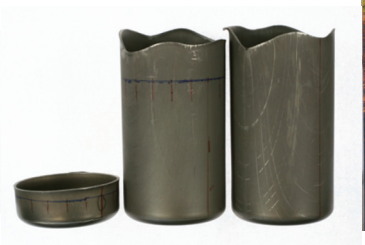
# The 1st German-Korean Workshop on the "Production and industrial applications of semi-finished Mg products"

**Feb. 06. – Feb. 09. 2012, Irsee, Germany**

## Program & Abstracts




**Organisers:** Dr. Dietmar Letzig (Helmholtz-Zentrum Geesthacht)
Dr. Bong Sun You (Korea Institute of Materials Science)

**Sponsors:**

posco

WPM 수송기기용 초경량 Mg 소재 사업단
Mg Material R&D Project for the Super-light Vehicle

KIMS Korea Institute of Materials Science

Bundesministerium für Bildung und Forschung

NRF National Research Foundation of Korea

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

# I. Program overview (Preliminary)

| | Feb.06. (Mon) | Feb.07. (Tue) | Feb.08. (Wed) | Feb.09. (Thu) |
|---|---|---|---|---|
| 09:00 | | Dr. Carsten Blawert (D1) | Dr. Shin-Woo Kang (K2) | Dr. Stefanie Sandlöbes (D14) |
| 09:30 | | Dr. Thomas John-Schillings (D9) | Dr. Martin Kunst (D11) | Dipl.Ing. Martin Ostermair(D12) |
| 10:00 | | Dr. Chang-Hyun Park (K8) | Dr. Hans-Peter Vogt (D17) | Coffee break |
| 10:30 | | Coffee break | Coffee break | Heon Young Kim (K3) |
| 11:00 | | M.Sc. Ilya Ostrovsky (D13) | Dr. Elke Hombergsmeier (D7) | Dr. Dirk Steglich (D16) |
| 11:30 | | Dr. Mun Cheol Kim (K5) | Dr. Yusik Min (K7) | Dr. Jan Bohlen (D2) |
| 12:00 | | Lunch | Lunch | Lunch |
| 12:30 | Lunch | | | |
| 13:00 | | | | Optional excursion to castle Neuschwanenstein |
| 13:30 | | | Excursion to BMW plant Landshut | |
| 14:00 | Welcome | Prof. Jürgen Hirsch (D6) | | |
| 14:30 | Dr. Taewook Kang (K1) | Dr. Young Jin Ko (K6) | | |
| 15:00 | Prof. Karl Ulrich Kainer (D10) | Dr. Soenke Schumann (D15) | | |
| 15:30 | Dr. Bong Seon You (K11) | Coffee break | | |
| 16:00 | Prof. Dr. Michael Höck (D8) | Dr. Min Hong Seo (K9) | | |
| 16:30 | Coffee break | Dr. Jens Grigoleit (D4) | | |
| 17:00 | Prof. Kwang Seon Shin (K10) | Dr. Jae Joong Kim (K4) | | |
| 17:30 | Dr. Martin Hillebrecht (D5) | Dr. Simone Ehrenberger (D3) | | |
| 18:00 | | | | |
| 18:30 | Dinner | Dinner | | |
| 19:00 | | | Dinner | |

**- As a social program of the workshop, a tour to the castle Neuschwanstein in Füssen will be organised on Thursday afternoon (Feb. 09.). This is an optional tour-program for whom has own interest.**

# II. Speakers and Titles of Presentations

: in alphabetical order

## - Germany -

D1: **Dr. Carsten Blawert (HZG)**: Magnesium alloy design for improved corrosion resistance

D2: **Dr. Jan Bohlen (HZG)**: The influence of alloying elements and processing parameters on the mechanical properties of extruded magnesium alloys

D3: **Dr. Simone Ehrenberger (DLR)**: Potentials for the reduction of greenhouse gas emissions in the life cycle of magnesium parts for vehicles

D4: **Dr. Jens Grigoleit (TU Bergakademie Freiberg)**: Magnesium research at TU Bergakademie Freiberg: Joint R&D for and with industrial partners

D5: **Dr. Martin Hillebrecht (EDAG):** When is open innovation successful? Multimaterial concepts of the EDAG light car open source

D6: **Prof. Jürgen Hirsch (Hydro Aluminium)**: The Super Light Car project

D7: **Dr. Elke Hombergsmeier (EADS)**: Potential magnesium applications in aeronautics

D8: **Prof. Dr. Michael Höck (TU Bergakademie Freiberg)**: A technology roadmap for magnesium sheet, profile and wire

D9: **Dr. Thomas John-Schillings (Henkel)**: Metal pretreatment of Mg substrates

D10: **Prof. Karl Ulrich Kainer (HZG)**: Research activities at the Magnesium Innovation Centre, Helmholtz-Zentrum Geesthacht

D11: **Dr. Martin Kunst (BMW)**: Magnesium in automotive engineering

D12: **Dipl.-Ing. Martin Ostermair (UTG):** (in preparation)

D13: **M.Sc. Ilya Ostrovsky (Aero Magnesium)**: Multifunctional surface treatment of wrought magnesium components in aeronautic applications

D14: **Dr. Stefanie Sandlöbes (MPIE)**: Combining ab initio calculations and high resolution experiments to improve the understanding of advanced Mg alloys

D15: **Dr. Soenke Schumann (VW)**: Potential for Mg sheet applications in cars

**D16: Dr. Dirk Steglich (HZG)**: Modelling of magnesium materials: The link between physics and industrial application

**D17: Dr. Hans-Peter Vogt (MgF)**: Competence Network for Wrought Magnesium Alloys - TeMaKplus

## - Korea -

**K1: Dr. Taewook Kang (POSCO)**: WPM Mg national project and POSCO's Mg business

**K2: Dr. Shin-Woo Kang (Central Co.)**: Die forging of magnesium chassis components

**K3: Prof. Heon Young Kim (Kangwon Nat'l Uni.)**: Temperature-dependent hardening behavior of AZ31B Mg sheets

**K4: Dr. Jae Joong Kim (RIST)**: Wide strip casting technology of magnesium alloys

**K5: Dr. Mun Cheol Kim (RIST)**: High efficient vertical magnesium thermal reduction process

**K6: Dr. Young Jin Ko (Hyundai Motor)**: Recent development and applications of magnesium alloys in the Hyundai and Kia Motor Corporation

**K7: Dr. Yusik Min (Dongyang Gangcheol)**: Developing high-precise magnesium extrusion technology

**K8: Dr. Chang-Hyun Park (Noroo Coil Coating)**: Preparation and characterization of conversion coating on magnesium alloy AZ31 sheet

**K9: Dr. Min Hong Seo (POSCO)**: New challenges in the application of Mg sheet to automotive parts

**K10: Prof. Kwang Seon Shin (Seoul Nat'l Uni.)**: Development of high performance alloys at Magnesium Technology Innovation Center

**K11: Dr. Bong Seon You (KIMS)**: Development of noble magnesium alloys: Non-combustible alloys and high performance wrought alloys

# III. Abstracts

D1

# Magnesium alloy design for improved corrosion resistance

C.Blawert*, U. Burmester and V. Heitmann

*Helmholtz-Zentrum Geesthacht*
*Centre for Materials and Coastal Research*
*Institute of Materials Research*
*Magnesium Innovation Centre*
*Corrosion and Surface Technology*
**carsten.blawert@hzg.de*

**Abstract**

The development of magnesium alloys with improved corrosion resistance requires additional concepts compared to standard alloys which obtain their corrosion resistance mainly by reducing the levels of impurities below certain alloy and process depending limits. A number of different approaches (e.g. use of corrosion barriers, reducing internal micro galvanic corrosion, embedding of impurities etc.) are available. The presentation will discuss how requirements of the intended application, knowledge about the corrosion mechanisms and of the electrochemical properties of the phases present as well as studies of the microstructure and prediction of phase fractions by thermodynamic calculations can be used to design modified magnesium alloys with improved corrosion resistance. Based on a real example such an alloy development will be demonstrated.

**Keywords**: magnesium alloy, corrosion mechanisms, corrosion testing, corrosion resistance, alloying

D2

# The influence of alloying elements and processing parameters on the mechanical properties of extruded magnesium alloys

Jan Bohlen*, Dietmar Letzig, Karl Ulrich Kainer

*MagIC – Magnesium Innovation Centre, Helmholtz-Zentrum Geesthacht*
*Max-Planck-Str. 1,D-21502 Geesthacht / Germany*

Jan.bohlen@hzg.de

The extrusion of profiles is a significant step towards an expansion of the potential of magnesium alloys in light weight construction. In this regard, alloy and process development are a concern to enhance the mechanical properties of wrought magnesium alloys. Further, the comparably simple process consisting of a single deformation step allows the influence of parameters such as temperature and deformation rate (extrusion rate) on the microstructure and texture development to be studied.

In this presentation the behaviour of magnesium alloys during extrusion experiments is analysed. The effects of the extrusion parameters on essential properties such as grain size and texture will be discussed and related to the resulting room temperature mechanical properties. A variation of the alloy composition of basic Mg-Al, Mg-Zn and Mg-Mn-alloys due to the addition of further elements such as Zr, rare earth elements (Ce, Nd) and Y is used to refine and stabilise the microstructure of the extrudates. Microstructure characterisation before and after extrusion reveal the changes resulting from deformation and recrystallisation during processing. The influence of alloying elements on the mechanical properties of wrought magnesium alloys will be discussed.

D3

# Potentials for the reduction of greenhouse gas emissions in the life cycle of magnesium parts for vehicles

Simone Ehrenberger*, Horst E. Friedrich

*German Aerospace Centre, Institute of Vehicle Concepts, Stuttgart, Germany*
**simone.ehrenberger@dlr.de*

**Abstract**

For a few years now, magnesium supply has been dominated by Chinese producers who provide about 80 % of primary magnesium in the world. The Pidgeon process as used there, however, has been shown to have high greenhouse gas emissions per kg pure magnesium compared to electrolysis technology, which is used in other magnesium producing countries. But when using magnesium as lightweight material for automotive applications, the reduction of emissions over the whole life cycle of a vehicle is one of the main goals.
As production processes in China have changed significantly concerning efficiency and energy consumption, we surveyed Chinese magnesium producers and analyzed the data with regard to gaseous energy carriers, process improvements and resulting greenhouse gas emissions. We compare our results to the performance of magnesium from the electrolysis process.
Magnesium is used for various automotive parts. As a light material it lowers $CO_2$ emissions at the tail pipe, though its production is more energy intensive than in case of aluminium or steel. We discuss this by showing break-even distances from the use of two different magnesium components in comparison with other materials. Furthermore, we show the state and the constraints for the reuse of magnesium parts and how recycling influences the results of the greenhouse gas balance over the whole life cycle.

**Keywords**: life cycle assessment, greenhouse gas balance, magnesium production, recycling, automotive application

D4

# Magnesium Research at TU Bergakademie Freiberg: Joint R&D for and with Industrial Partners

Jens Grigoleit, Rudolf Kawalla
*Technische Universität Bergakademie Freiberg*
*Institute for Metal Forming*
*www.magnesium.tu-freiberg.de*

**Abstract**
Research on magnesium alloys and on the production of magnesium sheet material, specifically, has been a relevant research topic of the Institute for Metal Forming (IMF) since the 1990s. The research focus is on developing semi-finished long and flat products such as strip and sheet material from different magnesium alloy especially by using the innovative twin-roll casting technology. When in 2002 an industrial-scale pilot plant for twin-roll casting of magnesium strip up to a width of 700 mm went into operation, this was the worldwide first facility of its kind. This plant is operated in cooperation by the IMF together with its partner ThyssenKrupp MgF and was extended by a hot rolling mill for magnesium strip in late 2009. With an experience of almost ten years of research on twin-roll casting and production of magnesium flat products the IMF gained expertise for developing processes and technologies for magnesium strip materials. Systematical application of advanced scientific approaches on micro-structural development of magnesium alloys in thermo-mechanical treatment and other findings of modern material science are used to achieve further improvements of process efficiency as well as materials properties to meet highest demands. To support these efforts, the IMF has an excellent range of research facilities. Besides the before mentioned worldwide unique combination of twin-roll casting and hot rolling mill, a multiple-stand hot rolling mill for bar and strip production with integrated heating and cooling systems, a rolling stand that is usable as duo or quarto as well as a trio hot rolling mill and further rolling mills for cold-strip production are available. Additionally, the IMF is equipped with a broad range of testing facilities like e.g. metallography and different appliances for heat treatment and mechanical testing as well as modern software for simulations of casting and forming processes. On this basis, and building on the considerable body of existing experience, there are broadest potentials for conceiving new cooperative research projects together with partners from other research institutions and industrial enterprises. One current example for such cooperative work is the research network TeMaK and TeMaKplus in which partners from 11 industrial companies and 2 research institutes are developing innovative technologies for producing high-quality components from magnesium sheet and strip. Covering the whole production chain from the production of the strip material up to the finished component and its integration into more complex products TeMaKplus develops technological solutions for a broad range of industrial applications of wrought magnesium alloys. This encompasses automotive and aerospace applications as well as components for industrial, household and medical appliances as well as leisure and sports equipment.
The presentation will offer a general view on current research on magnesium alloys by the Institute for Metal Forming with a special focus on joint industrial R&D programs. It outlines the potentials for joint research projects with industrial partners in the future and will also offer a lookout an the future development of magnesium alloy research from the perspective of the TU Bergakademie Freiberg and its Institute for Metal Forming.

**Keywords**: Wrought Magnesium Alloys, Twin-roll Casting, Hot Rolling, Sheet and Strip Material, Production Technologies

D5

# When is Open Innovation successful? Multimaterial Concepts of the EDAG Light Car Open Source

Dr.-Ing. Martin Hillebrecht

*Head of Competence Center Lightweight Design*

*EDAG GmbH & Co KGaA*
*Reesbergstraße 1, 36037 Fulda*
**martin.hillebrecht@edag.de*

**Abstract**

When designing pioneering vehicles, new and sometimes controversial demands need to be taken into account. Special electric vehicles produced in small quantities require novel lightweight construction methods. Even for conventional cars, there is an increasing emphasis on economical considerations in view of requirements for CO2 reduction through decreased weight along with improved safety, comfort and road performance. Regarding urban electric mobility, the vehicle weight in particular is a major factor affecting its energy consumption. Rolling resistance and aerodynamic aspects are also significant influences, but due to acceleration and braking manoeuvres they are of secondary importance. This underlines the need for finding suitable methods of producing very lightweight components, whilst keeping costs reasonable and minimising investment.

The motivation behind "Light Car - Open Source" was to develop a concept for urban electric mobility in 2015 in the form of a scalable vehicle structure. The multi-material concept involves innovative metal and plastic technologies, along with metal/plastic bonding methods. Correct functioning was established by virtual means together with a production concept, while a prototype "space frame demonstrator" provided a real example. This prototype was exhibited at the Geneva Motor Show 2010 and also displayed at the OEMs premises in the form of a roadshow.

In order to push the innovation agenda, the challenge lies in establishing good-quality partnerships between developers such as EDAG and material and technology specialists who are active on the market, this aspect being a vital factor for success. Project-based cooperation allows the strengths of the partners involved to be combined. EDAG has a long-standing experience in "open innovation" creation and realisation. The cooperation can be bilateral in nature, and can also be in the form of networks focussing on specific projects or topics. The EDAG "Light Car - Open Source" concept demonstrates how weight- and cost-saving potential can be realised by implementing effective lightweight construction strategies, and by using efficient construction and production methods, appropriate materials and simulation technologies.

As a final point, we mention the potentials out of the application of magnesium in the body structure of future cars out of the view from EDAG as an international leading, independent development company of the automobile industry.

**Keywords**: Lightweight design, demonstrator, body-in-white, open source

D6

# THE SUPERLIGHT-CAR PROJECT "UP TO 35% WEIGHT SAVING IN MASS-PRODUCED COMPACT CARS

Jürgen Hirsch

*Hydro Aluminium Rolled Products GmbH - R&D Center Bonn*

**Abstract**

The European project SuperLIGHT-Car demonstrates an efficient solution for innovative light-weight design with a car-body weight reduction of up to 35% in an existing VW-Golf V compact class car. A multi-material approach was used where each specific body part is made from the most suitable material to fulfil the requirements while minimising the weight. The car-body is composed from aluminium (sheet, castings, extrusion), new high strength steels, magnesium sheet and castings, and fibre reinforced plastics. Appropriate design and manufacturing technologies were developed and tested to allow for the production of high volume series. The body-in-white concept developed by SuperLIGHT-Car has exceeded the initial target and offers, with a weight reduction of > 100 kg compared to the reference car, showing equivalent performance. A full body-in-white prototype was built and presented that requires additional costs of €7,8 per kg of weight saved. Clearly, the SuperLIGHT-Car project is a significant step towards the sustainable mass-produced vehicles of tomorrow.

D7

# Potential Magnesium Applications in Aeronautics

Elke Hombergsmeier

*EADS Deutschland GmbH, Innovation Works*
*elke.hombergsmeier@eads.net*

**Abstract**

Magnesium had widely been used in aircrafts up to the 1950s. However, due to some major drawbacks, high corrosion sensitivity and - under extreme conditions – flammability, other materials, metals and plastics have replaced magnesium more and more. Nowadays the renaissance of Magnesium and new Magnesium applications are coming up, again.

The density of Magnesium is only 65% of the density of commonly used aluminium alloys in the aeronautic industry and therefore can be a break through technology if used for low weight airframe structures. However to use this low weight material several mechanical properties should be increased and the technological behaviour improved, to meet the general aeronautic requirements.

The modification of existing and the development of new Magnesium products that provide significantly improved static and fatigue strength properties for lightweight fuselage applications is an essential task. Furthermore the technological behaviour such as corrosion properties and flammability must be improved. Finally good reproducibility as well as low and stable price level has to be maintained.

As a conclusion, several potential Magnesium applications within civil aircraft industry, military air systems, helicopters and space products are described, discussed and evaluated, here.

**Keywords**: Magnesium, Aeronautics, Requirements

D8

# A Technology Roadmap for Magnesium sheet, profile and wire

Prof. Dr. Michael Höck*, and Dipl.-Kffr. Anne Stoermer

*Department of Industrial Management, Faculty of Business Administration, Technische Universität Bergakademie Freiberg, Freiberg, Saxony, Germany*
**Michael.Hoeck@bwl.tu-freiberg.de*

**Abstract**

Although the high potential and advanced properties of magnesium as construction material are widely recognized, its industrial application still falls short of expectations. Within this context a major stream of research focuses on the engineering of lightweight magnesium sheets, profiles and wires. For this primary study, the roadmapping technique was applied to address the requirements regarding material and system properties for magnesium wrought alloy products to be met in further research and development activities. Having distinguished between the applicant's and the technology's perspective, it could be shown, that different priority levels are assigned to the properties from both sides. Furthermore, a comparison between the different process technologies was made, allowing one to stand out in terms of competitiveness and R&D potential. Finally, the results suggest that research should be dedicated on reaching congruency between the applicant's expectations and the developer's focus.

**Keywords**: Magnesium wrought alloy; Roadmap; Process technology; Properties

D9

# Metal pretreatment of Mg substrates

Dr. Thomas John-Schillings

*Henkel AG & Co. KGaA*
*thomas.john-schillings@henkel.com*

**Abstract**

In the industry both mechanical and chemical processes are widely used for cleaning and pretreatment of metal surfaces prior to an organic coating. Especially for the Mg surface treatment processes the technical requirements are very high compared to other metal substrates. Foreign particles on and within the metal surface can either stimulate corrosion processes or reduce paint adhesion properties of the organic coating, which can also effect the corrosion protection. Because of the high reactivity of the Mg substrate towards water borne chemicals it is very challenging to balance within the cleaning and pretreatment process the removal of impurities from the surface, e.g. oil, grease, pigments, oxides, etc. and the building up of a conversion layer without damaging the physical properties of the material.
The mostly industrial used pretreatment process for Mg surface treatment in aqueous systems consists of three active steps: cleaning, etching and passivation. The process bathes are separated by 2-3 rinses to avoid contaminations of previous in the sequence used chemicals by drag over effects. After either spray- or dip application the Mg parts are finally coated with powder or liquid paints.
Due to the enormous environmental protection risks of the application of toxic chrome (VI) based conversion coatings and upcoming European regulations for the use of Cr(VI) the implementation of chrome free passivation processes into the industry starts within the early years of this century and are after aprox. ten years of experience state of the art for Mg surface treatment. Henkel AG & Co. KGaA is one of the most important global players within the surface treatment business and offers chrome free Mg pretreatment processes based on Zr and/or Ti under its Brand name Alodine®.

**Keywords**: cleaning, corrosion protection, paint adhesion, surface treatment, chrome free

D10

# Research activities at the Magnesium Innovation Centre

Prof. K.U. Kainer
Helmholtz-Zentrum Geesthacht

(in preparation)

D11

# Magnesium in automotive engineering

Dr. Martin Kunst
BMW

(in preparation)

D12

Dipl.-Ing. Martin Ostermair
UTG, TU München

(in preparation)

D13

# Multifunctional Surface Treatment of Wrought Magnesium Components in Aeronautic Applications

Ilya Ostrovsky, M.Sc., Ch. Eng.
*Aero-Magnesium DE UG, Germany*
ilya.ostrovsky@aero-magnesium.com

**Abstract**

Weight reduction has always been an important objective for aerospace industry.

Aluminium is a traditional light metal for airborne structures. The alloys used today for aerospace applications are already optimised concerning aeronautic requirements such as strength, fatigue and damage tolerance properties. Therefore weight reduction is more and more difficult to be reached with small advances in aluminium material development.

Magnesium, as it is well known, is the lightest structural metal available on Earth. Its specific gravity is 1.74 (SG of aluminium is 2.7 and of steel is of 7.9 in average). Therefore it is attractive for building structures that need to be light and strong.

The family of magnesium materials and especially magnesium wrought materials could be an excellent alternative to aluminium because of their low density, rather good mechanical properties and metallic behaviour.

Historically, magnesium has been used in aircraft since the thirties of the last century. In the fifties, magnesium passed a "boom" when it was broadly used in aircraft structures and components. Aircrafts and helicopters that were built in that period included hundreds kilogrammes of magnesium products.

However, present use of magnesium in aeronautic industry is limited by dozens kilogrammes. The main reason of this reduction is low corrosion resistance of magnesium and mainly – galvanic corrosion.

Aero-Magnesium Group in cooperation with Chemetall GmbH offers modern high-performance surface treatment solutions those already are used in aeronautic industry.

This presentation includes information about three core surface treatment technologies for magnesium: OXSILAN® MG Technology, Plasma-Gel Anodising and Composite coatings.

**Keywords:** aeronautic, corrosion protection, selective coatings

D14

# Combining ab initio calculations and high resolution experiments to improve the understanding of advanced Mg alloys

S. Sandlöbes[a*], M. Friák[b], A. Dick[b], S. Zaefferer[a], S. Yi[c], D. Letzig[c], Z. Pei[b], L.-F. Zhu[b], J. Neugebauer[b], D. Raabe[a]

[a] *Max-Planck-Institut für Eisenforschung, Department for Microstructure Physics and Alloy Design, Max-Planck-Str. 1, 40237 Düsseldorf, Germany*
[b] *Max-Planck-Institut für Eisenforschung, Department for Computational Materials Design, Max-Planck-Str. 1, 40237 Düsseldorf, Germany*
[c] *Helmholtz-Zentrum Geesthacht, Magnesium Innovation Center, Max-Planck-Str. 1, 21502 Geesthacht, Germany*
**s.sandloebes@mpie.de*

**Abstract**

Understanding the electronic, magnetic, and geometric effects of solutes on crystalline metals at an atomic scale opens a pathway from our current phenomenological descriptive picture towards a more physics based predictive understanding of the thermodynamic and kinetic properties of metallic materials. Such an approach is particularly feasible when minor alloy changes (such as in the case of solid solution Mg-RE alloys) lead to substantial improvement in the macroscopic behaviour.

On the example of ductile Mg-Y alloys the chances of Density Functional Theory (DFT) to obtain deeper understanding of the mechanical behaviour are presented aiming towards a more theory-guided design of ductile Mg alloys.

Mg and single phase solid solution Mg-Y alloys showed an increase in room temperature ductility by about 5 times, while maintaining comparable strength and well-balanced work hardening, through the addition of 3 wt.% Y.. 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, viz. an out-of-basal-plane shear contribution. Room temperature deformation of pure Mg is limited to mainly basal <a> slip and $\{10\bar{1}2\}\langle 10\bar{1}1\rangle$ extension twinning, resulting in strain localization, shear banding and premature failure of the material. It was observed that through alloying Y into solid solution the activity of $\{10\bar{1}1\}\langle 10\bar{1}2\rangle$ contraction and $\{10\bar{1}1\}\{10\bar{1}2\}$ secondary twinning as well as pyramidal <c+a> slip is much enhanced. The higher activation of <c+a> dislocations enables the material to accommodate a higher total strain through the higher number of available intrinsic deformation modes and causes a more balanced work hardening. In crystal kinematical terms this means that pyramidal <c+a> slip offers 5 (or more) independent slip

systems fulfilling the von Mises condition for general grain deformation compatibility, resulting in a more compatible and hence homogeneous deformation.
By combining DFT and high resolution experimental methods we get a deeper understanding of the structural atomistic and electronic influence of Y on the mechanical behaviour of Mg alloys. Understanding these atomistic and electronic-structure mechanisms would provide a systematic approach to identify further favourable alloying elements.

**Keywords**: Mg-RE alloys, Density Functional Theory (DFT), Transmission electron microscopy (TEM), deformation mechanisms

D15

# Potential for Mg sheet applications in cars

Dr. Sönke Schumann

*soenke.schumann@volkswagen.de*

**Abstract**

Today's magnesium applications in the field of land transportation are focused on die castings. To use the full potential of mg for lightweight design also mg sheet metal components should be realized. Several prototype mg sheet components were made and tested within the Volkswagen group in the past. The advantages and disadvantages compared to parts in steel or aluminium were analysed.
The main results of these projects will be presented and the shortcomings will be addressed. Proposales will be made for R&D activities which are necessary to come to competitive solutions . Another item will be the potential for Mg sheet applications in the interior and body of the car.

**Keywords**: mg sheet components, potential, joining

D16

# Modelling of Magnesium Materials: The Link between Physics and industrial Application

D. Steglich

*Helmholtz-Zentrum Geesthacht*
*Max-Planck-Str. 1,D-21502 Geesthacht / Germany*

**Abstract**

Modelling has become an important issue. Modern technology and product development benefit from its saving effects: expensive testing can be reduced, safety can be increased, product life cycle cost can be reduced and energy can be saved. "Modelling" in general has to combine and integrate computational and experimental efforts in order to proceed to an understanding of the physical phenomena which allows for realistic predictions of the performance, availability and safety of technical products and systems. Within the mechanics of materials, modelling is based on the testing, mathematical/physical theory and numerical analysis. This approach will be demonstrated by focussing on the mechanical behaviour of magnesium sheets. Its plastic deformation behaviour under biaxial loading conditions will be analysed and explained. A constitutive theory for its prediction will be presented. Numerical investigations including strain rate and temperature effects of sheet forming processes are performed. The predictive capability of the model is shown by reconciliation of the NUMISHEET 2011 benchmark. Finally, predictions of crash tests will be presented.

D17

# Competence Network for Wrought Magnesium Alloys - TeMaKplus

Dr.-Ing. Hans-Peter Vogt

*MgF Magnesium Flachprodukte GmbH, ThyssenKrupp Steel Europe AG*
*hans-peter.vogt@thyssenkrupp.com*

**Abstract**

The presentation outlines the innovative R&D network TeMaKplus which is focused on the development of innovative technologies for processing wrought magnesium alloys. The goal is to enable magnesium and especially magnesium sheet and strip material to be used in an even more broad range of new light-weight applications. The network of TeMaKplus consists of eleven industrial companies and two research institutes. It covers the whole production chain from the production of the sheet and strip material to the manufacturing of complex parts and components which can easily be integrated into more complex final products. The consortium of TeMaKplus encompasses partners which are specialized in the following technologies: Twin-roll casting and hot rolling of magnesium strip and sheet material, processing and forming of wrought magnesium alloys, joining, coating and surface protection as well as product development. The R&D effort is financially supported by the German Federal Ministry of Education and Research. The current R&D program was started in July 2011. First established in 2007 the network can already look back on four years of successful cooperation. Within the first stage of the project a complete car door made totally from magnesium has been produced using various new technologies. The current program focuses on economically improved processes and innovative production technologies for new fields of application for wrought magnesium alloys.

**Keywords**: wrought magnesium alloys, innovative technologies, industrial applications, industrial network

K1

# WPM Mg National Project and POSCO's Mg Business

Taewook Kang*, Sang Ho Cho, Oh Duck Kwon, Kang Yul Seo**

*Mg Flat Product R&E Project Dept. ,POSCO*
*100, Hodu-ri, Haeryong-myon, Suncheon-si, Jeonnam-do, 540-856, Korea*
**tkang@posco.com, **gok000@posco.com*

**Abstract**

In 2010, Korean government had launched the WPM(World Premier Materials) national R&D project for the growth of domestic materials industry which is characterized by long term (9 years), priviate enterprise-led with the aim of ultimate commercialization. Mg is one of the 10 materials in WPM programs and the WPM Mg project covers from the development of smelting technology to the application technology(surface treatment, deformation, joining etc.) for the purpose of adopting Mg to the automotive parts. This project is organized that POSCO is to play a role of leading company and the participants are divided into 2 sub-projects for the efficiency. The 1st sub-project is related to the Mg plate & its application technologies such as surface treatment and forming. The 2nd sub-project is focused on the bulk processes such as forging, extrusion, cast-forging, gravity casting and pressurized die casting. And, since 2002, POSCO had studied the Mg plate making process and already achieved some remarkable results in terms of the quality and cost competitiveness through successful development of Mg strip casting and continuous warm rolling mill processes. In 2011, to found a solid substantial basis for the Mg material industry in Korea, POSCO started the construction of Mg smelting plant to be completed on June 2012. Eventually, together with all the participants in the WPM Mg program, POSCO will proceed to expand the size of Mg market by harmonizing the raw materials (Mg plate, ingot) technology and the application technology.

**Keywords**: WPM, Mg project, POSCO, Mg strip casting, automotive parts

K2

# Die Forging of Magnesium Chassis Components

Sung-Hwan Kim, Shin-Woo Kang*, Seong-Gon Lim, and Keon-Hyeong Park

*R&D Center, CENTRAL Co., #551, Gongdan-Ro, Seongsan-Gu, Changwon-City, Gyeongnam, Korea*
**shinwoo@ctr.co.kr*

**Abstract**

The forging of magnesium is restricted to a few industries that aerospace parts. As increasing interests in the environment and enforcing strong regulations on exhaust gases and carbon dioxide in developed countries, efforts into developments in magnesium forging techniques have been making more briskly with transportation machine maker as the center. In particular, growing demands for a fuel-efficient vehicle, various efforts into lightweight of parts are putting forth. In this work, high strength commercial AZ80 and ZK60 Magnesium Alloys were forged in order to observe the changes in Characteristics to the process. Changing variable forging temperature and forging speed of magnesium feedstock, magnesium control arms for chassis component were manufactured. Carrying out different heat treatments (T4 and T6), the changes in characteristics were investigated.

**Keywords**: Magnesium, Magnesium alloy, Forging, AZ80, ZK60

K3

# Temperature-dependent hardening behavior of AZ31B Mg sheets

Ngoc-Trung Nguyen[1)], Oh Suk Seo[1)], Bum-jin Hwang[2)] and Heon Young Kim[1)]*

[1)] *Department of Mechanical and Biomedical Engineering, Kangwon National University, 192-1, Hyoja2-dong, Chuncheon, Gangwon-do, 200-701, South Korea*
[2)] *AUSTEM Co. Ltd., 173-299, Kajwa-dong, Seo-gu, Incheno-si, 404-250, South Korea*
**khy@kangwon.ac.kr*

**Abstract**

This paper aims at investigating the temperature-dependent hardening behavior of AZ31B magnesium alloy sheets. The large strain monotonic uniaxial tension and cyclic loading tests (tension-compression-tension, T-C-T, and compression-tension-compression, C-T-C) were performed with a newly designed tension/compression tester at different temperatures ranging from room temperature up to 250$^{o}$C. Besides the regular slip deformation mode as of FCC and BCC metals in the case of monotonic tension loading, experimental results of AZ31B Mg sheet show significant twinning during initial in-plane compression and untwining in a subsequent tension at lower temperature. At elevated temperatures deformation twinning and untwining is reduced. The resulting stress-strain curves of loading test cases reveal concave-up shape for tension followed by compression and the unusual S-shape for the cases of compression followed by tension. Also, with the limited symmetry crystal of a hexagonal closed packed (HCP) metal and due to the limited processing of slip systems, AZ31B Mg sheets show strong yielding asymmetry and nonlinear hardening behavior. Considerable Bauschinger effect, transient behavior and variable permanent softening response were observed in the investigated temperature range. The shrinkage of yield surface (elastic range) was also characterized and reported in this study. The 2D draw bending benchmark problem of NUMISHEET 1993 was selected to evaluate the springback prediction capability of several hardening models. Together with commonly used hardening models such as isotropic, kinematic and the combined hardening model by Chaboche in finite element (FE) softwares, a proposed constitutive equation were used to predict the springback and sidewall curl. The newly developed constitutive model was implemented in a user defined material subroutine (UMAT) in ABAQUS to enhance the prediction capability of the abnormal hardening features. The predicted results were compared and verified by experimental tests. Simulation of the stamping process of a main panel LH model for electric car was discussed.

**Keywords**: twining/untwining, yielding asymmetry, Bauschinger effect, transient behavior, tension/compression loading

K4

# Wide Strip Casting Technology of Magnesium Alloys

Jae Joong Kim*, Ki Ho Yun, Jae Sin Park, Deok Kim, Hyun Seok Lee
In Joon Kim, Woo Jin Park and Dong Kyun Choo

*Research Institute of Industrial Science and Technology (RIST)*
*San 32, Hyoja-dong, Nam-ku, Pohang, 790-600, Korea*
**jaej@rist.re.kr*

**Abstract**

Strip casting is a well-known process as an economical production technology to manufacture thin sheets of various metallic materials due to the process consolidation. POSCO purchased a twin roll caster in 2003 and worked to get it delivered and installed at RIST. After working and researching magnesium production steps, they decided to design and construct a separated magnesium sheet plant in 2007 using the 600mm strip caster as the main production unit. The group has also installed a wider strip casting machine with newly designed liquid delivery system. A 2,000mm wide strip caster is undergoing testing step by step in terms of the applied sheet width for lightweight of automotive parts in the near future. In this work, the current results for magnesium 'wide strip casting technology' - being able to produce the strip with 1,500mm width - are going to be overviewed. In addition, the as-cast microstructures of AZ31B and AZ61A magnesium alloys produced via this process are discussed.

**Keywords**: wide strip casting, automotive parts, magnesium alloys

K5

# High efficient vertical magnesium thermal reduction process

Ho Choi, Dae Gyu Park, Gil Soo Han and Moon Chul Kim*,

*Research Institute of Science & Technology, Gangneung,213-340, Korea*
**kim9001@rist.re.kr*

**Abstract**

Magnesium is produced commercially either by the thermal reduction process or by electrolysis process. One of the advantage in thermal reduction process is capable of producing high purity magnesium demanded by the automobile industry. Virtually China has produced about 80% of world magnesium production which is produced by the thermal reduction, pidgeon process.

Conventional pidgeon process is consisted of horizontal retort, furnace and refining system. In this study, a new production system of magnesium has been developed to improve productivity. The new production system is consisted of large-sized vertical retort, coal-gas regenerative furnace, automation system and refining system. Due to increased diameter of the retort and enhanced heat & mass transfer, productivity is increased remarkably. From pilot-scale experiments, it was validated that production rate could be highly increased compared to conventional horizontal reduction system. The trial magnesium ingot has a purity over 99.95% after the refining process. Energy consumption, retort's life cycle and labor costs could also be reduced with increased productivity.

**Keywords**: magnesium thermal reduction process

K6

# Recent Development and Applications of Magnesium Alloys in the Hyundai and Kia Motors Corporation

Y.J. Ko*, H.S Yoon and J.D. Lim*

*Materials Research Team, Advanced Technology Center, Research & Development Division for Hyundai Motor Company & Kia Motors Corporation, 772-1, Jangduck-Dong, Hwaseong-Si, Gyeonggi-Do, 445-706, Korea*
**yjko@hyundai.com*

**Abstract**

Global warming issue is getting more serious topic over the car industry, therefore each automotive companies has established their own weight reduction strategies. Magnesium might be one of fascinated solutions to achieve weight reduction targets. HMC/KIA has been successfully applying on magnesium seat frames of driver and passenger side for both D and E segment cars for 6 years. However we are now facing difficult situation to maintain mass production due to material cost instability, the cost is one of the important factors to be overcome for future potential application. Fortunately, there are huge amount of natural resources, dolomite in Korea, it could be boosted more R & D activities for near future. Large structural parts such as transmission case and road wheel might be candidate for the mass production components.

**Keywords**: Magnesium, lightweight, seat frame, transmission case, road wheel

K7

# Developing High-precise Magnesium Extrusion Technology

Sangwoo Park, Yusik Min*, Songchul Lim

*Dongyang Gangchul co.,Ltd, 275-2 Daehwa-dong, Daedeok-gu, Daejeon, Korea*
**ysmin@ialu.co.kr*

**Abstract**

Magnesium is classified as a light weight alloy among the nonferrous metals; for that reason, magnesium is widely used in the industry. However, magnesium products are only produced by Die Casting or Indirect Extrusion because it has hard mechinability. This project is developing magnesium manufacturing process by using Direct Extrusion which includes improvement of precision, and designing/ manufacturing the extrusion die to apply high speed extrusion. The goal of this project is to improve a Metal Flow of Magnesium alloy and to solve the profile crack and surface oxidation from increased profile degree and to achieve high productivity by improvement of extrusion speed.

K8

# Preparation and characterization of conversion Coating on magnesium alloy AZ31 sheet

Chang-Hyun Park*, Wook Hyun Song, Gab-Young Kim, Myung Hee Choi

*NOROO Coil Coating Co., Ltd*
**Changhyun.park@noroo.com*

**Abstract**

Magnesium alloys have been one of the most highly promising materials employed for high specific strength and stiffness application such as automobile industries. Most magnesium alloys, however, tend to suffer severe corrosion. Conversion coating layers are, therefore, indispensable for improving their corrosion resistance. Such layers can also enhance the adhesion of subsequent E-coating.
The properties of conversion coating on magnesium can be closely related to its surface microstructure and pretreatment of magnesium sheet. This study investigated the surface microstructure of conversion coating on AZ31 magnesium alloy and pretreatment AZ31 magnesium sheet. Results show that increasing the solution acidity increased cellular layer and E-coating adhesion varies depending on the pretreatment. The conversions coated on AZ31 were characterized via S.S.T (salt spray test), C.C.T (cross cut test), scanning electron microscopy (SEM) and focused ion beam-transmission electron microscopy (FIB-TEM).

**Keywords**: Magnesium alloy AZ31, Conversion coating, E-coating

K9

# New Challenges in the Application of Mg sheet to Automotive Parts

Min Hong Seo*, Kanghwan Ahn, Gyo-Sung Kim, Taewook Kang, Sang-Ho Cho

*POSCO Global R&D Center, 180-1 Songdo-dong, Yeonsu-gu, Incheon 406-840, Republic of Korea*
**mhseo@posco.com*

**Abstract**

Nowadays, fuel efficiency and light-weight vehicles are major interests of automotive companies owing to the environmental regulations being fortified. Under the current situation, magnesium alloys attracts the interest of automotive companies as a material for vehicle structure due to its lightweightness. However, there are lots of technical hudles to overcome to apply the magnesium sheet to vehicle structure in relation to welding, joining, surface treatment and so on. In this presentation, current issues and challenges in the application of Mg sheet to automotive parts are to be discussed.

**Keywords**: Mg sheet, Automotive parts, Lightweightness.

K10

# Development of High Performance Magnesium Alloys at Magnesium Technology Innovation Center

Kwang Seon Shin

*Magnesium Technology Innovation Center*
*School of Materials Science and Engineering*
*Seoul National University*
*Seoul 151-744, Korea*
*ksshin@snu.ac.kr*

**Abstract**

There have been active researches to develop new magnesium alloys appropriate for various processing routes such as die-casting, gravity casting, extrusion, and twin roll strip-casting. The Magnesium Technology Innovation Center (MTIC) at Seoul National University (SNU) has actively pursued the development of new advanced magnesium alloys that are appropriate for these applications. In order to develop new magnesium alloys, fundamental and strategic approaches have been utilized such as thermodynamic calculations for the expected phases and precipitates from the alloy composition, analysis of deformation behavior by visco-plastic self-consistent (VPSC) simulations, and characterization of microstructure with SEM, TEM, XRD and EBSD, and mechanical properties. Furthermore, the deformation and recrystallization behavior of magnesium single crystals has also been examined in order to obtain fundamental information about the critical stresses for various slip and twin modes and texture development. Recent achievements at MTIC will be discussed.

K11

# Development of Noble Magnesium Alloys: Non-combustible Alloys and High Performance Wrought Alloys

Bong Sun You*, Chang Dong Yim, Young Min Kim, Ha Sik Kim and Sung Hyuk Park

*Structural Materials Division, Korea Institute of Materials Science*
**bsyou@kims.re.kr*

**Abstract**

The R&D activities related to magnesium alloys and their application in Korea Institute of Materials Science (KIMS) are briefly introduced including, melt refining, casting, forming and surface treatment. The main results on development of new magnesium alloys, especially non-combustible alloys and wrought alloys with high strength and/or high formability, are introduced in more detail. The new non-combustible alloys have superior mechanical properties and ignition resistance to commercialized alloys and conventional ignition-proof alloys. The new wrought alloys with high strength and/or high extrudability are developed by control of alloy composition and microstructure.

**Keywords**: Non-combustible, Wrought, Ignition resistance, High strength, High extrudability