3]; [1]Aubert & Duval Pamiers; [2]Simap; [3]LMPM-ENSMA - UMR CNRS 6617

A well known issue encountered by forgers transforming 718 alloy consists in the apparition of coarse grain zones during the thermo-mechanical process. Although some industrial solutions have been implemented in order to get rid of this type of microstructural defect, the consequences of the presence of such coarse grain zones on the material's mechanical properties are of great interest. In this work, the microstructure of some zones that have undergone abnormal grain growth (AGG) have been first characterized by means of both optical and EBSD observations. A special attention was paid to grain orientation grain boundaries and grain size distributions. In a second time the consequences of these microstructures on 350°C deformation controlled fatigue crack initiation mechanisms and the subsequent lifetime have been assessed. The effects of AGG on 350°C tensile properties have also been evaluated. The results will be discussed with regard of microstructure/mechanical behavior relationships.

3:40 PM

Haynes 282 for Advanced USC Power Plant Components: *Jeffrey Hawk*[1]; Deepak Saha[2]; Robin Schwant[2]; [1]U.S. Department of Energy; [2]GE Energy

Haynes 282 is a relatively new high-strength, high-temperature nickel alloy that is being investigated as a potential construction material for the rotor and other thick section components in advanced ultra-supercritical (A-USC) power plants. Features that make Haynes 282 attractive for use as high-temperature, thick-section components include low gamma prime volume fraction, sluggish precipitation kinetics and good high temperature creep strength at temperature up to and exceeding 760C. Mechanical behavior will be discussed in general terms with respect to tensile strength and creep capability. The basic features of the alloy will be discussed as they pertain to phase formation during primary heat treatment and at 760C, and the long-term, elevated temperature microstructural stability at 760C. Creep deformation mechanisms will be discussed and the potential of using 282 in A-USC applications will be explored.

4:00 PM

A TEM Study of Creep Deformation Mechanisms in Allvac 718 Plus: Raymond Unocic[1]; *Kinga Unocic*[1]; Robert Hayes[2]; Glenn Daehn[3]; Michael Mills[3]; [1]Oak Ridge National Laboratory; [2]Metals Technology, Inc.; [3]The Ohio State University

A preliminary investigation into the creep deformation substructure in Ni-base superalloy Allvac 718Plus has been evaluated using diffraction contrast TEM characterization techniques for specimens crept at 517 and 620MPa and at temperatures ranging from 690-732ºC. Highly planar deformation modes tend to exist in all of the test conditions where shearing of the γ' precipitates occurred via the motion of partial dislocations along well-defined {111} slip planes. Additional deformation modes were present at 690 and 704ºC where dislocation cross slip activity of matrix dislocations on different {111} glide planes were observed. There is also evidence of microtwinning at the highest creep temperature which are created by identical a/6<112> Shockley partial dislocation that shear the γ matrix and γ' precipitates on consecutive close packed {111} glide planes. This talk will address the role of microstructure, stress, and temperature on the operative creep deformation mechanisms as well as the effect of grain boundary δ phase and Σ3 recrystallized grain boundaries on grain-to-grain dislocation slip transfer.

4:20 PM

Effects of Al and Ti on Haynes 282 with Fixed Gamma Prime Content: *Paul Jablonski*[1]; Christopher Cowen[1]; Jeffery Hawk[1]; [1]US Department of Energy

Traditionally, high temperature components within coal fired power plants are manufactured from ferritic/martensitic steels. However, the proposed steam temperature in the Advanced Ultra Supercritical (A-USC) power plant is high enough (760C) that ferritic/martensitic steels will not work due to temperature limitations of this class of materials; thus Ni-based superalloys are being considered. The life cycle requirements of such alloys are very demanding and are on the order of several hundred thousand hours. In this presentation we will explore a wrought Ni-based superalloy with a fixed amount of gamma prime strengthening phase, and either low Al or Ti (within the alloy specification). The effect that these changes have on the gamma prime misfit and its relevance to long term microstructural and creep strength stability will be explored both experimentally as well as with computational thermodynamics.

4:40 PM

Time-Temperature-Transformation Diagram of Alloy 945: *Sarwan Mannan*[1]; [1]Special Metals Corporation

INCOLOY® alloy 945 of nominal composition Fe-47Ni-20.5Cr-3Mo-3Nb-2Cu-1.5Ti is a newly developed high strength, corrosion resistant, precipitation strengthened superalloy designed for oil and gas applications. The alloy is NACE-ISO approved to the highest defined corrosion level. Alloy 945 is being qualified and specified by a number of O&G industries for wellheads and downhole completion/production equipments. Commercially produced alloy 945 was annealed and heat-treated in the temperature range of 650°C to 1038°C for the times of 15 minutes to 100 hours. Heat-treated specimens were tested for microstructure and hardness. Analytical analysis included optical microscopy, scanning electron microscopy, transmission electron microscopy and electrolytic extraction coupled energy dispersive x-ray analysis. Data generated from these analytical techniques is presented in the form of a time-temperature-transformation diagram.

5:00 PM
Long Term Thermal Exposure of HAYNES 282 Alloy: *Lee Pike*[1]; [1]Haynes International

HAYNES® 282® alloy was recently introduced for applications in both aero and land-based gas turbine engines. While possessing excellent high temperature strength and LCF resistance, the alloy was designed to ensure adequate fabricability. The new alloy is readily hot and cold worked and has superior weldability relative to other alloys in its class. A key attribute of 282 alloy is the excellent stability of its microstructure upon long term thermal exposure. As a result, the alloy is not prone to severe embrittlement as are certain other alloys in its class. The stability of the alloy is also believed to contribute to the high temperature strength of the alloy over long exposure periods. In this paper, the effects of thermal exposures at 1200, 1400, and 1600°F of up to 16,000 hours on the microstructure and properties of 282 alloy will be presented.

Microstructure, Properties, and Characterization

Wednesday AM — Room: Salon 4
October 13, 2010 — Location: Marriot Pittsburgh City Center

Session Chairs: Agnieszka Wusatowska-Sarnek, Pratt & Whitney; Timothy Gabb, NASA Glenn Research Center

8:00 AM Introductory Comments

8:05 AM Invited
Modeling and Simulation of Alloy 718 Microstructure and Mechanical Properties: *David Furrer*[1]; Robert Goetz[1]; Gangshu Shen[1]; [1]Rolls-Royce

Alloy 718 is a unique superalloy that has been in use for a number of years. It also has the distinction to be utilized throughout the aerospace and general industrial communities. The applications of this material are often very unique and require tailoring the microstructure and subsequently the mechanical properties to meet these specific needs. To support optimization of Alloy 718 mechanical properties and performance, considerable work has been conducted by the materials community to develop materials and manufacturing process models to aid in the simulation and prediction of the microstructure and mechanical properties of components produced from this alloy. This paper will review various modeling and simulation tools and applications to Alloy 718. This complex alloy is continuing to see optimization efforts through the use of modeling and simulation to support new and enhanced application requirements for this ubiquitous alloy.

8:30 AM
Overview on 718Plus Assessment within VITAL R&D Project: *Oscar Caballero Ruiz*[1]; Göran Sjoberg[2]; Tomas Gomez-Acebo[3]; [1]ITP; [2]Volvo Aero Corporation; [3]CEIT

Alloy Allvac 718Plus has been strongly pushed into the market by its inventor, Dr Cao, and producer company, Allvac. The new alloy claims to offer better mechanical properties at those temperatures where In718 has already exhausted its applicability, in the 650ºC range. Allvac 718Plus also assures that it holds improved metallurgical stability at even higher temperatures, up to 700ºC. In this upper range, no degradation of mechanical properties is said to happen noticed in the new alloy. A European R&D project named VITAL dedicated part of its efforts to assess these claims and verify the improvements. Castability and Forgeability assessments where completed, together with trials on weldability of the alloy. Mechanical tests and microstructural assessments on both alloys, 718 and 718Plus, in both materials forms, cast and wrought, and two different material conditions, as-heat treated and exposed to service temperatures, were completed and direct comparisons then established.

8:50 AM
Hold-Time Fatigue Crack Growth of Allvac 718Plus: Magnus Hörnqvist[1]; Leif Viskari[2]; Krystyna Stiller[2]; *Göran Sjöberg*[1]; [1]Volvo Aero Corporation; [2]Chalmers University of Technology

The hold-time fatigue behaviour of Allvac 718Plus was investigated both in the as-heat treated condition and after long-time exposure at temperature close to the maximum operating limit. The results show that at temperatures above 450°C the introduction of 90 s hold-time at maximum load significantly increased the fatigue crack growth rate. Both conditions show purely cycle dependent behavior at 450°C and close to purely time dependent behavior at 700°C. At 600°C intermediate behavior was observed. The long-time exposure had little effect on the cyclic (0.5 Hz) crack growth rates, but the resistance to crack growth with 90 s hold-time decreased. No microstructural effects of long-time exposure (700°C/140 h + 675°C/460 h) could be observed by SEM, but there were indications that the hardness of the material increases somewhat after exposure.

9:10 AM
Influence of Microstructural Characteristics on the Fatigue Life Variability at 450°C of IN 718 Direct Aged Alloy: Nicolas Fargues[1]; Ana Casanova[1]; *Patrick Villechaise*[2]; Jonathan Cormier[2]; Magali Jestin[3]; Julien Thébault[3]; Jean-Michel Franchet[3]; [1]Snecma SAFRAN Group - and - Institut Pprime - UPR CNRS 3346 - ENSMA; [2]Institut Pprime - UPR CNRS 3346 - ENSMA; [3]Snecma SAFRAN Group

The study deals with the fatigue durability at 450°C under total strain control ($R_\varepsilon = 0$) of a forged IN 718 direct aged alloy. A great variability of the fatigue life appears with some specimens exhibiting a life debit of at least one decade. The paper investigates the origin of this detrimental effect focusing on microstructural characteristics. Both the grain size, carbide and δ phase distributions were analyzed. For the δ precipitation, EBSD maps in a SEM-FEG were performed with a high spatial resolution. This approach permits to propose an indirect estimation of the γ'' volume fraction assuming a constant volume fraction of (δ+γ'') precipitation. The correlation between short/high fatigue lives and the fraction and size of the different microstructural elements will be discussed. A special attention will be paid on the δ/γ'' balance.

9:30 AM Break and Interactive Poster Session

10:00 AM Invited
Atomic-Level Characterization of Grain-Boundary Segregation and Elemental Site-Location in Ni-Base Superalloy by Aberration-Corrected Scanning Transmission Electron Microscopy: *Masashi Watanabe*[1]; [1]Lehigh University

Recent improvements in aberration correction have brought tremendous advantages not only in high resolution imaging but also in high resolution analysis by electron energy-loss spectrometry (EELS) and X-ray energy-dispersive spectrometry (XEDS) in a scanning transmission electron microscope (STEM). In this study, two aberration-corrected STEMs (namely a JEOL JEM-2200FS and the VG HB 603) were applied to the characterization of a Ni-base superalloy, which contains L12-ordered gamma' precipitates in a gamma matrix. With the improved spatial resolution and analytical sensitivity, Zr and Nb co-segregation was found first time at grain boundaries in composition levels below 1.0 wt %. In addition, it is possible to analyze materials in the atomic resolution. By EELS analysis on the gamma' phase, the Ti signal is mainly localized at the Al site not at the Ni site, which confirms that Ti atoms occupy preferentially the Al-site by the atomic scale analysis.

10:30 AM
An Integrated Approach to Relate Hot Forging Process Controlled Microstructure of IN718 Aerospace Components to Fatigue Life: *Michael Stoschka*[1]; Martin Riedler[2]; Martin Stockinger[2]; Hermann Maderbacher[1]; Wilfried Eichlseder[1]; [1]University of Leoben; [2]Böhler Schmiedetechnik GmbH

The goal of relating a local fatigue life approach with different microstructures enforces the consideration of the main forging process dependent influence factors and their effect on grain size, shape, contiguity a.o. The new developed microstructural based energy approach allows an alternative description of the microstructure and grain shape texture. First, the microstructural energy parameter e correlates to the ASTM grain size. Second, the factor of heterogeneity b characterizes the persistence and amount of both bimodal microstructure and as-large-as grains in a unique manner. Based on these two new microstructural parameters, a link to local fatigue parameters can be established. The microstructural evolution can be assessed during forging process simulation using the model introduced by Stockinger et.al. The new parameters e and b support the link between forging simulation and local fatigue. This enables the lifetime assessment of local forging process at design stage using advanced forging simulation tools.

10:50 AM
Systematic Evaluation of Microstructural Effects on the Mechanical Properties of ATI 718Plus® Alloy: *Rick Kearsey*[1]; Jonathan Tsang[1]; Peter Au[1]; Scott Oppenheimer[2]; Erin McDevitt[2]; [1]National Research Council of Canada; [2]ATI Allvac, an Allegheny Technologies Company

Four microstructural variants of ATI 718Plus® alloy are produced via modified heat treatments to elucidate the effects of grain size, precipitate size, morphology, and phase fraction (δ and γ'), on the advanced mechanical properties of low cycle fatigue (LCF) strength, fatigue crack growth rate (FCGR) properties, and creep-fatigue crack growth rate (CFCGR) behaviour at both 650ºC and 704ºC under 100s dwell and no dwell conditions. Similar testing is also performed on Waspaloy in two comparative microstructural conditions. FCGR results show that at both test temperatures, all microstructural conditions of 718Plus® and Waspaloy exhibit identical behavior in the steady state regime, except that 718Plus® exhibits a much higher threshold stress intensity. CFCGR results show that Waspaloy displays better steady state crack growth resistance under dwell conditions, however; precipitate optimization of 718Plus® shows considerable improvement. LCF test results demonstrate that all four microstructural conditions of 718Plus® have superior life compared to Waspaloy under all test conditions.

11:10 AM
Grain Boundary Engineering the Mechanical Properties of Allvac 718Plus® Superalloy: *Tim Gabb*[1]; Jack Telesman[1]; A. Garg[2]; Peter Lin[3]; Virgil Provenzano[3]; Robert Heard[3]; H. M. Miller[3]; [1]NASA Glenn Research Center; [2]University of Toledo; [3]Integran Technologies USA Inc.

Grain Boundary Engineering (GBE™) can enhance the population of structurally-ordered "low Σ" Coincidence Site Lattice (CSL) grain boundaries in the microstructure. In some alloys, these "special" grain boundaries have been reported to improve overall resistance to corrosion, oxidation, and creep resistance. Such improvements could be quite beneficial for superalloys, especially in conditions which encourage damage and cracking at grain boundaries. Therefore, the effects of GBE processing on high-temperature mechanical properties of the cast and wrought superalloy Allvac 718Plus™ were screened. Bar sections were subjected to varied GBE processing, and then consistently heat treated, machined, and tested at 650°C. Creep, tensile stress relaxation, and dwell fatigue crack growth tests were performed. The influences of GBE processing on microstructure, mechanical properties, and associated failure modes are discussed.

11:30 AM
Structure-Property Relationships in Waspaloy via Small Angle Scattering and Electrical Resistivity Measurements: *Ricky Whelchel*[1]; Rosario Gerhardt[1]; Ken Littrell[2]; [1]Georgia Institute of Technology; [2]Oak Ridge National Laboratory

The mechanical properties in superalloys are controlled by the distribution of the γ' precipitate phase. Electrical measurements have been shown to be sensitive to certain aspects of the precipitation process and show promise for predicting the evolving microstructural state in superalloys. Aging experiments were conducted on Waspaloy samples for temperatures between 600 and 950°C for times ranging from 2min to 500h. Particle size distributions were obtained by modeling of small angle scattering (SAS) data, whereas, small precipitate size information, strain, and lattice mismatch data were obtained from X-ray diffraction. The microstructural information was then used to create a figure of merit of electron scattering intended to correlate electrical properties to the precipitate microstructure. The proposed figure of merit shows an empirical correlation with the electrical resistivity data, demonstrating the sensitivity of the resistivity measurements to the precipitation process and coarsening behavior.

Micro-Characterization, Corrosion, and Environmental Affects

Wednesday PM Room: Salon 4
October 13, 2010 Location: Marriot Pittsburgh City Center

Session Chairs: Xingbo Liu, University of West Virginia; Agnieszka Wusatowska-Sarnek, Pratt Whitney

1:00 PM Introductory Comments

1:05 PM Invited
Oxidation of Superalloys in Extreme Environments: *Bruce Pint*[1]; Sebastien Dryepondt[1]; Kinga Unocic[1]; [1]Oak Ridge National Laboratory

Superalloys like 718 and its derivatives primarily rely on the formation of an external Cr-rich oxide layer or scale for environmental protection at high temperatures. Operating conditions where environmental resistance is more of a concern generally involve higher temperatures or more corrosive environments, especially where S is present, usually due to fuel impurities. With clean fuels, the presence of water vapor and oxygen, such as a combustion environment in a natural gas-fired turbine, chromia forms a volatile oxy-hydroxide leading to accelerated Cr loss. In laboratory experiments, mass losses are measured due to this volatilization. For sulfidizing or hot corrosion environments, the role of alloy and coating composition on corrosion resistance will be reviewed. An increasing area of interest is the interaction between environmental degradation and the stress-induced deformation of the superalloy including the influence of oxidation-resistant coatings on mechanical properties. Strategies to study this interaction will be discussed.

1:30 PM
Microstructure Evolution in the Nickel Base Superalloy Allvac 718Plus: *Katja Loehnert*[1]; Florian Pyczak[2]; [1]Rolls-Royce Deutschland Ltd&Co KG; [2]GKSS Research Centre Geesthacht GmbH

Electron microscopy and especially transmission electron microscopy (TEM) was used to characterise the microstructure changes in Allvac718Plus. The two major phases were found to be γ'- and δ-phase. By analysing selected area diffraction patterns from a large number of particles it could be shown that nearly no γ''-phase is present in Allvac718Plus. Emphasis was put on the development of γ'- and δ-phase during typical heat treatment steps performed during processing. Here particle growth, phase volume fractions as well as their crystallographic relationship and chemical composition were monitored using imaging, diffraction and energy dispersive spectroscopy in TEM. The interfaces between δ- and surrounding γ/γ'-phase were investigated using high resolution TEM. The interfaces are flat and parallel to the {111} plane of γ/γ'-phase and the (010) plane of δ-phase. By investigation of aged and crept specimens it was determined how stable the microstructure established during processing is under typical service conditions.

1:50 PM
Effect of the LCF Loading Cycle Characteristics on the Fatigue Life of Inconel 718 at High Temperature: *Fabio Taina*[1]; Marco Pasqualon[2]; Denis Delagnes[1]; Vincent Velay[1]; Philippe Lours[1]; [1]Université de Toulouse, Institut Clément Ader, Ecole des Mines Albi; [2]Norsk Hydro ASA

A series of both stress-controlled and strain-controlled low cycle fatigue tests are conducted on alloy IN718 to investigate the impact of various parameters on the behaviour of the material. Namely, focus is placed on the influence of major parameters such as the cycle frequency, the strain/stress rate, the holding time at various stress levels, the stress relaxation and the fatigue stress ratio. A detailed characterisation of the fatigue-induced rupture surfaces is performed to analyse the role of the alloy microstructure on the mode of crack propagation. In order to account for the time dependent effect of the mechanical response of the alloy, the Portevin-Le Châtelier effect and oxidation behaviour of the material are discussed. Results are analysed, in terms of Manson-Coffin plots, to discriminate the relative impact of the various tested parameters on the stress/strain response and the fatigue life of the material.

2:10 PM
Machining Conditions Impact on the Fatigue Life of Waspaloy – Impact of Grain Size: *Nihad Ben Salah*[1]; Serafettin Engin[1]; [1]Pratt & Whitney Canada

Several machining processes are used for the production of engine components. More specifically, broaching is used to achieve complicated geometry. Nickel-based superalloys are very sensitive to microstructure distortions during machining. Even though the impact of this distortion on the mechanical properties of the components is not fully understood, it is expected that their fatigue life, which strongly depends on surface properties, may be reduced. The present work demonstrates that aggressive machining does not always adversely affect the fatigue life of Waspaloy. The impact of the broaching tool geometry and wear on the surface microstructure was characterized as well as its effect on the notched LCF properties at high temperature (1100°F). SEM observations of crack surfaces and near-surface microstructure characterization were supplemented with nanohardness measurements to assess the impact of microstructure changes on the fatigue life.

2:30 PM Break and Interactive Poster Session

2:50 PM Invited

Oil-Grade Alloy 718 in Oil Field Drilling Applications: Jing Xu[1]; *Hendrik John*[1]; Gabriela Wiese[1]; Xingbo Liu[2]; [1]Baker Hughes Inc.; [2]West Virginia University

Due to continuous advancements of drilling technology, the materials have to fulfill higher demands of mechanical properties and corrosion resistance. The complex working loads and high vibration, the hostile downhole environments, together with the high working temperature and pressure when operating in ultra deep drilling, keep challenging the drilling tool materials. This paper focuses on the performance of oil-grade alloy 718 for applications in bottom hole assemblies (BHA's) under drilling conditions. Two experimental methods, namely potentiodynamic polarization and weight change, were applied to investigate the general corrosion and pitting attack. Key influencing factors were discussed including working temperature, cation species in corrosive medium, and post-mortem heat treatment. These results will help to direct the optimization strategy of Ni-base superalloys in oil field drilling.

3:20 PM

On the Influence of Temperature on Hydrogen Embrittlement Susceptibility of Alloy 718: *Florian Galliano*[1]; Benoit Ter Ovanessian[1]; Eric Andrieu[1]; Jean-Marc Cloué[2]; Christine Baret-Blanc[1]; Gregory Odemer[1]; [1]Cirimat Ensiacet; [2]Areva Np

Hydrogen is susceptible to step in mechanisms of stress corrosion cracking and hydrogen embrittlement of alloy 718 component structure elements of fuel assemblies in Pressurized Water Reactors, during service at temperature from 80°C to 340°C. In order to study hydrogen embrittlement susceptibility of alloy 718, samples have been firstly cathodically hydrogen charged in molten salts (NaHSO4, 46.5% wt. – KHSO4, 53.5% wt.) at 150°C. After charging, tensile tests were carried out at 80°C, 150°C and 300°C for a constant strain rate of 5.10-5s-1. Quantification of hydrogen embrittlement was performed by the analysis of rupture modes and loss of mechanical properties like elongation to failure as a function of hydrogen content. Rupture mode identification and tensile tests results evidence a maximal susceptibility to hydrogen embrittlement at 80°C whereas hydrogen activity is not noticeable at 300°C. From these results the evolution of interactions between hydrogen and dislocations with temperature is discussed.

3:40 PM

Cast Alloys for Advanced Ultra Supercritical Steam Turbines: *Gordon Holcomb*[1]; Paul Jablonski[1]; Ping Wang[1]; [1]National Energy Technology Laboratory

The proposed steam inlet temperature in the Advanced Ultra Supercritical (A-USC) steam turbine is high enough (760°C) that traditional turbine casing and valve body materials such as ferritic/martensitic steels will not suffice due to temperature limitations of this class of materials. Cast versions of seven traditionally wrought Ni-based superalloys are evaluated for use as casing or valve components for the next generation of industrial steam turbines. The full size castings substantial: 2-5,000 kg each half and on the order of 100 cm thick. Experimental castings were quite a bit smaller, but section size was retained and cooling rate controlled to produce equivalent microstructures. A multi-step homogenization heat treatment was developed to better deploy the alloy constituents. These castings were subsequently evaluated by characterizing their microstructure as well as their steam oxidation resistance (at 760 and 800°C).

4:00 PM

Effect of Phosphorus on Microstructure and Mechanical Properties of IN718 Alloy after Hot Corrosion and Oxidation: *Z. Q. Hu*[1]; X.M. Lou[1]; W.R. Sun[1]; L. X. Yu[1]; S. L. Yang[1]; W.H. Zhang[1]; [1]Institute of Metal Research, Chinese Academy of Sciences

In this paper, the IN718 alloys added with various phosphorus concentration underwent hot corrosion in the mixed salt of 75%Na_2SO_4 and 25%NaCl at 650°C and oxidation in air at 650°C, and then the microstructure and properties of the alloys were characterized. No differences were found of the tensile properties of IN718 alloy after soaking at 100h in air and in mixed salt. However, phosphorus exhibits an effect to inhibit the ingression of sulfur along the grain boundaries. The thermal exposure in air at 650°C makes no differences on the tensile properties, but reduces the total term of the primary and secondary creep stages of IN718 alloy, while the alloy added with 0.019% phosphorus exhibits the same creep curves with and without thermal exposure. The interaction mechanism between phosphorus and hot corrosion and oxidation is discussed briefly in the paper.

4:20 PM

Effect of Microstucture and Environment on the High-Temperature Oxidation Behavior of Alloy 718PLUS: *Kinga Unocic*[1]; Raymond R. Unocic[1]; Bruce A. Pint[1]; Robert W. Hayes[2]; [1]Oak Ridge National Laboratory; [2]Metals Technology Inc.

The effect of microstructure and composition on the oxidation behavior of 718 and 718Plus is being evaluated. To study the role of alloy composition, the high temperature oxidation behavior of alloys 718 and 718Plus were compared in various oxidizing (steam, dry air and wet air) environments at 650°C-800°C. Advanced characterization techniques (including analytical transmission electron microscopy) were used to compare the differences in the oxide scale formed on these alloys. To examine the role of microstructure, the stress rupture behavior of 718Plus was evaluated with a recrystallized and a worked microstructure. The recrystallized specimen was susceptible to brittle cracking (i.e. gas phase embrittlement) in a wet air environment performed at 704°C and 620 MPa. Without recrystallization, an increase in tensile elongation was observed under the same conditions. The oxide formed in dry and wet air was characterized for both alloy microstructures to develop a better mechanistic understanding.

Poster Session, in Parallel with Oral Sessions

Mon-Wed PM — Room: Salon 2&3
October 11-13, 2010 — Location: Marriot Pittsburgh City Center

Session Chairs: Jon Groh, GE Aviation; Anthony Banik, ATI Allvac/Allegheny Technologies

01 - Quantitative Characterization of Two-Stage Homogenization Treatment of Alloy 718: *Zhujun Miao*[1]; Aidang Shan[1]; Wei Wang[2]; Jun Lu[3]; Wenliang Xu[3]; Hongwei Song[3]; [1]Shanghai Jiao Tong University; [2]East China University of Science and Technology; [3]Baoshan Iron and Steel Co., Ltd.

The severe segregation of Nb in Alloy 718 superalloy will increase the difficulty in the subsequent homogenization treatment. In this study, segregation behavior of ϕ406 mm Alloy 718 ingot is investigated and two-stage homogenization treatment is employed to relieve the micro-segregation between dendrite structures. In the first stage homogenization, the Laves phase elimination percentage was expressed dependence of two parameters (time and temperature). In order to characterize the effects of second stage homogenization, a 900°C/1 h treatment is conducted after homogenization, which can form δ phase (Nb-riched) to trace the diffusion of Nb. It is found that average composition of δ phase area, quantity of δ phase precipitation and size, shape of δ phase precipitation will change with the proceeding of homogenization. As a result, homogenous structure can be achieved by means of two-stage homogenization treatment (1140°C/60 h + 1190°C/30 h).

02 - Selection of Heat Treatment Parameters for a Cast Allvac 718Plus Alloy: *Oscar Caballero Ruiz*[1]; Kepa Celaya[1]; Tomás Gómez-Acebo[2]; Antonio Julio Lopez Julio Lopez[2]; [1]ITP, Industria de Turbo Propulsores, S.A.; [2]CEIT Centro de Estudios e Investigaciones Técnicas

The selection of heat treating parameters for a cast Allvac 718Plus alloy is presented in this paper. The interest from aeroengine manufacturers in this alloy has driven its development also in the direction of making available a cast form of it. A first step was to use the available material (originally intended to be used in forged parts) as remelting stock for producing a couple of cast rings and use them as test material for assessment of different sets of heat treatment parameters. In particular, the application of homogenisation before HIP and the solution temperature after HIP are discussed. Use of hardness measurements and optical microscopy was made to help in the assessment of the effect of the homogenisation cycle, and also the effect of the different solution temperatures. Other techniques such as Scanning Electron Microscrope and X-Ray Difracction were tried for identification and quantification of hardening phases.

03 - Application of Confocal Scanning Laser Microscope in Studying Solidification Behavior of Alloy 718: *Hongwei Song*[1]; Zhujun Miao[2]; Aidang Shan[2]; Wenliang Xu[1]; Jun Lu[1]; [1]Baosteel Research Institute, Baoshan Iron & Steel Co., Ltd.; [2]Shanghai Jiao Tong University

Although Alloy 718 has a very long history, it is still used extensively, which accounts for more than 45% of commercial superalloy productions in the world. The reason is that Alloy 718 has a combined properties for good strength, excellent weldability and last, but most important, reasonable cost. Recently, Confocal Scanning Laser Microscope (CSLM) offers a convenient possibility of real-time and continuous observation of phase transformation at high temperatures. And several studies using CSLM have been reported involving low carbon steel, stainless steel and metallic glass. So, the aim of this paper is to study the solidification behavior of Alloy 718 using confocal scanning laser microscope. In addition to in-situ observation of solidification at different cooling rates, analysis of microstructures evolution is conducted by scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS). In summary, the confocal scanning laser microscope shows great potential for the solidification behavior research in superalloys.

04 - Effect of Compound Jacketing Rolling on Microstructure and Mechanical Properties of Superalloy GH4720Li: *Jinglong Qu*[1]; Minqing Wang[1]; Jianxin Dong[2]; Guilin Wu[3]; Ji Zhang[1]; [1]Central Iron and Steel Research Institute; [2]University of Science and Technology Beijing; [3]Northeast Special Steel Group Co., Ltd.

In this paper, a compound jacketed rolling technique for superalloy GH4720Li is experimentally investigated. The results show that microstructure of GH4720Li is susceptible to hot working parameters. When rolling temperature is about 1130ºC, a fine-grained microstructure, excellent mechanical properties and high yield strength can be obtained. In addition, the rolling temperature can be controlled effectively, friction force between ingot and roller can be reduced, surface cracking induced by rolling can be avoided, and uniform microstructure can be obtained using compound jacketing. When accumulative strain of rolling is greater than 65%, the coarse columnar dendritic microstructure can be refined completely and grain size of ASTM 8 obtained. After heat treatment, GH4720Li bars exhibit excellent mechanical properties.

05 - Manufacture and Property Evaluation of Super Alloy 44Ni-14Cr-1.8Nb-1.7Ti-1.5Mo-0.3V-Fe (Modified 706) – An Experience: *Gururaja Uppur*[1]; Pallab[1]; Myneni Rao[1]; [1]Midhani

The alloy 44Ni-14Cr-2.6Nb-1.7Ti-1.5Mo-0.3V-Fe is derived from the family of super alloys 706 and 718 compositions. It is a precipitation hardenable alloy with its primary constituents consisting of Niobium and Titanium. A balanced content of Nickel, Chromium and Aluminium in alloy 706 provides good hardenability and resistance against oxidation and corrosion. Further modified 706 with Molybdenum and Vanadium improve its high temperature capabilities. Modified 706 displays excellent mechanical properties in combination with good fabricability compared to structurally complex 718. This alloy finds application in aerospace field requiring high strength and ease of fabrication. The present paper describes the manufacturing practice adopted and presents mechanical properties evaluated on various products.

06 - Toughness as a Function of Thermo-Mechanical Processing and Heat Treatment in 718Plus® Superalloy: *Scott Oppenheimer*[1]; Erin McDevitt[1]; Wei-Di Cao[1]; [1]ATI Allvac

ATI 718Plus® is a new cost-effective alloy which fills the gap in temperature capability between 718 and Waspaloy. The effect of thermal mechanical processing and heat treatment on the room temperature fracture toughness and impact toughness of ATI 718Plus® has been evaluated. Fractography, microscopy and tensile testing were used to determine the microstrucutral features associated with high toughness. Impact toughness was measured with Charpy V-notch samples, while fracture toughness was determined using three point bend samples. The observed toughness was comparable to 718. Grain boundary delta phase was found to have the most significant influence on toughness where its presence had a net negative affect.

07 - The Microstructure and Mechanical Properties of Inconel 718 Fine Grain Ring Forging: *Zixing Wang*[1]; Dianhua Zhou[1]; Qun Deng[2]; Guosheng Chen[1]; Wei Xie[1]; [1]BaoShan Iron and Steel Co., Ltd; [2]High Temperature Materials Research Institute, Central Iron and Steel Research Institute

The microstructure and mechanical properties of fine-grained Inconel 718 ring forging were investigated in this paper. The results indicated that the fine-grained ring forgings can be obtained by forging the fine-grained Inconel 718 bars. The grain size can be as fine as ASTM 10 and the precipitated d phase are spherical. Heat treated at 980°C/1h/water cooling + 620°C /12h/air cooling, the ring forgings possessed very good mechanical properties. The impact toughness can be over 100J. In the fatigue test with the stress ratio -1, when the theoretical stress concentration factor is 1 and 2.7, the maximum stress for 107 fatigue cycles is over 620 MPa and 260 MPa, respectively.

08 - Numerical Simulation of Hot Die Forging for IN718 Disc: *X. D. Lu*[1]; J.H. Du[1]; D. Qun[1]; G.S. Chen[2]; X.F. Liu[3]; [1]Central Iron and Steel Research Institute; [2]Special Steel Company, Bao Steel Group; [3]Central Machine Science Research Institute

Numerical simulation of forging process is one of the most attractive tools. In order to obtain both practical prediction accuracy and acceptable computation time, the refined two-dimensional deformation model was proposed. The hot deformation behavior of IN718 superalloy has been characterized in the temperature range 900-1020ºC and strain rate range 0.001-0.1 s-1 using isothermal constant speed compression tests with a view to obtain a correlation between grain size and process parameters. Through comparison study of two forging methods, temperature-field and strain-field finite element analyses modeling were established. The load-time curves were obtained for disc under routine forging and hot die forging conditions. Results of numerical simulation show, in comparison with routine forging, total forging force is decreased effectively, temperature-field and strain-field of disc are uniform. Effect of cold die on the microstructure is decreased notably under hot die forging condition.

09 - The Effect of Process Route Variations on the Tensile Properties of Closed-Die Waspaloy Forgings, via Statistical Modeling Techniques: *Abdul-Hakeem Latinwo*[1]; Brad Wynne[1]; Mark Rainforth[1]; [1]University of Sheffield

The paper uses various statistical data modelling techniques in order to predict and optimise the tensile properties of a 2-stage deformation closed-die Waspaloy forging. The work is based on real industrial data collected from an aerospace forging facility. This data includes chemical composition, inner and outer region billet grain size, γ' solvus temperature, furnace set temperature and preform and final form furnace durations. These behaviours are used to model the behaviour of UTS, YS, E and R of A at 8 varied locations in the sample (including a hot tensile test) via linear and non-linear methods (multiple linear regression-cross validation ensemble neural networks etc…). The work also highlights how combinations of inputs (i.e. Al & Ti) interact and their combined impact on the tensile outputs. Final findings quantify the significance of each property and help re-engineer process route to optimise (a single or) all tensile properties simultaneously.

10 - Effect of Thermomechanical Working on the Microstructure and Mechanical Properties of Hot Pressed Superalloy Inconel 718: *Andrzej Nowotnik*[1]; [1]Rzeszow University of Technology

Experimental results on hot deformation and dynamic structural processes of nickel based alloy Inconel 718 are reviewed. The focus is the analysis of dynamic precipitation processes which operate during hot deformation of these materials at elevated temperatures. Hot compression tests were performed on the solution treated precipitation hardenable nickel based superalloy Inconel 718 at 720-1150°C with a constant true strain rates of 10-4 and 4x10-4s-1. True stress - true strain curves and microstructure analysis of the deformed nickel based superalloy is presented. The properties and dynamic behaviour are explained through observation of the microstructure using standard optical, scanning and transmission electron microscopy. Structural observations of solution treated Inconel 718 deformed at high temperatures, reveal non uniform deformation effects. The distribution of molybdenum-rich and niobium-rich carbides were affected by localized flow within the strain range investigated at relatively low deformation temperatures 720 - 850°C.

11 - Improved Superalloy Grinding Performance with Novel CBN Crystals: *Sridhar Kompella*[1]; Kai Zhang[1]; [1]Diamond Innovations

The superior thermal properties of nickel-based superalloys that make them suitable for use in gas turbine blades and vanes also make them difficult to grind. Cubic boron nitride (CBN) crystals which possess high thermal conductivity lend themselves to superalloy grinding by dissipating the grinding heat more effectively than conventional abrasives. Even so, productivity is constrained by the propensity of superalloys to suffer thermal damage when using accelerated grinding parameters. Furthermore, the grinding process economics hinge on maximizing wheel re-profiling intervals and the overall wheel life. In this paper the performance of two novel CBN crystals in grinding Inconel-718 as function of the wheel life, the workpiece surface characteristics and the process energy requirements is examined. The significantly improved performance of these new CBN crystals is compared with that from commercially available CBN. Possible mechanisms to explain the performance of the new crystals are discussed.

12 - The Creep and Fatigue Behavior of Haynes 282 at Elevated Temperatures: *Sara Longanbach*[1]; Carl Boehlert[1]; [1]Michigan State University

Haynes 282 is a wrought, gamma-prime strengthened nickel-based superalloy intended for use in high temperature structural applications. To investigate processing-microstructure-property relationships, the microstructure and elevated-temperature (760°C – 815°C) creep and fatigue behavior were evaluated after processing involving strain-recrystallization treatments. Microstructural evaluation was performed using SEM and EBSD. General high angle boundaries (GHAB), low angle boundaries (LAB), and coincident site lattice boundaries (CSLB) made up 38%, 4%, and 58% of all grain boundaries respectively. It is noted that 47% of the boundaries were twins. The creep and fatigue properties of this alloy were compared to those obtained for two solid solution-strengthened superalloys, Haynes 230 and Udimet 188. The Haynes 282 creep strain rates were significantly lower than those for the other alloys. The deformation behavior and mechanisms will be evaluated using electron microscopy and particular emphasis will be placed on characterizing the grain boundaries. Creep and fatigue synergisms will be noted.

13 - Aging Effects on the γ´ and γ” Precipitates of Inconel 718 Superalloy: Hui-Yun Bor[1]; Chao-Nan Wei[1]; Huu Tri Nguyen[2]; An-Chou Yeh[2]; *Chen-Ming Kuo*[2]; [1]Chung-Shan Institute of Science and Technology; [2]I-Shou University

The excellent mechanical properties of Inconel 718 are due to the γ´ and specifically the γ” precipitates. Solution heat treatment was performed at 1095ºC for 1 h followed by air cooling. A d-phase precipitation heat treatment was made at 955ºC, 1 h/AC. Finally a double-aging at 720ºC, 8 h/FC at 57 ºC/h down to 620ºC, 8 h/AC to precipitate both γ´ and γ” phases. The precipitation of both γ´ and γ” phases were studied in details after aging treatment by the use of transmission electron microscopy. The spherical precipitates were identified as γ´ phase and the ellipsoidal precipitates were γ” phase. At 720ºC for 8 h both γ´ and γ” are growing; the mean long-axis of γ” particle is 40 nm and the mean short-axis is 14 nm whereas the average diameter of the spherical γ´ particle is 17 nm. However, at 620ºC, γ” stops growing but γ´ continue to grow and the diameter increases to 21 nm.

14 - Effect of Microstructure on the High Temperature Fatigue Properties of Two Ni-Based Superalloys: Govindarajan Muralidharan[1]; Rick Battiste[1]; *Edward Kenik*[1]; James Bentley[1]; Bruce Bunting[1]; [1]Oak Ridge National Laboratory

There is significant interest in the use of Ni-based superalloys in the next generation automotive engines. The focus of this work is to evaluate the effect of microstructure on the high cycle fatigue properties of two Ni-based alloys, IN 751, an alloy used in these applications at lower temperatures, and Waspaloy®. High cycle fatigue lives of the alloys were measured using in-situ high temperature fatigue tests. SEM and TEM were used to characterize the microstructure of the alloys. Computational modeling was used to calculate the equilibrium microstructure and its evolution at 870ºC. This talk will present a summary of the observations linking microstructural evolution to the high temperature, high cycle fatigue properties of these alloys. *Research sponsored by Propulsion Materials Program, DOE Office of Vehicle Technologies, and the Scientific User Facilities Division, Office of Basic Energy Sciences under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

15 - The Effect of Primary γ’ Distribution on Grain Growth Behavior of GH720Li Alloy: *Maicang Zhang*[1]; Jianxin Dong[1]; Zhongnan Bi[1]; Qiuying Yu[1]; Yuchun Zhang[2]; [1]University of Science and Technology Beijing; [2]Northeastern Special Metals Co. (Group)

In this paper, a series of hot compression tests were carried out under different hot deformation parameters, covering the temperature range of 1000°C to 1170°C, strain rate range of 0.01/s to 1/s and different compression reduction. Then all specimens were heat treated standardly to investigate the grain growth behavior. The OM and SEM observation indicates that when hot deformation at the temperature below the γ/γ’ solvus,the bi-model grain size distribution (i.e. the coarse grain region and the fine grain region)always occurs; when forging temperature is up to 1170°C, the even grain size distribution obtained. Further hot working tests under given distribution of primary γ’ show that the normal or abnormal grain growth mainly determined by the different distribution of primary γ’ pinning at the γ-grain boundaries. The even distribution of primary γ’ induced the even grain size distribution, or the vice versa.

16 - Microstructural Evolution of ATI718Plus® Contoured Rings When Exposed to Heat Treatment Procedures: *Octavio Covarrubias*[1]; [1]Frisa Aerospace SA de CV

This contribution summarizes results when several contoured rings are exposed to selected heat treatment procedures in order to fulfill desired properties. Such properties are result of microstructural changes promoted during heat treatment processes as solution and precipitation. Microstructural evolution of ATI718plus® is evaluated by optical microscopy and electronic microscopy. Mechanical properties evaluation as tensile, hardness and stress-rupture testing complement these microstructural evolution results.

17 - Effect of Serrated Grain Boundaries on the Creep Property of Inconel 718 Superalloy: An-Chou Yeh[1]; Kang-Wei Lu[1]; *Chen-Ming Kuo*[1]; Hui-Yun Bor[2]; Chao-Nan Wei[2]; [1]I-Shou University; [2]Chung-Shan Institute of Science and Technology

The present study investigates the effect of serrated grain boundary with zigzag morphology on the high temperature creep deformation of IN718 superalloy. The experimental results have indicated that the morphology of grain boundary can be a function of heat-treatment condition. Experimental work includes XRD, DSC analysis, and SEM microstructure observations in order to investigate the underlying mechanism for the formation of zigzag grain boundary. Creep test under 650ºC/625MPa has been conducted on samples of IN718 with and without zigzag grain boundaries in order to determine its effects on deformation mechanisms. In conclusions, an improvement of 400 hours creep rupture life has been attributed by the serrated grain morphology.

18 - Influence of B and Zr on Microstructure and Mechanical Properties of Alloy 718: *Tatiana Fedorova*[1]; Joachim Rösler[1]; Bodo Gehrmann[2]; Jutta Klöwer[2]; [1]Technische Universität Braunschweig; [2]ThyssenKrupp VDM GmbH

The basic intent of this paper is to examine the role of the minor elements B and Zr within typical specification limits for alloy 718 with respect to (i) microstructure evolution, (ii) strengthening effects and (iii) thermal stability. For this purpose, thermodynamic calculations using the software THERMOCALC were performed, varying the content of B and Zr. In addition, alloys with precisely controlled chemical composition (with content variations of 20 to 100 ppm B and/or of 50 to 200 ppm Zr) were prepared by drop casting in a vacuum arc furnace and hot forged, so that it was possible to compare the theoretical predictions with experimental results. The microstructure evolution was studied in detail by means of scanning electron microscopy and x-ray diffraction. Furthermore, mechanical properties including tensile and creep behaviour were examined. Based on these results, dependencies between chemical composition, microstructure and mechanical properties will be elucidated.

19 - Application of Thermodynamic and Kinetic Modeling to Predict Different Phenomenon in the Superalloy 718 and Derivatives: *Johan Bratberg*[1]; Anders Engström[1]; Qing Chen[1]; Lars Höglund[1]; Paul Mason[1]; [1]Thermo-Calc Software AB

The power of computational thermodynamics applied on the superalloy 718 and some derivatives utilizing the software Thermo-Calc is demonstrated in this paper. These calculations can be based on both stable and metastable phase equilibria including all important phases for Ni-base superalloys. Simulation results of interdiffusion in Ni-base superalloy/NiAl-coating diffusion couples, by means of a thermodynamic and kinetic modeling approach available in DICTRA are shown. This code solves the multicomponent diffusion equations, combining assessed thermodynamic and kinetic data in order to determine the full composition dependent interdiffusion matrix. The successful homogenization model for diffusion in complex multiphase systems has been used. The simulation results obtained are validated against experimental data, and the agreement is very satisfactory given the complexity of the problem.

20 - Effect of Phosphorus on δ Phase Formation in IN718 Alloy: *W.R. Sun*[1]; W.H. Zhang[1]; F. Liu[1]; F. Qi[1]; D. Jia[1]; S.L. Yang[1]; Z.Q. Hu[1]; [1]Institute of Metal Research, Chinese Academy of Sciences

The δ-Ni_3Nb is the critical grain boundary strengthener for avoiding the notch sensitivity of IN718 alloy, while the excessive precipitation of the phase decreases the strength of the alloy. In addition, it is used to control the grain structure during the thermal processing. It was recently found that phosphorus greatly increases the stress rupture life and decreases the steady state creep rate of IN 718 alloy. To apply the beneficial function of phosphorus, its effect on the δ phase formation is investigated in this paper. It was found that phosphorus inhibits the δ phase precipitation slightly at the heat treated state, while greatly reduces the δ phase precipitation during creep. Phosphorus decreases the flow stress when deformed below 1000°C because it reduces the δ phase formation. The mechanism by which phosphorus influences the δ phase formation under different conditions is discussed in the paper.

21 - Surface Modification of Inconel 718 Superalloy by Plasma Immersion Ion Implantation PIII: *Ana Claudia Hirschmann*[1]; M. M. Silva[2]; Carlos Moura Neto[2]; M. Ueda[3]; C. B. Mello[3]; M. J. R. Barboza[4]; A. A. Couto[5]; [1]Vale Soluções em Energia (VSE) - Sao Jose dos Campos; [2]Instituto Tecnológico de Aeronautica- ITA Sao Jose dos Campos; [3]Laboratorio de Plasma, Instituto Nacional de Pesquisas Espaciais-INPE, Sao Jose dos Campos; [4]Escola de Engenharia de Lorena, EEL-USP, Lorena; [5]Instituto de Pesquisas Energética e Nucleares, IPEN, Sao Paulo

A superalloy is an alloy developed for elevated temperature service, where relatively severe mechanical stressing is encountered, and where high surface stability is frequently required. High temperature deformation of Ni-base superalloys is very important since the blades and discs of aeroengine turbine, because need to work at elevated temperature for an expected long period. Plasma immersion nitrogen implantation of a superalloy Inconel 718 was carried out to modify its surface tribological properties. The objective of this work is to investigate the improvement of a superalloy Inconel 718 surface properties through treatments by Plasma Immersion Ion Implantation (PIII) for 1 and 2 hours. Comparing the samples using X-ray diffraction (XRD) results have shown structural modifications in the samples treated by PIII. AFM technique shows an increase in the roughness after treatment.

22 - Effect of Environment on the Creep Behavior of the Superalloy Inconel 718: *Ana Claudia Hirschmann*[1]; Carlos Moura Neto[1]; [1]Institute Tecnologic of Aeronautic

A superalloy is an alloy developed for elevated temperature service, where relatively severe mechanical stressing is encountered, and where high surface stability is frequently required. High temperature deformation of Ni-base superalloys is very important since the blades and discs of aeroengine turbine, because need to work at elevated temperature for an expected long period. The objective of this work was to evaluate the creep behavior of the Inconel 718 focusing on the determination of the experimental parameters related to the primary and secondary creep states. Constant load creep tests were conducted with at 600, 650 and 700°C and the range of stress was from 625 to 814 MPa. Samples with a gage length of 18.5 mm and a diameter of 3.0 mm were used for all tests. The relation between primary creep time and stedy-state creep rate, the equation for both atmospherics conditions at 600, 650 and 700ºC.

A

B

C

D

E

F

G

H

J

K

L

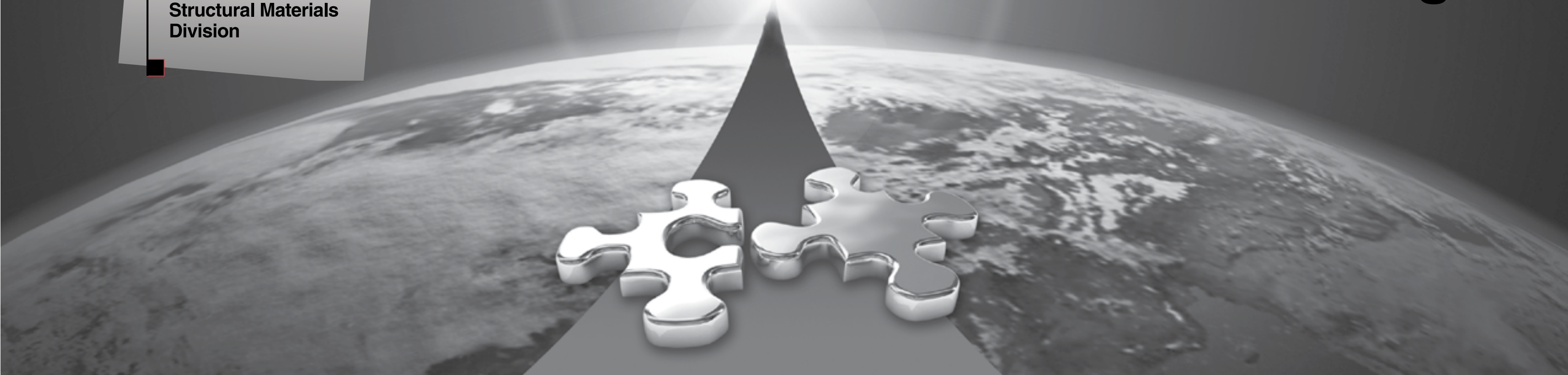
M

Notes

SUPERALLOYS CONFERENCE PROCEEDINGS ARCHIVE

This valuable tool offers free access to nearly 1,000 technical articles that document the 40-year history of these compelling materials. This collection is supported by the International Symposium on Superalloys Committee.

To access the archive, visit:
http://knowledge.tms.org/superalloys.aspx



ATI 718Plus® Alloy

In the quest for greater efficiency, jet engine manufacturers have long sought an alloy capable of use at higher temperatures than alloy 718, but with similar manufacturability. ATI 718Plus® alloy is designed for higher operating temperatures with comparable manufacturability to alloy 718.

Components designed using ATI 718Plus alloy can be more economical than those using Waspaloy, or other higher temperature capable alloys, due to the higher strength, superior formability, resistance to weld cracking, machinability and better wear resistance. Because of its unique combination of strength, formability, and thermal stability, ATI 718Plus alloy is being manufactured into components for gas turbines currently in production and specified for next generation engines because of the substantial cost savings it offers over competing alloys.

Now that ATI 718Plus is flying, why aren't you on board?

www.ATImetals.com

ATI 718 Plus®
Nickel-base Superalloy

www.ATImetals.com/allvac/718plus/home.htm