Mg Workshop

May 21-24, 2013 Madrid, Spain

institute imdea materials

Final Program

Welcome to the Magnesium Workshop Madrid 2013!!!

An International Workshop on Processing-Microstructure-Mechanical Properties of Magnesium Alloys

May 21-24, 2013 • Madrid, Spain

About your Registration

Full Conference Registration and Student Registration include the welcoming reception, coffee breaks, conference luncheons, access to the technical sessions, the guided visit to Toledo, the conference banquet in Toledo and the guided visit to the Old Madrid.

Guests may purchase tickets for the welcoming reception and the conference luncheons at the registration desk. Tickets are $20 (Guided Visit to Old Madrid) and $85 (guided visit to Toledo and conference banquet).
Badges must be worn to gain access to the technical sessions and social functions.

TABLE OF CONTENTS

CALENDAR OF EVENTS

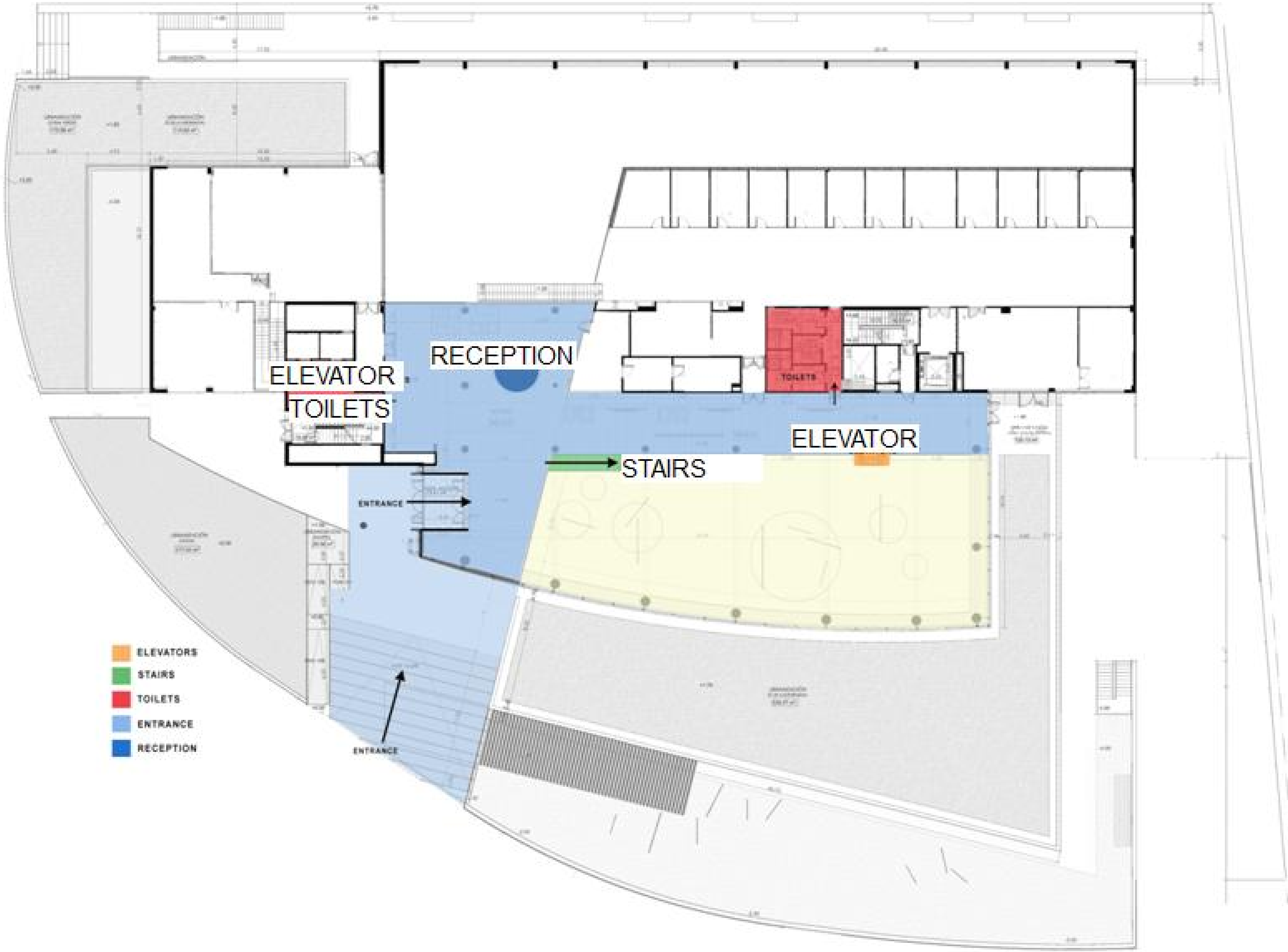
Tuesday, May 21	Time	Location
Registration	8:00 to 8:45 am	Main Hall
Conference Opening	8:45 to 9:00 am	Auditorium
Session1: Deformation and Recrystallization Mechanism – I	9:00 to 10:20 am	Auditorium
Poster Session 1 & Coffee Break	10:20 to 11:10 am	Main Hall
Session 2: Deformation and Recrystallization Mechanisms – II	11:10 to 12:50 pm	Auditorium
Lunch	1:00 to 2:00 pm	Main Hall
Session 3: Deformation and Recrystallization Mechanism – III	2:00 to 3:20 pm	Auditorium
Poster Session 1 & Coffee Break	3:20 to 4:10 pm	Main Hall
Session 4A: Deformation and Recrystallization Mechanism - IV	4:10 to 6:10 pm	Auditorium
Session 4B: Processing – I	4:10 to 6:10 pm	Seminar Room
Welcome reception and visit to IMDEA Materials Institute	6.15 to 7.30 pm	

Wednesday, May 22	Time	Location
Processing – II	9:00 to 10:20 am	Auditorium
Poster Session 2 & Coffee Break	10:20 to 11:10 am	Main Hall
Session 6: Deformation and Recrystallization Mechanisms – V	11:10 to 12:50 pm	Auditorium
Lunch	1:00 to 2:00 pm	Main Hall
Session 7: Deformation and Recrystallization Mechanisms – VI	2:00 to 3:20 pm	Auditorium
Poster Session 2 & Coffee Break	3:20 to 4:10 pm	Main Hall
Sesssion 8A: Processing – IV	4:10 to 6:10 pm	Auditorium
Session 8B: Advanced Characterization Techniques – I	4:10 to 6:10 pm	Seminar Room
Guided visit to the Old Madrid	7:30 to 9.30 pm	

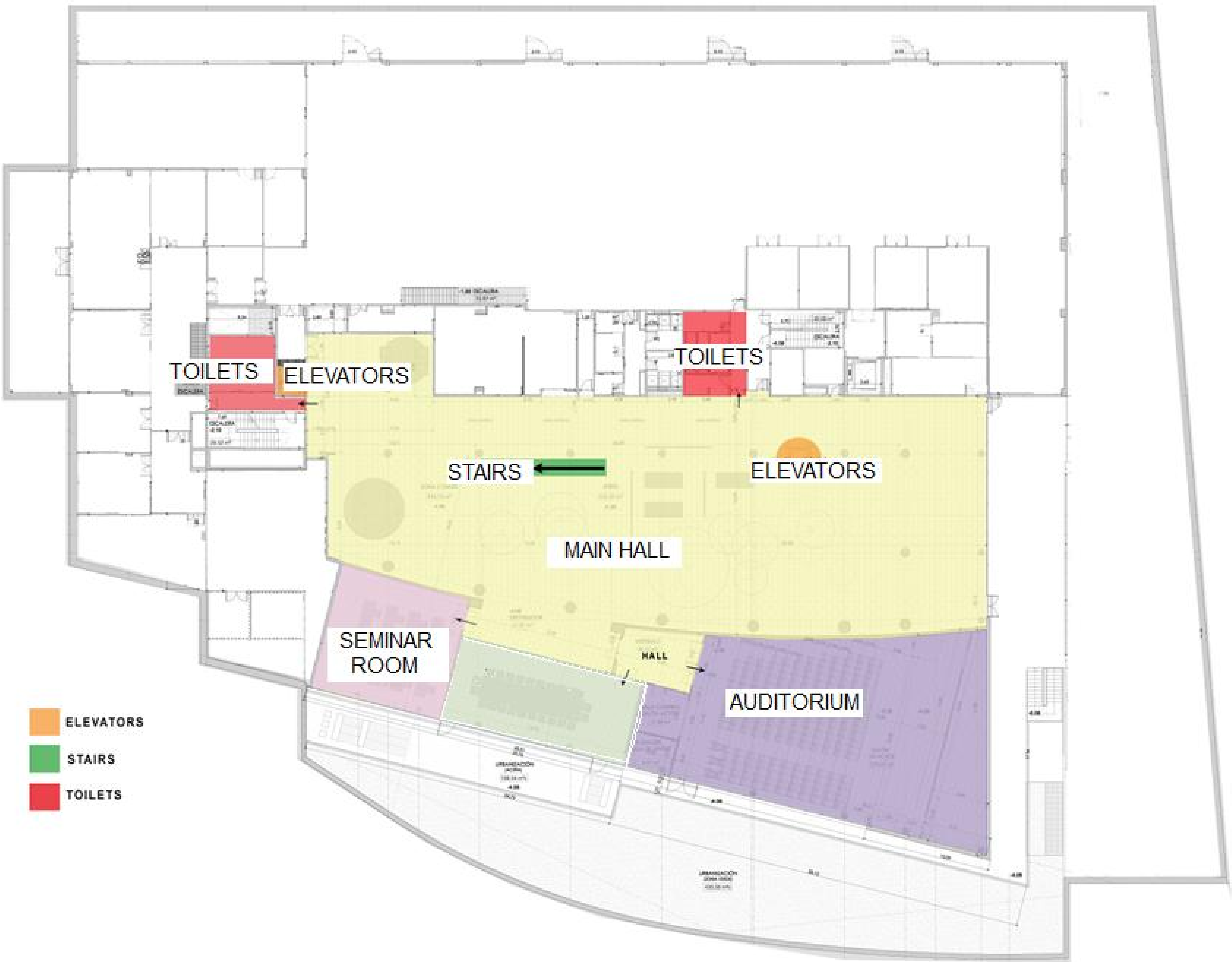
Thursday, May 23	Time	Location
Session 9: Deformation and Recrystallization Mechanisms VII	9:00 to 10:20 am	Auditorium
Coffee Break	10:20 to 11:10 am	Main Hall
Session 10: Advanced Characterization Techniques – II	11:10 to 12:50 pm	Auditorium
Lunch	1:00 to 2:00 pm	Main Hall
Session 11: Microstructure and Advanced Characterization Techniques – III	2:00 to 4:00 pm	Auditorium
Guided visit to Toledo	4:00 to 8:00 pm	
Conference Banquet in Toledo	8:00 to 10:00 pm	

Friday, May 24	Time	Location
Session 12: Modelling – I	9:00 to 10:20 am	Auditorium
Poster Session 3 & Coffee Break	10:20 to 11:10 am	Main Hall
Session 13: Modelling – II	11:10 to 12:50 pm	Auditorium
Lunch	1:00 to 2:00 pm	Main Hall
Session 14A: Microestructure, Deformation and Recristallization Mechanisms	2:00 to 4:00 pm	Auditorium
Session 14B: Modelling – III	2:00 to 3:20 pm	Seminar Room
Poster Session 3 & Coffee Break	4:00 to 5:00 pm	Main Hall
Conference Closure	5:00 to 5:15 pm	Auditorium

GROUND FLOOR



BASEMENT


TOILETS
ELEVATORS
TOILETS
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ELEVATORS
MAIN HALL
SEMINAR ROOM
HALL
AUDITORIUM
ELEVATORS
STAIRS
TOILETS

About the Conference Location

Computer/Network Facilities

IMDEA Materials Institute has guest wireless connection available in the whole building.
Wifi: IMDEA-GUEST
Password: ImdeaInternet

How to arrive to IMDEA Materials Institute

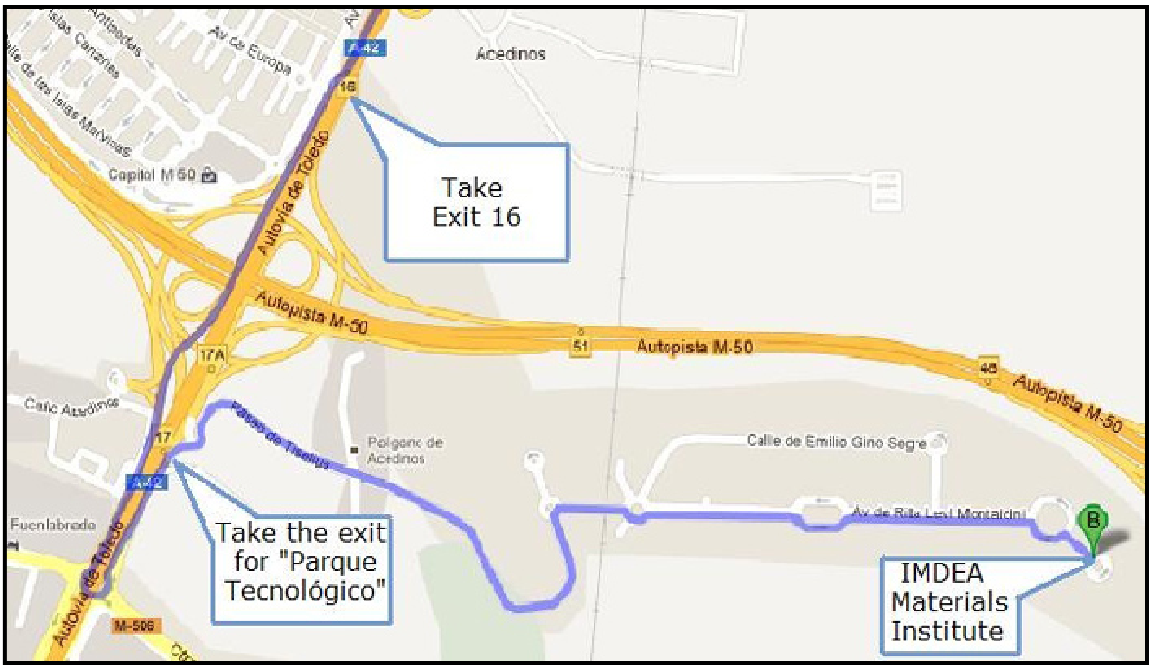
IMDEA Materials Institute is located at the Scientific and Technological Park of the Polytechnic University of Madrid in Tecnogetafe.
Address:
Calle Eric Kandel, 2
28906 Getafe

The conference provides shuttle services to and from the hotels to IMDEA Materials Institute. Please see below the shuttle schedule corresponding to each day of the workshop. The traveling time is approximately 30-40 mins. **It is highly recommended that all participants use this shuttle service, as it is the most convenient way to get to the venue.**

Alternative ways to arrive to IMDEA Materials Institute include taxi (approximately 25-35 euro, travelling time from Atocha: 30 min, see detailed directions and map below) and public transport (traveling time from Atocha: 1h30min, see directions below).

If you have any question about how to reach IMDEA Materials please contact Mariana Huerta at +34 915493422.

Map (to be printed and shown to the driver if taking a taxi)



SHUTTLE SCHEDULE FROM/TO THE HOTELS TO/FROM THE CONFERENCE VENUE

Hotel to IMDEA Materials Institute	IMDEA Materials Institute to Hotels, Old Madrid & Toledo
Tuesday , May 21st 7:45 am in front of NH Nacional 7:45 am in front of NH Sur 8:10 am in front of NH Hesperia 12:15 pm in front of NH Nacional 12:40 pm in front of NH Hesperia	Tuesday , May 21st 2:00 pm to NH Hesperia & NH Nacional 7:30 pm to NH Hesperia & NH Sur 7:30 pm to NH Nacional
Wednesday, May 22nd 8:15 am in front of NH Nacional 8:15 am in front of NH Sur 8:40 am in front of NH Hesperia 12:15 pm in front of NH Nacional 12:40 pm in front of NH Hesperia	Wednesday, May 22nd 2:00 pm to NH Hesperia & NH Nacional 6:15 pm to NH Hesperia and NH Sur 6:15 pm to NH Nacional (*)
Thursday, May 23rd 8:15 am in front of NH Nacional 8:15 am in front of NH Sur 8:40 am in front of NH Hesperia 12:15 pm in front of NH Nacional 12:40 pm in front of NH Hesperia	Thursday, May 23rd 2:00 pm to NH Hesperia & NH Nacional 4:00 pm to the guided visit to Toledo(**)
Friday, May 24th 8:15 am in front of NH Nacional 8:15 am in front of NH Sur 8:40 am in front of NH Hesperia 12:15 pm in front of NH Nacional 12:40 pm in front of NH Hesperia	Friday, May 24th 2:00 pm to NH Hesperia & NH Nacional 5:30 pm to NH Hesperia & NH Sur 5:30 pm to NH Nacional

(*) A bus will leave from NH Nacional at 7:20 pm to go to the Plaza de la Villa, where the visit to the old Madrid will start.

(**) A bus will leave from NH Nacional & NH Hesperia in order to take accompanying persons who want to come to the visit to Toledo to IMDEA Materials Institute, where the tour will start.
From NH Nacional 3:00 pm
From NH Hesperia 3:30 pm

By taxi

From Atocha Train Station (near NH Sur and NH Nacional)

- Head southeast toward Paseo de la Infanta Isabel (130 m)
- Exit the roundabout onto Paseo de la Infanta Isabel (42 m)
- Take the ramp onto Paseo de la Infanta Isabel (260m)
- At the roundabout, take the 3rd exit onto Plaza del Emperador Carlos V (280 m)
- Continue onto Paseo de Sta María de la Cabeza (1.9 km)
- Continue onto A-42 (signs for Toledo/R-5/Badajoz/Plaza de Fernández Ladreda) (13.2 km)
- Take exit 16 toward M-506/Pinto/Fuenlabrada (1.1 km)
- Merge onto Autovía de Toledo (200 m)
- At the roundabout, take the 4th exit and stay on Autovía de Toledo heading to M-50/Madrid (400 m)
- Keep right at the fork, follow signs for A-42/Getafe/Madrid (68 m)
- After 68 meters turn right immediately following the sign “Parque Científico Tecnológico *TECNOGETAFE*”.
- Continue onto Paseo de Tiselius, leaving Los Angeles school on your left until you reach a roundabout (entrance to Tecnogetafe) (1.2 Km)
- Take the first exit right and continue straight along the main avenue of the Technology Park (Avenida Rita Levi Montaicini) until the end of the avenue where you will reach a roundabout (1.0 Km)
- In the last roundabout take the first exit right onto Calle Eric Kandel, where IMDEA Materials Institute is located.

From Barajas Airport (Terminals T1, T2 y T3):

- Join the M-14 via the ramp on the left towards Madrid /Av.América/A-2/M-40/A-3/A-4/A-5.
- Take the left exit towards M-40/M-40 R-3/A-3/R-4/A-4/A-42/R-5 direction until you reach Exit 25 to take the A-42 towards Toledo. Keep driving along A42 highway (13.2 Km)
- Take exit 16 toward M-506/Pinto/Fuenlabrada (1.1 km)
- Merge onto Autovía de Toledo (200 m)
- At the roundabout, take the 4th exit and stay on Autovía de Toledo heading to M-50/Madrid (400 m)
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From Barajas Airport (Terminal T4):

- Go straight until you reach a fork where you must keep right to follow the signs to Madrid.
- Continue straight to take at a junction Eje-Aeropuerto/M-12 left towards Madrid/M-11/M-40 (In this highway will have to pay a toll).
- Take the M-40/M-40 Highway exit, continue in this sense and get to the fork, bear right and follow signs for M-40/E-90/A-2 / and merge onto highway Zaragoza/R-3/A-3/R-4/A-4/A-42/R-5 M-40/M-40.
- Take exit 25 to merge onto A-42 toward Toledo (10.5 Km)
- Take exit 16 toward M-506/Pinto/Fuenlabrada (1.1 km)
- Merge onto Autovía de Toledo (200 m)
- At the roundabout, take the 4th exit and stay on Autovía de Toledo heading to M-50/Madrid (400 m)
- Keep right at the fork, follow signs for A-42/Getafe/Madrid (68 m)
- After 68 meters turn right immediately following the sign “Parque Científico Tecnológico *TECNOGETAFE*”.
- Continue onto Paseo de Tiselius, leaving Los Angeles school on your left until you reach a roundabout (entrance to Tecnogetafe) (1.2 Km)
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- In the last roundabout take the first exit right onto Calle Eric Kandel, where IMDEA Materials Institute is located.

Public Transport (not recommended)

You should reach the Metro/Cercanías station of *Getafe Central* and then catch the Tecnogetafe shuttle service (The estimated duration of the trip is 1hr 20 minutes). The first stop of the bus service is located about 500 meters on the right/down as you exit the station, approximately by the red bus stop. The shuttle service is run by the bus company *M. Forest* (in the top front of the bus you will see a sign of *Tecnogetafe*). The last stop of this shuttle is right in front of IMDEA Materials Institute.

Tecnogetafe shuttle services

Monday to Thursday

Getafe Central - IMDEA

Departure	Arrival
7:30 am	7:50 am
8:10 am	8:30 am
8:55 am	9:20 am
9:40 am	10:00 am
1:50 pm	2:10 pm
2:30 pm	2:50 pm
3:10 pm	3:30 pm
3:50 pm	4:10 pm
5:35 pm	5:55 pm
6:15 pm	6:35 pm
6:55 pm	7:15 pm
7:35 pm	7:55 pm

IMDEA - Getafe Central

Departure	Arrival
7:50 am	8:10 am
8:30 am	8:55 am
9:20 am	9:40 am
1:30 pm	1:50 pm
2:10 pm	2:30 pm
2:50 pm	3:10 pm
3:30 pm	3:50 pm
5:15 pm	5:35 pm
5:55 pm	6:15 pm
6:35 pm	6:55 pm
7:15 pm	7:35 pm
7:55 pm	8:15 pm

Friday

Getafe Central - IMDEA

Departure	Arrival
7:30 am	7:50 am
8:10 am	8:30 am
8:55 am	9:20 am
9:40 am	10:00 am
1:50 pm	2:10 pm
2:30 pm	2:50 pm
3:10 pm	3:30 pm
3:50 pm	4:10 pm

IMDEA - Getafe Central

Departure	Arrival
7:50 am	8:10 am
8:30 am	8:55 am
9:20 am	9:40 am
1:30 pm	1:50 pm
2:10 pm	2:30 pm
2:50 pm	3:10 pm
3:30 pm	3:50 pm
6:00 pm	6:20 pm

Programming Notes

<u>Technical Sessions</u>
The Technical program will begin Tuesday, May 21 and conclude Friday, May 24

The conference will be organized to include plenary sessions on the different topics of the conference. Each session will start with a keynote lecture given by an internationally-recognized expert on a predetermined topic and will be followed by oral presentations on the same topic. Poster sessions will be scheduled between oral presentation sessions so graduate students, postdoctoral fellows, and young researchers can present their work. Time will be included in the program for ad hoc meetings, informal discussions, and/or outings to local cultural attractions. This format is designed to promote dialogue and enhance the exchange of ideas among the participants.

All participants are expected both to attend the entire conference and to contribute actively to the discussions. The conference will take place in an informal atmosphere.

Keynote Speakers:

- T. Al-Samman, *RWTH Aachen, Germany*
- S. R. Agnew, *University of Virginia, USA*
- M. R. Barnett, *Deakin University, Australia*
- In-Ho Jung, *McGill University, Canad*a
- Y. Kawamura, *Kumamoto University, Japan*
- D. Letzig, *Helmholtz-Zentrum Geesthacht, Germany*
- J. F. Nie, *Monash University, Australia*
- S. Sandlöbes, *Max-Planck-Institut für Eisenforschung, Germany*
- C. N. Tomé, *Los Alamos National Laboratory, USA*
- J. Wang, *Nanjing University of Science & Technology, China*

Policies

Audio/Video Recording Policy
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Photography Notice
By registering for the conference, all attendees acknowledge that they may be photographed by IMDEA Materials Institute personnel while at events and that those photos may be used for promotional purposes.

Organizing Committee

Conference Chairs

- C. J. Boehlert, Michigan State University & IMDEA Materials Institute
- M. T. Pérez-Prado, IMDEA Materials Institute
- J. LLorca, IMDEA Materials Institute & Polytechnic University of Madrid

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- D. Raabe, Max-Planck-Institut für Eisenforschung, Germany
- D. Rittel, Technion, Israel
- O. A. Ruano, CENIM, Spain
- N. Stanford, Deakin University, Australia
- J. J. Vlassak, Harvard University, USA

GUIDED VISIT TO THE OLD MADRID

The area known as *Austria's Madrid*, or the Madrid of the Habsburg, after the Austrian royal dynasty who reigned in Spain until 1700, is the oldest section of the city, and it is full of historical attractions. You will feel the charm of old medieval renaissance Madrid in the narrow quiet streets around Plaza de la Villa, the Convent of las Carboneras, la Basilica de San Miguel and, of course, the Plaza Mayor where you can find the Cava Baja street, which is very lively all nights of the week. Again, at the calle Mayor, there is the Mercado de San Miguel, a cute 1913 iron market. We will stop at the Cathedral of la Almudena, and will finish our journey at the Plaza de Oriente, in the vicinity of the Royal Palace.

GUIDED VISIT TO TOLEDO

TOLEDO, museum - city of great artistic beauty, was the capital of the country and one of the oldest cities in Europe. Toledo has wonderful examples of architecture from different cultures, Muslim, Jewish and Catholic. It was declared World Heritage by UNESCO. We will walk around the city to admire its streets and monuments, will visit the cathedral (classic gothic building built in white stone, with a magnificent choir, vestry, chapter houses and cloister), the church of Santo Tomas ("Burial of Lord of Orgaz", masterpiece of El Greco), the synagogue of Santa Maria La Blanca (a mudejar construction of the XII century) and the church of San Juan de los Reyes (built in commemoration of the Battle of Toro in the XV century with a unique gothic – flemish style).
After the tour, the conference banquet will take place in a typical restaurant.

Registration

Tuesday AM Room: Auditorium
May 21, 2013 Location: IMDEA Materials Institute

8:00 - 8:45 AM Conference Registration

Conference Opening

Tuesday AM Room: Auditorium
May 21, 2013 Location: IMDEA Materials Institute

8:45 - 9:00 AM Conference Opening
J. Llorca, C.J. Boehlert, M.T. Perez-Prado

Session 1: Deformation and Recrystallization Mechanisms - I

Tuesday AM Room: Auditorium
May 21, 2013 Location: IMDEA Materials Institute

Session Chair: Matthew Barnett, Deakin University

9:00 AM Keynote
Deformation Mechanisms of Magnesium Alloys: *Sean Agnew*[1]; [1]University of Virginia

No single topic of Mg metallurgy has been more actively studied than the deformation mechanisms which are responsible for the complex mechanical behaviors exhibited by Mg and its alloys. Historically, single crystal deformation studies provided the bulk of information on the subject. The use of new experimental (electron backscattered diffraction (EBSD) and in-situ x-ray and neutron diffraction) and computational (digital image correlation (DIC), crystal plasticity, and atomistic simulation) approaches have brought significant, new understanding which is providing guidance to current alloy and microstructure design strategies to improve strength, ductility and toughness. Nevertheless, there are significant issues of controversy and uncertainty surrounding each of the mechanisms which will be discussed (basal and non-basal slip, twinning, dislocation climb, and grain boundary sliding). Until these issues are resolved, the best alloy and microstructure design strategies to employ for particular property goals will remain elusive. There are three classes of mechanical properties that are of interest: (i) those which involve improved homogeneity of polycrystalline deformation including ductility and formability, (ii) those which involve increased strength and/or creep resistance, and (iii) those which involve a combination of both, such as toughness. That which is known and those aspects which remain elusive will be discussed for each of the mechanisms in light of these properties and their response to conventional and novel strengthening mechanisms. An effort will be made to address common misconceptions that repeatedly arise in discussion, such as the role of c/a ratio.

9:20 AM Invited
Understanding the Influence of Dilute Rare-Earth Additions on Texture in Wrought Magnesium Alloys: *Joseph Robson*[1]; David Griffiths[1]; Bruce Davis[2]; [1]University of Manchester; [2]Magnesium Elektron North America

The effect of dilute rare-earth (RE) additions to wrought magnesium alloys has been the subject of intense study in recent years due to their texture modification effect and associated improvements in formability. Despite this, it remains unclear what essential characteristic of RE elements produces the observed effect. Factors such as solubility, size misfit, tendency for segregation, and influence on stacking fault energy have all been identified as fully or partly responsible in previous work. One difficulty in isolating the dominant factor is the inter-relationships between them. In this paper, current observations regarding the RE-effect are summarized and each contributing factor is considered. Results of initial work using a range of binary Mg-RE to isolate the contribution of each variable are presented. In agreement with a previous suggestion, this work supports the idea that the RE-texture is a transition effect during recrystallization that does not persist after extended annealing.

9:40 AM Invited
The Microstructure and Texture of Cerium-containing Magnesium-zinc Sheets: *Jan Bohlen*[1]; Sangbong Yi[1]; Dietmar Letzig[1]; [1]Helmholtz-Zentrum Geesthacht

Mechanical properties and formability of magnesium sheets are distinctly influenced by the microstructure and texture of the sheet. It has been shown that alloys containing rare earth elements can lead to significantly weaker and also qualitatively different textures if compared to magnesium alloy sheets such as of alloy AZ31. In this paper the effect of rare earth elements will be reviewed with respect to the mechanisms that determine the microstructure and texture development. Differences between binary magnesium-rare earth alloys and their modifications with zinc will be emphasised. Results of rolling experiments on magnesium alloys that contain 2 wt% of zinc and a varying amount of cerium are presented and discussed with respect to the mechanisms that take control on the microstructure development. In comparison to alloys with a lower content of zinc the findings will be reviewed regarding possibilities to design the texture of magnesium sheets.

10:00 AM
The Effect of Neodymium on the Deformation Behavior of Extruded Mg-1Mn(wt%): *Ajith Chakkedath*[1]; Zhe Chen[1]; Carl Boehlert[1]; Ivan Gutiérrez-Urrutia[2]; Javier Llorca[3]; Jan Bohlen[4]; Sangbong Yi[4]; Dietmar Letzig[4]; Teresa Pérez-Prado[5]; [1]Michigan State University; [2]Max Planck Institute for Iron Research; [3]Polytechnic University of Madrid/IMDEA Materials Institute; [4]Magnesium Innovation Centre MagIC; [5]IMDEA Materials Institute

The tension and compression deformation behavior of magnesium-1 wt% manganese alloys with nominally 0.5 wt% and 1 wt% neodymium was studied over the temperature range of 25°C-250°C. In-situ tensile and compressive experiments were performed inside a SEM and EBSD was performed both before and after the deformation. A slip trace analysis technique was used to identify the distribution of the deformation systems as a function of strain. In the case of the 1 wt% Nd containing alloy, the deformation behavior under tension at all temperatures was dominated by basal slip, while in compression extension twinning was the major deformation mode. With the reduction of Nd content, grain boundary cracking was observed under tension at significantly lower strain values. The deformation behavior will be compared to conventional Mg alloys and in particular, the critical resolved shear stress ration of the deformation systems will be discussed.

10:20 AM Break

Session 2: Deformation and Recrystallization Mechanisms - II

Tuesday AM — Room: Auditorium
May 21, 2013 — Location: IMDEA Materials Institute

Session Chair: Sean Agnew, University of Virginia

11:10 AM Keynote
Strengthening Wrought Magnesium Alloys: *Matthew Barnett*[1]; [1]Deakin University

Strength is a critical property for any structural metal. To strengthen a magnesium alloy, it is necessary to consider the following characteristic phenomena: solute softening, texture hardening and the twinning stress. Recent findings on the role of these phenomena in polycrystalline alloys are examined in the present talk. It is shown that the grain size is important in quantifying their contribution. This is most marked in the case of solute softening; it is only seen for coarser grain sizes. Grain refinement interacts with texture hardening and it is also shown that both twin nucleation and growth are sensitive to the grain size. Explanations are proposed for these interactions.

11:30 AM Invited
The Effect of Rare Earth Alloying Additions on the Hot Deformation and Recrystallisation Behaviour of Magnesium-based Alloys: *Nicole Stanford*[1]; [1]Deakin University

The hot deformation and recrystallisation behaviour of two magnesium alloys, AZ31 and Mg-1.5Gd, have been examined in order to study the effect of rare earth additions. The as-cast alloys dynamically recrystallised during deformation, but retained a large amount of as-deformed microstructure. The as-deformed microstructure of Mg-Gd produced a more refined substructure and developed larger average misorientations compared to AZ31. From these observations it is inferred that Mg-Gd develops a higher stored energy than AZ31 during deformation, and that dynamic restoration is more inhibited in the Mg-Gd alloy. After deformation, the alloys were statically annealed. The alloy Mg-Gd, recrystallised significantly faster than AZ31. Despite faster recrystallisation kinetics, Mg-Gd developed the weaker recrystallisation texture associated with the addition of rare earth elements. It is proposed that solute partitioning of RE elements to dislocations during deformation creates a microstructure from which weaker recrystallisation textures are favoured.

11:50 AM Invited
Comparison Study of Microstructure and Phase Evolution in Mg-Nd, Mg-Gd and Mg-Gd-Nd Based Alloys: *Menahem Bamberger*[1]; Suzan Khawaled[1]; Galit Atiya[1]; Alex Katsman[1]; [1]Technion

Microstructure and phase evolution in Mg-Nd, Mg-Gd and Mg-Gd-Nd based alloys were analyzed in the as-cast, solution treated and aged conditions. Similarities between the as-cast microstructures and precipitation sequence during aging was revealed. Distinct features of eutectic compounds and crystal structure, composition and orientation relationships of Beta'' and Beta' phases were established. Nucleation and growth of Zn_2Zr_3 rods in Mg-Nd based alloy and Y-containing particles in Mg-Gd and Mg-Gd-Nd based alloys are discussed. The Zn_2Zr_3 rods, distributed in Mg-Nd grains, served as additional nucleation sites for precipitates, resulted in formation of T-like and H-like particles. The cuboid shaped particles found in the Mg-Gd and Mg-Gd-Nd based alloys were the fcc YH2-type hydrides which transformed during ST to the hcp Gd_4Nd-type compounds. The features of the age hardening curves in the investigated alloys were connected with difference in Beta'' to Beta' transformation and different diffusivity of Gd and Nd in Mg-matrix.

12:10 PM Invited
Temperature and Strain Rate Effects on the Deformation Behaviour of Extruded AZ31 and MN11 Magnesium Alloys: *Sangbong Yi*[1]; Jan Bohlen[1]; Jose Victoria-Hernandez[1]; Heinz-Günter Brokmeier[2]; Dietmar Letzig[1]; Young Min Kim[1]; Nobert Schell[1]; Andreas Schreyer[1]; Karl Kainer[1]; [1]Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung; [2]Clausthal University of Technology

The deformation behaviour of extruded AZ31 and MN11 alloy bars was examined under tensile loading at various strain rates and temperatures. Distinct deformation characteristics of the both alloys have been investigated in relation to the microstructural evolution during deformation, using high energy X-ray diffraction at a synchrotron beam-line and EBSD. Commercial AZ31 alloy shows a decrease of the yield and tensile strength with increasing loading temperature, which is related to the occurrence of dynamic recrystallisation. On the other hand, the experimental MN11 alloy containing 1 wt.% Nd shows only a slight decrease in the yield strength within the loading temperature range examined. Moreover, MN11 does not show an increase of the ductility with loading temperature, but smaller fracture strain at elevated temperatures. The appearance of dynamic strain aging and the different serration types observed in the MN11 alloy are analysed in terms of active deformation modes and loading conditions.

Session 3: Deformation and Recrystallization Mechanisms - III

Tuesday PM Room: Auditorium
May 21, 2013 Location: IMDEA Materials Institute

Session Chair: T. Al-Samman, University of Aachen

2:00 PM Keynote
Twin Nucleation, Propagation and Detwinning: Characterization and Modeling: *Carlos Tome*[1]; Anand Kanjarla[1]; Stephen Niezgoda[1]; Jian Wang[1]; Huamiao Wang[2]; Peidong Wu[2]; [1]Los Alamos National Laboratory; [2]McMaster University

Twinning plays a fundamental role in accommodating plastic deformation and explaining anisotropy and hardening of HCP materials. However, the stresses responsible for twin nucleation, propagation, and detwinning are still not well understood. This presentation discusses the characterization of local stress states associated with twinning using experimental diffraction techniques and local plasticity simulation methods. We discuss the role played by grain boundaries and neighbor misorientation, and show how this information can be incorporated into effective medium models.

2:20 PM Invited
The Crystallography of Shear and Shuffles of Twinning in Hexagonal Close-packed Structures and Mobility of a Faceted {1012} || (0 0 0 1) - {1010} Boundary: Haitham El Kadiri[1]; Christopher Barrett[1]; Mark Tschopp[2]; *Mohammed Cherkaoui*; [1]Mississippi State University; [2]Mississippi State University/ Army Research Laboratory

This presentation introduces a new crystallographic method, termed the "twin triangle", for calculating the atomic shear and shuffling accompanying twinning in hexagonal closed-packed structures. While the shuffling phenomenon is well known, analytical expressions for shuffles have not been previously derived. This method is generalized through a tensor-based theory and applied to the case of shears and shuffles in {1 1 2 2} for titanium and {1 0 1 2} for magnesium. It was found that {1 1 2 2} planes can be seen as merohedral in that they have a nearly stacking sequence of 14 with a very small error equal to a b7 twinning dislocation, which vanishes for hafnium. The shuffle for {1 0 1 2} although simple, its derivation is more complex, but an account for the shear established on each corrugated plane below the plane of the twinning dislocation allows the pure shuffles to be expressed along rational directions. The shuffle theory for {1 0 1 2} was demonstrated by atomistic simulations, which show a systematic faceting with the (0 0 0 1)-{1 0 1 0} boundary at the free surface. It was found that Mendelson's theory predicts well the height of the active zonal twinning dislocation which finds a low energy compromise in lowering, to a certain extent, the shear at the expense of more shuffles.

2:40 PM
Effect of Zn Content on the Volume Fraction of Twinning in Mg and Mg-2.3Zn Alloy: *Nagarajan Devarajan*[1]; Xufang Ren[1]; Carlos H Caceres[1]; John R Griffiths[2]; [1]The University of Queensland; [2]CSIRO Process Science and Engineering

The volume fraction and number-density of twins was measured as a function of the applied strain and the data were correlated with the amount of anelasticity in pure Mg and a Mg-2.3 at.%Zn. Pre-polished tensile samples were strained to predetermined amounts and optical micrographs taken using Nomarski interference contrast at different locations. The volume fraction and number-density of twins were determined using point counting method. Twinning appeared as a much more prominent deformation mechanism at very low strains in pure Mg than the alloy. The presence of solute reduced the volume fraction of twins drastically at all strains in the alloy. The anelastic strain increased linearly with the volume fraction in the alloy, but the relation was less clear in pure Mg. A better correlation was observed with the number-density of twins, suggesting that the anelastic effect is proportional to the number of twin interfaces rather than the volume fraction.

3:00 PM Invited
Deformation Behavior of Magnesium Single Crystals: Ming Zhe Bian[1]; Sung Ho An[1]; Hua Chul Jung[1]; Kyung Hoon Lee[2]; *Kwang Seon Shin*[1]; [1]Magnesium Technology Innovation Center, Seoul National University; [2]Solution Lab

In order to determine the CRSS values for various major slip and twin systems, single crystal specimens with different orientations were prepared and deformed at various temperatures. The deformed samples were systematically examined by optical microscopy, X-ray diffraction and transmission electron microscopy. Viscoplastic self-consistent (VPSC) simulations were utilized to obtain the best fitted critical resolved shear stresses (CRSS) and hardening parameters for various deformation modes when more than one deformation modes were involved due to the loading direction of single crystal specimens. From the experiment and simulation results, it was found that the CRSS for basal slip and {10-12} twin showed a weak temperature dependence, whereas the CRSS for prismatic <a>, <c+a> slip and {10-11} twin exhibited a strong temperature dependence.

3:20 PM Break

Session 4A: Deformation and Recrystallization Mechanisms - IV

Tuesday PM Room: Auditorium
May 21, 2013 Location: IMDEA Materials Institute

Session Chair: Teresa Pérez Prado, IMDEA Materials Institute

4:10 PM
Static Recrystallization Behavior of Cold-rolled Mg-Y(-Zn) Magnesium Alloys: *Young Min Kim*[1]; Sangbong Yi[1]; Stefanie Sandlöbes[2]; Stefan Zaefferer[2]; Dietmar Letzig[1]; [1]Helmholtz-Zentrum Geesthacht; [2]Max-Planck-Institut für Eisenforschung

The influence of Y and Zn on the static-recrystallization behavior and microstructural evolution during annealing of cold-rolled sheets was investigated by means of EBSD and TEM. A sharp basal-type texture is developed during the annealing of a cold-rolled pure Mg sheet, whereas annealed Mg-Y binary alloy sheets have weak texture representing double basal peaks tilted 15-20° along the RD. The recrystallization annealing of Mg-1Y-

1Zn (in wt.%) alloy leads to a slight strengthening of the (0001) pole density along the TD, while the overall texture intensity decreases. The change in texture evolution by Zn addition has been analyzed with a focus on the influence of solute and precipitates on the deformation mode and initial recrystallization behavior. Mechanical properties of the sheets having different types of texture, basal-type in pure-Mg, basal pole spread along the RD in Mg-Y and basal pole spread along the TD in Mg-Y-Zn, will be also presented.

4:30 PM

Effect of Yttrium on the Texture of Mg Alloy Sheet: *Stephen Yue*[1]; Seyed Farzadfar[1]; In-Ho Jung[1]; [1]McGill University

Alloys have been designed that either have yttrium bearing precipitates or have yttrium in solid solution, thus separating out the respective influences. It is found that the precipitates do not contribute to texture weakening. Yttrium in solid solution stops dynamic recrystallization generating a heavily twinned structure. Subsequent annealing leads to static recrystallization which continually weakens the basal texture, reaching a minimum basal intensity at the completion of static recrystallization. Further annealing leads to grain coarsening and texture strengthening. An alloy which did not contain yttrium was cold rolled in order to produce a heavily twinned structure. Subsequent annealing also led to texture weakening. Thus, the main effect of yttrium in these alloys was to stop dynamic recrystallization to create a heavily twinned structure by hot deformation.

4:50 PM

Influence of Ca, Mn and Ce-Rich Mischmetal Additions on the Microstructure and Mechanical Properties of Mg-8.5Zn-1.5Y Alloy: *Judit Medina*[1]; Gerardo Garcés[1]; Paloma Adeva[1]; Pablo Pérez Zubiaur[1]; [1]CENIM-CSIC

The effect of Ca, Mn and Ce-rich mischmetal additions on the microstructure and mechanical properties of the extruded Mg-8.5Zn-1.5Y (wt. %) alloy has been investigated. The microstructure of the alloys consisted of a magnesium matrix embedding second phase particles aligned along the extrusion direction. The nature and volume fraction of the second phases depended on the alloying element. Thus, Ce-rich mischmetal promoted the formation of T-phase while calcium additions resulted in the formation of ternary Mg-Zn-Ca compound. Only, Mn additions did not affect the existence of the I-phase present in the ternary alloy. The highest mechanical strength in the temperature range 25-200°C corresponded to the material modified with Ce-rich mischmetal, up to 30 % higher than that corresponding to the alloy with calcium additions. The mechanical behaviour can be rationalized on the basis of microstructural changes induced by the different elements added to the ternary alloy.

5:10 PM

Development of Highly Formable Micro-alloyed Mg Sheet Alloys: *Zhuoran Zeng*[1]; Chris Davies[1]; Nick Birbilis[1]; Jian-Feng Nie[1]; [1]Monash University

Poor room temperature formability is a significant barrier to the widespread commercial uptake of magnesium sheet alloys. An improvement in formability is associated with a weakening of the typical basal texture and can be improved by rare earth (RE) alloying additions. However, this study investigates whether such improvements can be achieved by the replacement or augmentation of RE elements by cheaper alloying elements. Several alloys were homogenised, hot rolled, cold rolled and annealed to produce thin sheets (about 0.5mm) that were then characterised via deep drawing, XRD and EBSD. A weakened texture intensity and improved formability was observed in the alloys micro-alloyed with a combination of alkali earth and/or RE elements. The influence of alloy composition and thermomechanical processing on texture development during deformation and recrystallisation is discussed in the context of development of formable Mg sheet alloys.

5:30 PM

Mechanical Properties of AZ31B Magnesium Alloy Processed by I-ECAP: *Michal Gzyl*[1]; Andrzej Rosochowski[1]; Raphael Pesci[2]; Evgenia Yakushina[1]; Paul Wood[1]; Lech Olejnik[3]; [1]University of Strathclyde; [2]ENSAM-Arts et Métiers ParisTech; [3]Warsaw University of Technology

Incremental equal channel angular pressing (I-ECAP) is a severe plastic deformation process used to refine grain size of metals, which allows processing very long billets. In this work, AZ31B magnesium alloy was processed by routes A, B_C and C of I-ECAP. Texture and grain size effects on mechanical properties and tension-compression anisotropy were investigated. Strong influence of processing route on yield and fracture behaviour of material was established. SEM technique was used to obtain microstructure images of I-ECAPed samples subjected to tension and compression. Different deformation mechanisms were activated during tension in samples with coarse and fine grained microstructures. In coarse grained samples large amount of twins was reported while fined grained microstructure exhibited slip dominated deformation. Influence of different deformation mechanisms on mechanical properties was discussed. It was concluded that material properties of AZ31B can be tailored for various applications by using different routes of I-ECAP.

5:50 PM

Development of Grain Refiner for Mg Alloys: *Leandro Bolzoni*[1]; Magdalena Nowak[1]; Nadendla Hari Babu[1]; [1]Brunel University

The grain refinement practice is well established for aluminium-based wrought alloys. However, for magnesium casting alloys, the practice of adding grain refiners is not well established in industries. Historically, zirconium is widely known to be an effective refiner for Al-free Mg alloys. However, due to the undesirable reaction between Zr and Al, stable intermetallic phases form and this adversely poisons the effect on grain size refinement. Hence, the anticipated effect of grain refinement seen for Al-free Mg alloys has not been achieved for Al-containing Mg-alloys. Research at Brunel University has identified a novel grain refiner (NGR) which can effectively refine the grain structure of various commercially used Al-containing and Al-free Mg alloys. Experimental results for AZ91D and AM50 alloys are reported. It was found that the addition of the NGR not only refines the grain structure but also makes the grain size less sensitive to the cooling rate.

Session 4B: Processing - I

Tuesday PM Room: Seminar Room
May 21, 2013 Location: IMDEA Materials Institute

Session Chair: J.T. Wang, Nanjing University of Science and Technology

4:10 PM
Enhanced Mechanical Response of Hierarchical Mg Nano-Composite as a Function of Temperature: *Meisam Kouhi Habibi*[1]; Abdelmagid Hamouda[1]; Manoj Gupta[2]; [1]Qatar University; [2]National University of Singapore

The effect of temperature change on quasi-static mechanical response of monolithic Mg alongside hierarchical Mg/Al-Al_2O_3 nano-composites synthesized through powder metallurgy route followed by microwave assisted rapid sintering technique and hot extrusion in 25-200°C temperature range is investigated here. It was observed that in the case of both monolithic Mg and hierarchical Mg/Al-Al_2O_3 nano-composites, due to temperature increase, strength compromised while failure strain tremendously increased. The asymmetry in tension and compression also tends to vanish as temperature increases. These observed variations in strength and ductility were ascribed to the activity of non-basal slip systems and dynamic recovery at high temperature. It was also observed that presence of composite Al-Al_2O_3 particles (level-I particles) significantly assisted in improving mechanical response of Mg either at ambient or elevated temperature. Considering the crystallographic texture, the different mechanical response of Mg due to presence of level-I particles as a function of temperature is differentiated here.

4:30 PM Invited
Mg Sheet and Tube Warm Forming: From Incremental to Electromagnetic Forming: *Ibai Ulacia*[1]; Lander Galdos[1]; Jon Ander Esnaola[1]; Gurutze Arruebarrena[1]; Eneko Saenz de Argandoña[1]; Iñaki Hurtado[1]; [1]Dept. of Mechanical and Manufacturing Eng., Mondragon University

Magnesium alloys are generating interest in automotive and aeronautic industries due to their low density and thereby reducing gross vehicular weight. However, formability of these alloys is poor and they are very difficult to be formed at room temperature. In this paper magnesium formability at warm conditions is studied with several forming processes and different strain rates. Four different forming technologies are studied: incremental forming (IF), deep drawing (DD), hydroforming (HF) and electromagnetic forming (EMF). It is observed that for all the forming processes increasing temperature increases formability. Moreover, during the experimental tests of IF, vertical forming forces have been monitored and different deformation mechanics taking place are outlined. Deep drawing experiments were performed using a 400 Tn servo-mechanical press in order to change the forming speed. Hydroforming experiments were carried out for tube and sheet materials. Finally, in electromagnetic experiments (at high strain rates), drawing and bending experiments were analyzed.

4:50 PM
The Texture and Microstructure Evolution in Two Alloying Systems of Mg-Zn-Ce and Mg-Zn-Nd after High Speed Rolling: *Mehdi Sanjari*[1]; Seyed Farzadfar[1]; Elhachmi Essadiqi[1]; Hiroshi Utsunomiya[2]; Tetsuo Sakai[2]; Steve Yue[1]; [1]McGill University; [2]Osaka University

The texture evolution in two alloying systems of Mg-Zn-Ce and Mg-Zn-Nd was studied and compared to that of Mg-3Al-1Zn (AZ31) alloy following rolling and subsequent isothermal annealing. Of the studied compositions, the Mg-1Zn-1Ce and Mg-1Zn-1Nd, which had the highest (Ce or Nd)/Zn ratio, showed the weakest as-rolled texture and homogenous shear banding/twinning. Changing the Zn content changed particle size and, in alloys subject to texture weakening, the static recrystallization mechanism altered. The Mg-1Zn-1Ce (with the highest Ce/Zn), texture weakening is maintained even after full recrystallization, when grain coarsening occurs. However, in the Mg-4Zn-1Ce and AZ31 alloys, texture strengthening occurs when grain coarsening occurs, and the double split basal peak is replaced by a single peak. It is concluded that the differences between the Ce bearing alloys is related to Zn; increasing Zn decreases the solubility of Ce, which can influence the texture changes.

5:10 PM
Texture Modification and Microstructural Design of AZ31 Mg Alloy Plate for Better Formability: *Ebubekir Dogan*[1]; Ibrahim Karaman[1]; David Foley[1]; Karl Hartwig[1]; [1]Texas A&M University

Interest on Mg alloys has significantly increased in recent years for weight-critical applications such as automotive structures. However, challenges still exist such as its limited formability. Rolled Mg alloys plate and sheets show strong basal texture that causes remarkable in-plane tension-compression asymmetry, which negatively influence the formability. Formability can be improved by weakening the basal texture in Mg alloy sheets. Equal channel angular processing (ECAP) can induce different deformation textures as opposed to conventional sheet rolling. In this study, a commercial AZ31 Mg alloy plate has been processed using a multiple-temperature ECAP to investigate grain size-texture-mechanical flow response relations. It has been shown that strong basal texture and flow response of AZ31 Mg alloy plate can be modified in such a way to improve formability through different multi-temperature ECAP routes. Latent hardening behavior of AZ31 Mg alloys has been also studied; specifically the latent hardening due to twinning was investigated.

5:30 PM
Microstructure and Mechanical Behaviour of PM MgGd1Zn0.5(at.%) Alloy: *Sandra Cabeza*[1]; Gerardo Garcés Plaza[1]; Pablo Pérez Zubiaur[1]; Paloma Adeva Ramos[1]; [1]CENIM (CSIC)

Rare-earth containing magnesium alloys receive considerable interest due to their potential for improving strength and creep resistance. Additions of Zn to Mg–Gd alloys can generate a strong precipitation hardening. In MgGd1Zn0.5 alloy, thin plates precipitated in the Mg basal plane, though hardening effect at room temperature was low. Powder metallurgy (PM) route was proposed to increase the strength of the alloy. Atomized powders were cold compacted and extruded at high temperature. For comparative purpose MgGd1Zn0.5 cast alloy was also extruded. Microstructural characterization indicated a bimodal structure with magnesium grains and intermetallic particles located at grain boundaries. Grain size was 7 and 1µm for cast and extruded and PM alloy, respectively. The yield stress and UTS values at room temperature increased from 212 to 297 MPa and from 297 to 374 MPa, respectively by the PM processing. At high temperatures, the PM alloy shows superplasticity (700%) at high strain rate.

Session 5: Processing - II

Wednesday AM May 22, 2013 | Room: Auditorium | Location: IMDEA Materials Institute

Session Chair: Y. Kawamura, Kumamoto University

9:00 AM Keynote

New Developments in the Field of Wrought Magnesium Alloys: *Dietmar Letzig*[1]; Sangbong Yi[1]; Gerrit Kurz[1]; Jan Bohlen[1]; [1]Helmholtz-Zentrum Geesthacht

The application of wrought magnesium components lacks in a better understanding of the influence of a thermo-mechanical treatment, such as rolling, extrusion or forging, on the properties of the resulting parts. Furthermore, properties of structural parts are dependent on the evolved microstructure from the process. A better understanding is needed for outlining the needs in microstructure development for designing suitable properties of wrought magnesium components. The presentation will give a general overview on the special needs of wrought processes and a process-specific alloy design. Further, the research activities at the Magnesium Innovation Centre-MagIC will be presented with respect to the above mentioned aspects. Special focus of the presentation will be given to the recent understanding on the effects of deformation and recrystallisation on the texture and microstructure evolution during different process routes, e.g. extrusion, rolling and continuous strip casting, and the resulting mechanical properties.

9:20 AM Invited

A Novel Approach to Mg Alloy Sheet Development by Combined Thixomolding and Thermomechanically Processing: *J. Wayne Jones*[1]; Tracy Berman[1]; Raymond Decker[2]; [1]University of Michigan; [2]Thixomat, Inc

Formability in magnesium alloy sheet is strongly limited by a strong basal texture in the as-rolled material, which is difficult to remove by thermal processing. Here we describe an approach that sequentially combines Thixomolding and Thermomechanical Processing (TTMP) to produce rolled sheet without strong basal texture. Plates of AZ61L with a divorced β-Mg17Al12 eutectic are produced by Thixomolding to produce a non-textured, fine-grained (2.8 µm) precursor plate. Sheet produced from the plate by single pass warm-rolling exhibits only a weak texture and a significant improvement in both strength and ductility over that observed in conventionally processed AZ-series alloy sheet. Furthermore, a stable finer-grained, low-texture microstructure can be produced by recrystallization of TTMP sheet that further improves strength and ductility. The influence of the evolving microstructure, particularly ß-phase distribution throughout the TTMP process, on the mechanisms of microstructure and texture control and subsequent deformation behavior will be described.

9:40 AM Invited

Development of Very High Strength and Ductile Mg-alloys by Dispersion of Quasicrystal Phase: *Alok Singh*[1]; Yoshiaki Osawa[1]; Hidetoshi Somekawa[1]; Toshiji Mukai[2]; Catherine Parrish[3]; Donald Shih[3]; [1]National Institute for Materials Science; [2]Kobe University; [3]The Boeing Company

A quasicrystalline Mg_3Zn_6Y phase exists in direct equilibrium with a-Mg phase in the Mg-Zn-Y system. Thus Mg-Zn-Y alloys containing various amounts of quasicrystal phase can be prepared by solidification. This phase is dispersed in the matrix by wrought processing such as rolling and extrusion. Recently we showed yield strengths of about 400MPa in tension as well as compression, accompanied by ductility of 12-16%, in a Mg-6at%Zn-1at%Y alloy fabricated by chill casting direct extrusion. We show here production of alloys with yttrium content 0.5at% and less (with proportional zinc content) with yield stresses of over 350 MPa and ductility of over 12%. These alloys have been prepared by simple solidification and extrusion. Microstructure of these alloys will be shown and strengthening mechanisms discussed.

10:00 AM

Influence of the Extrusion Conditions and the Neodymium Content on the Microstructure, the Texture and the Deformation Behaviour of Magnesium-manganese Alloys: *Paloma Hidalgo-Manrique*[1]; Sangbong Yi[2]; Jan Bohlen[2]; Dietmar Letzig[2]; María Teresa Pérez-Prado[1]; [1]IMDEA Materials Institute; [2]Magnesium Innovation Centre MagIC, Helmholtz Zentrum Geesthacht

Magnesium alloys are promising structural materials due to their weight-saving possibilities. However, magnesium extrusions are typically characterised by direction dependent mechanical properties such as yield asymmetry and mechanical anisotropy due to their sharp prismatic fibre texture. It has been shown that the addition of certain rare-earth (RE) elements leads to weaker and more random textures. Here, extrusion experiments were carried out at different temperatures and speeds on two variations of the Mg-1 wt.% Mn alloy containing different Nd amounts. The microstructures and the textures developed under the different extrusion conditions have been investigated in order to understand the recrystallization and the grain growth mechanisms. Room temperature tensile and compressive tests along the extrusion direction are also performed with the aim of correlating the microstructure, the texture and the mechanical behaviour. Based on the experimental results, the predominant deformation mechanisms are investigated.

10:20 AM Break

Session 6: Deformation and Recrystallization Mechanisms - V/Processing - III

Wednesday AM   Room: Auditorium
May 22, 2013   Location: IMDEA Materials Institute

Session Chair: Dietmar Letzig, Helmholtz Zentrum Geesthacht

11:10 AM Keynote

Deformation Structures and Recrystallization in Magnesium Single Crystals: Konstantin Molodov[1]; *Talal Al-Samman*[1]; Dmitri Molodov[1]; Günter Gottstein[1]; [1]RWTH Aachen University

Single crystals of pure magnesium were subjected to plane-strain compression to investigate the microstructure and texture evolution during deformation. Specimens were tested in different orientations with respect to the compression direction yielding different deformation characteristics. For c-axis compression at room temperature the specimen showed high strength of 280 MPa before breaking at 7% strain. At elevated temperatures macroscopic {10-11}-compression twinning was important for strain accommodation and DRX. For compression perpendicular to the c-axis two prismatic orientations were investigated, which allowed activation of different {10-12}-twin variants resulting in distinct deformation characteristics. While at RT the <10-10>-orientation failed at 11% and remarkably high stress of 360 MPa, the <11-20>-orientation demonstrated outstanding ductility exceeding 100%. The microstructure was heterogeneous comprising large grains and small equiaxed grains with grain sizes below 10 µm. Microstructure analysis revealed three generations of extension twinning that lead to the development of numerous new orientations favorable for basal slip.

11:30 AM Invited

Developing Superplasticity in Magnesium Alloys through Severe Plastic Deformation: *Roberto Figueiredo*[1]; Terence Langdon[2]; [1]Federal University of Minas Gerais; [2]University of Southern California

The interest in improving the properties of magnesium alloys has led to the development of technology to refine the grain structure especially through the use of severe plastic deformation. The present paper summarizes recent developments in processing commercial magnesium alloys through Equal-Channel Angular Pressing (ECAP). Optical microscopy and tensile tests were used to evaluate the grain structure and high temperature mechanical properties in order to determine the effect of processing by ECAP. An analysis of grain structure shows that ECAP effectively reduces the average grain size. High temperature tensile tests demonstrate that ECAP reduces the flow stress and improves the strain rate sensitivity and the elongation to failure. Superplastic elongations in excess of 1000% were achieved after ECAP.

11:50 AM

Advanced Processing for Advanced Performance of Mg-Zn-Zr Alloy: *Dmitry Orlov*[1]; Alexei Vinogradov[2]; Kei Ameyama[1]; Yuri Estrin[3]; [1]Ritsumeikan University; [2]Togliatti State University; [3]Monash University

The key factors that limit the use of magnesium products are difficulty in processing, their relatively low strength and restricted ductility, as well as unacceptable levels of corrosion in many environments. Recently we proposed an integrated process in which a single extrusion step is combined with two passes of equal channel angular pressing. The processing of Mg-Zn-Zr alloy ZK60 with this integrated process allowed us to achieve simultaneous enhancement of several properties that are commonly inversely correlated. Namely, the material demonstrated yield strength of 310MPa and ultimate tensile strength of 351MPa, total elongation of 17.1% and area reduction of 42.5%, fatigue strength of 160MPa as well as improved corrosion resistance in mild NaCl electrolytes. In the presentation, the improvement in corrosion resistance and the unique combination of mechanical properties are correlated with grain refinement, texture evolution and redistribution of Zn and Zr solutes within the microstructure.

12:10 PM Invited

The ExoMet Project: EU/ESA Research on High-Performance Light-Metal Alloys and Nano-Composites: *Wim Sillekens*[1]; David Jarvis[1]; [1]European Space Agency

The performance of structural materials is commonly associated with such design parameters as strength and stiffness relative to their density; a recognised means to further enhance the weight-saving potential of low-density materials is thus to improve on their mechanical attributes. The European Community research project ExoMet that started in mid-2012 targets such high-performance aluminium- and magnesium-based materials by exploring novel grain-refining and nanoparticle additions in conjunction with melt treatment by means of external fields (electromagnetic, ultrasonic, mechanical shearing). The consortium of 27 companies, universities and research organisations from 11 countries integrates various scientific and technological disciplines as well as application areas – including automotive, aircraft and space. This paper gives an overview of the project, including its scope for development, objectives, targeted innovations, activities and partnership. In addition to a state-of-the-art description for the field at hand, initial results will be presented.

Session 7: Deformation and Recrystallization Mechanisms - VI

Wednesday PM   Room: Auditorium
May 22, 2013   Location: IMDEA Materials Institute

Session Chair: J.F. Nie, Monash University

2:00 PM Keynote

Mechanism-based Behavior and Texture-independent Hall-Petch Relation of a Mg–3Al–1Zn Alloy: *Jing Tao Wang*[1]; [1]Nanjing University of Science and Technology

With their HCP lattice structure, Mg and Mg alloys have complicate mechanical features based on the variety of deformation mechanisms activated in alternative combinations. This paper summarizes some of these features of an Mg-3Al-Zn alloy: a. the well-known compression/tensile yielding asymmetry related with texture and polarized behavior of twining is found originated from the different population of twinned grains; b. the different low-cycle tension-tension fatigue properties in twinning- or dislocation slip-dominated tests is found resulted from the stronger cyclic hardening and roughness-induced crack closure in twinning-dominated tests; c. texture evolution and

TEM observation reveal that (c+a) non-basal slip contribute significantly in deformation under high hydrostatic pressure; d. with the proposed concept of equivalent Schmid factor of the variety of crystallographic deformation mechanisms, a model is developed to separate the contribution to yield stress from grain refinement and texture, which leads to a texture-independent Hall-Petch relation.

2:20 PM Invited

Ultrastrong Mg-Alloy via Nano-Spaced Stacking Faults: Weiwei Jian[1]; Weizhong Xu[1]; Hao Yuan[1]; Ming-Hung Tsai[1]; Carl Koch[1]; Yuntian Zhu[1]; *Suveen Mathaudhu*[2]; [1]North Carolina State University; [2]U.S. Army Research Office

Mg alloys are among the lightest alloys but their strengths are usually low. Here we report a new mechanism to make them ultrastrong and moderately ductile. Stacking faults with nanoscale spacing were introduced into a Mg-8.5Gd-2.3Y-1.8Ag-0.4Zr (wt.%) alloy by conventional hot rolling, which produced a yield strength of ~575 MPa, an ultimate strength of ~600 MPa, and a uniform elongation of ~ 5.2%. Low stacking fault energy played an essential role in producing a high density of stacking faults which impeded dislocation slip and promoted dislocation accumulation. These findings provide guidance for development of Mg alloys with superior mechanical properties.

2:40 PM Invited

Creep and Fatigue Behaviour of Calcium-containing AZ91 Magnesium Alloys: *Dorothea Amberger*[1]; Heinz Werner Höppel[1]; Philip Eisenlohr[2]; Mathias Göken[1]; [1]Universität Erlangen-Nürnberg; [2]Max-Planck-Institut für Eisenforschung

The low density of magnesium alloys makes them attractive for light-weight constructions. However, an important issue are the rather poor mechanical properties of the most commonly used Mg alloy AZ91 at elevated temperatures. Hence, the use of AZ91 is limited to low temperature applications. Alloying AZ91 with calcium leads to a significant improvement of the mechanical properties. The microstructure of AZ91 consists of the alpha-Magnesium solid solution and the intermetallic phase $Mg_{17}Al_{12}$. With an increasing addition of calcium, $Mg_{17}Al_{12}$ is substituted more and more by the intermetallic phase $A_{l2}Ca$. Additionally, the morphology of the intermetallic phases changes from rather isolated particles in case of the calcium-free alloy AZ91 towards a skeleton with increasing interconnectivity with increasing calcium content. These changes in the microstructure lead to a significantly enhanced creep resistance. Fatigue lives of the calcium containing alloys can be compared to calcium-free AZ91. The damage mechanisms will be discussed.

3:00 PM Invited

Creep Deformation Mechanisms in Magnesium Alloy AZ31: *Oscar Ruano*[1]; Jorge del Valle[1]; [1]CENIM-CSIC

In this work, the hot workability and the creep behavior of the magnesium alloy AZ31 is analyzed based on own work and also that from various researchers. A wide range of temperatures and strain rates was considered. The existence of three deformation mechanisms, grain boundary sliding , solute drag creep and climb-controlled- dislocation creep, in the temperature range 200 to 450ºC and the influence of grain size and grain growth are analyzed. The superplastic regime, where grain boundary sliding is controlling deformation and the stress exponent, n, is close to 2, is shown to be influenced strongly by the low thermal stability of the alloy. As a consequence, the analysis of deformation mechanisms could, erroneously, conclude on the occurrence of a creep mechanism involving a n=3 exponent, interpreted as the evidence of viscous glide-controlled deformation.

3:20 PM Break

Session 8A: Processing - IV

Wednesday PM — Room: Auditorium
May 22, 2013 — Location: IMDEA Materials Institute

Session Chair: Jan Bohlen, Helmholtz Zentrum Geesthacht

4:10 PM Invited

Deformation Behavior of Mg-Zn-Ca Alloy Sheets under Biaxial Loading: D.-W. Kim[1]; B.-C. Suh[1]; M.-S. Shim[1]; D. H. Kim[2]; S. Lee[1]; *Nack J. Kim*[1]; [1]POSTECH; [2]Yonsei University

High formability at room temperature is one of the most important property requirements for commercial applications of Mg alloys. Although it has been shown that weakened or randomized texture enhances the formability at room temperature in Mg alloys, the detailed deformation behavior of Mg alloys under biaxial loading condition, experienced during stretch forming, is not well understood. In this presentation, we report the room temperature deformation behavior under biaxial loading condition of Mg-Zn-Ca alloy sheet, whose texture is characterized by the broadening as well as splitting of basal poles along the transverse direction. It shows that the deformation at an initial stage of biaxial loading is dominated by tension twinning although the stress state is not favorable for tension twinning. At a later stage of biaxial loading, these tension twins become de-twinned, resulting in a final fracture. The origin of such prevalence of tension twinning will be discussed.

4:30 PM

Analysis of the Protective Behaviour of Different Inhibitors for Magnesium Investment Casting: *Nuria Herrero-Dorca*[1]; Gurutze Arruebarrena[1]; Haritz Sarriegi Etxeberria[1]; Pedro Pablo Rodríguez[2]; Unai Andres[2]; Yoana Bilbao[2]; Iñaki Hurtado[1]; [1]Mondragon Unibertsitatea; [2]ALFA IDEI

Molten magnesium reacts with the refractory oxides present in the commercial investment casting shells. Consequently, a non-desired surface layer is formed on the casting surface, but severe reactions can even lead to mould destruction. Thus, magnesium investment casting industry requires the development of specific mould materials and/or inhibitors that can avoid the formation of the non-desired surface reactions. In this work conventional gaseous SF_6, non-conventional liquid $NaBF_4$ and KBF_4, and environmentally friendly liquid FK inhibitors have been tested on alumina-based investment casting moulds. Chemical analysis of the different surface films by SEM/EDS and XRD has provided the information needed to understand the role that the inhibitors play in the formation of the surface films, based in fluorine compounds: the arrangement of MgF_2 through the surface layer determines the protective character of the films. As a result, KBF_4 has been selected as the most suitable inhibitor.

4:50 PM
Effect of Mg_2Sn Precipitate on Microstructure and Texture Evolution of Hot Deformed Mg-Al-Sn Alloy: *Abu Syed Humaun Kabir*[1]; Jing Su[1]; In-Ho Jung[1]; Steve Yue[1]; [1]McGill University

During deformation in common magnesium alloys, recrystallization is usually not accompanied with a noticeable change of deformation texture resulting in, strong mechanical anisotropy. The aim of this work is to investigate the effect of precipitates on microstructure and texture evolution during hot deformation of Mg-Al-Sn alloy. Mg-Al-Sn alloy has been designed using thermodynamic modeling software, FactSage, based on forming target Mg_2Sn precipitate at hot deformation temperatures between 250 and 350 ºC. Uniaxial compression has been introduced at these elevated temperatures to enhance the formation of precipitates. The formation of dynamic Mg_2Sn precipitate, during the recrystallization process may slow down the grain growth by grain boundary pinning effect resulting in, finer grain size, grain size homogenization and randomization of texture.

5:10 PM
Hot Deformation Behavior and Workability Characteristics of AZ91 Magnesium Alloy Powder Compacts: *Mohammad Ali Jabbari Taleghani*[1]; Jose Manuel Torralba[1]; [1]Institute IMDEA Materials

This study examined the hot deformation behavior and workability characteristics of AZ91 Mg alloy powder compacts by performing hot compression tests with a Gleeble 3800 machine. To this end, powder compacts with a relative green density of 94 % were hot-compressed at temperatures ranging from 150 to 500 °C and at true strain rates ranging from 0.001 to 10 s-1. The true stress-true strain curves peaked at low strains, after which the flow stress increased slightly or remained constant. The work hardening rate decreased with increasing deformation temperature or strain rate. Processing maps were developed for all of the hot compression tests at strains of 0.1 and 0.5, which represented two safe deformation domains. According to these processing maps and the side views of the hot-compressed specimens, the optimum hot working window for AZ91 Mg alloy powder compacts was determined to lie between 150-300 °C and 0.001-0.01 s-1.

5:30 PM
Process-Structure-Property Correlation of Mg-(5.6Ti+1SiC) BM Composite: *Sankaranarayanan Seetharaman*[1]; Rama Sabat[2]; Jayalakshmi Subramanian[1]; Satyam Suwas[2]; Abdelmagid Hamouda[3]; Manoj Gupta[1]; [1]National University of Singapore, Singapore; [2]Indian Institute of Science, Bangalore, India; [3]Qatar University

This study involves the synthesis of Mg composites containing hybrid reinforcements (5.6 wt.% micron-sized titanium (Ti) particulates and 1 wt.% nano sized silicon carbide (n-SiC) particles) through the disintegrated melt deposition technique, followed by hot extrusion. The role of ball milled, hybrid,(5.6Ti+1SiC)BM particulate reinforcements addition, in improving the mechanical response of pure magnesium was studied through the microstructure, texture and mechanical properties correlation. Mechanical property evaluation by tensile and compression tests indicate significant strength properties improvement without affecting the ductility, due to hybrid reinforcements addition. The crystallographic studies carried out to identify the grain morphology and orientation using electron backscattered diffraction and x-ray diffraction analysis indicate a significant grain refinement and texture sharpening due to hybrid reinforcements addition. The observed mechanical properties enhancement in Mg-(5.6Ti+1SiC)BM composite attributing to the microstructural and crystallographic texture changes due to ball milled, hybrid reinforcements addition, will be presented.

Session 8B: Advanced Characterization Techniques - I

Wednesday PM — Room: Seminar Room
May 22, 2013 — Location: IMDEA Materials Institute

Session Chair: Stefanie Sandlöbes, Max Planck Institute for Iron Research

4:10 PM Invited
In-situ Synchrotron Diffraction of Magnesium Matrix Composites: Influence of SiC Particles on Plastic Deformation: *Gerardo Garces*[1]; Elvira Oñorbe[1]; Pablo Pérez[1]; Manuela Klaus[2]; Christof Genzel[2]; Paloma Adeva[1]; [1]CENIM-CSIC; [2]Helmholtz-Zentrum Berlin

Synchrotron Radiation Diffraction during in-situ tensile and compressive tests have been used to evaluate the internal elastic strains within the grains of AZ31 magnesium alloy, un-reinforced and reinforced with 5 and 10 %vol. of SiC particles. Composites present initial thermal residual stresses, which are positive (tensile) in the matrix and negative (compressive) in the reinforcing particles. Internal elastic strains evolve in a similar manner in both the un-reinforced AZ31 and in the composites. However, the accumulated elastic strains are reduced in the case of the composite because part of the applied load is borne by the ceramic particles. In compression, the plasticity of extruded composites is controlled by the tensile twining process, as in the un-reinforced alloy. However, the volume fraction of twins is rapidly saturated as the volume fraction of reinforcement increases. SiC particles balance the tensile stress generated by twins during plastic deformation.

4:30 PM
Characterisation of Nano-scaled Precipitates in a Peak Aged Mg-8Gd-2Dy Alloy: *Chamini Mendis*[1]; Williams Lefebvre[2]; Lei Yang[1]; Yuanding Huang[1]; Karl Kainer[1]; Norbert Hort[1]; [1]Helmholtz Zentrum Geesthacht; [2]Université et INSA de Rouen

Mg-Gd-Dy alloys are developed for their potential applications as degradable biomaterials. Mg-10Dy alloy shows a good combination of strength and resistance to corrosion in simulated body fluid. Though the strengthening due to precipitation is very low for the Mg-10Dy alloys, it can be significantly enhanced with the addition of Gd so that microstructures and mechanical properties can be tailored. The Mg-8Gd-2Dy alloy showed significantly large enhancement in age hardening response compared with the binary Mg-10Dy alloy. Conventional transmission electron microscopy (TEM) investigation has shown that the strengthening is due to fine scale precipitates forming on prismatic planes of magnesium. In this contribution we report the characterization of the precipitates found using electron micro diffraction and high angular annular dark field scanning TEM

(HAADF-STEM).

4:50 PM
An in-depth TEM/SAXS Study of Ageing-Induced Precipitation in MgZn: *Brian Pauw*[1]; Julian Rosalie[1]; [1]National Institute for Materials Science

Complementary small angle x-ray scattering (SAXS) and transmission electron microscopy (TEM) have been used to follow (in-situ and ex-situ) precipitate size and volume fraction evolution during isothermal ageing in an Mg-Zn alloy containing rod-shaped precipitates. After determination of texture and precipitate morphology through electron back-scattered diffraction and TEM, sufficient information was available for advanced analysis of the SAXS data. SAXS enables the determination of bulk-averaged size- and volume fraction information from sample populations many orders of magnitude greater than practically achievable with TEM. Furthermore, the The Monte-Carlo method employed in this SAXS data analysis allows for form-free determination of the size distribution, and returns uncertainty estimates on the resulting distribution and volume-fraction parameters. This contribution will expand upon the working methodology which underscores the synergetic relationship between TEM and SAXS, using the MgZn alloys as a real-world example to which the stereological analysis has been applied.

5:10 PM
Lattice Strain Evolution during In-situ Deformation of AZ31 Alloy using Conventional Laboratory X-ray Diffraction: *Sitarama Kada*[1]; Peter Lynch[1]; Matthew Barnett[1]; [1]Deakin University, Australia

The elastic lattice strain is a very useful entity to evaluate the micro-plastic deformation behaviour of metals and alloys. Neutron diffraction is the most common technique used for this purpose. In this paper, we develop an in-situ laboratory based transmission X-ray diffraction approach. This technique is employed to reveal the normal lattice strain perpendicular to the applied load during the tensile deformation of Mg alloy AZ31. Extruded samples with a mean grain size of ~ 7\956m were deformed in tension perpendicular to extrusion direction. Based on the deviation of the lattice strain from its linear elastic trajectory, basal slip is identified in (10-12) and (10-13) grains at ~ 75 and 90 MPa respectively. Tensile twinning ({10-12}<10-11>) is observed in (0002) and (10-13) grains at ~ 108 and 135 MPa respectively. The mean critical resolved shear stress for tensile twinning in (0002) and (10-13) grains are 54 and 45 MPa respectively.

5:30 PM
Identifying the Deformation Mechanisms in Coarse- and Fine-grained Mg-Zn-Zr Alloy by Analysis of Acoustic Emission: *Alexei Vinogradov*[1]; Dmitry Orlov[2]; Yuri Estrin[3]; [1]Togliatti State University ; [2]Ritsumeikan University; [3]Monash University

Understanding of deformation mechanisms in magnesium alloys is a key to the improvement of their structural efficiency. However, techniques allowing in-situ monitoring of operative mechanisms are very limited. We employed acoustic emission (AE) to understand synergetic interplay between two primary deformation mechanisms – dislocation slip and twinning. Through the analysis of AE time series performed with the aid of spectral transform and a variety of categorisation methods, the sequences of predominant deformation mechanisms in a wrought alloy ZK60 were identified with a high degree of confidence. The effect of the grain size on the relative contributions of these deformation mechanisms was analysed. To that end, coarse-grained microstructure in the initial material was refined by a single-step integrated process involving extrusion followed by equal-channel angular pressing. This investigation provided further insights in the deformation mechanisms in Mg alloys and may help developing processing routes leading to their improved structural performance.

Session 9: Deformation and Recrystallization Mechanisms VII

Thursday AM — Room: Auditorium
May 23, 2013 — Location: IMDEA Materials Institute

Session Chair: C.J. Boehlert, Michigan State University

9:00 AM Keynote
High Strength Magnesium Alloys Strengthened by Synchronized LPSO Phase: *Yoshihito Kawamura*[1]; [1]Kumamoto University

New high strength alloys, which are duplexes of α-Mg phase and a novel phase with a long period stacking ordered (LPSO) structure, have been developed in Japan. LPSO structure is formed in Mg-TM-RE alloys, in which the TM element is Co, Ni, Cu, Zn or Al, and the RE (rare earth) element is limited to Y, Gd, Tb, Dy, Ho, Er or Tm. In the LPSO structure, the TM and RE elements are enriched in four atomic layers on basal planes at intervals of 5, 6, 7, and 8, respectively. The LPSO structure can be called "Synchronized LPSO Structure", because the stacking and chemical modulations are synchronized. This phase has better mechanical properties than α-Mg phase and undergoes kink deformation. This kink deformation drastically improves the mechanical properties of LPSO phase. This kinking can be a new concept for the strengthening of metals.

9:20 AM
Tensile Properties and Microstructure of Mg-Sc Alloys with Ordered-BCC/HCP Dual-phase: *Daisuke Ando*[1]; Yuji Stou[1]; Junichi Koike[1]; [1]Tohoku University

Mg alloys have poor formability and limited ductility at room temperature due to their HCP structure. Meanwhile, Mg-Li alloys with above 15 at% Li have BCC/HCP dual-phase. They show good ductility at room temperature and exhibit superplasticity at above 423K. However, Mg-Li alloys have low tensile strength and poor high-temperature strength. In this study, we propose Mg-Sc alloys with BCC/HCP dual-phase. According to diffusion couple methods, a ß-Sc BCC phase was found to exist in much higher Mg content than the results of previous studies and a BCC/HCP dual-phase was obtained in the composition range of ~12 at% < Sc < ~20 at% at 773K. Mg-15at%Sc alloy with a BCC/HCP dual-phase showed several times higher tensile strength than Mg-Li alloys. In our presentation, we are going to discuss about the relation between mechanical properties and microstructure of BCC/HCP dual-phase Mg-Sc alloys.

9:40 AM
STEM Investigations of Synchronized LPSO Structures in Mg-Zn-Y Alloys: *Daisuke Egusa*[1]; Eiji Abe[1]; [1]University of Tokyo

Mg alloys with small additions of TM (transition metal) and RE (rare earth) have attracted great attentions due to their excellent mechanical properties. One of the unique microstructural features of the alloys is formation of novel type of long period stacking/ordered (LPSO) structures. We have successfully constructed model structures of the complex LPSO Mg alloys based on STEM atomic imaging effectively combined with first-principle calculations [1], demonstrating that state-of-the-art microscopy is now able to provide a precise structure model with the aid of energy-based optimizations. We further attempt to tune the LPSO Mg-Zn-Y structures based on both theoretical calculations and STEM experiments including a unique annular bright-field (ABF) imaging [2], finding novel insights that the significant local relaxations would generate interstitial atomic sites even in the close-packed LPSO structures. [1] D. Egusa and E. Abe, Acta Mater., 60 (2012) 166. [2] R. Ishikawa et al., Nature materials, 10 (2011) 278.

10:00 AM
Geometric Features of Kink Bands in Deformed Mg-Zn-Y Alloys with LPSO Phase: *Michiaki Yamasaki*[1]; Koji Hagihara[2]; Yoshihito Kawamura[1]; [1]Kumamoto University; [2]Osaka University

Mg-Zn-rare earth alloys containing the long-period stacking ordered (LPSO) phase are given large attentions because of their excellent mechanical properties. The LPSO phase in Mg-Zn-Y alloy is found to have a (0001) basal plane which is the same as that in Mg (2H), but its stacking periodicity is lengthened 9-fold (18R) along the c-axis. The 18R-LPSO phase has chemical modulation, in which solute elements are enriched in four atomic layers on the closely packed plane at six-period intervals. The change in the atomic arrangement and peculiar segregation of Y and Zn atoms on the specific layers in LPSO phase strongly hinder the formation of a deformation twin; instead, a deformation kink appears. It is expected that unique microstructure evolution occurs during extrusion. In this study, therefore, distribution of intragranular misorientation axis (IGMA) in an Mg-Zn-Y alloy composed mostly of LPSO phase was investigated by using IGMA analysis using EBSD.

10:20 AM Break

Session 10: Advanced Characterization Techniques - II

Thursday AM — Room: Auditorium
May 23, 2013 — Location: IMDEA Materials Institute

Session Chair: Erica Lilleoden, Helmholtz Zentrum Geesthacht

11:10 AM Keynote
Combination of High Resolution Experiments and ab initio Calculations to Design Ductile Mg Alloys: *Stefanie Sandlöbes*[1]; Martin Friak[1]; Stefan Zaefferer[1]; Zongrui Pei[1]; Fulin Wang[1]; Li-Fang Zhu[1]; Sangbong Yi[2]; Dietmar Letzig[2]; Jörg Neugebauer[1]; Dierk Raabe[1]; [1]Max-Planck-Institut für Eisenforschung GmbH; [2]Helmholtz Zentrum Geesthacht Zentrum für Material und Küstenforschung GmbH, Magnesium Innovation Centre

Compared to pure Mg, single phase Mg-Y alloys show an increase in room temperature ductility up to 5 times, while maintaining comparable strength and well-balanced work hardening. We showed that the enhancement of the mechanical properties of Mg-Y alloys is caused by a facilitated activation of additional deformation mechanisms providing a <c>-deformation component enabling the material to accommodate a higher total strain. Combining complementary high-resolution characterization methods and ab initio calculations we identified the I1 stacking fault energy (SFE) as a guiding parameter for ductility in Mg alloys. Using the parameter SFE I1 we performed ab initio calculations and selected further favourable elements which decrease the SFE I1 in Mg. Based on these predictions we designed and produced new binary Mg alloys. Mechanical testing and microstructure characterization show increased room temperature ductility which is caused by the activity of non-basal deformation modes in the newly designed Mg alloys.

11:30 AM Invited
An Investigation of the Local Mechanical Response at the Grain Level for Magnesium: *Warren Poole*[1]; Ghazal Nayyeri[1]; Guilhem Martin[1]; Chad Sinclair[1]; [1]The University of British Columbia

In this work we have used a combination of spherical nanoindentation and local strain measurements to investigate the deformation behaviour of individual grains in a polycrystal. The orientation of individual grains was determined from EBSD measurements for high purity magnesium and for a magnesium 1 wt% Zn, 0.5 wt%Nd alloy. Individual grains with orientations of interest were tested with spherical nanoindentation and the variation of local plastic strain was analyzed from a grid fabricated on the surface for different levels of far field deformation. The stress-state under the nanoindenter was calculated using Hertzian contact mechanics and then the stresses were resolved onto the various crystallographic slip/twin planes to understand how plasticity is initiated under the indenter. The combination of local strain distribution and the nanoindentation hardness as a function of the far-field strain provides insight into the differences between deformation mechanisms observed in magnesium and a model rare earth alloy.

11:50 AM
Deformation Mechanisms in Magnesium Characterized by Single Crystal Indentation: *Claudio Zambaldi*[1]; Christoffer Zehnder[1]; [1]Max-Planck-Institut für Eisenforschung

We present recent findings on the indentation behavior of pure magnesium during indentation. Large grains were indented far away from the grain boundaries to achieve quasi single-crystal indentation. Orientations of the indented grains were determined by orientation microscopy (EBSD). The indent microstructures were characterized by EBSD and electron microscopy. Impression topographies were measured by white-light confocal microscopy. The experimental data cover the orientation space of magnesium to good extent. The orientation dependent indent microstructures are presented in a systematic fashion following Zambaldi & Raabe, Acta Mater. (2010). We discuss the relative contributions from slip and twinning systems to the total deformation by correlating their respective shear strengths to calculated stress fields around the indenter. Our method provides accurate characterization of active deformation systems in magnesium with unmatched efficiency. It is therefore ideally suited to guide the alloy design process.

12:10 PM Invited
Ab Initio and Atomistic Study of Generalized Stacking Fault Energies in Mg and Mg-Y Alloys: *Martin Friak*[1]; Zongrui Pei[1]; Li-Fang Zhu[1]; Stefanie Sandloebes[1]; Johann von Pezold[1]; Howard Sheng[2]; Chris Race[1]; Stefan Zaefferer[1]; Bob Svendsen[3]; Dierk Raabe[1]; Joerg Neugebauer[1]; [1]Max Planck Institute for Iron Research; [2]School of Physics, Astronomy and Computational Sciences; [3]RWTH Aachen University

Magnesium-yttrium alloys show significantly improved room temperature ductility when compared with pure Mg. We study this interesting phenomenon theoretically at the atomic scale employing quantum-mechanical (so-called *ab initio*) and atomistic modeling methods. Specifically, we have calculated generalized stacking fault energies for five slip systems in both elemental magnesium (Mg) and Mg-Y alloys using (i) density functional theory (DFT) and (ii) a set of embedded-atom-method (EAM) potentials. These calculations predict that the addition of yttrium results in a reduction in the unstable stacking fault energy of basal slip systems. We find a similar reduction for the stable stacking fault energy of the {11-22}<11-23> non-basal slip system. Other energies along this particular γ-surface profile increase with the addition of Y.We have also developed a new EAM Mg-Y potential and tested its performance. The comparison of quantum-mechanical and atomistic results indicates that the new potential is suitable for future large-scale atomistic simulations.

Session 11: Microstructure and Advanced Characterization Techniques - III

Thursday PM	Room: Auditorium
May 23, 2013	Location: IMDEA Materials Institute

Session Chair: Warren Poole, University of British Columbia

2:00 PM Keynote
Precipitation and Strengthening in Magnesium Alloys: *Jian-Feng Nie*[1]; [1]Monash University

This presentation provides a review of precipitation in most precipitation hardenable magnesium alloys and its relationship with strengthening. It will be demonstrated that the precipitation phenomena in these alloys, especially in the very early stage of the precipitation process, are still far from being well understood, and that there are still many fundamental issues remaining unsolved even after some extensive and concerted efforts made in the past decade. The challenges associated with precipitation and age hardening will be discussed, and guidelines for rational design and development of higher strength, and ultimately ultra-high strength, magnesium alloys via precipitation hardening will be outlined.

2:20 PM
Microcompression Investigation of Slip and Twinning in Pure Mg Single Crystals: *Erica Lilleodden*[1]; Gyu Seok Kim[1]; [1]Helmholtz-Zentrum Geesthacht

Microcompression testing has been performed on high purity magnesium single crystals in order to investigate the mechanisms of slip and twinning. While columns compressed along the [0001], [2-1-12], and [10-11] axes undergo dislocation plasticity only, the columns compressed along the <11-20> and <10-10> axes are dominated by deformation twinning. In the case of the <11-20> compression direction, twinning leads to a reorientation of the crystal favorable for basal slip. At a critical twin thickness massive basal slip is activated within the twin. The combination of rapid twin propagation and massive basal slip is indicated by a large strain burst in the stress-strain response. In contrast, twinning in the <10-10> oriented columns does not lead to strongly favorable basal slip, and the observed massive strain burst is due only to rapid twin propagation. Such a mechanistic picture of the deformation behavior is revealed through SEM, EBSD and TEM characterization.

2:40 PM
Evaluating the Plastic Anisotropy of AZ31 using Microscopy Techniques: María Teresa Pérez Prado[1]; Z. Chen[2]; J. Llorca[3]; C. Boehlert[4]; [1]IMDEA Materials Institute; [2]Michigan State University and Washington State University; [3]IMDEA Materials Institute and Polytechnic University of Madrid; [4]Michigan State University and IMDEA Materials Institute

The tensile deformation mechanism of a rolled AZ31 alloy at 50°C, 150°C, and 250°C was investigated by a combination of in-situ tensile testing, electron backscatter diffraction analysis, as well as ex-situ atomic force microscopy analysis. With increasing temperature, there was a significant difference in the activity of the various deformation modes, along with a decrease in the plastic strain ratio. Extension twinning was only observed at 50°C, while at higher temperatures, a combination of basal and prismatic slip accounted for a large percentage of the observed deformation activity. Prismatic slip was prevalent at all testing temperatures and exhibited increased activity with increasing temperature. Ex-situ atomic force microscopy measurements suggested that the contribution from grain boundary sliding to the overall strains increased with increasing temperature. Overall, the in-situ experiments combined with atomic force microscopy suggested that grain boundary sliding contributed more to the reduction in plastic strain ratio with increasing temperature than non-basal slip activity.

3:00 PM
Damage during High Temperature Deformation of Mg Alloys Studied by Continous 3D Characterisation: Pierre Lhuissier[1]; Luc Salvo[1]; Elodie Boller[2]; Mario Scheel[2]; Marco Di Michiel[2]; *Jean-Jacques Blandin*[1]; [1]Université de Grenoble / CNRS; [2]ESRF Grenoble

Magnesium alloys are generally sensitive to strain induced cavitation when they are deformed at high temperature. X-ray micro tomography is an efficient tool for imaging strain induced damage processes. However, 3D characterisations are usually performed in samples deformed up to given strains and then characterised (i.e. post mortem conditions). Thanks to particularly short acquisition times, damage developed during high temperature deformation of magnesium alloys has been continuously characterised by tomography in the present work. Such conditions provide opportunities for distinguishing nucleation, growth and coalescence of cavities since it allows to follow each cavity up to the fracture step.

3:20 PM

Measuring the Critical Resolved Shear Stresses in Mg Alloys by Instrumented Nanoindentation: *Raul Sanchez*[1]; Teresa Pérez-Prado[1]; Javier Segurado[2]; Iván Gutierrez[3]; Javier Llorca[2]; Jon M. Molina-Aldareguia[1]; [1]IMDEA Materials Institute; [2]IMDEA Materials Institute and Polytechnic University of Madrid; [3]Max-Planck-Institut für Eisenforschung GmbH

Conventional magnesium alloys have high anisotropy and therefore poor formability. Rare-earth (RE) alloys constitute an important alternative as they exhibit a more isotropic behavior. This has been attributed to their weak textures and to the reduction of the difference between the CRSS values of the slip systems. However, the effect of RE elements in Mg alloys is still unknown. We propose a new methodology to measure the CRSSs, combining nanoindentation and finite element simulations based single-crystal plasticity. Nanoindentations have been performed in individual grains of rolled and annealed pure Mg and AZ31 and in an extruded Mg-1%Mn-1%Nd alloys. Grain-to-grain variations in the hardness have been attributed to the activation of different slip systems as a function of the grain crystallographic orientation. The observed trends were compared with the outcome of finite element simulations. The effect of the different alloying elements in the CRSSs has been inferred from these measurements.

Session 12: Modelling - I

Friday AM
May 24, 2013

Room: Auditorium
Location: IMDEA Materials Institute

Session Chair: Javier Llorca, IMDEA Materials Institute

9:00 AM Keynote

Thermodynamics Database and Kinetics Simulation for Mg Alloy Design: Paliwal Manas[1]; Sazol Kumar Das[1]; Junghwan Kim[1]; *In-Ho Jung*[1]; [1]McGill University

Thermodynamic and kinetic knowledge is indispensable to understand the microstructural development of alloys. In order to keep pace with Mg alloy developments and the expansion of the Mg industry, Mg alloy thermodynamic databases have been developed over the last 10 years. Recently, fundamental solidification and diffusion studies for Mg alloys have been also performed to understand the evolution of solidification structure and diffusivities of solute in Mg. In the present study, the current state of development of the optimized FactSage thermodynamic database and our new kinetic simulation tool for solidification and homogenization process for Mg alloys will be presented along with several application examples for Mg alloy development.

9:20 AM Invited

First-Principles Modeling of Deformation Mechanisms in Mg and Mg Alloys: *W. Curtin*[1]; M. Ghazisaedi[2]; [1]EPFL; [2]Brown University

We present core structures for c+a screw and twinning dislocations in Mg, as computed using density functional theory combined with a multiscale method. We then present a model for solute strengthening [1] of basal slip that uses first-principles input on solute/basal-dislocation interaction energies [2]. The model makes quantitative predictions of basal strengthening of versus temperature and concentration for Mg-Al [3] and Mg-Zn. We extend the model to predict solute strengthening of twinning in Mg, with application to Mg-Al, Mg-Zn, and Mg-Ga. Based on these analyses, we conclude with some discussion of future directions for fruitful progress in first-principles-based multiscale modeling of c+a –type slip in Mg and its alloys. [1] G. Leyson et al., Nature Materials 9, 750 (2010); Acta Mater. (2012). [2] J. A. Yasi et al., Acta Materialia 58, 5704 (2010). [3] G. Leyson et al., Acta Mater. (2012).

9:40 AM Invited

Beyond Binaries: Solid Solution Strengthening and Softening in Magnesium: *Dallas Trinkle*[1]; Joseph Yasi[1]; Louis Hector[2]; [1]University of Illinois, Urbana-Champaign; [2]General Motors R&D Center

Modern first-principles methods predict dislocation core geometries in magnesium, interactions with solutes, and allowed for predictive modeling of solute effects on CRSS in magnesium. In addition, high-throughput computational studies predict how solutes change magnesium lattice constants, stacking fault energies, and interact directly with basal and non-basal dislocation cores, correlating with predictions of strength. To extend this data beyond single species predictions requires models for the interaction of solutes with each other, the distribution of solutes in the matrix, and the interaction of dislocations. The solute-solute interaction energies determine the propensity to form clusters, and the distribution of different size clusters affects the energy landscape for dislocation motion. This connects our dislocation/solute interaction energies to atomic-scale solute distribution to model the effect of clustering on the predictions of plastic deformation in magnesium alloys. The solute-solute interaction data connects to characterization studies of solute distribution and measurements of strength for magnesium alloys.

10:00 AM Invited

Integrated Computational Materials Engineering (ICME) for Development of Magnesium Alloys, Manufacturing Processes and Engineering Products: *John Allison*[1]; [1]The University of Michigan

Compared with other structural metals, magnesium alloy development is relatively immature thus motivating global interest in new alloys and processes. Traditionally this alloy and process optimization process has been conducted empirically and iteratively. Integrated Computational Materials Engineering (ICME) offers the promise of accelerating the development of new materials and increasing the efficiency of new product and process development. This talk will provide an overview of three separate but related research activities involved in development of an ICME capability for development of magnesium alloys and products. The first is a US Automotive Materials Partnership consortia program developing ICME models for predicting the age hardening response of super vacuum die cast magnesium alloys. The second is a program developing tools for predicting the influence of manufacturing process on location-specific tensile ductility of high pressure die cast magnesium alloy products. Finally, an overview will be provided of a new University of Michigan Software Innovation Center for Integrated Multi-Scale Modeling of Structural Metals. This Center is focused on development of advanced models and experiments for predicting the fatigue and fracture response of extruded magnesium alloys. It involves development of advanced, integrated open-source software, collaborative community building and The Materials Commons, an open knowledge repository.

10:20 AM Break

Session 13: Modelling - II

Friday AM
May 24, 2013

Room: Auditorium
Location: IMDEA Materials Institute

Session Chair: Bill Curtin, École Polytechnique Fédérale de Lausanne

11:10 AM Invited
First-Principles Investigation of Mg-Rare Earth Precipitates and LPSO Structures: Ahmed Issa[1]; James Saal; *Chris Wolverton*; [1]Northwestern University

To help understand the large strengthening response of RE additions to Mg, we use density functional theory calculations to study the energetic stability and elastic properties of β'' and β' precipitate phases and LPSO phases. We investigate the coherency strain energy of Mg-β'' binary systems using first principles and find the β'' precipitates to strongly prefer prismatic, as opposed to basal, habit planes for all Mg-RE systems. This anisotropy in strain energy provides an explanation for the observed precipitate morphology in these systems, and hence the large strengthening response. Although long-period stacking ordered (LPSO) structures have been known to improve mechanical strength in Mg alloys for over a decade, only recently have LPSO crystal structure models been proposed. Using density functional theory (DFT), we explore the thermodynamic stability of several LPSO structural models across a wide range of Mg-ternary systems, and predict new systems where LPSO phases should form.

11:30 AM
Quantification of Internal Stresses in Magnesium: *Laurent Capolungo*[1]; Nicolas Bertin[1]; [1]Georgia Institute of Technology

The proposed study presents a multi-scale modeling strategy allowing for quantifications of the development of internal stresses in polcrystalline magnesium during elasto-plastic loading. Focus is first given here on the development of Eshelbian micromechanics methods to allow for a rendering of the coupling between parent phases and twin phases. This is done via the introduction of a two-step homogenization method. The idea is to render here of long range coupling between twin and parent domains. Second, this study presents a constitutive model allowing for a the quantification of the effect of short range interactions between dislocation and twin boundaries on hardening of Mg. The method employed to bridge the scales is based on discrete dislocation dynamics.

11:50 AM
Development of a Crystal Plasticity Model for Mg Alloys: *Vicente Herrera*[1]; Javier Segurado[2]; Javier Llorca[2]; [1]Polytechnic University of Madrid; [2]Polytechnic University of Madrid and IMDEA Materials Institute

In order to predict the macroscopic response and texture evolution in polycrystals of Mg single crystal plasticity model (SCP) has been developed and implemented to be used as constitutive equation inside FE models. The model is adapted to reproduce Mg alloys and includes plastic deformation by both slip and twinning. The model is formulated on true finite deformations and, for each time increment, the resulting non-linear equations are solved using a special implementation of Newton-Raphson. This method is developed in order to improve the convergence problems associated with large visco-plastic exponents and the very small yield stress of basal plane. The methodology includes a line search technique and a subincrementation scheme. Finally, the SCP model has been tuned to reproduce the behavior of polycrystals of different Mg alloys including Mg with rare earths. The model was able to reproduce both macroscopic response and microscopic slip and twinning activity.

12:10 PM
3D Polycrystalline Continuum Model of Deformation Mechanisms in Rolled Magnesium Alloys: *Ana Fernández*[1]; Maria Teresa Pérez-Prado[1]; Antoine Jérusalem[2]; [1]IMDEA Materials Institute; [2]University of Oxford

The potential of lightweight magnesium (Mg) alloys to replace heavier materials is now clearly established. Wrought Mg alloys present strong textures and thus specific deformation mechanisms are preferentially activated depending on the orientation of the applied load. Developing models that can contemplate the complexity inherent to deformation of Mg alloys is now timely. In particular, a comprehensive crystal plasticity model including both twin and slip systems as well as their interactions through hardening mechanisms will provide a numerical tool directly relating texture and deformation mechanisms. Here, a Crystal Plasticity Finite Element Model (CPFEM) developed previously has been expanded to represent more realistic polycrystal features considering the topological information of grains. This new model, a 3D polycrystal is represented as a 3D Voronoi tessellation, thus allowing for the study of the local intragranular mechanical fields. The experimental calibration and validation of the model are carried out with an AZ31 rolled sheet.

12:30 PM
Effects of Alloying Elements on Ideal Strength, Stacking Fault, and Twinnability of Mg-base Alloys by First-principles Calculations: *Zi-Kui Liu*[1]; Shun Li Shang[1]; Yi Wang[1]; William Wang[1]; K. A. Darling[2]; L Kecskes[2]; S Mathaudhu[3]; [1]The Pennsylvania State University; [2]US Army Research Laboratory; [3]US Army Research Office

The effects of alloying elements on mechanical properties of Mg are investigated through first-principles calculations. 14 alloying elements are considered: Al, Ca, Cu, La, Li, Mn, Sc, Si, Sn, Sr, Ti, Y, Zn, and Zr. The variations of ideal strength, stacking fault, and twinnability as a function of alloying elements as well as charge density are analyzed and their implications to design Mg-base alloys discussed. It is shown that deformation electron density and electron localization function based on charge transfer provide physical interpretations of property variations. It is observed that rod-like directional bonds in non-fault layers transfer into the tetrahedral shape in fault layers, revealing the local HCP-FCC phase transition. The bonding between Mg and alloying elements, represented by the electron density or the size of tetrahedral between them, is strengthened for alloying elements of HCP or FCC structures and weakened for alloying elements with the BCC structure.

Session 14A: Microstructure, Deformation and Recrystallization Mechanisms

Friday PM
May 24, 2013

Room: Auditorium
Location: IMDEA Materials Institute

Session Chair: C.N. Tomé, Los Alamos National Laboratory

2:00 PM
Stabilization of an HCP-Li Phase at Room Temperature in a Mg-Li Alloy by High Pressure Torsion: *Srinivasa Rao Bonta*[1]; Zhilyaev Alexander P.[2]; Gutierrez-Urrutia Ivan[3]; Maria Teresa Pérez-Prado[1]; [1]IMDEA Materials Institute; [2]University of Southampton; [3]Max Plank Institut für Eisenforschung

Recent studies have demonstrated that high pressure torsion (HPT), that is, the simultaneous application of pressure and shear to a disk shaped sample, can lead to the stabilization of high pressure phases under ambient conditions in Zr and Ti pure metals and alloys. However, the potential of this technique to stabilize metastable phases has still not been thoroughly explored. Here, a BCC Mg-Li solid solution was transformed to a mixture of HCP-Mg and HCP-Li precipitates in a BCC Mg-Li matrix after HPT processing. The transformation is enhanced when the pressure is increased without shear. The subsequent application of shear resulted in the dissolution of the metastable phases and in significant grain growth of the BCC Mg-Li grains.

2:20 PM
Microcompression Study of Orientation and Alloying Effects in Single Crystalline AZ31: *Julia Hapke*[1]; Norbert Huber[1]; Erica Lilleodden[1]; [1]Helmholtz-Zentrum Geesthacht

To further the understanding of Mg deformation, an assessment of the individual dependencies on crystal orientation, microstructure and alloying content is highly desirable. We have used microcompression testing to analyse the stress-strain responses and associated slip and twinning activities in the Mg alloy AZ31. Single crystalline specimens of three different orientations were tested both *in situ* in the SEM and *ex situ*. Representative samples were cross-sectioned after testing and the crystal orientations determined by EBSD. Results show strong anisotropy in stress-strain behaviour, deformation morphology and elastic modulus. In contrast to high purity Mg, striking differences in terms of maximum strength, hardening behaviour, onset and progress of slip and deformation morphology can be observed. While pure Mg generally showed smooth elastoplastic loading followed by a large strain burst associated with catastrophic strain localization, the AZ31 showed serrated loading responses and a high number of activated slip planes.

2:40 PM
Investigation of Deformation Mechanisms in Cast Magensium Using Advanced In-Situ Methods: *Kristian Máthis*[1]; Jan Capek[1]; Petr Lukáš[2]; Donald Brown[3]; Bjørn Clausen[3]; [1]Faculty of Mathematics and Physics, Charles University; [2]Nuclear Physics Institute; [3]Los Alamos National Laboratory

The high-resolution neutron diffraction and acoustic emission (AE) techniques have been used for in-situ investigation of deformation twinning and microstructure evolution in cast polycrystalline magnesium. The combination of these two techniques results in obtaining complementary information about the twinning mechanism and evolution of the dislocation structure during the straining. The analysis of AE response allowed to distinguish between the signals of twinning and dislocation motion. The high resolution diffraction line profile analysis provided information about the active slip systems. The conclusions are supported by microscopy investigations.

3:00 PM
Quantitative Characterization of Precipitate Microstructures in Magnesium Alloys: *Emmanuelle Marquis*[1]; Jiashi Miao[1]; John Allison[1]; [1]University of Michigan

Magnesium alloys are becoming increasingly important for use in the transportation industry however current limitations in their capabilities require new alloys. Integrated computational materials engineering (ICME) is a powerful tool for designing new magnesium alloys or optimizing the processing techniques of magnesium alloys currently in industry application. Precipitation hardening is an important strengthening mechanisms for magnesium alloys, however our current predictive, quantitative understanding of alloying effects on precipitate evolution is limited. In this study, we study evolution of precipitate microstructures in the magnesium alloy AZ91 as a “model” material for development of a more comprehensive understanding of this important phenomenon. A combination of quantitative TEM, STEM and Atom Probe Tomographic characterization were used in conjunction with phase field and first-principles modeling (which are the focus of a companion paper). This talk focuses on the techniques required for quantifying morphology, 3D size and number density of precipitates in this alloy. Atomic structure of precipitates and interfacial structure between precipitates and magnesium matrix was characterized using high angle annular dark field-STEM method. The distribution of different alloying elements in precipitation microstructure was quantitatively determined using atom probe tomography. These experimental results have been used as critical inputs for an ICME tool developed for magnesium alloys. A physically based precipitation strengthening models was developed for this alloy to predict the effects of different heat treatment parameters on the yield strengthen of this alloy.

3:20 PM
Precipitation Hardening of Microalloyed Mg-Zn Based Alloys: *Brian Langelier*[1]; Shahrzad Esmaeili[1]; [1]University of Waterloo

Utilization of wrought magnesium alloys can be expanded through improvement of their mechanical properties – both strength and formability. The addition of microalloying elements to a base Mg alloy has the potential to increase strength by enhancing precipitation hardening. Furthermore, microalloying with rare earth elements can improve alloy formability by promoting a random texture. In this study, Mg-Zn alloys are microalloyed with Ce and Ce-Ca additions to improve the precipitation hardening response, while also modifying texture. The precipitation hardening behaviour and mechanical properties of these novel Mg-Zn-Ce-(Ca) alloys are reported, and related to the effects of alloying/microalloying elements and the alloy microstructures. Particular focus is placed on how these microalloying additions affect precipitate nucleation and evolution, which are examined using multi- scale characterization

FRIDAY PM

methods and thermodynamic analysis.

3:40 PM
Fatigue Behavior of Magnesium Single Crystals under Cyclic Loadings: *Qizhen Li*[1]; [1]University of Nevada, Reno

Magnesium and its alloys become increasingly attractive candidates for various structural components in aerospace industries due to their low density and high specific strength. Materials often experience different loading conditions such as cyclic loading conditions. Cyclic tests were performed on 0001 and 1¯014 magnesium single crystal samples at room temperature. The tested samples were then studied using various microstructure characterization tools including X-ray diffraction, scanning electron microscopy, and high resolution transmission electron microscopy. The sample heavily strained and deformed for 1¯014 single crystal, and the ratcheting strain was about ten times of that for 0001 single crystal. There was no cyclic hardening for 0001 single crystal, while 1¯014 single crystal experienced cyclic strain hardening. Microstructure observations indicated that twinning was the main deformation mechanism for 0001 single crystal and basal slip, pyramidal slip, secondary pyramidal slip, and tension and compression twinning operated for 1¯014 single crystal.

4:00 PM Break

Session 14B: Modelling - III

Friday PM — Room: Seminar Room
May 24, 2013 — Location: IMDEA Materials Institute

Session Chair: In-Ho Jung, McGill University

2:00 PM Invited
Material Characterization and Continuum Modeling of Commercial Grade AZ31B and ZEK100 Magnesium Alloy Sheets: *Michael Worswick*[1]; Srihari Kurukuri[1]; Dariush Tari[1]; Jon Carter[2]; Raja Mishra[2]; [1]University of Waterloo; [2]General Motors R & D – Chemical Sciences and Materials Systems Laboratory

Wrought magnesium alloys are attractive for automotive industry applications due to their low density and high specific strength. However, commercial magnesium alloys, such as AZ31B sheet usually have poor formability at room temperature due to limited activity of slip systems. Additionally, due to the twinning deformation mechanism activated in specific loading directions, magnesium alloys exhibit an asymmetric stress-strain response in uniaxial tension and compression tests. The formability of magnesium alloys can be improved by deforming at elevated temperatures; however, warm forming requires more complex tooling setup which increases the cost of the forming operation. Alternatively, the formability can be improved by the addition of rare-earth elements such as Ce, Nd, Y and Gd, for example, which have been shown to weaken the basal texture. The aim of this work is to compare and identify the effect of initial crystallographic texture on the mechanical response of commercial AZ31B-O and rare-earth ZEK100 magnesium alloy sheets in light of known deformation mechanisms operating at different orientations and strain rates. Tensile and compression testing was performed on AZ31B and ZEK100 sheets along different directions to characterize the material response under a wide range of temperature (23-250°C) and strain rate (0.001s-1-1000s-1). A digital image correlation system (DIC) was used to capture the evolution of plastic strain during the deformation. Three point bend tests were also performed on the AZ31B samples and surface strain on the tensile surface of the bend was measured using the DIC method. The instantaneous R-values and their evolution with respect to the plastic strain were measured from the tensile and compressive DIC data. The ZEK100 sheet exhibits strong in-plane anisotropy both in tension and compression as the orientation changes from the RD to TD. The low to high strain rate experiments reveal a significant orientation dependence of the strain rate sensitivity of ZEK100. In contrast, the rate sensitivity of AZ31B, while pronounced, does not depend upon loading direction. In the RD, the rate sensitivity of ZEK100 is manifest in significant changes in yield strength, but only mild changes in hardening rate. In contrast, along the TD, the yield strength is not affected by strain rate, while the hardening rate increases significantly with strain rate. This behavior is attributed to different deformation mechanisms being activated at different strain rates depending on the load path, sheet orientation and texture. As temperature is increased, the degree of anisotropy and asymmetry is reduced for both alloys.An evolving asymmetric/anisotropic continuum-based approach, adopting Cazacu-Plunkett-Barlat (CPB) yield surfaces, is proposed to model the complex behavior of magnesium alloys at room and elevated temperatures. The model shows that the material response of AZ31B at room temperature is highly anisotropic and asymmetric; while a minor asymmetry between uniaxial tension and compression results is predicted at elevated temperature, consistent with experimental data. The proposed material model is used to simulate 3-point bending experiments on AZ31B and predict both the load-displacement response as well as the distribution of strains on the outer bend radius. The results of the simulation using the new "evolving continuum model" compare well with experimental data over predictions using other material models such as classical von Mises and non-evolving CPB based models.

2:20 PM
Bias Fields and Cast Microstructure: *Martin Glicksman*[1]; [1]Florida Institute of Technology

Small quantities of energy released, or removed, at diffusion-limited interfaces are described as 'capillary bias fields'. These scalar fields are shown to be responsible for branching during dendritic solidification. Bias fields act as weak interfacial energy sources, and their effects on cast microstructures were discovered recently from earlier melting experiments conducted in microgravity. Bias fields derive straightforwardly from the Gibbs-Thomson-Herring equilibrium relation, often used as a boundary condition in microstructure models. Although extremely weak compared to ordinary thermal fields in castings responsible for macroscopic heat transfer, bias fields are deterministically causal for the onset and details of dendrite branching. Examples will be shown of capillary bias fields derived analytically for several dendrite and nucleus shapes, with quantitative comparisons given among the analysis, simulation, and experiments. Understanding the physics of branching dynamics remains essential for further progress in the modeling and simulation of cast microstructures.

2:40 PM
Development of the Thermodynamic Description of the Gd-Mg-Zn and Mg-Y-Zn Systems by Considering the Experimental Microstructures: *Hailin Chen*[1]; Qing Chen[1]; Johan Bratberg[1]; Anders Engström[1]; [1]Thermo-Calc Software AB

Mg-Zn-RE (Rare earth) alloys have attracted lots of attentions because of their remarkable aging hardening effects and high creep resistances. Long-Period Stacking Ordering (LPSO) phases, icosahedral quasicrystalline phases, and an extended solution based on Mg3RE had been reported in these systems, which makes the phase formation in these systems of both industrial and scientific interest. However, the phase equilibria of these systems are far from being well determined and significant discrepancies may exist. A systematic investigation of several Mg-Zn-RE systems was therefore performed in this work, which highlights the similarity and differences among these systems. Thermodynamic modeling was tentatively performed by reproducing the phase equilibria data and reasonably accounting for the experimental microstructures, i.e. phase formation and phase fractions. The obtained thermodynamic descriptions were implemented into the TCMG database. Extensive calculations and comparisons show that the Mg-rich descriptions are reliable and can be used for guiding the magnesium alloy design.

3:00 PM
Modeling of Dynamic Recrystallization in Magnesium Alloys Using a Coupled Crystal Plasticity FEM and Probabilistic Model: *Kaan Inal*[1]; Eugene Starasolski[1]; Abhijit Brahme[1]; Raja Mishra[2]; [1]University of Waterloo; [2]General Motors Research and Development Center

Magnesium has limited ductility and poor formability at room temperature due to lack of available slip systems. Warm/hot forming can increase the formability of magnesium alloys as this process increases the number of available slip systems due to thermal activation. When magnesium alloys are deformed at elevated temperatures, deformation is accommodated by slip and/or twinning until a critical value is reached. After this the material often exhibits dynamic recrystallization (DRX), which results in softening instead of hardening of the flow curve and can be detrimental or beneficial to Mg processing depending on the application. The resultant texture and the properties of Mg alloys deformed at elevated temperature are determined by the nucleation and growth of recrystallized grains conditioned by the deformation process. Accurate prediction of nucleation in the deformed state is essential to predict the final microstructure, texture and properties. This paper presents a coupled approach to model DRX where the crystal plasticity based finite element (CPFEM) method is employed together with a probabilistic model to simulate both nucleation of a new grain and growth of the nucleus at the expense of deformed matrix. The proposed numerical framework employs the local gradient in the dislocation density tensor in the deformed material to determine the nucleation of recrystallized grains. A nucleus is defined as a region (subgrain) of microstructure, which has relatively lower dislocation content as compared to the surrounding matrix. The CPFEM is employed to calculate the "Nye tensor" to determine critical differences (jump) in dislocation contents locally within the microstructure. The growth of the nuclei is then calculated using a probabilistic approach using the mobility of the boundary and stored energy as driving force. Simulations of DRX are performed for AM30 and AZ31 magnesium alloys deformed at 300oC in compression. The predicted textures are in good agreement with experimental data.

3:20 PM Break

Confernece Closure

Friday PM — Room: Auditorium
May 24, 2013 — Location: IMDEA Materials Institute

Session Chair: J. Llorca, C.J. Boehlert, M.T. Perez-Prado

5:00 PM Conference Closure

Poster Sessions

Poster Session A: Processing

Room: Main Hall
Location: IMDEA Materials Institute

Session Chairs: Sangbong Yi, Helmholtz Zentrum Geesthacht

P1: Effect of Manganese Carbonate Addition on the Grain Refinement and Mechanical Properties of AZ80 Alloy: *Jun Ho Bae*[1]; Sung Hyuk Park[1]; Chang Dong Yim[1]; Byoung Gi Moon[1]; Ha-Sik Kim[1]; Bong Sun You[1]; [1]Korea Institute of Materials Science

Grain refinement is an effective way to improve the properties of cast and wrought magnesium alloys. A fine-grained structure is also expected to lead to a more uniform distribution of solute elements, secondary phases and microporosity in the final metal components. The grain refining methods reported for Mg-Al based alloys are super-heating, ferric chloride inoculation, carbon inoculation, rapid cooling and addition of alloying elements. Among them, it is reported that the carbon inoculation is the most effective method of refining the Mg-Al based alloys. However, addition of carbon agents such as C2Cl6 or C6Cl6 causes environmental problems due to the release of toxic gas during refining. In this study, the effect of manganese carbonate inoculation on grain refinement of Mg-Al base alloy was investigated. Simultaneously, the mechanical properties of the as-cast and heat treated AZ80 alloy refined according to the addition of manganese carbonate has been examined.

P2: Effect of the Processing Route on the Microstructure and Mechanical Properties of Mg-Zn-Y-RE Alloy: *Pablo Pérez Zubiaur*[1]; Gerardo Garcés[1]; Paloma Adeva[1]; [1]CENIM-CSIC

The microstructure and mechanical properties of the alloy Mg-1.5Zn-0.6Y-1.2RE (wt%) processed by a powder metallurgy (PM) route as well as by casting and extrusion (conventional route) was studied. The microstructure of the PM material was more homogeneous and finer than that of the alloy processed conventionally. The microstructure of both alloys consisted of a magnesium matrix embedding Mg-RE and long period structure (LPS) phases. The different morphology and size of these phases as well as the smaller grain size of the PM material resulted in a considerable increase in the yield stress, 400 MPa against 230 MPa for the alloy prepared conventionally. Both alloys retained high strength up to 200°C and they exhibited superplasticity above 300°C. At 10-4 s-1, maximum elongations were attained at 300°C in the PM alloy (130 %) and at 400°C for the alloy processed following the conventional route (730 %).

P3: The Microstructure Evolution of Wrought Twin Roll Cast AZ31B Magnesium Alloys Sheet for Different Strain Rates and Temperatures: *Ana Rodriguez*[1]; Ghassan Kridli[2]; Georges Ayoub[1]; Hussein Zbib[3]; [1]Texas A&M University at Qatar; [2]University of Michigan-Dearborn; [3]Washington State University. Pacific Northwest National Laboratory.

This study investigated the effect of the strain rate and temperature on the microstructure evolution of twin roll cast wrought AZ31B sheets. This was achieved through static heating and through tensile test performed at strain rates from 10-4 to 10-1 s-1 and temperatures between room temperature and 300ºC. While brittle fracture with high stresses and limited elongation was observed at room temperature, ductile behavior was obtained at higher temperatures with low strain rates. The strain rate sensitivity and activation energy calculations indicated that grain boundary diffusion and lattice diffusion are the two rate controlling mechanisms at warm and high temperatures, respectively. An analysis of the evolution of the microstructure provided an insight on the deformation mechanisms of the material: twinning (including double twinning) operates at lower temperatures while dynamic recrystallization (DRX) dominates at higher temperatures. The static evolution of the microstructure was also studied, proving a gradual static grain growth of the AZ31B with annealing temperature and time.

P4: Final Assessment of Pre-Industrial Solid-State Route for High Performance Mg-System Alloys Production: Conclusion of the Green Metallurgy EU Project: *Paloma Adeva*[1]; Fabrizio D'Errico[2]; Gerardo Garcés[1]; Markus Hofer[3]; Shae Kim[4]; [1]CENIM-CSIC; [2]Politecnico di Milano; [3]Buhler AG; [4]Korea Institute of Industrial Technology

The Green Metallurgy Project, a LIFE+ project co-financed by the EU Commission, is now completed. The purpose of the Green Metallurgy project was to establish and assess a pre-industrial process capable of utilizing nanostructured based high performance Mg-Zn(Y) magnesium alloys and fully recycled Eco-Magnesium alloys. In this work the Consortium presents the final outcome and verification of the completed prototype construction. To compare upstream cradle to grave footprints when ternary nanostructured Mg-Y-Zn alloys or recycled Eco-Magnesium chips are produced during the process cycle using the same equipment, an LCA was completed. During tests to fine tune the prototype machinery and comparing the quality of semi-finished bars produced using the scaled up system, the Buhler team produced interesting and significant results. Their tests showed the ternary Mg-Y-Zn magnesium alloys to have a rotating bending fatigue resistance of about 140MPa comparable to 7000 series wrought aluminium alloys usually employed in automotive components.

P5: Influence of Calcium Additions on the Microstructure and Properties of Commercial Magnesium Alloy AZ91: *Delphine Thielleux*[1]; Yves Bienvenu[1]; Sylvain Rathery[2]; [1]Mines Paristech; [2]Renault SA

Researches to increase the autonomy of electric vehicles are underway either on the batteries technology or on the lightening of the vehicle parts. For the second approach, one way is to replace aluminium parts by magnesium parts without losing mechanical performance. The present work investigates the interest of variants of commercial cast alloy AZ91 with calcium as an alloying element. At this stage sand casting was chosen for the comparison of microstructures and properties. First, metallographic observations were performed with an optical microscope and a SEM in order to identify the changes in microstructure when alloying with Ca. Combined with DTA and X-ray diffraction analysis, they are useful to understand the solidification sequence of the complex alloys. Tensile and hardness tests were then performed in order to quantify the mechanical strength of the different samples. Fractographic observations were also done to characterize the rupture of the specimens.

P6: Melt Quality and Tensile Property Relationship in HPDC of AM60: *Derya Dispinar*[1]; Cato Dørum[2]; Sebastian Tewes[3]; Erik Hepp[4]; [1]Istanbul University; [2]SINTEF; [3]RWTH; [4]Magma Giessereitechnologie GmbH

The mechanical properties of an alloy depend on the defects that may be present in the matrix. Inclusions, basically oxides, play an important role in casting operations. Particularly in high pressure die casting operations, with casting speeds of minimum 15 m/s up to 40 m/s, the liquid metal advances into the mould in jets that introduces the surface oxide to become incorporated into the melt. However, the oxide inclusions can not exist in melts as a single, because the only way they can become incorporated into the liquid is by entrainment action. During such a simple folding action, the two non-wetted oxide surfaces come in contact to form a bifilm that acts as a crack in the casting. Therefore, in high pressure die castings, the casting will have a spatial distribution of casting defects that will act as the initiation points for porosity nucleation and also as stress risers.

P7: The Effect of Dry Plunge Milling Conditions on Surface Integrity of a Wrought Mg-Zn-Zr-RE Alloy: *Isabelle Danis*[1]; [1]Institut Clément Ader

Plunge milling is a machining process used to remove material rapidly in roughing operations. It is known to permit a significant increase in productivity compared to conventional milling, especially in the case of deep parts. However, high productivity means increasing machining conditions, so plunge milling should present an even more important impact on surface integrity than conventional machining. In this study the authors consider the case of dry plunge milling process applied to a wrought Mg-Zn-Zr-RE alloy. First, the study consists in obtaining surfaces through a design of experiments. Second, plunge milling conditions are correlated with surface integrity factors, such as roughness, material microstructure and microhardness. This study suggests optimal plunge milling conditions to offer a compromise between surface integrity and chip flow.

P8: The Effect of Machining Conditions on the Surface Integrity and Fatigue Life of a Wrought Mg-Zn-Zr-RE Alloy: *Nathalie Wojtowicz*[1]; [1]Institut Clement Ader

Surface integrity of machined components, which includes roughness, residual stress and microstructure has a significant impact on fatigue life. In this study, the influence of machining conditions in turning on fatigue properties of a wrought Mg-Zn-Zr-RE alloy was investigated. The authors propose to determine optimal cutting conditions to achieve a given fatigue strength. First, the study focuses on the characterization of turned surfaces obtained by a design of experiments. Changes of the surface integrity (tensile/compressive residual stress, twinning, enhanced surface roughness) were correlated with cutting parameters : depth of cut, speed, nose radius, feed. In the second part of study, some machining conditions were reproduced on fatigue test specimen. The low cycle fatigue life behavior of the Mg-Zn-Zr-RE alloy is shown to be independant of surface integrity, but correlated with the accumulated plastic strain. For longer fatigue life, machining conditions modify crack initiation mechanism.

P9: The Effect of Strain Rate and Temperature on Microstructural Evolution in Pure Magnesium during ECAE: *Nicholas Krywopusk*[1]; Laszlo Kecskes[2]; Robert Cammarata[1]; Suveen Mathaudhu[2]; Timothy Weihs[1]; [1]Johns Hopkins University; [2]US Army Research Laboratory

Magnesium is an attractive material for investigation due to its high strength to weight ratio, but its mechanical processing is challenging due to a lack of primary slip systems in hcp crystals. Equal Channel Angular Extrusion (ECAE) is a process that has been successful in warm working magnesium, and with careful selection of various processing parameters, can lead to a uniform microstructure. However, the relationship between processing parameters and final microstructures has yet to be fully characterized for magnesium and its alloys. An investigation is underway to fully characterize the effects of strain rate and temperature on microstructural evolution during ECAE processing of magnesium such that desired microstructures may be achieved more easily. Strain rate and temperature will be independently varied and the resulting microstructure studied using Electron Backscatter Diffraction. Experiments are ongoing and initial results will be presented.

P10: Unique Features at the Start of Friction Stir Welds in AZ80 Plate: *Jessica Hiscocks*[1]; Adrian Gerlich[2]; Brad Diak[1]; Mark Daymond[1]; [1]Queen's University; [2]Dept. Mechanical and Mechatronics Engineering, University of Waterloo

Friction stir welding (FSW) is a practical joining method for magnesium alloys. This solid state deformation process removes problems of cracking, porosity, and high thermal distortion associated with conventional arc welding, but introduces unique features related to the texture and phase stability. During metallographic examination of bead-on plate friction stir welds in Mg AZ80, periodic patterns were observed at the start of the welds. The extent of these patterns in the direction of longitudinal travel is directly related to the amount of heat input during welding, with lower heat input resulting in greater extent. The periodicity of these patterns was correlated with the advancement of the welding tool per rotation. The short and long range microstructures and texture dependency on the macroscopic periodicity will be presented. The mechanism of generation of these patterns will be discussed, as well as their implications for common weld mechanics testing procedures.

P11: Weld Seam Characterisation for Extruded AZ31 Magnesium Alloy: *Marcus Engelhardt*[1]; Norbert Grittner[1]; Christian Klose[1]; Hans Maier[1]; [1]Leibniz Universität Hannover

The manufacture of high quality extruded profiles for the automotive and aerospace industry was long time dominated by aluminium alloys. For lightweight design, the use of materials with lower specific density such as magnesium alloys is very attractive. In extrusion industry, porthole dies are used for the production of complex hollow profiles. The investigation of weld seams produced during extrusion of hollow profiles, a key issue in the aluminium extrusion industry, now comes in focus for magnesium alloys. The presented investigations deal with the characterization of extruded weld seams for the alloy MgAl3Zn1 (AZ31). Microstructural analysis and material properties have been analysed with respect to variations in billet temperature, extrusion speed and subsequent cooling. Changes in extrusion parameters yield distinct differences in recrystallization behaviour and microstructure of the weld seams and the surrounding base material.

P12: Evaluation of Tribology of Magnesium Alloy in Plastic Deformation: *Liqun Ruan*[1]; Akihide Maeda[1]; Yasuo Marumo[1];

Yasuhiro Imamura[1]; [1]Kumamoto University

Magnesium alloy is known for its light weight and high strength. Due to the desirable properties, magnesium alloy is required in the fields such as transportation from the energy-saving point of view. The development of forming methods especially is highly expected. In order to manufacture high dimensional accuracy with good surface without defects productions, it is important to evaluate tribological characteristic of forging of magnesium alloys. In this research, the characteristic of tribology of a Magnesium alloy was investigated with the wavy dies which can express surface area expansion. The localized rod-drawing deformation like an experiment was analyzed, and estimated the tribological characteristic between tool and workpiece materials interface.

P13: Role of Nanoscale Boron Carbide Particulates on the Microstructural Evolution and Tensile Response of Mg/1.5B4C Composites: *Sankaranarayanan Seetharaman*[1]; Rama Sabat[2]; Jayalakshmi Subramanian[1]; Satyam Suwas[2]; Abdelmagid Hamouda[3]; Manoj Gupta[1]; [1]National University of Singapore, Singapore; [2]Indian Institute of Science, Bangalore, India; [3]Qatar University

In this study, Mg composite containing (1.5 wt. %) nanoscale B4C particulates was synthesized through the disintegrated melt deposition technique, followed by hot extrusion. Microstructural characterization revealed significant grain refinement and reasonably uniform distribution of nanoparticulates in Mg matrix. EBSD studies conducted on the composite indicate a reduction in the volume of recrystallized grains and c-type fibre when compared to pure Mg. Mechanical properties evaluation in terms of microhardness and tensile properties showed a significant improvement in the overall mechanical behaviour of the composite due to nanoparticulate addition. An attempt is made in the current study to correlate the observed improvement in mechanical properties of Mg-1.5B4C composite with the microstructural and crystallographic texture changes due to B4C addition.

P14: Modification of Pure Mg Anodized Surface by Pulse Power Additional Glycerol for Biodegradable Material: *Yukyoung Kim*[1]; Jeonghui Ji[2]; IlSong Park[2]; TaeSung Bae[2]; Min Ho Lee[2]; [1]Institute of Oral Bioscience and BK 21 Program ; [2]Institute of Oral Bioscience and BK 21 Program

Pure magnesium is good biodegradable material, but is has low corrosion resistance and weak natural oxide layer on magnesium surfaces Anodization is used to in this study which is one of representative wet surface treatment, and it is increased corrosion resistance for control of biodegradation rate. Recently, many studies are used an alkaline solution for electrolyte, and addition of silicate in electrolyte reduces the critical voltage required for the formation of a porous oxidation layer such as sodium silicate(Na_2SiO_3). But Na_2SiO_3 is present in solution in the form of $Si(OH)_4$, and is converted into SiO_2 which could remain in the body for the undegradable particles. Therefore, the aim of this study is used by glycerol variation except sodium silicate by examining its relationship with additives of anodic oxidation for biodegradation material. This work was supported by 'National Research Foundation of Korea(NRF) grant funded by the Korea government (MEST)(No. 2011-0028709)'.

P30: Produce of Al/Mg/Al Laminate Composite using Hot Roll Bonding: *Haitham Saleh*[1]; Friederike Schwarz[2]; Reichelt Stephan[2]; Matthias Schmidtchen[2]; Rudolf Kawalla[2]; Lutz Krüger[2]; [1]TU/Freiberg ; [2]TU/Freiberg

Magnesium cladding with aluminium is used widely in aerospace, car and sport industries, to improve corrosion behavior of magnesium and reduce production costs. To produce this combination the hot roll bonding method is used. It is a solid-state welding process to join similar and dissimilar metals. This method is a well-established and widely used manufacturing process. In this study, Commercial purity aluminium (AA 1050) and Twin Roll Casted (TRC) AZ31 magnesium alloy strips were hot roll-bonded as Al/TRC AZ31/Al composite. The effect of the parameters such as reduction ratio and rolling temperature on the bonding properties were investigated. The microstructure at interface was observed by optical and scanning electron microscopes. Elemental distributions across the Mg/Al interface of the laminated composites were evaluated using EDX.

P31: Effects of Cerium on the Microstructure and Mechanical Properties of as-extruded ZK60 Alloy: *Sung Hyuk Park*[1]; Hui Yu[1]; Jun Ho Bae[1]; Young Min Kim[1]; Chang Dong Yim[1]; Bong Sun You[1]; [1]Korea Institute of Materials Science

The effects of cerium (Ce) addition on the microstructure and mechanical properties of ZK60 alloy were investigated using SEM, EBSD, and TEM and by performing tensile tests of indirect-extruded ZK60 alloys with 0.5, 1.0, and 1.5 wt% Ce contents. The as-extruded ZK60 alloy showed a bimodal grain structure composed of fine recrystallized grains and coarse unrecrystallized grains. The fraction of dynamic recrystallization (DRX) increased with increasing Ce addition, which was attributed to the promotion of DRX by particle stimulated nucleation (PSN) at the Mg– Zn–Ce particles, resulting in a reduced average grain size and weakened basal fiber texture. The tensile strengths, and especially the yield strength, were improved by the addition of Ce due to the fragmented Mg–Zn–Ce particles, more precipitates, and refined grains, while the elongation was decreased due to the hard Mg–Zn–Ce particles.

Poster Session B: Alloying and Microstructure Effects in Deformation and Recrystallization Mechanisms

Room: Main Hall
Location: IMDEA Materials Institute

Session Chair: Joseph Robson, University of Manchester

P15: Deformation Modes in Mg (0001)- and (01-11)-oriented Single Crystals: Simulations vs. Experiments: *Aitor Luque Gomez*[1]; Maryam Ghazisaeidi[2]; William Curtin[1]; [1]EPFL; [2]Brown University

Twinning and basal-slip are studied atomistically, in Mg single-crystalline pillars, at 300K, over a wide strain-rate range, using two embedded-atom-method potentials. (0001)-orientation deformation shows extension and compression-twinning at ~1.4GPa and ~1.7GPa (experimental-rate extrapolation). Twin-nuclei only being stable above 1.15GPa, nanotwinning not being observed, and twin-growth velocity being ~400m/s, Yu and coworkers' nanotwinning-mechanism is thus not supportable. Twins present $(0001)_{matrix}/\{01\text{-}10\}_{twin}$ boundaries, due to a much lower energy compared to standard boundaries (~10-40mJ/m^2 vs. 114mJ/m^2 and 75mJ/m^2, for extension and compression-twin boundaries). TEM observations in Co and Mg corroborate these non-standard twin-orientations. (01-11)-orientation deformation shows basal dislocations, with successive nucleation of leading and trailing-partials at stresses estimated to be 1-1.25GPa (tension) and 0.65-0.9GPa (compression). Overall, deformation mechanisms mirror those experimentally observed, but stresses, even considering experimental-rate extrapolations, remain above experimental levels. This suggests deformation controlled by pre-existing dislocations in micro-pillars, and nucleation influenced by surface defects or FIB damage/contamination in nano-pillars.

P16: Kink-deformed Microstructures in LPSO-Mg Alloys: *Yoshiaki Tanaka*[1]; Daisuke Egusa[1]; Eiji Abe[1]; Takaomi Itoi[2]; Michiaki Yamasaki[3]; Yoshihito Kawamura[3]; [1]University of Tokyo; [2]Chiba University; [3]Kumamoto University

Mg alloys with small additions of tm (transition metal) and re (rare earth) form a unique long period stacking/ordered (lpso) structures and show excellent mechanical properties. kink-deformation is believed to play a key role for realization of the excellent properties of lpso-based mg alloys. phenomenologically, kink deformation is understood as a result of pile-up of a large number of dislocations that have migrated on the limited (0001) plane for hcp-based anisotropic crystals. however, there are few detailed observations of dislocation microstructures of kink-deformation bands. using advanced electron microscopy, we investigate kink-deformed microstructures in the lpso-mg alloys systematically from micron- to atomic-scale, focusing particularly on dislocation characters around the kink-band. interestingly, we preliminary find that a number of dislocations are piled up and regularly arrayed along the c-axis to form remarkably sharp interfaces.

P17: Microstructural and Mechanical Characterization of AZ31 Magnesium Alloy after Multi-temperature Equal Channel Angular Pressing: *Peter Molnar*[1]; Ales Jäger[1]; [1]Institute of Physics, ASCR

Grain refinement of magnesium alloys at temperatures lower than 200°C is challenging task. Equal channel angular pressing is one of the severe plastic deformation techniques which can significantly refine grain size. In the present work AZ31 magnesium alloy was processed by different multi-temperature ECAP cycles with and without backpressure down to 150°C. The microstructure after individual ECAP passes was identified by electron backscatter diffraction (EBSD) technique. Some ECAP cycles lead to the shear bands formation with microcracks inside. EBSD revealed that the microcrack propagation is parallel to the basal planes of grains surrounding microcrack. Crystallographic information of deformed but un-refined large elongated grains was analyzed. Grain size was refined to 1.2 μm and the highest ultimate tensile strength was 380 MPa. Room temperature tensile properties of AZ31 alloy after different multi-temperature ECAP cycles were also measured. Different shapes of the stress-strain curves are confronted with microtextures and microstructure observation.

P18: The Orientation Dependence of Strain Hardening and Texture Development in an Extruded Magnesium Alloy during Compression: Dyuti Sarker[1]; *Daolun Chen*[1]; [1]Ryerson University

Magnesium, having a hexagonal close-packed crystal structure, shows mechanical anisotropy due to the development of sharp crystallographic texture during forming process. In the present study, the strain hardening behavior and texture evolution of an extruded AM30 magnesium alloy were studied in compression using cylindrical samples oriented at 0°, 15°, 30°, 45° and 90° from the extrusion direction (ED). The initial samples were chosen to have a strong basal texture with the basal planes parallel to the ED. A special emphasis was laid upon the influence of sample orientation on the flow behavior and the development of texture and microstructure at varying strain levels. A stage of accelerated strain hardening characterized by an increasing strain hardening rate was observed for samples oriented in the ED. The results indicate that the formation of extensive twins was dependent on crystal orientation and was responsible for the increased strain hardening rate and texture development.

P19: Dislocation Structure of <0001> and <11-20> Mg Single Crystals under Quasi-static and Dynamic Loading Compressions: *Kelvin Xie*[1]; Kevin Hemker[1]; [1]Johns Hopkins University

Magnesium (Mg) and its alloys have attracted increasing research and industrial interest due to their light weight and high specific strength, making them potential structural materials in automobile and aerospace applications. However, current understanding on their deformation mechanisms and dislocation/twinning activities is limited by the complexity of their hexagonal-close-packed crystal structure and the complicated slip systems, especially under high rate loading conditions. In this study, high purity Mg single crystals were compressed along <0001> and <11-20> directions under both quasi-static and high rate compression tests. Two-beam and weak-beam dark-field techniques were employed to discern the <a> and <c> components of the dislocations in both specimens prior- and post-compression under different strain rates. The results presented in this study aim to provide fundamental understanding of dislocation structures in

POSTERS

pure Mg and to serve as a benchmark for the future dislocation and mechanical properties studies in Mg based alloys.

P20: Mechanical Properties of Magnesium and AZ31 Nano-pillars: *Zachary Aitken*[1]; Julia Greer[1]; [1]CalTech

When microstructural (intrinsic) or external material dimensions of materials are reduced to nano-scale they exhibit size-dependent strengths. To date, most studies on "size effects" have focused on single crystalline metals with cubic lattices. Much less is known about the deformation of small-scale hexagonal close-packed crystals, where the limited number of slip systems facilitates deformation twinning to accommodate the applied strain. For Mg, the results of few existing studies are contradictory and provide basis for further investigation. We present results of room temperature and below uniaxial compression experiments on single crystalline Mg and AZ31 alloy micro- and nano-cylinders fabricated by the Focused Ion Beam (FIB). Samples were deformed along a range of crystallographic orientations with respect to the loading direction to elicit dislocation slip vs twinning. Experiments were conducted at room temperature, as well as at 160K. The effects of crystallographic orientations, low temperature, and alloying elements on the mechanical properties of sub-micron Mg are discussed. Deformation characteristics are described in the framework of dislocation nucleation-governed plasticity, twinning, and intrinsic lattice resistance.

Poster Session C: Microstructure

Room: Main Hall
Location: IMDEA Materials Institute

Session Chair: Oscar Ruano, National Center for Metals Research

P21: Core Structure of Long Periodic Stacking Order Phases in Mg-RE Alloys: *William Wang*[1]; Shunli Shang[1]; Yi Wang[1]; Zi-Kui Liu[1]; Kristopher Darling[2]; Laszlo Kecskes[2]; Suveen Mathaudhu[3]; Xidong Hui[4]; [1]The Pennsylvania State University; [2]US Army Research Laboratory; [3]US Army Research Office; [4]University of Science and Technology Beijing

Long period stacking order (LPSO) phases, such as 6H, 10H, 14H, 18R and 24R, have been known to play a significant role in enhancing the mechanical properties of Mg alloys. In the present work, comparisons between the deformation electron density in growth and deformation faults (I1 and I2), and LPSOs are made with simulated high resolution transmission electron microscopy (HRTEM) images and structural characterizations. For the formation energy, it is found that the electron core structures of LPSOs are similar to those of deformation faults (I2), but with different electron densities that correspond to LPSO morphologies. HRTEM simulations of the stacking faults and LPSOs on the prismatic plane show that the I1 with three points in line and I2 with four points in line crossing the fault layer are the same as the electron core structures of 6H and other LPSO phases.

P22: Application of Stereological Method for Measurement of Five-parameter Grain Boundary Distribution in AZ31 Magnesium Alloy: *Andriy Ostapovets*[1]; Peter Molnár[1]; Aleš Jäger[1]; [1]Institute of Physics ASCR

Grain boundaries are generally described by five parameters: three parameters describe lattice misorientation across the boundary and two parameters describe orientation of boundary plane. Stereological method is a way how to estimate five-parameters grain boundary distribution in material from two-dimensional electron back scatter diffraction (EBSD) map. In the present work, this method is applied to characterize grain boundaries in as-rolled AZ31 magnesium alloy. The information about grain boundary distribution is obtained from statistical analysis of EBSD maps. In order to evaluate method's precision, experimental results are compared with results obtained from different theoretically generated maps. It is shown that EBSD maps collected from one side of textured sample do not provide sufficient statistics for application of stereological method. For this reason, EBSD maps must be collected from two perpendicular sides of the sample.

P23: Effects of Microstructure on Compression Behavior of AM80 Mg Alloy: *Taeyoung Choi*[1]; Dae-Hwan Kim[1]; Sugun Lim[1]; [1]i-Cube Center, ReCAPT, Gyeongsang National University

The effects of microstructure on compression behavior of AM80 Mg alloys in this study with its macrostructure were investigated. The specimen used to examine the compression behavior of the Mg alloy was obtained by the cooling slope and permanent mold casting, respectively. Hot compression behavior of the cast Mg alloys has been studied at temperatures from R.T to 350°C and at strain rates from 0.001 to 0.1/s. The cast Mg alloy by cooling slope casting have equiaxed and fine(about 70µ) grains than that permanent mold casting. After hot compression, the experimental results show that microstructures of the cast Mg alloy has on the peak flow stress and soundness of the Mg ally molding. Strain rate sensitivity which was calculated from the slope the of strain rate and flow stress curve, was increased with increasing deformation temperature.

Poster Session D: Corrosion and Oxidation

Tuesday AM Room: Main Hall
May 21, 2013 Location: IMDEA Materials Institute

Session Chair: Bonta Srinivasarao, IMDEA Materials Institute

P24: Development of Protective Surface Oxides on AZ31 via Microalloying Additions: *Alejandro Samaniego*[1]; Kateryna Gusieva[2]; Sebastián Feliu[3]; Nick Birbilis[2]; [1]Monash University/ National Centre for Metallurgical Research (CENIM-CSIC); [2]Monash University; [3]National Centre for Metallurgical Research (CENIM-CSIC)

The Pilling-Bedworth coefficient of magnesium oxide (<1) and its spontaneous transformation to magnesium hydroxide in the presence of moisture makes the inherent corrosion resistance of Mg-alloys via a natural oxide unsatisfactory. In the present study, Mg-alloy AZ31 (nominally 3 wt. % Al, 1 wt. % Zn) has been micro-alloyed with specific elements with a greater tendency to form oxides that Mg, with the view that a more protective surface oxide film can be generated. To study this effect, the micro-alloyed AZ31 was thermally treated at 400ºC. Elements studied include Sc, Y, Lu, Ca and Nd. The subsequent corrosion performance was then analysed using electrochemical techniques, mass loss and hydrogen collection measurements; along with physical characterisation of the microstructure via SEM and surface film characterisation using XPS. The influence of alloy composition upon surface films and microstructure, along with impact on corrosion, are discussed in the present study

P25: Corrosion Inhibition by Turmeric Extract: *Jinendra Chauhan*[1]; [1]Sirt, bpl

The inhibition effect of turmeric extract on Cu corrosion in 0.5N HCl acid has been studied by impedance, Polarisation, Cyclic-Voltametry and FTIR techniques between the 303K to 333 K. The inhibition efficiency increased with the concentration of turmeric extract. The corrosion rate increased with the increase in temperature and it redused when the extract is mearged in solution. The adsorption of extract on metal surface is obeying Langmur's and Temkin's isotherm. The thermodynamic data and results of other technique found that the rate of corrosion is redused. Key words: Turmeric extract, FTIR,, Langmur's and Temkin's isotherm.

P26: Ignition Resistance of CaO Added Mg-Al Alloys for Commercial Aircraft Components: *Hyun Kyu Lim*[1]; Shae Kim[1]; Donald Shih[2]; [1]Korea Institute of Industrial Technology; [2]The Boeing Company

It's been reported that the addition of CaO into conventional Mg alloys, e.g. AZ31, changes the porous surface oxide layer to be more dense and duplex. Therefore CaO added Mg alloys can critically enhance passenger safety during application and security during manufacturing by significantly raising the oxidation and ignition resistances. Two different methods were used to evaluate the ignition resistance of CaO added Mg-Al alloys. The ignition temperatures of the alloys have been measured using DTA with spherical specimen to minimize sharp edge effects. In addition, to obtain the data which are more relevant for aerospace applications, a torch ignition test was utilized for measuring time to ignition and the duration time between ignition and extinguishment. These two methods were applied to various alloys and specimen geometries. It's concluded that CaO containing Mg alloys are nonflammable and could be used for seat components and brackets in commercial airplane payload areas.

P27: New Ignition-resistant Magnesium Alloys: *Bong Sun You*[1]; Young Min Kim[1]; [1]Korea Institute of Materials Science

Simultaneous improvement in ignition resistance and mechanical properties of magnesium alloys can be achieved by the formation of protective oxide layer on the melt and the change in the morphology by alloying. In this study, the effects of alloying elements on the ignition-resistance and mechanical properties of magnesium alloys were investigated. The results of this study show that the combined addition of calcium and yttrium can lead to significant increase in both ignition temperature and tensile properties. This is because the reduction of calcium content and the addition of a small amount of yttrium bring about a reduced amount Ca-containing phases and the formation of multi-layered protective oxides consisting of CaO, Y2O3, MgAl2O4, and MgO that effectively prevent oxygen penetration into the melt.

P28: The Effect of Al2O3 Content on Properties of Cold Spraying Al-Al2O3 Composite Coating Deposited on AZ31 Magnesium Alloy: *Suyuan Yang*[1]; Qiwen Guo[1]; Jing Wang[1]; [1]Beijing Institute of Technology

In this paper, pure Al coating and Al-Al2O3 composite coatings were prepared on AZ31 magnesium alloy using the cold spraying technology. The effect of Al2O3 content on the mechanical properties and corrosion resistance of coatings were studied. In the Al-Al2O3 composite coatings, with the addition of Al2O3 content, the hardness of coatings increased, porosity reduced, bonding strength increased. The corrosion resistance of coatings was analyzed by the electrochemical experiment and salt spray test. Coating corrosion potential was increased greatly compared with AZ31 magnesium alloy substrate. The corrosion resistance of the composite coating added Al2O3 is better than pure Al coating, but the content of Al2O3 content has no significant effect on the coating corrosion resistance.

P29: Influence of Corrosion Damage on Fatigue Behaviour of AZ31 Magnesium Alloy: *Miroslava Horynová*[1]; Ivana Modrácková[1]; Pavel Doležal[1]; Pavel Gejdoš[1]; Josef Zapletal[1]; [1]Brno University of Technology

The fatigue of as received and pre-corroded AZ31 magnesium alloy in the stress amplitude control mode was studied. Two sets of test specimens were exposed to corrosion environment prior to fatigue test. Corrosion of test specimens was carried out in a spray of neutral 5% sodium chloride solution for period of 480 and 1000 hrs. In order to assess the corrosion rate and corrosion mechanism of experimental material, reference specimens were exposed to corrosion environment for period ranging from 1 to 1000 hrs. Fatigue tests in the stress amplitude control mode were carried out on smooth and pre-corroded specimens. Analysis of hysteresis curves was preformed. Comparison of cyclic deformation curves showed that cyclic deformation response is not affected by corrosion damage. Experimental data in both, the low and high cycle fatigue regions were fitted by means of regression functions. S-N curves exhibited smooth transition from the low to the high cycle fatigue regions. Presence of corrosion damage resulted in decrease in fatigue life by 23 % (480 hrs) and 42 %

POSTERS

(1000 hrs) compared to the as received specimens. Furthermore, metallographic and fractographic analysis were performed. In the smooth specimens, fatigue cracks initiated from the specimen surface or at inclusions. In the pre-corroded specimens, the corrosion damage served as initiation site.

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