C2. Light Metals and Alloys—Magnesium: I
Symposium Organizers:
Xianhua Chen, Chongqing University, China; Yoshihito Kawamura, Kumamoto University, Japan; Young Min Kim, Korea Institute of Materials Science (KIMS), Korea; Jian-Feng Nie, Monash University, Australia; Diran Apelian, Worcester Polytechnic Institute, USA
Tuesday AM Room: Room 406 (4th Floor) August 20, 2019 Symposium: C2
Chairs:

13:30-13:40
Opening Remark
Fusheng Pan, Chongqing University, China

8:30-8:55 Keynote (1265714)
Kink Strengthening of LPSO and Mille-Feuille Structures in Mg Alloys
Eiji Abe, The University of Tokyo, Japan,

Dilute Mg alloys containing a few atomic percent of transition-metal and rare-earth element have attracted increasing attentions because of their excellent mechanical properties. The remarkable microstructural feature common for all of these Mg alloys is formation of a novel type of long-period stacking/order (LPSO) structures; though, it is found that the LPSO structures themselves are not directly responsible for the excellent properties, but the properties can be realized only when the kink-deformation regions are densely introduced through the warm-extrusion process. From the extensive studies of the LPSO-structured Mg alloys for more than a decade, it has become apparent that the kink regions indeed play a critical role for effective strain storage of the alloys, but its detailed mechanism is not fully understood yet.

In order to deepen our understanding of the veiled work-hardening mechanism related to kink, we have just launched the new project aiming the establishment of the “Kink strengthening phenomenon” as a universal strengthen principle. In the meantime, the LPSO structure can be generally viewed as “Mille-feuille structure (MFS)”, in the sense that they are constructed by alternate stacking of microscopic hard- and soft-layer. Our preliminary studies have confirmed that the MFS Mg alloys indeed reveal the kink strengthening, whose effect seems to be more prominent than LPSO Mg alloys. Therefore, solving the critical condition and universality on the kink-strengthening phenomenon will certainly lead to a further development of lightweight structural materials, including novel Al and Ti alloys, and even polymer materials in the future.

8:55-9:20 Keynote (1235690)
Casting and Solidification of Magnesium Alloys
Yuanding Huang, Kainer Karl, Norbert Hort, Helmholtz-Zentrum Geesthacht, Germany

Magnesium alloys have a high specific strength with their good castability and machinability which are interesting for lightweight construction applications. However, they have a poor room temperature formability and low high-temperature strength. Microstructural modifications such as refining and precipitation were popularly used to improve their ductility and strength. Regarding the subsequent microstructural optimizations, the first step casting and solidification plays a key important role because the quality of initial microstructure directly influences the subsequent one. The present paper introduces some recent investigations on the casting and solidifications in MagIC. First, the influence of alloying elements on the hot tearing of magnesium alloys is simply summarized, including the elements Al, Zn, Y, Gd and Ca. With the increment of alloying element content, the hot tearing susceptibility increases till to a maximum, and then reduce with further increasing the content of alloying element. Second, the applications of synchrotron radiations in the in-situ observations of solidification is introduced for magnesium alloys. It was found that synchrotron radiations could identify the solidification process and also the solidified phases. Finally, the grain refinement of magnesium alloys inoculated by the external particles SiC is reported. When adding the SiC particles to Mg-Al alloys, the casting microstructure was largely refined. The responsible refinement mechanism is due to the formation of Al2MgC2 by the reactions of SiC particles with Mg-Al melt. This ternary compound has a very close crystal structure to that of magnesium. As observed in Mg-Al alloys, the additions of SiC particles could also refine the grains of as-cast Mg-Zn alloys. But the refinement mechanism is different from that for Mg-Al alloys. It is attributed to the formation of (Mn, Si)-enriched intermetallics by the interactions between SiC and impurity Mn in Mg-Zn alloys.

9:20-9:40 Invited (1224205)
Achieving High Strength and High Ductility of Ultrahigh Pressure Mg Alloys
Qiuming Peng, State Key Laboratory of Metastable Materials Science and Technology, China

The compelling need for lightweight, energy-efficient, environmentally benign engineering systems is driving the development of a wide range of structural and functional materials for energy generation, energy storage, propulsion, and transportation. As the lightest
metallic structural materials, Mg-Li alloys have been used for various industrial products such as automobile, aerospace, defence, biomedical, sporting and electronic goods sectors owing to their high stiffness, good castability, good electro-magnetic shielding and high damping properties. However, the strength of Mg-Li alloys is reduced with the increasing of Li content. A lot of work has demonstrated that it is possible to improve both strength and ductility simultaneously, but this has mostly been limited to systems with ultrafine microstructures, such as nanotwin Cu or twinning-induced plasticity steels. A high strength duplex-phase Mg-Li alloy without sacrificing the ductility was prepared by ultrahigh pressure technique. The strengthening mechanism is attributed to densely hierarchical \( \{101\{--\}1\}\{101\{--\}1\} \) double contraction nanotwins (DCTWs) and full-coherent hexagonal close-packed (HCP) particles in twin boundaries. These hierarchical nanoscaled DCTWs with stable interface characteristics not only bestow a large fraction of twin interface but also form interlaced continuous grids, hindering possible dislocation motions. Meanwhile, orderly aggregated particles offer supplemental pinning effect. In addition, the phase transformation of the coherent phase was investigated. Those cutting-edge results provide underlying insights toward designing alternative and more innovative hcp-type structural materials with superior mechanical properties.

9:40-10:00 Invited (1233898)

Effects of Microstructure on Fracture Toughness of Wrought Mg-8Gd-3Y-0.5Zr Magnesium Alloy

Jing Li, Li Jin, Jie Dong, Fenghua Wang, Shuai Dong, Shanghai Jiao Tong University, China

Fracture toughness is a critical property for Mg alloys applied as structural parts. However, its improvement mechanism has rarely been investigated on newly developed Mg-Gd-Y-Zr alloys. Here, The toughness and uniaxial tensile tests were conducted on a Mg-8Gd-3Y-0.5Zr (wt.\%) alloy (GW83) prepared by three different processing methods: rolling, extrusion and forging. The effects of microstructure on the fracture toughness were investigated. The results showed that the fracture toughness was highest in the forged sample but lowest in the rolled sample, which due to the secondary phase strips and high-density dislocations in the forged samples. Careful microstructural characterization revealed that the secondary phase strips which could cause dimples and secondary cracks, and then deflect the main cracks to enhance the fracture resistance for the extruded and forged sample. In addition to the reactivation of the mobile dislocations, initial substructures and dislocations by increasing strain hardening in the plastic zone led to high fracture toughness for the forged sample further. Moreover, it was proposed that fracture toughness and ductility did not always show the same trend, which was due to the difference in the magnitude of plastic zone and stress field in two test samples and thus resulted in different deformation mechanisms.

10:00-10:20 Invited (1235545)

Improved Understanding of the Microstructure and Mechanical Behaviour of Mg-Al-RE Alloys

Mark Easton, Suming Zhu, Charlotte Wong, Hua Qian Ang, Dong Qiu, RMIT University, Australia; Trevor Abbott, Magontec Ltd, Australia; Kazuhiro Nogita, Stuart McDonald, David StJohn, University of Queensland, Australia; Jian Feng Nie, Monash University, Australia; Mark Styles, Mark Gibson, CSIRO, Australia

Magnesium – Aluminium – Rare Earth alloys are the most commonly used specialty alloy system with alloys such as AE42 and especially AE44 being commonly used in powertrain applications. Over the past few years, we have been investigating the microstructure and mechanical behaviour of these alloys. The microstructure of the alloys include intermetallics found at grain boundaries (and sometimes within grains). The morphology and identity of these intermetallics and the ternary phase diagrams are not fully consistent with what has been reported previously including the identification of a previously unknown phase. Whilst the particular rare earth additions affect the identity of intermetallic phases, it is actually the Mn content that is critical to the mechanical properties and creep response of these alloys due to precipitation hardening. This means that using low cost REs such as La and Ce to produce alloys without Nd and Pr additions does not significantly degrade the properties. With strength matching AZ91 and ductility matching AM60, the Mg-Al-RE alloys, particularly AE44, are excellent candidates for structural applications. However, since the Mg-Al-RE alloys are primarily strengthened through grain refinement, dispersion strengthening by grain boundary intermetallics and precipitation hardening, they do behave differently to AZ91 and AM60 which have a significant contribution from solid solution strengthening. In particular, AE44 is more strain rate sensitive and has less anelasticity at low strain rates compared with AZ91 and AM60, especially in the aged condition.

10:20-10:35(1221881)

Experimental Investigation on the Anisotropy of Extruded AZ31 Magnesium Alloys by Combined Tension-Torsion Test

Baodong Shi, Chong Yang, Yan Peng, Yanshan University, China

The urgent need for reducing CO\(_2\) emissions due to the accelerated deterioration of environment is driving increased applications of lightweight engineering
materials in automobiles. The properties of magnesium alloys (e.g. low density, high specific strength, good castability and recyclability) make them attractive replacement for the more mass-intensive materials, and the promising energy efficiency improvements with Mg alloys as vehicle components are significant. However, as one of the Hexagonal Closed Packed (HCP) metals, rolled magnesium alloy sheets typically exhibit strong anisotropy (including tension-compression yield strength asymmetry, known as Strength Differential effect, SD effect) due to the presence of a strong basal texture, with the c-axis of the crystals parallel to the norm direction of the sheet. This strong anisotropy contributes to poor cold formability and hinders wider applications of this material. Although the microscale modelling work is straightforward to characterize the mechanical behaviour of metals, there are still difficulties with the deformation of macro-scale parts due to computational efficiency. From this point of view, macro-scale modelling of the anisotropic behaviour based on phenomenological descriptions are more promising.

Focusing on the strong anisotropy during forming process of HCP metals, the distortional evolution of yield surfaces of AZ31 Mg alloy are investigated experimentally and numerically under combined tension-torsion/tension-tension test. Strong anisotropy including initial strength differential effect and subsequent distortional hardening are observed. The underlying deformation mechanisms are discussed based on microstructure observation. In particular, isotropic, kinematic and distortional hardening are employed to capture the anisotropic deformation of AZ31 Mg alloy. The expansion, movement and distortional shape evolution of yield surfaces are governed by specifically designed evolution equations. It is found that the number of twinning decrease with pre-axial tension stress increasing, resulting from the restricted activity of twinning with c/a ratio decreasing. Furthermore, the subdivision of twin boundaries leads to large strain hardening rate. Therefore, the strain hardening rate and flow stress under pure torsion are much higher than other loading paths. Consequently, the strong anisotropy is obtained during large plastic deformation.

10:35-10:50  Tea Break

10:50-11:1 Invited (1299244)

Significantly Enhanced Mechanical Properties of Mg-9Al Alloy by Using Multi-Walled Carbon Nanotubes

Wenbo Du, Beijing University of Technology, China,

In the present study, Mg-9Al/MWCNTs composites were synthesized by using powder metallurgy followed hot extrusion techniques. MWCNTs were dispersed in Mg-9Al matrix with an ionic gemini dispersant. The results of the present study established that MWCNTs could be effectively and uniformly dispersed by the ionic gemini dispersant C12-DSDM without structural damage. Matrix-MWCNT was found to be absence of voids and debonding. The addition of MWCNTs could significantly affect the size of Mg17Al12 phase, which decreased from micron to nano length scale. Compared to Mg-9Al alloy, the mechanical properties of Mg-9Al/MWCNTs composites, especially the ductility, were significantly enhanced. In the case of Mg-9Al/0.4MWCNTs composite, the elongation and UTS were 15% and 355MPa, showing 150% and 18% increase, respectively. The remarkable enhancement of the mechanical properties achieved was mainly attributed to two factors: (i) The nanoscale distributed Mg17Al12 s phase in composite, which was in situ formed by using MWCNTs as heterogeneous nucleus substrates and (ii) the strong and effective interface bonding between MWCNTs and matrix due to the partially inserted interface relationship with Mg matrix. This work may provide an alternative method to fabricate MWCNTs reinforced metal matrix composite, which could efficiently enhance ductility and strength of Mg-9Al matrix simultaneously.

11:10-11:25(1221729)

Dislocation-Templated Gd Nano-Fiber Patterns: a New Strategy of Tailoring Mechanical Properties in Mg Alloys

Yangxin Li, Xiaojin Zeng, Shanghai Jiao Tong University, China,

Microstructure engineering is a persistently vigorous technique in altering material’s properties through tailoring geometrical features of structural units at multiple length scales and modifying three-dimensional arrangements of structural units. Structural units can be classified into three, two, one, or zero dimensions, such as three-dimensional volumes (phases, grains, particles/precipitates), two-dimensional surfaces (boundaries, interphases), one-dimensional lines (triple lines, edges, dislocations) or zero-dimensional points (quadruple points, vertices on polyhedral particles). In advancing the material’s performance resulted from these structural units, arranging their distribution provides different strategies in addition to regulating the dimensions and shapes of these structural units. To realize specific microstructure, heat treatment, mechanical deformation, and/or their combinations can be applied while adjusting chemical compositions of a material. Rare-earth (RE) elements has a demonstrated significance in tuning the microstructure of Mg alloys, such as weakening basal texture of Mg alloys, refining grain sizes, forming long-period stacking-ordered structure, etc. RE solutes can also be trapped in twin boundaries, and in turn, impeding migration of twin...
Superelastic Property of Mg-Sc Binary Alloys at Room Temperatures

Keisuke Yamagishi, Daisuke Ando, Yuji Sutou, Junichi Koike, Tohoku university, Japan

Mg alloys have been expected as a next generation structural material for many decades due to its light weight and high specific strength. However, conventional Mg alloys show a poor formability at room temperature because of their hcp structure, which exhibits a high plastic anisotropy. Therefore, many researchers have attempted to change hcp crystal structure to bcc crystal structure in Mg-Li alloy system. These Mg-Li alloy with bcc structure show excellent ductility and superplasticity with fine grain even at room temperature. But the volume fraction of the bcc phase is uniquely determined upon the Li composition. Mg-Sc alloy system is only other Mg alloy which transforms from hcp structure to bcc structure depending on temperature even at the same composition. It means that microstructure can be controlled by thermomechanical treatment like Ti alloys and the metastable bcc phase might transform to other phase during deformation like stress-induced martensitic transformation. Actually, we found and reported for the first time in Mg based alloy that Mg-20.5 at. % Sc alloy shows stress-induced martensitic transformation from bcc phase to orthorhombic phase, therefore exhibits superelasticity at a low temperature of -150°C. The density of this alloy is about 2.0, which is one-third of that of NiTi based shape memory alloys. However, the working temperature of the superelasticity is too low to use this Mg-20.5 at. % Sc alloy for various industrial applications.

Now, we have challenged to develop a room temperature superelastic Mg-Sc alloy. In previous study, we have noticed that its martensitic transformation temperature shows a strong dependence on the alloy composition and increases with decreasing Sc content. Therefore, in this study, we investigated the martensitic transformation temperature of Mg-(18-19) at. % Sc alloys and confirmed that the transformation temperature certainly increases with decreasing Sc composition. Furthermore, we have successfully realized superelasticity at room temperature in this composition range. In this presentation, I would like to show our results in detail.

11:40-11:55 (1233223)

Grain Refinement of Magnesium Alloy for Road Wheel Application

Jun Ho Bae, Ha Sik Kim, Young Hoon Moon, Young Min Kim, Bong Sun You, Korea Institute of Materials Science, Korea

In recent years, demands of light weight in transportation systems dramatically increase because of more stringent environment regulations and changing in consumer perceptions of fuel efficiency improvement. For this reason, magnesium alloy, the lightest structure material, has been used increasingly in transportation systems. Although magnesium alloys have been used for many decades, in order to expand the application area more aggressively, it is necessary to develop new technology and alloys capable of satisfying various requirements of the field such as high strength, toughness, corrosion resistance. Grain refinement is an effective way to improve the mechanical properties of both cast and wrought magnesium alloys. It can also lead to more uniform microstructural features and enhancement of strength, ductility and workability, leading to considerable cost reduction, and it enables further increase the industrial applications of magnesium alloys. However, the grain refinement technology rarely used for casting industries, which make up a significant portion of magnesium alloy parts, except high-pressure die casting due to the absence of high-efficiency grain refinement techniques for various casting processes. Recently, several grain refinement methods focused on a suitable technology, i.e. effective, reliable and easy to apply for industry, have been developed, such as carbon inoculation, melt conditioning, master alloy addition, etc. In this presentation, it is investigated that how to use the grain refinement technology in industrial casting process effectively. The SiC containing grain refiner was applied to 1 ton scale low pressure die casting for the fabrication of magnesium road wheel. And its grain size and mechanical properties compared to commercial AZ91 alloy was investigated.
C2. Light Metals and Alloys-Magnesium: II
Symposium Organizers:
Xianhua Chen, Chongqing University, China; Yoshihito Kawamura, Kumamoto University, Japan; Young Min Kim, Korea Institute of Materials Science (KIMS), Korea; Jian-Feng Nie, Monash University, Australia; Diran Apelian, Worcester Polytechnic Institute, USA

Tuesday PM Room: Room 406 (4th Floor)
August 20, 2019 Symposium: C2

Chairs:

13:30-13:55 Keynote (1235013)
Development of Corrosion Resistant Magnesium Alloys
Bong Sun You, Young Min Kim, Korea Institute of Materials Science, Korea; Jong Il Kim, Chungnam National University, Korea; Hui Yu, Hebei University of Technology, China

The main reason for abandoning magnesium alloy after the beginning of the active use in the automobile and aircraft industries in the 1940s, which is still the key issue not to use very large amounts of magnesium alloys in the automobile industry, is its high corrosion rate compared with other metals. Studies have been done to develop corrosion resistant magnesium alloys via the addition of active metallic elements in commercial alloys, but there have not been any meaningful results except when using certain rare earth elements. As in the case of Cr addition to stainless steel to make a dense oxide film that can act as passive film to resist continuous corrosion, we need new additional elements for magnesium alloys to make stable passive films. However, almost all the elements that have been studied have shown negative results except when using high purity alloys by minimizing some harmful elements such as Fe, Cu and Ni, the corrosion resistance improves significantly.

KIMS have been studied on new corrosion resistant magnesium alloys by the addition Ca and Y together which was originally designed to improve non-flammability of AZ series magnesium alloy. A controlled amount Ca and Y containing phases and the formation of multi-layered protective oxides consisting of CaO, Y2O3, MgAl2O4, and MgO effectively improve the corrosion resistance. This paper introduces the mechanism of corrosion resistance of Ca and Y containing alloys, and compares the corrosion behaviour with that of commercial alloys. Also, it introduces field test results on several items which are made by die casting, billet making and extrusion processes for the application in electronic, railway, automotive and aerospace industries.

13:55-14:20 Keynote (1383009)
Study of the Alloying Effect on Mg’s Ductility by in Situ Synchrotron X-ray and Electron Microscopy Experiments
Xiaqin Zeng, Shanghai Jiao Tong University, China,

14:20-14:40 Invited (1224411)
Advanced Protective Coating Strategy for Mg Alloys
Xiaobo Chen, RMIT University, Australia

Utilisation of light-weight magnesium (Mg) alloys as engineering materials is limited due to their high affinity for oxygen and water, and hence vulnerability to corrosion. Many efforts have been attempted to address the corrosion issue of Mg alloys to pave a path for wider implementation of Mg in various applications, such as automotive, airplane, electronic devices and biomaterials. There are two straightforward methodologies to suppress corrosion progress of Mg alloys. Addition of alloying elements, such as Al, Zn and even As, into the bulk Mg matrix which may lead to favorable microstructure, grain size or kinetic restriction to corrosion kinetics (with attendant changes in properties and cost). The other intensively exploited approach is applying stable and inert coatings onto the surface of Mg alloys as a barrier to provide protection functionality. Compared to alloying, surface properties will be altered rather than the fundamental properties of the bulk materials and desirable protection can be obtained by means of simply and efficient processing procedures.

The most successful commercial coatings are chromate based, however, the extreme carcinogenicity to organisms and environments has led to a strict ban on the utilisation of chromate coatings globally. Therefore, there is an urgent need to develop alternative coatings to tackle the corrosion issue of Mg alloys as chromate did. Herein, we introduce some advanced techniques to develop coatings onto Mg alloys to perform either as a barrier or functional coating in order to address the corrosion of Mg. The coating characteristics, formation mechanism and their specific roles in corrosion protection will be presented and discussed. In addition, a novel pretreatment method will be introduced to demonstrate its vital role in generating a homogenous surface condition that is favorable for subsequent growth of desirable coatings. The results indicate that superior corrosion resistance of Mg alloys could be yielded through high-performance coatings.
The high texture dependence of a Hall-Petch slope (k) for Mg alloys has been frequently reported. Several important equations used to calculate k have been previously developed, and although they seem to work well for fcc and bcc materials, they often fail to predict the highly texture-dependent k in Mg alloys. A new equation based on the dislocation pile-up model was developed in this study. The validity of this new equation was tested through a comparison of the predicted k values with the experimental values as well as the calculations from older equations. The results indicate that the new equation can achieve an accurate prediction for several previously reported texture effects on k, whereas the k values predicted by the older equations often exhibit a clear deviation. The reasons for this were analyzed and discussed. The strong deformation anisotropy for Mg alloys leads to a complex texture effect on k, including the effects from both external and internal stresses. Both effects are well expressed in the new equation. In contrast, the old equations consider the external stress effect, but do not express well the internal stress effect. In addition, the old equations consider only the predominant deformation mode. However, our results indicate that the activation of a portion of another deformation mode other than the predominant one plays an important role in the k value. Using the important parameters of the new equation, the mechanisms for several texture effects on k as previously reported were discussed and new understandings were obtained.

Mg alloys have been expected as a next generation structural material for many decades. Especially, Mg-Al based and Mg-Zn based alloys have been developed and used for various industrial products due to weight reduction. However, these conventional Mg alloys show poor plastic deformability at room temperature because of their hexagonal closed packed (hcp) structure, which exhibits high plastic anisotropy. And also, the strength of Mg alloys is insufficient compared with Al based alloy. These poor workability and insufficient strength of most Mg alloys limit their practical application. Therefore, many attempts have been made to improve those properties. Among them, Li addition is very effective method to enhance the ductility of Mg alloys. Small addition of Li can reduce the c/a ratio of hcp lattice and enhance the activation of \(<c+a>\) slip, which leads to the enhancement of ductility. The alloys with Li content between 5.5 and 8.5wt.% have a bcc/hcp dual phase structure. The dual phase alloys have an excellent ductility and show super-plasticity at 423K. Furthermore, it was reported that the alloys with Li contents up to 12.5wt.% have a bcc single phase structure. Recently, the low corrosion resistance has improved by the alloy composition and thermo-mechanical processing routes. These Mg-Li alloys were accepted as main flame material in mobile notebook PC. However, according to the phase diagram of Mg-Li alloy, the dual-phase boundary is almost vertical up to high temperature, which indicates that the volume fraction ratio of the bcc/hcp dual phase can be controlled only by Li content, but not by temperature. It means phase transformation could not happen during thermo-mechanical processing. In this study, we propose Mg-Sc alloys with phase transformability. This alloy shows ultra-high strength after aging due to fine hcp precipitation from metastable bcc matrix. The maximum Vickers hardness is over 230HV aging at 200 degree C for 25 hours. The sample exhibits brittle fracture in tensile deformation at room temperature because of severe strain hardening during phase transformation. However, after straightening anneal at 300 degree C for a few minutes, the samples shows excellent mechanical properties at room temperature and elevated temperature. Furthermore, the alloys show super-elasticity of 4.4% at -150 degree C and shape recovery upon heating. The shape memory properties are caused by reversible martensitic transformation from bcc to orthorhombic phase. This behavior resembles that of Ti alloys. The martensitic transformation temperature strongly depends on the Sc contents. After optimizing the Sc contents, Mg-Sc alloy shows super-elasticity even at room temperature. The density of Mg-Sc alloy is around 2g/cm³, which is one-third less than that of practical TiNi Shape memory alloy.

The study shows a possibility to use metastable bcc phase for novel microstructural control and adding functionality into Mg alloys.
subjected to multi-directional impact forging (MDIF) with 520°C. The microstructure and mechanical properties of the two MDIFed samples were investigated. Their deformed microstructure was typical bimodal grain structure consisting of deformed coarse grains and dynamic recrystallization grains. A MDIFed sample exhibits an average 0.2% proof stress (YS) of 306MPa, an average ultimate tensile strength (UTS) of 354MPa and an average elongation to failure of 3.3% at room temperature. Nevertheless, the other MDIFed sample exhibits lower YS (212 MPa) and UTS (297MPa), which is attributed to its weaken random texture. On the other hand, static recrystallization (SRX) behavior of as-MDIFed Mg-6.58Gd-5.7Y-0.55Zr alloy were investigated by annealing treatment at 520°C with different time using in-situ-optical microscopy (OM). During this process the deformed coarse grains were gradually replaced by recrystallization grains and they almost have been consumed by SRX grains at annealing time of 5min. Finally, a completely recrystallization microstructure with average grain size of ~50μm was obtained at annealing time of 10min. After annealing treatment, UTS decrease but elongation-to-failure significantly increases. This should be ascribed to further texture randomization and vanishing work hardening caused by SRX during annealing treatment.

15:35-16:05 Tea Break

16:05-16:25 Invited (1228344)

Improvement in Room-Temperature Yield Asymmetry of Extruded AZXW9100 Alloy by Precipitation Hardening

Joung Sik Suh, Korea Institute of Materials Science, Korea; David Klauumenzer, Volkswagen AG, Korea; Young Min Kim, Dong Sun You, Korea Institute of Materials Science, Korea / Korea Institute of Geoscience and Mineral Resources, Korea

Tension-compression yield asymmetry at room temperature of extruded AZ91 based Mg alloy is investigated regarding precipitation hardening. Non-flammability is a key prerequisite for application of Mg extrusion products to advanced transport such as aircraft and high-speed train. It has been known that conventional Mg alloys are reactive in molten state and thus rapidly ignited as contacting with oxygen in air. In order to solve this problem, a non-flammable high-strength Mg alloy was developed by a trace addition of Ca and Y to AZ91 (Mg-9Al-0.6Zn-0.1Mn-0.3Ca-0.2Y wt. denoted as AZXW9100). As engineering materials, one of the main challenges is how tension-compression yield asymmetry of Mg alloys can be reduced so as to suit industrial applications. It is well known that Mg alloys are low-symmetry materials with hexagonal-close packed structures having axial ratios of around 1.633. In this case, yield asymmetry can be attributed to the prevalence of (10-12) twinning. Based on this, the analysis of mechanical behavior of extruded AZXW9100 plates presents that aging treatment increases yield strength in uniaxial tension and compression. Especially, this distinct increase in compressive yield strength makes close to yield symmetry compared with as-extruded condition. This reduction in yield asymmetry is attributed to the presence of Ca containing Mg17Al12 precipitates, which suppress tensile twinning in compression. EBSD measurements confirms a reduction in the scale and area fraction of (10-12) tension twins in aging-treated samples at equivalent levels of strain.

16:25-16:40(1287594)

Effect of Ca, Sm and La Additions on Microstructures and Tensile Properties of as-Cast and as-Extruded AZ31 Alloys

Li Fu, Zheng Jia, Shenyang University, China; Iuchi Le, Yanxia Niu, Yonghui Jia, Northeastern University, China

Magnesium alloys are more and more attractive for structural materials of metal in automotive due to their low density and easy recycling, while their applications are still limited due to their lower absolute strength and plasticity at room temperature, especially they can not work for a long time when the temperature is over 120°C. Alloving of rare earths is recognized to be an effective method improving properties of magnesium alloys. In this study, 1.3%Ca is first added to AZ31 alloy and 1.0% Sm+0.3% La is further added, then microstructures and tensile properties of AZ31 alloys with Ca, Sm and La additions are investigated. Detailed analysis and characterization results on structures and morphologies of second phases by XRD and SEM-EDS indicate that Al2Ca is formed after Ca additions, while Al2Sm irregular strips and Al2Sm polygons are formed with further additions of Sm and La. Formations of these new phases could decrease Mg17Al12 phases and refine grains of both as-cast and as-extruded AZ31 alloys obviously. Texture analysis results of as-extruded AZ31 alloy by XRD show that (0002) basal texture changes little with Ca additions, while it is significant strengthened with further additions of Sm and La. Tensile tests results at room temperature reveal that Rp0.2 (Yield strength) of as-extruded AZ31 alloy is enhanced by about 20MPa and A (elongation) is approximate to 25% with Ca additions, while with further adding Sm and La, Rp0.2 is enhanced by over 50MPa and A is decreased to less than 20%. Tensile tests results at 150°C reveal that both Rp0.2 and Rm (ultimate tensile strength) is significantly enhanced with Ca additions, which change little with further additions of Sm and La.
Study of the Dislocation Activity in a Mg-Y Alloy by Differential Aperture X-ray Microscopy

Leyun Wang, Bijin Zhou, Xiaquin Zeng, Wenjiang Ding, Shanghai Jiao Tong University, China; Wenjun Liu, Argonne National Laboratory, USA; Jian Wang, University of Nebraska-Lincoln, USA

As the lightest metallic structural material, Mg and its alloys have strong potential for weight reduction applications in the automotive and aerospace industries. Yet, the ductility of Mg still needs to be improved to ensure good formability at room temperature. Recent studies have shown that the addition of yttrium (Y) can substantially improve the ductility of Mg alloys. This phenomenon was attributed to the enhanced activity of non-basal <a> and <c+a> slips according to previous TEM studies. However, relative activity among different non-basal slip modes and how non-basal slips improve the material’s ductility is still unclear due to the small observation area associated with TEM and the post-mortem sample status. In this paper, a novel technique of differential aperture X-ray microscopy (DAXM) with submicron resolution is employed to map the distribution of geometrically necessary dislocations (GNDs) among five grains in a Mg-5wt%Y alloy (grain size ~ 100μm) after an in situ bending test. The DAXM experiment was conducted at Beamline 34-ID-E of the Advanced Photon Source. The GND contents are determined voxel by voxel based on the diffraction peak streaking in the corresponding Laue diffraction patterns. Among those voxels with peak streaking, 56% contain GNDs associated with basal slip, while the other 44% contain GNDs associated with prismatic slip (8%), pyramidal <a> slip (13%), and pyramidal <c+a> slip (23%). The deviatoric part of the elastic strain tensor was further calculated for each voxel from the Laue diffraction patterns. It is found that non-basal GNDs were often related to local stress concentrations. Long-range lattice rotation that was measured from the position movement of diffraction peaks across multiple voxels is not always consistent with the distribution and characters of GNDs in the grain. We attribute the high ductility of Mg-Y alloys to the extensive activation of non-basal <a> and <c+a> slip to prevent premature crack initiation at grain boundaries.

Atomistic Microstructure of Kinks Formed in Dilute Mg Alloys

Daisuke Egusa, The University of Tokyo, Japan; Eiji Abe, The University of Tokyo, Japan / National Institute of Materials Science, Japan

Magnesium (Mg) alloys are promising for structural materials due to their high strength-to-weight ratio. Recently, Mg alloys with a small addition of TM (Transition Metals) and RE (Y and Rare Earth elements) have attracted much attention, owing to their high strength by simply applying a conventional hot extrusion. Microstructural features, which are believed to be essential for the excellent properties of the alloys, are formation of long period stacking/order (LPSO) phase and activations of kink deformations.

The LPSO structures are consist of 2H (ABAB) structure and 12-type stacking faults (ABCA), which are interpreted as periodical stacking of close-packed planes. In addition, TM/RE elements located at the layers relevant to stacking faults. Owing to these structural and chemical order along the stacking direction, LPSO phases have anisotropic structural features which is accepted to cause limitations of several deformation modes, such as non-basal slip and twinning.

Due to these limitations, kink deformation is one of the important deformation modes for homogeneous deformations of the alloys. Hess et al proposed a microscopic mechanism of kink deformation, which comprehend “kinks” as cooperative motion of basal dislocations; however, details have not clarified yet. Based on the proposed model, kink deformation introduces high dense of dislocation which cause dynamic recovery/recrystallization during hot workings, so that kink as itself cannot contribute the strength of alloys without suppressing the recovery/recrystallization behavior. This fact suggests a presence specific microstructural feature within kinks of the Mg-TM-RE alloys which make kinks stable once they were formed. In the present study, we investigated microstructural features of kink formed in dilute Mg-TM-RE alloys with transmission electron microscopy (TEM) and scanning transmission electron microscopy (STEM). Based on TEM observations and image analysis, atomic structure of faults embedded in kinks are identified as Shockley-type and Frank-type partial dislocations that form i2-type and i1-type stacking faults within hcp structure, respectively. In addition, STEM images show that there are characteristic distributions of trace elements that are combined with faults around kinks. The selective enrichments of trace elements on these faults, considered as Suzuki segregation and Cottrell atmosphere, suggest occurrences of structural accommodation within kink formation which may be origin of thermodynamic stability of kink. We will discuss about formation mechanism of kink in Mg-TM-RE alloys based on microscopic features of kinks.
High Stretch Formability of As-Rolled Magnesium Alloys with Additions of Er/Zn at Ambient Temperature
Ke Liu, Wenbo Du, Zhaohui Wang, Shubo Li, Jinxue Liu, Beijing University of Technology, China

As a lightweight structural material, the wrought magnesium alloy has a unique advantage in 3C fields owing to its high specific strength and excellent electromagnetic shielding characteristic. However, as the hexagonal close packed structure (HCP), it is difficult to make the magnesium alloy undergo a homogeneous deformation. In generally, the wrought magnesium alloy has a strong basal texture and a notable anisotropy, which is harmful to the formability. Modifying texture is one of key factors to improve formability at room temperature. In the present investigation, the macrostructure, mechanical properties and stretch formability at room temperature of magnesium/magnesium alloy sheets were investigated. The magnesium alloys were alloyed with different alloying elements (Zn/Er). The result suggested that a trace addition of Zn and Er played a key role in texture modification, shear bands formation and nano-scale secondary phase precipitation, which resulted in obvious increase in stretch formability and mechanical properties at the same time. It was indicated the Mg-0.5Zn-0.5Er alloy sheet exhibited better tensile strength along the rolling direction. The values of yield strength (YS) and ultimate tensile strength (UTS) were 180MPa and 201MPa, respectively, companying with superior Erichsen value (IE) of 7.0mm at room temperature. The good performances of the alloy sheet were ascribed to the weak basal texture intensity, formation of shear bands and precipitation of nanoscale W-phase (Mg3Zn3Er2).

The effects of electromagnetic frequency on macro- and microstructure evolution, phase distribution, element segregation, and conductivity distribution were discussed in detail. It was observed that the solidified structure under pulse oscillation electromagnetic field is sensitive to the electromagnetic frequency, which has an effective frequency range. The grain size can be effectively controlled with different electromagnetic parameters. The grain size decreases from 815 ~ 951μm (without MF) to 402 ~ 486μm at the frequency of 30Hz. The segregation ratio is reduced evidently at the frequency of 30Hz. As the frequency decreases or increases, the grain size and segregation ratio increase. As the frequency further increases to 40Hz, the grain size and the difference of electrical conductivity on the cross section of billet increases. In addition, the conductivity distribution of the cross section of the billet is more uniform, which is closely related to the solidification structure of the billet in the presence of oscillation electromagnetic field.

Microstructure and Properties of Ultrasonic Assisted Magnesium Alloy MAO Coating
Guanqun Chen, Sheng Lu, Jinwei Zhang, Zexin Wang, Lei Xu, JiangSu University of Science and Technology, China

Magnesium alloys are the best candidates for implant materials and can avoid reoperation and stress shielding because of excellent biodegradability, bio-safety and similar density and elastic modulus with human bone. However, inferior corrosion resistance of magnesium alloys could cause fast degradation during clinic application therefore cannot meet the requirements of implants. Ultrasonic-assisted micro-arc oxidation(UMAO) is a promising surface modification technology to improve the density and biological activity of coatings prepared by micro-arc oxidation(MAO). In the present work, the ultrasonic power is adjusted in the optimized composite bio-electrolyte system and the AZ60 magnesium alloy is subjected to MAO treatment. The processing current-time curve was recorded to analyze the growth characteristics of MAO coating. Scanning electron microscopy (SEM) coupled with energy disperse spectroscopy (EDS) and X-ray diffraction (XRD) were used to analyze the micro-morphologies, chemical components and phase. And Nanoscratch tester was used to characterize the adhesion of the coating. Electrochemical workstation was used to evaluate the degradation behavior. The results show that the peak current of MAO decreases after applying ultrasonic waves, it is possible that the explosion of the ultrasonic cavitation bubble provides energy, reducing the voltage drop required for the electrolysis reaction.
for breakdown; the thickness decreases first and then increases; the phases of the film layer was Mg, MgO, Mg$_2$SiO$_4$, Mg$_3$(PO$_4$)$_2$ and CaCO$_3$; the wetting angle of the film layer was 13.47° and the coating exhibited good hydrophobicity; the corrosion current density decreased by one order of magnitude compared to bare ZK60 alloy which demonstrates excellent corrosion resistance; the highest critical load is 9.91N, This is mainly due to the compact, uniform coating with high bonding strength.
C2. Light Metals and Alloys-Magnesium: III
Symposium Organizers:
Xianhua Chen, Chongqing University, China; Yoshihito Kawamura, Kumamoto University, Japan; Young Min Kim, Korea Institute of Materials Science (KIMS), Korea; Jian-Feng Nie, Monash University, Australia; Diran Apelian, Worcester Polytechnic Institute, USA
Wednesday AM  | August 21, 2019  
Room: 406 (4th Floor)

8:30-8:55 Keynote (1267957)
Texture Evolution of Ca-Containing Mg-Zn Alloys during Annealing
Nack J. Kim, Jae H. Kim, T.T.T. Trang, Jihyun Hwang, Postech, Korea; Byeong-Chan Suh, KIMS, Korea

Mg alloys have the lowest density among commercially available structural alloys, which can provide significant weight savings in automobiles. For the widespread application of Mg alloys, however, Mg alloys should overcome a critical shortcoming; poor formability at room temperature mainly originated from strong basal texture developed during thermomechanical processing. Although several Mg alloys show random/weak texture and accordingly good room temperature formability, most of such alloys rely on the usage of expensive rare earth elements. It has been recently reported that the addition of Ca to Mg-Zn alloys weakens and randomizes the texture, similar to the effect of RE addition on modifying the texture. The texture of these Ca containing Mg-Zn alloys can be described as the broadened angular distribution of basal poles along the transverse direction (TD) and split of basal poles along the rolling direction (RD) in as-rolled condition. However, a significant change in texture occurs after annealing process; splitting of basal poles toward the TD from the original RD in particular. Despite the weak texture intensity, their texture is less than ideal since one directional orthotropic texture developed during annealing would result in non-uniform deformation during stretch forming. However, the detailed mechanism of such texture evolution has not been clearly revealed yet. In the present work, an attempt has been made for having a better understanding of the texture evolution during annealing process of Ca containing Mg-Zn alloys. The details of their texture evolution have been analyzed by quasi-in-situ EBSD after various stages of annealing with particular emphasis on recrystallization and growth behavior.

8:55-9:20 Keynote (1233910)
High Performance Magnesium Alloy Plate and Its Novel Process
Bin Jiang, Guangsheng Huang, Jiangfeng Song, Dingfei Zhang, Fusheng Pan, Chongqing University, China

Magnesium (Mg) alloys have attracted considerable attention for a promising application in the automotive and electronics owing to their high specific strength and high electromagnetic shielding. However, the application of wrought Mg alloys has been limited by poor room temperature ductility. It was ascribed to the large difference in critical resolved shear stresses (CRSS) between basal and prismatic slip in hexagonal close-packed (hcp) crystal structure in Mg alloy. This results in a lack of the active slips systems and can hardly offer an arbitrary shape change at the grain level. Conventionally extruded Mg alloy sheets possess poor mechanical properties due to the strong basal texture where c-axes of the grains are predominantly aligned parallel to the sheet normal. This brings about a poor deformation capability of sheet thinning and a stronger anisotropy and consequently results in limited number of available plastic deformation modes. In this work, a novel extrusion approach to get high strength magnesium alloy plates will be introduced through differential speed processing. A suitable constitutive model of differential speed extrusion is established to ameliorate the texture-dependent mechanical properties. The velocity evolutions of the extruded sheets at near-surface and mid-layer region are different due to the extra asymmetric shear deformation. This simple shear enforces the near-surface microstructure to exhibit more dynamically recrystallized grains having the c-axis tilted toward the extrusion direction. The yield stress of AZ31 alloy sheet has been increased from 161.2MPa to 179.9MPa and the elongation has been improved from 15.4% to 20.1%. Moreover, as for the high strength AZ61 alloy sheets, the ultimate tensile strength was increased from 387.9MPa to 427.1MPa and the yield stress was improved from 147.7MPa to 195.9MPa. Grain refinement and tilted weak basal texture obtained by differential speed extrusion process. This approach is an efficient substitute to increase the texture-induced softening and ductility and thus favorable for the thin sheet fabrication.
Technical Program

9:20-9:40 Invited (1406083)
Searching for Stainless Magnesium Alloy – a First Principal Based Approach
Yang Guo, General Motors, USA; Mingfei Zhang, Liang Qi, University of Michigan, USA

A significant challenge for applications of Mg alloys is their poor corrosion resistance and hence Mg alloys designs with built-in corrosion resistance are of significant interest. Corrosion can result from the coupling of anodic dissolution of Mg and cathodic reduction of water on impurities such as Iron (Fe)-rich second-phase particles. Experiments have shown that small quantities of Arsenic (As) or Germanium (Ge) can inhibit Mg corrosion, possibly slowing the hydrogen evolution reaction (HER) as the cathodic reaction on Fe surfaces. Since a broader experimental search across the periodic table for other Mg corrosion inhibiting elements is unavailable, we designed thermodynamic and HER criteria, and used high-throughput computations to search a pool of 68 elements including As and Ge that can segregate from bulk Mg to surfaces of Fe particles and impede the HER there. Our computational procedure predicts that six p-block elements meet these criteria, and they rank according to their ability to reduce H adsorption energies and the HER rate as follows: As > Ge > Si > Ga > P=Al. Results for As, the most effective corrosion-inhibiting element, and Ge are in qualitative accord with recent experiments. While none of the 68 elements was found to enhance H adsorption, the six p-block elements reduce H adsorption via strong orbital overlap (Pauli repulsion) between their outer shell orbitals and the s orbitals of H adsorbates. These p-block elements are also found to have the potential to reduce HER on surfaces of Ni second-phase particles in Mg according to the same criteria, but not on surfaces of Cu second-phase particles.

9:40-10:00 Invited (1373176)
Carbon nanomaterials reinforced Mg matrix composites
Xiaojun Wang, Kun Wu, Harbin Institute of Technology, China

Carbon nanomaterials are considered as the ideal reinforcement for metal matrix composite, due to their ultra-high mechanical properties. However, CNTs were very chemically active and easy to get tangled. Thus, it is very difficult to fabricated CNTs reinforced metal matrix composite. In this paper, a novel liquid processing was developed to fabricate CNTs reinforced Mg matrix composites. The processing included pre-dispersion, semisolid stirring and ultrasonic vibration in Mg melts. And then the CNTs/Mg-6Zn composites were extruded. Pre-dispersion is necessary to obtain uniform dispersion of CNTs in CNTs/Mg-6Zn composites. In as-cast composites, the CNTs distribution was uniform. The good interfacial bonding between matrix and CNTs was observed. Moreover, Raman spectroscopy shows that the damage to CNTs was not evident during fabrication. Hot extrusion eliminated CNT segregation and improved CNT distribution. Compared with as-cast composites, the yield strength and ultimate tensile strength of the CNTs/Mg-6Zn composites were significantly enhanced. Graphene nanoplatelets (GNPs) reinforced magnesium (Mg) matrix composites were synthesised using the multi-step dispersion route. ell-dispersed but inhomogeneously distributed GNPs were obtained in the matrix. Compared with the monolithic alloy, the nanocomposites exhibited dramatically enhanced Young’s modulus, yield strength and ultimate tensile strength and relatively high plasticity, which mainly attributed to the significant heterogeneous laminated microstructure induced by the addition of GNPs. With increasing of the concentration of GNPs, mechanical properties of the composites were gradually improved. Especially, the strengthening efficiency of all the composites exceeded 100%, which was significantly higher than that of carbon nanotubes reinforced Mg matrix composites. The grain refinement and load transfer provided by the two-dimensional and wrinkled surface structure of GNPs were the dominated strengthening mechanisms of the composites.

10:00-10:15 (1231576)
Effects of Twinning Deformation on Aging Precipitation and Hardening Response in AZ80 Mg Alloys
Renlong Xin, Feiya Liu, Chunpeng Wang, Qing Liu, Chongqing University, China

Mg17Al12 is the hardening phase in Mg-Al based alloys such as AZ80 and AZ91. It generally precipitates in two different forms: the coarse discontinuous precipitation and the fine continuous precipitation. The discontinuous phase may act as crack initiation and deteriorate the strength and ductility. The continuous precipitation is responsible for most of the age-hardening response. Obviously, promoting continuous precipitation is the key to enhance the mechanical properties of such alloys. Recently it has been found that the continuous precipitates prefer to nucleate within twins in Mg-Al based alloys. However, the effects of twinning deformation on the characteristic of precipitates and the subsequent age hardening response are not very clear. In this talk, we will present the effects of twinning, detwinning and multiple twinning on the size, morphology and distribution of precipitates in Mg-Al based alloys. Then the improvements in aging hardening and mechanical properties will be discussed. Moreover, it is known that Mg17Al12 is plate-like, formed on the basal plane of Mg matrix (named basal plates). These basal plates generally give poor strengthening
compared to the prismatic plates formed in Mg-Y alloys. Currently, it is hard to promote prismatic plates in Mg-Al based alloys. Recently we found that the orientation of basal precipitates in AZ80 Mg alloy can be altered by coupling twinning, aging and detwinning processes. This gives the prismatic precipitates with their broad plane parallel to one of the \{10-10\} Mg. Such prismatic precipitates significantly improve the compressive and tensile strength of AZ80 Mg alloys compared to the basal precipitates. This provides a new way to regulate precipitate orientation and hence its hardening response in Mg alloys.

10:15-10:30 (1365090)
**Quasi-in-Situ EBSD Insight into the Role of Annealing in the Microstructure and Texture Behavior of Extruded Mg-Zn-Gd alloy**

WASI ULLAH, Institute of Metal Research, CAS, China; Hong Yan, Rongshi Chen, Institute of Metal Research, CAS, China / University of Science and Technology of China, China

The present abstract reports a quasi-in-situ EBSD approach for studying the role of annealing in the microstructure and texture behavior of extruded Mg-1.58Zn-0.52Gd (wt%) bar alloy. The samples was annealed at 400°C and increased the annealing time gradually to investigate the effect of annealing and annealing time on the microstructure. Based on quasi-in-situ EBSD the annealing temperature have significant influence on the microstructure and texture, it is seem to be static recrystallization (SRX) begins at the beginning of annealing treatment i.e 400°C for 5 minutes. By increasing annealing time the average grain size increased from 16.9µm to 20.7µm as a result of merging the huge number of grains and some grains growth by increasing the annealing time. The texture is slightly converted from basal texture to rare earth texture. The rare earth texture favored the operation of both basal slip and \{10-12\} extensions twins, thus leading to improved strength of the alloy. It is hypothesized that the segregation of solutes atoms to the special boundaries greatly influences the recrystallization behavior and thus contributes to the formation of rare earth texture.

10:30-10:45 Tea Break

Wednesday AM | August 21, 2019

10:45-11:05 Invited (1286154)
**Research on High Performance Magnesium-Based Functional Materials**

Xianhua Chen, Jingfeng Wang, Jian Peng, Yong Wang, Fusheng Pan, Chongqing University, China

The development and application of magnesium alloys have special important strategic significance, especially in solving the light weight problems of key equipment and important engineering. In the past ten years, the development and application of magnesium-based structural materials have made great progress, but the high-performance magnesium-based functional materials with great potential are relatively lagging behind. The key problem that restricts high-performance magnesium-based functional materials is that the functional properties and mechanical properties of magnesium alloys are difficult to achieve and even contradict each other. Aiming at the problems faced by magnesium-based functional materials, we carried out basic scientific research for improving the comprehensive performance of magnesium-based functional materials. The effects and mechanisms of purification, asymmetric deformation, second phase, solid solution atoms and surface modification on mechanical properties and functional properties of magnesium alloys such as electromagnetic shielding, damping, thermal conductivity, corrosion degradation and biocompatibility were clarified. New synergistic regulation criteria and theory for functional properties and mechanical properties of magnesium-based functional materials were constructed recently, and a series of new high performance magnesium-based functional materials and their preparation methods were developed. These high performance magnesium-based functional materials have achieved engineering applications in aerospace, railway vehicles, automotive, 3C products and other areas.

11:05-11:25 Invited (1222645)
**Development of High Performance Magnesium Base Metal Matrix Nano Composites for Aerospace Applications Using Powder Metallurgy Technology**

Spartak Makovskyi, Vyacheslav Boguslayev, Volodymir Kloychkhen, Volodymir Lukinov, MOTOR SICH JSC, Ukraine; Vadym Shalomeyev, Eduard Tzyvirko, MOTOR SICH JSC, Ukraine / Zaporozhye National Technical University, Ukraine

Application of lightweight high strength magnesium based materials in the contemporary aero engine manufacturing and rotorcraft industries plays an important role in attaining high performance characteristics, such as low specific fuel consumption, higher payload and low emissions level. Cast magnesium alloys of Mg-Al-Zn system are widely used for the manufacture of structural parts of aero engines and rotorcraft gearboxes thanks to their low specific gravity, relatively high strength and high castability. However, this class has some disadvantages, such as low operation temperature (up to 150°C) and susceptibility to internal porosity. Therefore, at present the development of lightweight magnesium based materials of a new generation with improved room temperature mechanical properties and
high temperature capability via control of the structure is of great current interest in the aerospace industry. The paper presents data on the development of a magnesium metal matrix nano composite (MMNC) on the basis of a magnesium cast alloy of Al-Mn-Zn system with the use of carbon nano particles as a reinforcement phase.

A series of experimental samples of MMNC has been fabricated by the stir casting process using a magnesium casting alloy of Mg-Al-Zn system as a matrix. Incremental additives of carbon black and nanographite were added into the melt as a reinforcement phase in the form of consolidated pellets. In order to increase the inoculation effect of the carbon nanoparticles the chemical composition of the matrix alloy was tailored within the alloy specification ranges based on a thermodynamic calculation.

Preliminary a master alloy was produced by making a highly homogenous mix of the matrix alloy elements and the reinforcement by powder metallurgy processing route to obtain consolidated pellets. Mechanical tensile tests of MMNC specimens demonstrated a unique set of improved properties; a 45% increase in the ultimate tensile strength has been attained as compared with a commercial magnesium alloy Mg-1-5 with simultaneous improvement in ductility. A higher stress-rupture strength at elevated temperature was also achieved. The new MMNC displayed a lower susceptibility to hot tearing.

Metallographic examination and the electron microprobe analysis of the MMNC showed a pronounced grain refinement effect, uniform distribution of Mg17Al12 on the grain boundaries and high homogeneity of the micro- and microstructure, which contributed to attaining more consistent mechanical properties of the material. Based on the results of the study a mathematical model of the new composition was developed and a mechanism of the influence of the carbon particles on the structure and mechanical properties has been put forward.

One of the key elements in the concept of the MMNC is the powder metallurgy technology, which ensures effective introduction of the carbon nano particles into the alloy and their uniform distribution. The new MMNC is a promising lightweight high strength material for a cost-efficient production of critical structural components of aero engines and rotorcraft assemblies.

11:40-11:55
Overview of Advancement and Development Trend on Magnesium Alloys based on The Journal of Magnesium and Alloys

Xiaodong Peng, Yan Yang, Tiancai Xu, Jiangfeng Song, Fusheng Pan, Chongqing University, China

Magnesium alloys are characterized by their low density, high strength, large modulus of elasticity, good heat dissipation, good shock absorption, greater ability to withstand impact load than aluminum alloys, good corrosion resistance to organic matter and alkalinity. According to the statistical analysis of literature data collected by Web of Science Core Collection, it can be found that the growth rate of publications on magnesium alloy during 2008-2018 is significantly higher than the overall growth rate of alloy research papers. In the past 11 years, the Web of Science Core Collection has
collected 21440 papers on magnesium alloys, averaging nearly 2000 papers annually, of which 2768 papers were collected in 2018, an increase of 206% over 2008, accounting for more than one fifth of the total literature on alloy research. Magnesium alloys have become an important lightweight metallic structural material and have been widely studied worldwide. As the only journal focusing on magnesium alloy research which devoted to the coverage and dissemination of global research on magnesium alloys. This article statistically analyzes all the academic articles published by Journal of Magnesium and Alloys from 2013 to 2018 and compares them with all the articles containing magnesium alloy in their titles on the Web of Science during this period. The development trends of magnesium alloys are summarized based on these articles, and the influence and academic value of the articles published by the Journal of Magnesium and Alloys are summarized as well. This paper hopes to better realize the value of JMA, help better spread the academic research of magnesium alloys, and promote the development of global magnesium alloy research.
As a new functional material, hydrogen-chromic film is mainly composed of a core composite film with reversible hydrogen storage property. It converts between transparent and reflective states through hydrogenation and dehydrogenation, regulates light at the visible and infrared spectrum intelligently. Therefore, it is widely used in smart switchable energy-saving window and hydrogen sensor. Magnesium has high hydrogen storage capacity and abundant output, then it is easy to be combined with various elements, these characteristics make magnesium-based materials play an important role in hydrogen energy application. For the past two decades, the reported magnesium-based gasochromic switchable mirrors have been limited to magnesium alloys. Herein, inspired by the excellent catalytic property of some transition metal oxides (TMO) for the magnesium-hydrogen reaction, we fabricated the novel gasochromic switchable mirrors based on Pd/0.9Mg-0.1TiO2 film with no trace of Pd.

The results show that the mirror based on Pd/0.9Mg-0.1TiO2 film exhibits larger optical dynamic range at visible wavelengths and excellent structural recovery even after 100 cycles of hydrogenation and dehydrogenation compared with Pd/Mg film. The brookite TiO2 crystalline Mg and some amorphous phases coexist in the MgTiO2 layer of Pd/0.9Mg-0.1TiO2 film with no trace of Pd. Interestingly, the TiO2 nanocrystal clusters are distributed in stripe among Mg matrix. In contrast, the Pd/0.63Mg-0.37TiO2 film consists of crystalline Mg and MgTi2O5 phase, where MgTi2O5 phase is derived from the reaction of superfluous TiO2 with a part of Mg and deteriorates the optical properties of the mirror dramatically. In addition, the Pd/Mg-Nb2O5 and Pd/Mg-V2O5 films have better performances on reflectance conversion range and optical dynamic range, respectively. In summary, the optical performance of Mg-based switchable mirrors can be improved by introducing transition metal oxides into switchable layer.

13:35-14:20 Keynote (1233802)

Solute Effects of Rare Earth Elements on Deformation Behaviors and Mechanical Properties of Mg

Jing Zhang, Fusheng Pan, Chongqing University, China

The application of magnesium alloys for lightweight structural components in microelectronics, aerospace, and automobile industries has significantly increased during the last decade. However, the potential use of magnesium alloys in wrought forms, such as sheets and extrusions, is still limited due to their poor ductility and strong directionality of properties. Alloying is known to be one of the most effective approaches to improve materials properties; among them, rare earth elements have attracted the most scientific attention. Taking rare earth elements for example in this presentation, the solute effects of alloying elements on the deformation behaviors and mechanical properties of Mg are evaluated from the perspective of the interaction between solute and basal dislocation, the solute segregation and pinning at twin boundary, and the activation of \(<c+a>\) slip system and its competition with crack propagation on \(\{0001\}\) cleavage plane, by using first-principles calculations and molecular dynamics simulation. The underlying mechanism are proposed and design maps based on alloying effects are constructed which could serve as the basis for the design of high-ductility Mg alloys. The results are not only helpful to deepen our understanding of alloying effects in Mg, but also essential to develop new Mg alloys with better combined properties.

14:20-14:40 Invited (1235028)

Development of a Magnesium Metal Production Process Using North Korean Magnesite


In order to produce high-purity magnesium metal from North Korean magnesite (MgCO3), the conventional process involving the electrolysis of anhydrous MgCl2 produced from MgCO3 and a novel and environmentally sound process using the electrolysis of MgO were investigated. Anhydrous MgCl2 was prepared with combination of HCl leaching of MgCO3 at 343 K, removal of impurities in the MgCl2 solution by precipitation using
MgO and H₂O₂ condensation at 373K after dissolving NH₄Cl in the MgCl₂ solution, and dehydration of NH₄Cl-MgCl₂·6H₂O at 593K under Ar gas atmosphere. As a result, 99.3% pure anhydrous MgCl₂ was produced. To produce Mg metal, the electrolysis of MgCl₂ was conducted at 973~1040K using molten salt consisting of MgCl₂, NaCl, CaCl₂, and CaF₂. By applying voltage of 7.0 V between an iron cathode and a graphite anode, Mg metal with purity of 99.8% was obtained, and the current efficiency was 81.2%~83.9%. In spite of high efficiency of the conventional electrolytic process, it incurs an environmental burden because chlorine gas is generated at the anode. Therefore, a novel Mg production process involving the electrolysis of MgO using a liquid metal cathode and vacuum-distillation of Mg alloy was investigated. In this process, copper, silver or tin for the cathode and graphite or platinum for the anode were immersed in molten CaF₂-MgF₂-NaF at 1273K or MgF₂-LiF at 1083 K. When 3.0 V was applied between electrodes, Cu-Mg, Ag-Mg, or Sn-Mg alloy was obtained depending on the cathode material, and the current efficiency was 75.8%~85.6% under certain conditions. Vacuum-distillation was conducted at 1100 ~1400K with the Mg alloy obtained, and Mg metal with purity of 99.97% was obtained. Therefore, the feasibility of the novel electrolytic process was demonstrated for the production of high-purity Mg metal from MgCO₃.

14:40-15:00Invited (1259044)
Development of Room Temperature Reciprocally Bendable Magnesium Sheets in China Baowu
Shiwei Xu, Yu Xie, Weineng Tang, Yun Qin, China Baowu Steel Group Corporation Limited, China; Jianfeng Nie, Monash University, Australia

In this presentation, the recent industrial application of magnesium alloy in China Baowu will be firstly introduced. From 2015 to 2018, China Baowu has developed two types magnesium instrument panel beams for China’s domestic cars and five types magnesium alloy parts for China’s high-speed trains, which significantly boosts the industrialization of magnesium alloys. Since the beginning of 2019, China Baowu has become the shareholders of sever scale magnesium enterprises through commercial cooperation. The recent research progress of high-performance magnesium sheets in China Baowu will be then introduced. Several kinds of non-rare-earth-containing magnesium alloy sheets with the thickness from 0.5 to 1.5mm were successfully developed, which could be manually bent at room temperature by 180 degrees over and over again without cracking. It should be emphasized that this remarkable phenomenon was hardly achieved in industrial products that were manufactured merely by one pass optimized extrusion process and the following two or three passes rolling. These findings provide a new pathway for designing and developing magnesium alloy products with high formability at room temperature, compared to those traditionally difficult to form at room temperature. After heat-treatment, some sheets exhibit a tensile 0.2% proof stress of 228 MPa along the rolling direction (RD) and of 234MPa perpendicular to the RD with an elongation to failure more than 20% in both directions. It means that these sheets show no anisotropy. The microstructure evolution in these sheets during three-point bending tests were also systematically investigated by the in-situ electron backscattering diffraction (EBSD) analysis and transmission electron microscopy (TEM).

15:00-15:15(1220714)
In-Situ High-Energy X-ray Characterization of LPSO Reinforced Mg Alloy under Tensile Deformation
Jie Wang, Leyun Wang, Gaoming Zhu, Xiaojin Zeng, Shanghai Jiao Tong University, China

Mg alloys containing long period stacking ordered (LPSO) phases often display excellent mechanical properties. The underlying mechanism is yet unclear. In this work, in situ synchrotron X-ray diffraction was employed to study the tensile deformation of a Mg97Y2Zn alloy that contains 18R-type LPSO phase. The material showed a high strength and good ductility at both room temperature and 200°C, but the strength dropped a lot when the temperature increased to 330°C. From lattice strain measurement, it is found that the LPSO phase has a similar elastic modulus as Mg. After material yielding, lattice strain in the Mg phase decreased, while lattice strain in the LPSO phase increased further. This load transfer effect from Mg matrix to LPSO can maintain up to 200°C, while it disappeared when the temperature up to 330°C. The lose strengthening effectiveness of LPSO at higher temperature have been examined elaborately. Fiber LPSO phase is no more thermal-stable and broke into small particles during the tensile deformation at a higher temperature. Due to the diffusion of Zn and Y tends to concentrate into the defects, stress in the local areas are high and microcracks are easily nucleated in the vicinity of stacking faults (SF). By analyzing the lattice strain evolution of different Mg peaks, deformation mechanisms at different temperatures have been concluded. That is, basal slip and deformation twinning are identified as the dominant deformation mechanisms at room temperature, while non-basal slip and grain boundary slide are active at elevated temperatures. These findings are further confirmed by ex situ electron microscope techniques (e.g. surface slip trace analysis using electron backscattered diffraction (EBSD) and TEM examination of the postmodern samples). Additional analysis of diffraction peak broadening...
15:15-15:30 (1222161)
Effect of Stress State on Microstructure Evolution of AZ31 Magnesium Alloy during Bending Process
Yuanping Jin, Lili Chang, Yaru Zhao, Jing Guo, Shandong University, China

The present study aims to investigate the twinning behavior and texture evolution of the as-rolled commercial AZ31 magnesium alloy using three kinds of three-point bending tests (bending, flattening and rebending with a reversal loading). Microstructure evolution after the bending, flattening and rebending processes was characterized by an electron back-scattered diffraction (EBSD) technique. Meanwhile, a three-dimensional finite element (FE) model of the bending processes was set up using ABAQUS/Standard to theoretically predict the stress state during bending. The experimental results revealed that deformation mode remarkably influenced twinning development and (10-12) tension twin was the main twin type in the bent samples. EBSD maps and pole figures showed twinning, detwinning and retwinning processes. For the case of the region close to punch and the center region, (10-12) tension twin could be found after the bending process, while detwinning appeared in the flattening process and retwinning happened in the rebending process. Twinning occurred in the region away from punch of the sample during the bending process, then detwinning could be found in the flattening process, and retwinning could be observed in the rebending process. Numerical simulation results showed the contours of Von Mises stress and the contours of the stress components corresponding to the longitudinal (ψ 11), width (ψ 22), and thickness (ψ 33) directions developed in the bent samples following bending process, flattening process and rebending process. In addition, analysis results showed the evolution of stress components developed at three points (point close to punch, center point and point away from punch) of each sample in the three bending processes. The Von Mises stress contour revealed that the stresses increased with increasing the displacement from the center region to the region close to punch and the region away from punch during the three bending processes. Stress components analysis for all three bent samples revealed that the region close to punch was under compression while the region away from punch was under tension.

15:30-16:00 Tea Break

16:00-16:20 Invited (1219914)
Strengthening of Mg-based Long-Period Stacking Ordered (LPSO) Phase Alloys Induced by the Formation of Deformation Kink Band
Koji Hagihara, Takayoshi Nakano, Osaka University, Japan; Michiaki Yamasaki, Yoshihito Kawamura, Kumamoto University, Japan

The LPSO phase is expected as a suitable strengthening phase of Mg alloys. The recent hot topic found in Mg-alloys containing large amount of long-period stacking ordered (LPSO) phase is the unusual increase in the strength by the extrusion. Recently we clarified the mechanisms which induce the drastic strengthening of the LPSO-phase alloys by extrusion, on the basis of the quantitative analysis. In this presentation, the details of this are discussed. In order to achieve this, the temperature and loading orientation dependence of the deformation behavior of the Mg88Zn4Y7 extruded alloy which contains a ~86vol.% of LPSO-phase were examined, in addition to the test using the directionally solidified (DS) LPSO-single-phase crystals. Using several extruded alloys with different extrusion ratio, the influence of extrusion ratio to the microstructure formation and the following mechanical properties were examined. Rectangular specimens were cut by electro-discharge machining from the as-cast ingot and extruded alloys, and the mechanical properties of them were examined by compression tests. The tests were conducted in a temperature range between the room temperature and 400℃ in a vacuum. Two loading orientations were selected for the compression test; one is parallel to the extrusion direction (0° orientation), and the other is inclined at an angle of 45° from the extrusion direction (45° orientation), to clarify the anisotropic mechanical properties of the extruded alloys. As a result, the yield stress of the LPSO phase alloy was found to exhibit a strong orientation dependence varied with the extrusion ratio. Especially, the yield stress of the extruded alloy with the reduction ratio of 10 showed an extremely high value of ~460MPa when loaded at 0° orientation, while it was largely reduced when loading at 45° orientation. This strong anisotropy of the plastic deformation behavior was considered to be derived from the variation in the deformation mechanisms depending on the loading orientation because of the development of strong (10-10) fiber texture along the extrusion direction. Basal slip was found to govern the deformation behavior at 45° orientation, while the predominate deformation mechanism varied from basal slip to the formation of deformation kink band at 0° orientation, as increasing in the extrusion ratio. In addition, it was found that the introduction the deformation kink band boundary during the extrusion process effectively act as strong obstacles against the motion of basal slip. That is, "the kink band strengthening" was first quantitatively elucidated, which
contributes to the drastic increase in the yield stress of the extruded LPSO-phase alloys in the wide temperature range below 400°C. The further details on this "kink band strengthening" will be discussed on the basis of the new results obtained by using the DS crystals.

**16:20-16:35(1223357)**

The Effect of Twin Boundary on Precipitation Crystallography in Magnesium Alloy

*Xinfu Gu*, University of Science and Technology Beijing, China

Precipitation on deformation defects is essential for enhancing mechanical properties of age-hardenable alloys. The deformation defects act as heterogeneous nucleation sites and promote precipitation; in turn, these precipitates pin the movement of effects and improve the mechanical properties. Similar to other alloy systems, the precipitates in magnesium alloy also often exhibit preferred crystallographic features, such as specific orientation relationship (OR) between precipitates and matrix, interfacial orientation, morphology, and growth direction. These crystallographic features are one of the determinant factors of mechanical properties. Therefore, the understanding of precipitation crystallography at deformation defects in magnesium is indispensable in controlling the mechanical properties, but the related studies are limited.

The crystallographic restriction of deformation defects on precipitation was studied in the alloy systems mostly with cubic matrix due to the importance of steel, titanium alloy, etc. In magnesium alloys, twinning is an important deformation mode to accommodate the deformation strains due to limited slip systems. Therefore, it is important to study the effect of the twin boundary (TB) on the precipitation process.

In this work, we revealed how TB influences precipitation in Mg-Al-Zn alloys. As-cast Mg-9Al-1Zn (AZ91) alloy was homogenized at 415°C for 24 hours and subsequently quenched by water. Compression samples with outer diameter of 10mm and height of 15mm were cut from the solution-heat-treated sample and then compressed at room temperature with ~ 4pct strain to introduce the proper amount of deformation twins. Finally, the samples were aged at 300°C for 2 to 6 hours. The method for preparing TEM specimens was prepared by ion milling. The TEM observation was carried out with Talos F200 (200kV, FEI, OR, USA), and the statistic study of the crystal orientation was based on EBSD (Oxford Instruments, Oxfordshire, England).

It is shown that the precipitates on the TBs are different from those in matrix. Most precipitates hold the reproducible OR only with twin or matrix. Moreover, certain precipitate variants are absent and a new rule for variant selection on TB is proposed.

**16:35-16:50(1301842)**

Effects of Solution Temperature on Microstructure and Mechanical Properties of a Sand Cast Mg-Gd-Y Magnesium Alloy

*Bo Zhou*, Institute of Metal Research, Chinese Academy of Sciences, China / University of Science and Technology of China, China; *Di Wu*, Rongshi Chen, Enhou Han, Institute of Metal Research, Chinese Academy of Sciences, China

Solution treatment at different temperatures ranging from 475°C to 545°C and subsequent aging treatment were performed to investigate the microstructure evolution during solution treatment and the effects of solution temperature on the mechanical properties of sand cast Mg-6Gd-5Y (GW65) Mg alloys. The microstructure of as-cast samples consists of α-Mg, eutectic Mg24(Gd, Y)5 phase and sparse cuboid phase. After solution treatment, the eutectic Mg24(Gd, Y)5 phase is almost completely dissolved into the matrix, and a large amount of cuboid phase is observed mainly in grain boundaries and with small amount within grains. In addition, the grain size increases and the fraction of cuboid phase decreases gradually with increasing the solution temperature. Quasi in-situ examination shows that clusters of cuboid phase are observed probably due to the decomposition of coat and surround of Mg24(Gd, Y)5 phase. Interestingly, there is almost no appreciable difference of hardness (varying from 125HV to 130HV) in peak-aged samples with different solution treatments. All samples exhibit similar age hardening response in spite of the solution temperature variations. The best comprehensive mechanical properties are obtained in cast-T6 samples with previous solution treatment at 500°C. It is mainly because of the moderate grain size and relatively small amount of cuboid phase left in matrix.

**16:50-17:05(1222598)**

Heat Resistance Improvement in Mg-Al-Si System Alloy AS31 with tin Addition

*Seiji Saikawa*, Satoru Ishihara, University of Toyama, Japan

The vehicle weight reduction is needed to achieve high fuel efficiency. Therefore, aluminum and magnesium high-pressure die-casting (HPDC) is applied for automobile parts because of high productivity, good dimension accuracy and relatively low cost. Magnesium alloy components produced by HPDC, which have the characteristic with high specific strength and lightweight property, is widely used for auto mobile industry. Heat-resistant magnesium alloy is focused as a suitable material for weight reduction of the engine and power train parts in automotive field. Recently, heat-resistant magnesium alloy in automobile field, Mg-3mass%Al-
Analysis on Edge Failures and Construction of Edge Cracks Pre-Criterion Model of AZ31 Magnesium Alloy Plate

Fangkun Ning, Qichi Le, Northeastern University, China

Edge failure of AZ31 plate during hot rolling, including damages and cracks, would increase the edge cutting amount, reduce yields and also destroy the production continuity. The meso- or micro-failure called damage would induce the cracks growing when it is cumulated to some extent. In this paper, morphologies and types of edge damages or cracks during the rolling under various initial rolling temperatures and rolling reductions were compared and analyzed. Based on normalized C-L criterion, FE simulation was carried out and hot rolling experiments under a temperature range of 200~350℃, the rolling reduction rate of 25%~40% and rolling speed from 7~21r/min were implemented. The microstructure was observed by optical microscope and damage values of simulation results were contrasted with the length of cracks on diverse parameters. The results showed that there were no obvious cracks but the 1~2mm damage scopes distanced from the edge during the 200~350℃ rolling with a small rolling reduction. Nevertheless, edge cracks depth were approximate 10mm with a larger rolling reduction under various initial rolling temperatures. With the increase of the reduction, the depth of cracks increased. At the same temperature, the depth of chevron cracks was shallow than slash cracks and the amounts of slash cracks were less than chevron cracks. The plate generated fewer edge cracks and the microstructure emerged slight shear bands and fine dynamic recrystallization grains rolled at 350℃, 40% reduction and 14r/min. The edge cracks pre-criterion model was obtained combined with the Zener-Hollomon equation and deformation activation energy.

Active Corrosion Protection by a Smart Coating Based on Layered Double Hydroxide on Mg Alloy

Liang Wu, Gen Zhang, Xingxing Ding, Aitao Tang, Fusheng Pan, Chongqing University, China

The fabrication of traditional LDHs films usually involves the introduction of foreign metal ions. In this study, it was found that micro-arc oxidation coatings or anodic oxide films contains magnesium and aluminum oxides, when it was carried out in the bath containing aluminum element. Mg-Al LDHs films can be fabricated by using Mg-Al mixed oxides, which can provide a source of Mg and Al for the transformation. In addition, the films can load inhibitors through ion exchange to improve their corrosion resistance. The structure and composition of Mg-Al LDHs conversion coatings are investigated by scanning electron microscope (SEM), energy dispersive spectrum (EDS), X-ray diffraction (XRD), and Fourier transform infrared (FT-IR), respectively. Furthermore, the corrosion resistances of Mg-Al LDHs films are investigated by potentiodynamic polarization, electrochemical impedance spectroscopy (EIS), and Scanning Vibrating Electrode Technique (SVET), respectively. The results show that Mg-Al LDHs films can be formed directly by the conversion of anodic oxide films, without the introduction of other ions. The corrosion resistance mechanism of Mg-Al LDHs films have two aspects: (i) The pores of the micro-arc oxidation coating or anodic oxide films were sealed by LDHs nanosheets, which can act as a good physical barrier to prevent chloride ion erosion; and (ii) as a kind of nano-container, LDHs can store and release inhibitors to protect the substrate actively.
straightness and parallelism. The porous structures of the ingots could be controlled through adjusting and optimizing the withdrawing rates during the processing. Also, the porosity, pore diameter, and pore length could be modified by changing the solidification speed and the hydrogen pressure. The porosity of the ingots was nearly constant under different solidification speeds, but decreased with the increase of the hydrogen pressure. The pore growth direction bended outward when the withdrawing speed was lower than 1.75mm/s. However, when the withdrawing speed increased above 2mm/s, the pore growth direction started to bend inward. With the increase of the hydrogen pressure from 0.1MPa to 0.6MPa, the average porosity of the ingots decreased from 53.6% to 38.4%, and the average pore diameter decreased from about 2512μm to 327μm. The phase constitution of Mg-2wt.%Mn ingots was the α-Mg matrix and the α-Mn precipitates. The compressive properties and corrosion resistance of the porous Mg-2wt.%Mn alloys were studied. The yield strength of the porous Mg-2wt.%Mn alloys was varied with increasing the angle between the pore axis and the compressive direction. Meanwhile, the electrochemical polarization curves exhibited that the self-corrosion potential of the Mg-2wt.%Mn alloys was influenced by the porosity and pore diameter. Moreover, based on a model for estimating activity coefficient of multi-component molten alloys, the hydrogen solubility in molten alloys was calculated, and the calculated results showed good agreements with the experimental results. All the work above was to evaluate the structures and properties of the Mg-2wt.%Mn alloys including their microstructure, porosity, pore size, mechanical properties and corrosion resistance, aiming to investigating the possibility of being considered as a biomaterial candidate.

17:50-18:05(1222766)
Effect of Ca, Y Addition on Recrystallization and Texture Evolution of Mg-Al Based Alloy Sheets
Young Min Kim, Su Mi Jo, Bong Sun You, Korea Institute of Materials Science, Korea

With respect to the improvement in the room-temperature formability of magnesium sheets, many researchers have carried out to investigate the modification of texture through the addition of alloying elements such as rare-earth (RE) elements (e.g. Ce, Nd, Y) and non-RE elements (e.g. Zn, Zr, Ca). Recently it was reported that the addition of Ca or Y into Mg-Zn based wrought magnesium alloys led to texture weakening by activating non-basal slip systems and twinning, which can resultantly improve the room-temperature formability. However, there were few reports that investigated the effect of Ca and Y addition on recrystallization behavior and texture modification of Mg-Al based alloys. The present study aims at investigating the effect of alloying elements and process parameters on recrystallization and texture evolution of modified AZ31 magnesium alloys with Ca and Y addition subjected to a cold rolling and subsequent recrystallization annealing process. In this study, it was found that severely deformed structures such as shear bands formed during cold rolling could provide nucleation sites of new grains during annealing. Cold-rolled and annealed sheets showed much finer grain size and lower maximum intensity of basal pole, indicating better mechanical properties and formability. In addition, the studied alloys shows dramatically increased ignition temperature and corrosion resistance. Detailed analyses with EBSD and TEM on microstructural evolution and texture changes during annealing will be shown in this presentation.
Forming Characteristic of Wrought Magnesium Alloy Sheet during Cold Roll Forming

Hisaki Wwtari, Ryohei Suzuki, Harunori Kobayashi, Toru Shimizu, Tokyo Denki University, Japan; Yuji Kawamura, Kumamoto University, Japan; Young Min Kim, Korea Institute of Materials Science (KIMS), Korea; Jian-Feng Nie, Monash University, Australia; Diran Apelian, Worcester Polytechnic Institute, USA

In recent years, expectation to innovate lightweight technologies for reducing carbon dioxide emission has been gradually increasing. Under such circumstances, lighting technologies which can reduce products weights by using light metals such as aluminum alloys and magnesium alloys has been attracting much attention. However, there are few practical examples of magnesium alloy products in automotive industries although the magnesium alloy can be recognized that it can contribute to reduce product weight dramatically because the specific weight of magnesium alloys are two third of aluminum alloys. There are three barriers in practical use of the magnesium alloys. The following three reasons are considered to be main problems for overcoming the difficulties of magnesium alloys, namely, (i) The prices of magnesium alloys for plastic working (wrought magnesium alloys) are normally very expensive, (ii) Magnesium alloys have poor workability at room temperature due to its crystal structure (hexagonal closed pack). (iii) There are not so much established manufacturing technologies in forming magnesium alloys when in considering large scale production at room temperature, die casting is only practical process for large scale production at high temperature. Over the past years, although the production of magnesium has gradually increased, the production of magnesium alloy plates (wrought magnesium alloy sheet) has remained at a very low level at practical level, which is far from the recent dramatic change in automotive manufacturing industries.

One of the authors has been investigating into possibilities magnesium alloy sheets (wrought magnesium alloy sheet) by using cold roll forming process while considering future possibilities of cold roll forming of wrought magnesium alloys. If cold forming of the magnesium alloy is possible, it can greatly contribute to establishing the manufacturing process which can reduce the product weight while maintaining the strength of the product.

The aim of the present work is to establish the roll forming of wrought magnesium alloys, which have complicated stress-strain curves of tension–compression asymmetry. Firstly, a three-dimensional elasto-plastic analysis in simple V bending process has been conducted to investigate into effect of stress-strain curves in tension and compression on simple V bending process. Secondary, after the testing of the V-bending simulation which can consider different stress-strain curves in tension and compression state, a finite element analysis for V-section during cold roll forming of a wrought magnesium alloy has been performed. A simple V-sections were formed by a tandem six stands roll forming machine to demonstrate effectiveness of the proposed simulation method which can consider stress-strain curves of tension–compression asymmetry. The variation of longitudinal strain as well as bending strain in width direction at bent corner were shown by suing finite element simulation. Spring back analysis has been conducted to investigate exact cold roll forming phenomenon for wrought magnesium alloy sheets.

Four-Point Bending Behaviour of Hot-Rolled Mg-0.8Zn-0.4Ca Alloy

Kourosh Tavighi, Chris H. J. Davies, Monash University, Australia

Complex stress states are a feature of engineering applications. We studied the effects of grain size on the four-point bending behaviour of hot-rolled Mg-0.8wt.%Zn-0.4wt.%Ca strips with a thickness of 0.9mm. Microstructural evolution was examined in the through-thickness direction of the strip because the stress state changes from tension to compression through the thickness when subjected to bending. Grain sizes were selected to give ratios of sample thickness to grain size over two orders of magnitude. Strips were heat treated at 400°C, 470°C and 490°C for 2 hours, leading to grain sizes of 11.7µm, 29.4µm and 76.1µm, so there are 80, 30 and 10 grains at the strip wall approximately. The original material has a grain size of 6.2µm resulting in the presence of 145 grains at the wall.

This work explores the relationship between increasing grain size (decreasing thickness to grain size ratio), microstructural evolution, and mechanical response of the alloy using electron backscattered diffraction metallography of areas close to the tensile surface, near the neutral axis, and close to the compressive surface of the strip. Implications are explored for the design, manufacture, and deployment of magnesium alloy thin-
Mg alloys, being the lightest metallic structural materials, are particularly attractive for transportation applications such as automobiles and aircrafts for weight reducing and higher fuel efficiency and biocompatible and biodegradable features ideal for implant applications. The improvement of both the strength and the ductility is still a challenge in the development of advanced Mg alloys. Recent works have shown that the fault layers enriched of solute atoms could stabilize the long period stacking ordered (LPSO) structures described by a common structural unit composed of local FCC-type stacking sequence and improve the mechanical properties of Mg alloys. Here we show the strategies to strengthen Mg alloys through modifying the matrix by planar faults and optimizing the local lattice strain by solute atoms. The anomalous shifts of the local phonon density of state of stacking faults (SFs) and long periodic stacking ordered structures (LPSOs) toward the high frequency mode are revealed by HCP-FCC transformation, resulting in the increase of vibrational entropy and the decrease of free energy to stabilize the SFs and LPSOs. Through integrating bonding charge density and electronic density of states, electronic redistributions are applied to reveal the electronic basis for the "strengthening" of Mg alloys. Moreover, the atomic and electronic basis for lattice-distortion-mediated formation of stacking faults, i.e., localized face-centred-cubic (FCC) structures, within a Mg-Zn-Y alloy with a hexagonal close-packed (HCP) structure. The atomic motion trajectories from ab-initio molecular dynamic simulations show that the Mg atoms occupying the nearest neighbour positions of Zn and Y solute atoms undergo a local HCP-to-FCC transition. It is revealed that a local lattice distortion caused by the solute atoms enables the Mg atoms to move and rearrange into a local FCC configuration, which is validated by high resolution scanning transmission electron microscopy and in-situ synchrotron X-ray diffraction. Our simulations provide profound insight into the formation mechanism of stacking faults in HCP Mg and their physical nature of phase transformations; this is not only critically important because conventional defects, such as dislocations and vacancies, are important to deformation are rare for Mg and its alloys, but also because they serve as a potential new approach to the design of advanced Mg alloys when defects are actually phase transformations.

Magnesium (Mg) has been widely used as structural materials, for example, frame of electrical devices, parts of automobile, due to its light weight. Several reports are available about addition of rare-earth element (RE) on Mg, and Mg alloys show precipitation hardening by aging treatment of super saturated solid solutions (S.S.S.S.). Lorimer et al. reported the precipitation sequence in Mg-Y alloys aged at 473K as S.S.S.S. → β′(D019) → β′(cbbc) → β(Fm-3m). Scandium (Sc) addition on Mg alloy is known that it enhances a heat resistance. This study uses high-resolution transmission electron microscopy (HRTEM), selected-area electron diffraction (SAED) pattern and energy-dispersive X-ray spectroscopy (EDS) to identify the crystal structure of a metastable phase in a Sc-added Mg-Y alloy, which we compared with the crystal structure of the β′ phase in binary Mg-Y alloy. Mg-3.6at.%Y and Mg-3.5at.%Y-0.9at.%Sc used in this study were prepared by casting using 3N Mg ingot, 3N Y and 2N Sc chips. The fabricated alloys were homogenized at 773K for 43.2ks and then hot-rolled at 773K. The hot-rolled sample were subjected to solution heat-treated at 773K for 3.6ks in an argon gas atmosphere. Then, quenched into water of 293K, and aged using a silicone oil bath at 473K. TEM samples were thinned by the twin-jet electro polishing technique using a solution of 10% perchloric acid-ethanol at 253K. For HRTEM observation was conducted using TOPCON EM-002B, under the applied voltage of 120kV. HRTEM simulation images were calculated using the multislice method. Simulation images are obtained for each defocus and TEM sample thickness. The model used for the HRTEM simulation using a rectangular cell of 1.92nm x 2.22nm x 0.52nm including 96 atoms based on the hcp structure of Mg by MacTempasX. HRTEM images and HRTEM simulation images contrast were measured using Gatan Digital Micrograph software. In HRTEM observation, zig-zag structure and pre-β′ were observed. Also, both precipitates were confirmed in SAED pattern as diffuse spots in the early stage of aging. SAED and HRTEM images of the β′ phase in the Sc added Mg-Y alloy were similar to those of the β′ phase in the binary Mg-Y alloy. However, Sc-added
the HRDSR process, the I-phase network structure was icosahedral phase (I-phase) at low temperatures. During (2 and 3) was applied to cast Mg-Y-Zn alloys with the severe plastic deformation by high-ratio differential rate superplasticity and low-temperature superplasticity (HSRS) above 0.5Tm. The material with the second type of microstructure (produced at the roll speed ratio of 3), which consists of ultrafine grains (~1m) with a high portion of high-angle boundaries (i.e., a mixture of low- and high-angle boundaries), showed a better LTSP than the material with the first type of microstructure but did not show HSRS at temperatures above 0.5Tm. At low temperatures, grain boundary sliding occurred more readily along the high-angle grain boundaries than along the low-angle grain boundaries, leading to a better LTSP in the material with the first type of microstructure. At high temperatures, suppressing grain growth during the sample heating and holding stages for tensile testing or during tensile deformation was important in achieving HSRS. Rapid grain coarsening occurred in the material with the first type of microstructure during the sample heating and holding stages at temperatures above 0.5Tm, leading to the loss of HSRS. In the material with the second type of microstructure, however, the fine-grained microstructure could be maintained during the sample heating and holding stages. This was because low angle boundaries have a lower energy compared to high angle boundaries, such that the formers have a reduced driving force for grain growth. The dispersion of agglomerated I-phase particles into the matrix during deformation, which was promoted by grain boundary sliding, was also equally important in achieving HSRS from the material with the second type of microstructure. This was because as the fine I-phase particles were dispersed during deformation, the pinning effect of I-phase particles increased, resulting in an effective suppression of dynamic grain growth of the fine grains. 

9:45-10:00(1235492)

Achievement of Excellent High-Strain-Rate Superplasticity and Low-Temperature Superplasticity through Low-Angle Boundary Formation in a Mg-Y-Zn Alloy with the Icosahedral Phase

Taejin Lee, Woojin Kim, Hongik University, Korea

Severe plastic deformation by high-ratio differential speed rolling (HRDSR) with different roll speed ratios (2 and 3) was applied to cast Mg-Y-Zn alloys with the icosahedral phase (I-phase) at low temperatures. During the HRDSR process, the I-phase network structure was fragmented. The roll speed ratio of 3 provided a higher degree of refinement and dispersion of the I-phase than the roll speed ratio of 2, but a high portion of the refined I-phase particles were agglomerated along the rolling direction. Two types of microstructures with ultrafine grains (~1m) were obtained, depending on the roll speed ratio. The material with the first type of microstructure (produced at the roll speed ratio of 2), which consists of ultrafine grains with low-angle boundaries, showed both low-temperature superplasticity (LTSP) at temperatures below 0.5Tm (Tm: melting temperature) and high-strain-rate superplasticity (HSRS) above 0.5Tm. The material with the second type of microstructure (produced at the roll speed ratio of 3), which consists of ultrafine grains (~1m) with a high portion of high-angle boundaries (i.e., a mixture of low- and high-angle boundaries), showed a better LTSP than the material with the first type of microstructure but did not show HSRS at temperatures above 0.5Tm. At low temperatures, grain boundary sliding occurred more readily along the high-angle grain boundaries than along the low-angle grain boundaries, leading to a better LTSP in the material with the first type of microstructure. At high temperatures, suppressing grain growth during the sample heating and holding stages for tensile testing or during tensile deformation was important in achieving HSRS. Rapid grain coarsening occurred in the material with the first type of microstructure during the sample heating and holding stages at temperatures above 0.5Tm, leading to the loss of HSRS. In the material with the second type of microstructure, however, the fine-grained microstructure could be maintained during the sample heating and holding stages. This was because low angle boundaries have a lower energy compared to high angle boundaries, such that the formers have a reduced driving force for grain growth. The dispersion of agglomerated I-phase particles into the matrix during deformation, which was promoted by grain boundary sliding, was also equally important in achieving HSRS from the material with the second type of microstructure. This was because as the fine I-phase particles were dispersed during deformation, the pinning effect of I-phase particles increased, resulting in an effective suppression of dynamic grain growth of the fine grains.
Magnesium Alloy Low Cost Preparation of Ultrafine AZ31

Peng Peng, Aitao Tang, Jia She, Xiaoxi Mi, Fusheng Pan, Chongqing University, China

Grain refinement is very important to magnesium alloys due to the higher k value in Hall-Petch relationship compared to the Fe, Al alloys. The severe plastic deformation methods to fabricate ultrafine grain structure (UFG) structure are complicated and high cost. To date, preparation of UFG structure in a common extruder is still a great challenge. In this work, double strain was achieved by reducing the billet diameter during the extrusion process, and this novel extrusion process was called continuous forging extrusion (CFE). After CFE, with the increment of equivalent strain, the average grain size of Mg-3Al-1Zn (AZ31) alloy was successfully refined to submicron scale (~0.6 μm). The UFG AZ31 alloy exhibited an excellent combination of yield strength of 307MPa and ductility of 26.3 %. The formation of submicron grains were attributed to the accelerated dynamic recrystallization process. The CFE process was easy to achieve because the manufacturing equipment was only a common extruder. The low cost process could be industrialized both readily and economically.

10:15-10:30

Low Cost Preparation of Ultrafine AZ31 Magnesium Alloy

Peng Peng, Aitao Tang, Jia She, Xiaoxi Mi, Fusheng Pan, Chongqing University, China

10:30-10:45 Tea Break
C2-1: Effect of LPSO Template and Precipitation Behavior on Mechanical Properties in Mg-Y-Al Alloys (1222280)

Qingchun Zhu, Yangxin Li, Yuxuan Liu, Huan Zhang, Xiaojin Zeng, Shanghai Jiao Tong University, China

To date, the applications of Magnesium alloys are still limited due to their low strength, low ductility as well as low creep resistance. Magnesium alloys containing rare earth (RE) in conjunction with other alloying elements, such as Zn, have drawn increasing interest due to their high strength, high ductility and high creep-resistance with the existence of long period stacking ordered (LPSO) phases.

It is widely accepted that intragranular precipitates strengthen the matrix via impeding the movement of dislocations, and the magnitude of strengthening effect on the matrix strongly depends on the size, morphology and crystallography of precipitates. Since the LPSO phase is essentially periodic stacking faults that usually form on the basal plane, it is very difficult to achieve a significant improvement in strength by merely introducing dispersive LPSO precipitates at ambient temperature. In addition, it is well-known that LPSO phase exhibit high stability at elevated temperature, showing excellent pinning effect for grain boundaries. Meanwhile, the LPSO phase can obstruct the movement of \(<a+c>\) dislocation which can enhance the mechanical properties of magnesium alloys performing at high temperatures.

Therefore, the combination of LPSO and other strengthening precipitates, such as the plate-shaped \(\beta\) phase (c-axis base-centered orthogonal, \(a = 0.642\text{nm}, b = 2.224\text{nm}, c = 0.521\text{nm}\)) that forms on prismatic plane of \(\alpha\)-Mg matrix, is believed to be a promising approach to achieve excellent mechanical properties both at the ambient and elevated temperatures.

In our work, superior thermal stability of refined grains was found in the Mg-11.7Y-1Al (wt. %) alloys at elevated temperatures. The observed 18R-LPSO phase, of which distribution can be controlled by solution treatment parameters, can pin the grain boundary and impede grain growth during solution treatment. After solution treatment at 550°C for 16 hours, the LPSO phase was mainly formed at grain boundary. After solution treatment at 520°C for 8h, the refined LPSO phase was uniformly distributed within the grains and formed a template with an average distance of 100 nm. The peak hardness was attributed to the precipitation of \(\beta\) phase obtained during ageing at 225°C for 10 days. The size of \(\beta\) particles can be limited when they are formed between LPSO laths, which leads to an abnormal yield strength increase at elevated temperatures.”

C2-2: Effects of High Strain Rate on the Microstructure Evolution of GW103K Magnesium Alloy (1222363)

Huan Zhang, Yangxin Li, Qingchun Zhu, Yuxuan Liu, Xiaojin Zeng, Shanghai Jiao Tong University, China

As the lightest metallic structure material, magnesium alloys have a large range of applications in automotive industry due to their low density and high specific strength. However, it is crucial for automotive components to withstand high strain rate impact without failure. As we all know, strain rate is an important factor for the deformation of magnesium alloys, which influences both dislocations and twinning modes. However, the deformation mechanism of magnesium alloys with high strain rates has not been thoroughly investigated yet, especially for magnesium alloys containing rare-earth (RE) elements.

In this work, the microstructure evolution of GW103K alloy with different conditions (T4 and T6) is investigated after high strain rate deformation by split Hopkinson bar (SHPB) at room temperature. A considerable amount of mechanical twins were observed both in the T4 and T6 GW103K alloys after SHPB treatment, where the \(\{10-12\}<10-11>\) extension twin and \(\{10-11\}-\{10-12\}\) double twin are commonly found in TEM and EBSD. In addition, a high density of stacking faults was found to be uniformly distributed both in the matrix and mechanical twins. Magnesium alloys usually exhibit poor ductility with quasiloading at room temperature. The activation of multiple twinning modes can effectively improve the plasticity because twins can accommodate the deformation along c axis. After SHPB deformation, the Vickers hardness was increased a lot due to the work hardening in both the T4 and T6 alloys. However, for the T6 alloy, the existence of \(\beta\) phase limits the formability of high strain rate deformation and suppresses the occurrence of other twinning modes, compared with the T4 alloy under the same strain, where the unusual \(\{11-21\}<11-26>\) extension twin was also observed. In addition, a high density of \(<c+a>\) dislocations were activated. Therefore, multiple mechanical twinning modes and dislocation slip systems during the SHPB deformation lead to a better formability of the T4 alloy.
C2-3: Multi-Scale Study on Tensile Plastic Deformation Mechanism of Biaxially Separated Non-Basal Textured AZ31 Magnesium Alloy Sheet at Room Temperature(1222419)
Yu Chen, Tu Jian, Hu Li, Tao Zhou, Chongqing University Of Technology, China

As to AZ31 magnesium alloy sheet fabricated by the conventional plastic processing technology, the poor deformability at room temperature results from its forming stable basal texture, and therefore its maximum deformation degree per pass in the process of rolling at room temperature has never exceeded 22%. However, in the present study, based on the technique of equal channel angular rolling continuous bending (ECAR-CB), AZ31 magnesium alloy sheet with the bimodal non-basal texture is fabricated, in which the basal poles are completely separated. As a result, its maximum deformation degree per pass in the process of rolling at room temperature has reached 32%, which illustrates that the unfavorable effect of basal texture on the deformability in the process of rolling at room temperature can be basically eliminated, and moreover the breakthrough with regard to bottleneck in the application of traditional wrought magnesium alloy is overwhelmed with expectation. However, deformation mechanisms of AZ31 magnesium alloy sheet with this kind of special non-basal texture are still not clear. Therefore, it is meaningful to investigate the relative deformation mechanism, from the macroscale, mesoscale, microscale and nanoscale perspective, by combining microstructure characterization experiment of materials and crystal plasticity finite element simulation, it shall be able to lay the theoretical and technical foundations for the industrial production of magnesium alloy sheet with perfect properties by means of exploring the basic laws of microstructure evolution of sheet in the case of rolling at room temperature, analyzing the interaction mechanisms between dislocation and dislocation, between dislocation and twin, between twin and twin, between dislocation and grain boundary during rolling process of sheet at room temperature, establishing the crystal plasticity constitutive model in consideration of the synergetic interaction between dislocation and twin, revealing the deformation mechanisms of AZ31 magnesium alloy sheet with the bimodal non-basal texture in the process of rolling at room temperature.

C2-4: Effects of the Heat Treatment Conditions on the Creep Properties and Microstructure Evolution of Mg-10Gd-0.4Zr Alloy(1234615)
He Qin, Guangyu Yang, Wanqi Jie, Northwestern Polytechnical University, China

Effects of the heat treatment conditions on the creep properties and microstructure evolution of Mg-10Gd-0.4Zr magnesium alloy under the applied stress of 80MPa and the temperature of 523K have been investigated by high resolution transmission electron microscopy (HRTEM) and high-angle annular detector dark-field scanning transmission electron microscopy (HAADF-STEM) in this work. It is found that the creep resistance of T4 and T6 state experimental alloys are much higher than that of the as-cast alloy respectively, which mainly owing to the coarse and unevenly distributed intergranular second phase in the as-cast alloy. It is also showed that the strain of T4 state alloy within the primary creep stage is larger than that of T6 state alloy due to the less precipitated phase. However, the steady creep rate of T4 state alloy is lower than that of T6 state alloy. The main reason for this lies in the fact that the ellipsoidal β precipitates gradually form and then grow into prismatic plates to enhance the creep resistance of T4 state alloy, and the formation and coarsening of β, and β' phases at the expense of β' precipitates in T6 state alloy lead to the deterioration in creep resistance during the steady state creep stage.

C2-5: The Formation and Orientation of Static Recrystallization Grains in Mg-Zn-Gd Alloys (1305402)
Lingyu Zhao, Institute of Metal Research, Chinese Academy of Sciences, China / University of Science and Technology of China, China; Hong Yan, Rongshi Chen, Enhou Han, Institute of Metal Research, Chinese Academy of Sciences, China

The formation of non-basal texture is reported to be associated with the recrystallization process in magnesium-rare earth alloys. The orientation and misorientation of static recrystallization (SRX) grain relative to the matrix in cold-rolled Mg-Zn-Gd alloys during annealing at 300~400°C for 1h were investigated using electron backscattered diffraction method. Our results show that the orientation of SRX grains varies with SRX mechanism. SRX grains formed at grain boundary (GB) show random orientations. In addition, the misorientation between these SRX grains and matrix is mostly more than 50°. However, the orientation of SRX grain formed by sub-grain is near the matrix and the misorientation is less than 30°. Interestingly, a new way to form SRX grains is observed in this study. That is, many small sub-grains surrounded by short low angle GBs are in the original matrix grain. Then short low angle GBs transform into long low angle GBs which divide the matrix into several parts. With the transformation from long low angle GBs to long high angle GBs, these parts become new SRX grains at last. SRX grains formed by this new way show larger size than traditional SRX grains and similar orientation to the matrix (the misorientation is less than 35°).
C2-6: Bending Deformation Behavior of Mg-Y Alloy Single Crystals(1220355)
Kenta Oka, Ryota Fukumori, Masayuki Tsuchida, Hiromoto Kitahara, Shinji Ando, Kumamoto University, Japan

Magnesium has a hexagonal close-packed (hcp) structure with low symmetry, and the main slip and twin systems of magnesium is basal slip and {10-12} twin, respectively. However, when the loading axis is perpendicular or parallel to basal planes, basal slips never occur geometrically. Also, when the loading direction is perpendicular to basal planes in compression tests, or parallel to basal planes in tension tests, {10-12} twinning does not occur. It is, therefore, known that the deformation behavior of magnesium shows strong orientation dependence. Here, bending deformation is a key process for producing various products from magnesium sheets. In bending tests, both tensile and compressive stresses simultaneously loaded in a specimen. Thus, bending deformation behavior is more complex, compared to that in tensile and compression tests. Therefore, bending deformation behavior of magnesium remains unclarified. In recent years, it has been reported that bending deformation behavior of pure magnesium single crystals shows strong orientation dependence. In this study, Mg-Y alloy single crystals with different crystal orientations and yttrium contents were prepared, and then they were subjected to three-point bending tests to investigate the influence of yttrium on the bending deformation behavior, ductility and strength. The composition of each specimen was Mg-0.07at%Y and Mg-0.15at%Y. Three-point bending tests were carried out at room temperature and the loading rate was 1.67 x 10^-2 mm/s. Specimens whose neutral planes are parallel to (0001) and neutral axes are [11-20] deformed due to basal slips and showed gull-shape. Yield stresses were found to increase with increasing yttrium contents and to be determined by the shear stress loading on the basal plane. On the other hand, when the neutral planes are parallel to (1-100) and neutral axes are [11-20], the specimens deformed due to {10-12} twinning occurred in the compressive side and showed V-shape. It was also found that twinning also occurs in the tensile side of magnesium in three-point bending tests when yttrium was added.

C2-7: Microscopic Phase structure of the As-Cast and the Peak-Aged Mg-Yb-Zn-Zr Alloy(1220778)
Deping Zhang, Tohoku University, Japan / Changchun Institute of Applied Chemistry Chinese Academy of Sciences, China; Soo-Hyun Joo, Jing Jiang, Hidemi Kato, Tohoku University, Japan; Qiang Yang, Jian Meng, Changchun Institute of Applied Chemistry Chinese Academy of Sciences, China; Yaqin Zhang, Taiyuan Institute of Technology, China

Detailed microstructures of the as-cast and the peak-aged metal mould casting Mg-xYb-0.5Zn-0.4Zr (x = 0.5, 1, 2, and 3wt.%) alloys were thoroughly investigated. The results indicate that Yb has better grain refinement effect, solid solution strengthening effect and dispersion enhancement effect of precipitated phase under peak-aged on the Mg-Zn-Zr based alloys compared with the conventional rare earth elements such as Nd, Sm, and Gd, and the dominant intermetallic phase in the as-cast samples is Mg-Yb, although with a few Mg41Sm3 particles. In addition, the studied alloys also exhibit good aging hardening response when aged at 200°C. During aging treatment, obvious precipitation of T phase formed on grain boundaries can be observed in the alloys with Yb is less than 2wt.%, while Mg-Yb precipitate chains in the grain center and discrete Mg-Yb particles homogeneously distributed near grain boundaries in the samples with Yb addition over 2wt.%. Under the same aging conditions, with the increase of Yb content, the type, size, shape, quantity and distribution of the second phase changed obviously. At the same time, the precipitate chains precipitated in the grain center can effectively prevent the grain dislocation slip, and the dispersed phase particles uniformly distributed near the grain boundary can pin the grain boundary and avoid the occurrence of grain boundary slip. The coexistence of the two phases results in the alloy having the most superior comprehensive properties at this time. Finally, ultra-fine needle-like precipitates were detected in all peak-aged samples, although with distinct difference on sizes and distribution densities. Based on energy dispersive spectrometer mappings of Mg, Yb, Zn and Zr and the SAED patterns, the needle-like precipitates were identified as g’ phase (MgZnRE containing, hexagonal structure, a = 0.55nm and c = 0.52nm) and followed an orientation relationship as (1.0)g’||(11.0)Mg and [00.1]g’||[00.1]Mg.

C2-8: Effect of Y on Microstructure Evolution and Mechanical Properties of Mg-13Li-3Al Alloys (1221476)
Lili Chang, Jing Guo, Shandong University, China

Mg-13Li-3Al alloys with different amounts of addition Y were prepared by vacuum melting followed by hot-extrusion and annealing process. Microstructure evolution was characterized by using optical microscopy.
scanning electrical microscopy, transmission electrical microscopy, X-ray diffraction and mechanical properties were examined by tensile test. The results indicated that the main phase constitutes of Mg-13Li-3Al ingots included β-Li, AlLi and MgLiAl₂. When Y was added in to Mg-13Li-3Al, Al₃Y was detected. Fine AlLi particles located inside grain interior, blocky MgLiAl₂ phases distributed along grain boundaries, while corase Al₂Y clusters aggregated inside β-Li matrix. After hot-extrusion, an typical equiaxed grain structure was observed, indicating dynamic recrystallization occurred during extrusion and the average grain size was in the range of 117-144 µm. Except phases in the ingots, Mg17Al12 was characterized by XRD. The macrotexture results by XRD indicated a weak basal texture was formed in Mg-13Li-3Al due to hot-extrusion and the maximum intensity of basal texture was about 2. After annealing at 300 degree for 2h, compared to the parameters of mechanical properties, the ultimate tensile strength was decreased due to softening while elongation at room temperature was enhanced. Mg-13Li-3Al without Y addition exhibits a better comprehensensive mechanical properties with an ultimate tensile strength of 209 MPa and a elongation of 31%.

**C2-9: Microstructure and Corrosion Evolution of As-rolled Mg-4Li-6AlSi Alloy(1221504)**

**Cheng Zhang, Liang Wu, Guangsheng Huang, Fusheng Pan, Chongqing University, China**

The microstructure and corrosion evolution of the two hot-rolled alloys, Mg-4Li and Mg-4Li-6AlSi alloys (weight percent) were investigated. The microstructure and composition were carried out by using a X-ray fluorescence (XRF), an optical microscope (OM) and a scanning electron microscope (SEM) equipped with an Oxford electron backscattered diffraction (EBSD) system and also equipped with an energy-dispersive X-ray spectroscopy (EDS). The corrosion behavior was investigated by hydrogen evolution tests, weight loss tests and potentiodynamic polarization curves.

The grain size of the Mg-4Li alloy is relatively coarse, and there are a lot of low-angle grain boundaries which can provide the ability and nucleation points for further dynamic recrystallization. The grain orientation of the Mg-4Li alloy mostly tends to (0001) orientation while the grain orientation of the Mg-4Li-6AlSi alloy mostly tends to cone and cylinder direction, and the texture are mostly formed with the conical and cylindrical texture. Moreover, the addition of 6wt.% AlSi can achieve the effect of weakening and dispersing the texture of the base surface. For the Mg-4Li-6AlSi alloy, the dynamic recrystallization grain is the least, and the dynamic recrystallization tendency to nucleate at the crystal. It is also easy to produce dislocation entanglement at the grain boundaries, and can also provide a nucleation point for dynamic recrystallization. In addition, the results of corrosion tests show that the Mg-4Li alloy has much better corrosion resistance compared with the Mg-4Li-6AlSi alloy. The hydrogen evolution rate of the Mg-4Li-6AlSi alloy was measured to be as high as 0.145 mL·cm⁻², while the hydrogen evolution rate of the Mg-4Li alloy was 0.048mL·cm⁻². The addition of 6wt.% AlSi results in the precipitation of Al3Li and Mg2Si within the hot-rolled alloys by OM and EBSD, which precipitates as some small spherical particles. The increase of the corrosion rate might be attributed to the precipitation strengthening imparted by the Al3Li and Mg2Si phases.

**C2-10: Effect of Temperature on Deformation Behaviors of Mg-0.1at.% Y Alloy Having Various Grain Sizes(1221772)**

**Kazuhiro Oki, Akinobu Shibata, Nobuhiro Tsuji, Kyoto University, Japan; Ruixiao Zheng, Kyoto University, Japan / Beihang University, China**

Magnesium (Mg) alloys are drawing great interest as structural material because of its light weight and good strength-to-weight ratio. It is well known that addition of rare-earth, such as Yttrium (Y), improves strength and ductility even if the alloying amount is very small. Recently it was found that there is a strong grain size dependence of deformation mechanism in Mg-Y dilute alloy. On the other hand, testing temperature has been revealed to be very important parameter which affect the mechanical property of Mg alloys. However, these works were mostly carried out at elevated temperature with conventional coarse grain specimens. Therefore, the present study aimed to systematically investigate the effect of testing temperature on deformation behaviors of a Mg-0.1at.% Y having various grain sizes. Mg-0.1at.% Y alloy specimens with various grain sizes ranging from 0.4µm to several tens of micrometers were prepared by high pressure torsion (HPT) and subsequent annealing. Mechanical property of the specimens was examined by a tensile test at room temperature and -196°C with an initial strain rate of 8.3 × 10⁻⁷s⁻¹. Microstructures of the specimens before and after the tensile deformation were characterized by scanning electron microscopy (SEM), electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM). At room temperature, the yield strengths obeyed a typical linear relationship (Hall-Petch relationship) when the grain size was larger than 1 µm, and a clear softening from the Hall-Petch relationship was observed in the ultrafine grained (d < 1µm) specimens. However, the softening phenomenon was less pronounced at -196°C, which was believed to be due to the inhibition of grain boundary sliding at low temperature. In addition, for a given grain size, the work-hardening rate (ds/de) at -196°C was much higher than that at room temperature. EBSD observations of the tensile deformed specimens suggested enhanced activity of (10-12) deformation twinning at -196°C, which seemed one of the reasons for
the enhanced work-hardening rate. Furthermore, all the specimens tested at -196°C showed premature fracture before achieving Considère plastic instability condition. Fracture surfaces of the specimens tested at -196°C were almost covered by intergranular fracture patterns, especially in the coarse grained specimens. The fracture behavior will be furthermore discussed based on microcrack observations using EBSD.

C2-11: Microstructure Observation of Mg-Zn-Ag Alloy Aged at 473K(1222233)
Rie Kudo, Tomoyoshi Maeda, Taiki Tsuchiya, Lee Seungwon, Susumu Ikeno, Kenji Matsuda, University of Toyama, Japan

Several reports are available about precipitation hardening of Mg-Zn alloys. Nie et al. suggested the precipitation sequence of Mg-Zn alloy like: S. S. S. S. → G.P. zone → β1' → β1. The recent study showed Mg-Zn alloy combined trapezoidal addition of Ag has more aging effectiveness. C.L. Mendis et al and T. Bhattacharjee et al. However, nucleation sequence, crystal structure and orientation relationship with a matrix of Mg-Zn-Ag alloy are not clearly revealed yet. In this study, Mg-Zn alloy and Mg-Zn-Ag alloy by detailed microstructure observant using high-resolution transmission electron microscopy (HRTEM) and the effect of added elemental has been investigated. Mg-2.2mol%Zn (2Zn) and Mg-2.2mol%Zn-0.2mol%Ag (2ZQ) were prepared by gravity casting. 2Zn alloy and 2ZQ were homogenized at 603K for 12h and at 653K for 48h, and alloys were undergone the hot rolling from 3mm to 1mm thickness, respectively. Then, samples were subjected to solution treated at 603K and 653K respectively for 1h using a quartz tube of argon atmosphere and quenched into water. Aging process was conducted using an oil bath at 473K. The mechanical property was investigated using Vickers microhardness measurement. Microstructure observation was conducted using TEM (transmission electron microscopy, TOPCON EM-002B) under accelerated voltage of 120kV. Thin foils were prepared by twin jet electrolytic polishing using a solution of nitric acid: methanol = 1: 3 cooled to 253 K. Microstructure observation was carried out using transmission electron microscope (TEM) Topcon EM-002B under accelerated voltage of 120kV. At the initial stage of aging of the Mg-2 at.% Zn alloy, the structure observation and the HRTEM simulation were carried out, and the aging precipitation behavior of this alloy and the structure of the precipitate were investigated.

C2-12: Microstructure Observation of Mg-2.2at.%Zn Alloy Aged at 473K(1222246)
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General interest in Mg alloy is increasing due to its good mechanical properties as structural application. Zn addition can enhance room temperature strength by solid solution effect. Also Mg-Zn alloy can be strengthened by precipitation hardening by aging treatment using super saturated solid solution (S.S.S.S). Recent studies have revealed the structure and morphology of precipitates of Mg-Zn alloys, and the precipitation sequence of Mg-Zn alloy is suggested that like S.S.S.S → G.P.zones → β1' → β1 → β. β1' phase is considered as a reinforcing phase has a rod shape and parallel to the [0001] Mg direction of matrix. β1' phase forms from β1 and has plate shape on (0001) Mg plane of matrix. Recent work has reported that the Mg1/2Zn, and MgZn phases can coexist in β1'. However, precipitation process, nucleation and growth process of precipitates are not completely known. In this study, Mg-2.2 at.% Zn alloy was prepared to observe the precipitation sequence.

In this study, Mg-2.2at.%Zn alloy was prepared to observe the precipitation sequence. This alloy was prepared by gravity casting. Homogenization was carried out at 603 K for 43.2ks, and the sample cut to a thickness of 3mm was hot rolled to 1mm. The solution treatment was performed at 603K, 3.6ks in an argon atmosphere and then quenched into water at 293K. Aging treatment was conducted at 473K. TEM specimens were prepared by twin jet electrolytic polishing method and then using a solution of nitric acid: methanol = 1: 3 cooled to 253 K. Microstructure observation was carried out using transmission electron microscope (TEM) Topcon EM-002B under accelerated voltage of 120kV. At the initial stage of aging of the Mg-2 at.% Zn alloy, the structure observation and the HRTEM simulation were carried out, and the aging precipitation behavior of this alloy and the structure of the precipitate were investigated.

C2-13: Room-Temperature Tensile Behavior and Plasticity Improvement of Columnar Crystal Mg-Gd-Y Alloy(1222445)
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Columnar crystal Mg-xGd-0.5Y (x=3,6) with vertical grain boundaries and less lateral grain boundaries were prepared by directional solidification technique at a pulling speed of 50 μ m/s. Back scattered electron diffraction (EBSD) technology was employed to investigate the effects of columnar crystal growth orientation and grain boundaries on the room-temperature tensile behavior of
the alloy. The results showed that in the Mg-3Gd-0.5Y alloy, the angle between the c-axis of the columnar crystal and the tensile direction (ie, the direction of temperature field) were 30° ~60° (A orientation, taking up about 60%) and 80° ~90° . (B orientation, taking up about 40%), and consequently the majority of grain boundaries were determined as A-A and the less ones were A-B. During deformation, the {101(—)}2 tensile twins were preferentially activated at the A-oriented grain near the A-B grain boundary and expanded into the interior of the A grain. As the deformation continued, the {101(—)}1 compression twins were activated in the B-oriented grains (near the A-B grain boundary) with a misorientation of 56° with the matrix. The {10-12} twins tended to be activated in the {101(—)}1 compression twins, forming {101(—)}1-{101(—)}2 double twins. The compression twins and double twins formed on both sides of the B-oriented crystal grains simultaneously expanded into the crystal, and stopped growing after colliding with each other. As the deformation continued, small angle grain boundaries stacked up near the twin boundary and A-B grain boundary, causing severe stress concentration, resulting in alloy fracture at ε = 13%.

In the Mg-6Gd-0.5Y alloy, the angles of the c-axis between the stretching axis were 30° ~60° , and the grain boundary type were identified as A-A. At the early stage of deformation, the {101(—)}2 tensile twins were activated on both sides of the A-A grain boundary and expanded into the crystal, turning the c axis to be perpendicular to the stretching direction (ie, B orientation). With the continuation of the deformation, the new orientation crystal with the same orientation with B undergone compression twinning and double twinning again (such as Mg-3Gd ~0.5Y) and eventually caused the material to break at ε = 36%.

C2-14: Dynamic Tension-Compression Asymmetry and Microstructure Evolution of Extruded EW75 Magnesium Alloy at High Strain Rates (1222471)
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The tension-compression asymmetry of extruded EW75 magnesium alloy deformed at high strain rates (from 1000s⁻¹ to 3000s⁻¹) along extrusion direction (ED) were investigated by Split Hopkinson Tension Bar (SHTB) and Split Hopkinson Pressure Bar (SHPB). The specimens after dynamic tension and dynamic compression were examined with optical microscope (OM), scanning electron microscope (SEM), electron back-scatter diffraction (EBSD) and transmission electron microscope (TEM). The results show that extruded EW75 magnesium alloy along ED exhibits positive strain-rate sensitivity both in dynamic tension and dynamic compression. Due to the strong basal texture, extruded EW75 magnesium alloy exhibits a significant dynamic tension-compression asymmetry that dynamic compressive flow stresses are higher than dynamic tensile flow stresses. The dynamic tensile n0.005 at the strain rate of 3010s⁻¹ is only 63MPa while the dynamic compressive σ0.005 / dynamic tensile σ0.005 = 0.39. The dynamic tensile σmax at the strain rate of 3010s⁻¹ is only 271MPa while the dynamic compressive σmax at the strain rate of 2826s⁻¹ is 534MPa (dynamic tensile σmax / dynamic compressive σmax = 0.51). Microstructure analysis demonstrates that {10-12}<11-20> tensile twinning causes the dynamic tension-compression asymmetry of extruded EW75 magnesium alloy along ED. High density dislocations, deformation twins and strong twin-dislocation interactions were observed in the TEM micrographs of extruded EW75 magnesium alloy under dynamic deformation at high strain rates. Dislocation pile-ups and twin intersections could increase the flow stress and strain hardening during dynamic plastic deformation. A kind of Nanocrystalline were observed after dynamic deformation. Fracture surfaces are relatively flat and significant amounts of deformed micro-dimples are produced during dynamic compression. It can be observed that this area consists of continuous tiny steps which suggests the dynamic compressive behavior of extruded EW75 magnesium alloy becomes more ductile at higher strain rate.

C2-15: Annealing Effect on Recrystallization and Grain Growth of Caliber-Rolled AZ31 Mg Alloys (1222558)
Taein Kong, Byung Je Kwak, Taekyung Lee, Pusan National University, Korea

Mg alloys have recently attracted a great deal of interest for lightweight structural applications in the automotive industry due to their low density and superior specific strength. Researchers and engineers have made an effort to improve the strength and toughness to substitute other competitive metals. Although severe plastic deformation (SPD) processes, such as equal-channel angular pressing and high-pressure torsion, have been developed for this purpose, the applications are limited to the laboratory scale owing to a small product, low productivity, and necessity of additional heat treatment to recover ductility. Multi-pass caliber-rolling can be an alternative approach in the current situation. We fabricated a caliber-rolled AZ31 Mg alloy with a bulk dimension and satisfying mechanical strength. Tensile strength monotonically increased as the number of caliber-rolling passes was increased due to the grain-boundary strengthening. The 7-pass caliber-rolled alloy exhibited yield strength of 280MPa and with bulk dimension (~1m in length) for the industrial applications. Effect of annealing for this alloy at 473~673K and 10~360 min were investigated in
terms of recrystallization, grain growth, and mechanical characteristics. Increasing annealing temperature led to the reduction of strength in general as a result of grain growth. Though, the annealing at 473K resulted in a fine-grained structure (d ~ 2μm) and enhanced ductility with rarely decreased tensile strength. Such a mechanical enhancement was attributed to the inhibited activation of mechanical twins. In a coarse-grained AZ31 alloy, the tension loading perpendicular to the c-axis facilitates {10-11} contraction twinning and subsequent {10-12} extension twinning. These double twins degrade a ductility by dislocation pile-ups at twin boundaries. They were inhibited for the caliber-rolled AZ31 alloy annealed at the low temperature, since the caliber-rolling process increased the stress required for the onset of twinning. In conclusion, the inhibited mechanical twinning contributed to the enhanced ductility.

C2-16: Enhanced Yield Isotropy and Mechanical Strength of Caliber-Rolled ZK60 Mg Alloy

Byung Je Kwak, Taein Kong, Taekyung Lee, Pusan National University, Korea; Jeong Hun Lee, Korea Institute of Industrial Technology, Korea

Multi-pass caliber rolling, often called groove rolling, has attracted particular attentions for a recent decade since the report of 1600% increase in Charpy V-notch impact energy of a low-alloy steel caused by a ultrafine-grained structure and nano-sized precipitates (Y. Kimura, T. Inoue, F. Yin, K. Tsuzaki, Science 320 (2008) 1057–1060). A recent study attributed the mechanical improvement via this process to its capability of imposing higher strain with more uniform distribution due to complex three-dimensional stress states. It is also worthwhile noting the industrial applicability of the caliber-rolling as the process is able to manufacture ultrafine-grained bulk products (T. Lee, M. Koyama, K. Tsuzaki, Y.-H.H. Lee, C.S. Lee, Mater. Lett. 75 (2012) 169–171; T. Lee, D.S. Shih, Y. Lee, C.S. Lee, Metals 5 (2015) 777–789), which had been difficult with conventional severe plastic deformation (SPD) processes including equal-channel angular pressing and high-pressure torsion. In spite of the importance of this process, studies on caliber-rolled Mg alloys have been focused only on Mg-Al-Zn alloys owing to the short history of research (T. Inoue, H. Somekawa, T. Mukai, Adv. Eng. Mater. 11 (2009) 654–658; A. Tripathi, S.V.S.N. Murty, P.R. Narayanan, J. Magnes. Alloy. 5 (2017) 340–347). This is the first report applying the caliber-rolling to a Mg-Zn-Zr alloy. The homogenized cast alloy was heated at 673K for 1 h and then subjected to the caliber-rolling process with a reduction of area of 84%. The material exhibited tensile yield strength (TYS) of 340MPa, ultimate tensile strength of 390MPa, and the total elongation was 18%. This is a marked increase in mechanical strength with preserved ductility compared to conventionally extruded ZK60 alloys. Interestingly, its compressive yield strength was nearly comparable to TYS, resulting in the yield point symmetry ratio of 0.99. We have analyzed such mechanical characteristics in terms of microstructural evolution.

C2-17: Effect of Extrusion Ratio on the Microstructure and Mechanical Properties of Mg-8Gd-4Y-1Zn-0.5Al Alloy Sheet

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The microstructure, texture and mechanical properties of extruded Mg-8Gd-4Y-1Zn-0.5Al alloy sheet with different extrusion ratios (ER=9 and 22) were systematically investigated in the present paper. The two as-extruded alloy sheets are both composed of the fine dynamic recrystallized (DRXed) grains with random orientation, coarse hot-worked grains with strong basal texture, and the broken long-period stacking ordered (LPSO) structure and Mg4Y2ZnAl3 phase aligned along the extrusion direction. The broken LPSO structure and Mg4Y2ZnAl3 phase can promote dynamic recrystalization (DRX) via particle stimulated nucleation mechanism during the hot-extrusion process. When the DRXed grains contact with the particles, the grain boundaries will be pinned by these particles and then prevent the growth of grains further. The distribution of LPSO structure and Mg4Y2ZnAl3 phase are more small and dispersive with ER of 22, which result in the fine average size of DRXed grains. Smaller grain size could reduce the slip distance of the dislocations, then release the stress concentration at the grain boundaries and improve the ductility of the alloy. Furthermore, the volume fraction of DRXed grains increases significantly with increasing the ER. Consequently, the maximum pole intensity of the extruded alloy sheet with higher ER is significantly weakened. As the ER increases, the ultimate tensile strength increases from 345MPa to 364MPa, and the elongation to failure obviously increases from 6.5% to 11.0%, which can be seen as a result of the weaker texture and fine grains. In addition, many deep dimples were clearly observed in fracture surface of higher ER alloy, showing significant ductile characteristics. The peak-aged alloy with ER of 22 during isothermal aging at 473K obtains the highest mechanical properties, with the ultimate tensile strength and yield strength of 438MPa and 348MPa, respectively. The improvement in strength is mainly ascribed to fine DRXed grains, coarse hot-worked grains with strong basal texture, and dense distribution of the fine β′′ precipitates in Mg matrix.
C2-18: Refining the Microstructure, Modifying the Texture and Enhancing the Toughness of AZ31B Alloy Rod by the Extrusion and Upsetting(1222614)
Zhenghua Huang, Guangdong Institute of Materials and Processing, China; Yi Yao, Han Ma, Hao Zhang, Guangdong Institute of Materials and Processing, China / Xi'an University of Technology, China; Zhongming Zhang, Chunjie Xu, Xi'an University of Technology, China

Ultrafine grained (UFG) materials exhibit attractive mechanical properties including the high strength and good ductility. Severe plastic deformation (SPD) is an effective technique in fabricating bulk UFG materials. Some SPD methods, like equal channel angular extrusion (ECAE), multidirectional forging (MDF), and cyclic extrusion and compression (CEC), have been employed to prepare UFG magnesium alloy materials successfully, and change the texture. Based on the grain refinement and texture change, the mechanical properties including the strength and ductility of the processed materials can be enhanced significantly. Moreover, in recently several new SPD methods have also been proposed and employed successfully to prepare bulk UFG magnesium alloy materials, such as integrated forward extrusion and torsion deformation, repetitive upsetting (RU), accumulative back extrusion (ABE), and repetitive extrusion and upsetting (REU). However, the above-mentioned methods are complex, expensive and hard to be industrialized. Therefore, the present paper will propose a simple, inexpensive and novel SPD method for grain refinement and texture modification, named extrusion and upsetting (EU), consisting of conventional direct extrusion (CDE) and upsetting.

AZ31B alloy rods with a diameter of 35mm were prepared by a novel severe plastic deformation method combined EU and CDE, respectively. The microstructure and texture of the rods were investigated by optical microscopy (OM) and electron back-scatter diffraction (EBSD). Meanwhile, the hardness, tensile and compressive mechanical properties, and impact toughness were tested. The results show that the totally fine dynamically recrystallized (DRXed) grains are obtained for the EUed specimen. However the CDEed specimen exhibits a bimodal microstructure comprising coarse elongated hot-worked grains and fine DRXed grains. Both of the specimen exhibit strong texture, however the types of texture are completely different. The (0001) basal plane is parallel to the extrusion direction (ED) for the CDEed specimen, while it is perpendicular to the ED for the EUed specimen. And the change in texture strongly influences the yield strength of the alloys. Due to the grain refinement and texture modification, the EUed specimen exhibits much better ductility, where the elongation increases from 13.5% and 41.0% for the CDEed specimen to 26.0% and 106.0% at room and elevated temperatures. Meanwhile, the corresponding mechanical anisotropy decreases from 0.47 to 1.21. EU is an effective and simple method to refine the grain size, modify the texture and enhance the elongation to failure of wrought magnesium alloys.

C2-19: In Situ Synchrotron X-ray Total Scattering Studies of the Atomic Structures of the Mg Alloys During Solidification(1222696)
Shifeng Luo, Northwestern Polytechnical University, China / University of Hull, UK; Jiawei Mi, University of Hull, UK; Guangyu Yang, Wanqi Jie, Northwestern Polytechnical University, China

The atomic structures of Gd containing Mg based alloys during solidification were investigated in situ by synchrotron X-ray total scattering at the I15 beamline of Diamond Light Source, UK. The alloys were melted, contained and processed in a special designed quartz tube crucible which can effectively prevent samples from oxidation during experiments. The total scattering data were analysed using pair distribution functions. The research is focused on studying the atomic structures of Gd added Mg alloys and the different roles played by Gd, Nd and Zr elements in nucleating nanoscale crystals. In addition, anomalous X-ray scattering at the absorption edge of elements was also used to obtain the information of element partial atomic pairs with the aim of clarifying the contribution of each individual element on the formation of the short-range-ordered and medium-range-ordered atomic structures in the liquid state and immediately before nucleation occurs. Using the combined total scattering and anomalous scattering techniques, we are able to elucidate, for the first time, the atomic structures of multiple-component Mg alloys in liquid state and the effectiveness of Gd, Nd and Zr on nucleation. The research provides much more quantitative understanding on how to design novel and high performance Mg based alloys for critical engineering applications.

C2-20: Effect of the LPSO Content on the Mechanical Properties of As-Cast Mg-Ni-Y Alloys (1223043)
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In recent years, the ternary Mg–RE–X (RE: Y, Gd, Dy, Ho, Er, Tm or Tb; X: Zn, Cu, Ni or Co) alloys have attracted considerable attention due to the formation of long-period stacking ordered (LPSO) phase and excellent mechanical properties. In this work, the effect of LPSO phase content on mechanical properties of as-cast Mg-Ni-Y alloys were investigated. Four key alloys Mg96.0Ni1.2Y2.8, Mg92.3Ni2.0Y5.7, Mg91.2Ni2.4Y6.4 and Mg89.3Ni3.2Y7.5 (designated as1#, 2#, 3# and 4#)
were selected based on the thermodynamic calculation. The microstructure and mechanical properties of the alloys were investigated by optical microscopy (OM), scanning electron microscopy equipped (SEM) with energy dispersive spectrum (EDS), X-ray diffraction (XRD) and tensile tests at room temperature (RT). The experiment results indicate that the four alloys are composed of α-Mg and LPSO phase. They exhibit typical cast microstructure of primary α-Mg dendrites and network LPSO phases. The LPSO phase contents of the four alloys are 15wt.%, 25wt.%, 35wt.% and 45wt.%, respectively. The EDS results indicate that the average chemical compositions of LPSO phase in 1~4# alloys are Mg$_{90.41}$Ni$_{4.34}$Y$_{5.26}$, Mg$_{91.57}$Ni$_{3.44}$Y$_{4.99}$, Mg$_{91.85}$Ni$_{3.43}$Y$_4.72$ and Mg$_{91.43}$Ni$_{4.31}$Y$_{4.36}$, respectively. Therefore, all of the network LPSO phases in 1~4# alloys might belong to 14H-type. The tensile tests at room temperature exhibit that the 1# alloy shows the optimal mechanical properties with the ultimate tensile strength of 222MPa and elongation of 10.5%. In order to investigate the influence of LPSO phase content on the mechanical properties, the fracture microstructure of the alloys was analyzed. There exist the small-size dimples which are distributed on the fracture surface of 1# and 2# alloys. However, the dimples disappear and large-sized cleavage facets and deep cracks dominate the whole fracture surface of 3# and 4# alloys. The results show that with the increase of LPSO phases, the fracture mechanism of as-cast alloys transforms quasi-cleavage fracture to cleavage fracture.

C2-21: Influence of Yttrium and Lithium on Activities of Non-Basal slips of Magnesium (1224583)
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Light weight and high specific strength, magnesium alloys has gained attention for use in transport industries. However, magnesium shows low ductility at room temperature. Not only (0001)<11-20> basal slips (BS) but also non-basal slips, such as (10-11)<11-23> first order pyramidal <c+a> slip (FPCS) or {11-22}<11-23> second order pyramidal <c+a> slip (SPCS) must be activated required to deform a crystal to any arbitrary shape. Therefore, controlling slip systems is a key to improving ductility of magnesium. However, details of slip systems and their influence by alloy element addition have yet to be elucidated. Rikihisa et. al. has reported that tensile tests of single crystalline and polycrystalline Mg-Y alloys were carried out at room temperature. Mg-(0.6~1.1)at%Y alloy single crystals yielded due to the FPCS. Yield stress and ductility of Mg-Y alloy single crystals and polycrystals were higher than those of pure magnesium. The number of grains where SPCS were activated was the largest in those where non-basal slips were activated in pure magnesium, while those where FPCS were activated was the largest in Mg-0.9at%Y alloy. High ductility of Mg-0.9at%Y alloy would be caused by activation of FPCS due to yttrium addition. And it was reported that critical resolved shear stress of SPCS was decreased when lithium added. However, details of activation of non-basal slip have yet to be elucidated in Mg-Li polycrystals. In this study, tensile tests of Mg-(0.5, 1.2at)%Y alloy and Mg-6.2at%Li alloy polycrystals were carried out to investigate that influence of yttrium and lithium on non-basal slip systems and considered the relationship between ductility and yield stress of magnesium and activation of slip systems. Rolled Mg-Y alloy and Mg-Li alloy sheets were annealed to obtain grains with the sizes of approximately 60μm and cut into tensile specimens parallel to its rolling direction. Tensile tests were carried out at room temperature. In Mg-Y alloy polycrystals, the yield stress was increased with increasing yttrium addition. The ductility was 20% when yttrium content was 0.5at% and 0.9at%, however it decreased to 15% at 1.2at%. Slip lines of BS, FPCS, SPCS and PS were observed. The frequency of FPCS didn’t change when yttrium content was 0.5at% and 0.9at%, however it decreased at 1.2at%. The frequency of SPCS decreased and PS increased with increasing yttrium content, respectively. In Mg-6.2at%Li alloy polycrystals, the ductility was slightly increased in comparison with pure Mg. The frequency of FPCS was increased, while those of SPCS and PS were not affected by lithium addition. These results indicate that to improve ductility of magnesium alloy require increasing totally frequency of non-basal slips.

C2-22: The Effect of Sn and Ca Addition on Microstructural Evolution and Mechanical Properties of Magnesium Alloys Subjected to Direct Extrusion Process(1231947)
Young Min Kim, Yohan Go, Joung Sik Suh, Bong Sun You, Korea Institute of Materials Science, Korea

Magnesium alloys are recognized as promising materials for lightweight transportation vehicles due to the lightest density and good specific strength among structural metallic materials. Particularly in aircraft application, where safety and high strength are required, magnesium alloys must have both high ignition resistant and high absolute yield strength. We have recently reported that the addition of Ca and Y greatly improves ignition resistance and corrosion resistance of magnesium alloys. For further improvement in yield strength, Sn is known to be an effective element leading to precipitation hardening through the formation of fine Mg$_2$Sn. In this study, it was found that Sn addition led to complete dissolution of Mg$_{17}$Al$_{12}$ eutectic phase into Mg matrix and greatly improved the yield strength through the formation of fine precipitates. On the other hand, when a large amount of Sn and Ca was added,
the ductility of the magnesium alloys greatly decreased by the formation of coarse Mg-Sn-Ca eutectic phase, of which influence on mechanical properties was not been fully understood. In this study, the microstructural evolution, especially the formation of second phases, during solidification in Mg-9Al-1Zn-0.2Y-Ca-Sn alloys was systematically investigated, and the optimization of chemical compositions and extrusion process parameters for the application to an aircraft interior component was also carried out.

C2-23: Pair Interaction Energy in Stacking-Faulted Mg Matrices and Formation Mechanism of Stacking Order in LPSO Mg Alloys(1232281)
Taku Murakami, Nobuhisa Fujima, Toshiharu Hoshino, Shizuoka University, Japan; Mitsuhiro Takeda, Kazuya Konno, Sendai National College of Technology, Japan

Magnesium-Metal-Rare-Earth (Mg-M-RE) ternary alloys with the long-period stacking ordered (LPSO) phase have attracted much attention as new lightweight structural materials because of their high tensile strength, elongation, high heat resistance, and so on. In recent years based on these knowledges about LPSO materials, it is widely attempted to extend research targets to various Mille-feuille materials, which are consisted of hard layers and soft layers. In order to develop more functional Mille-feuille candidate materials, it must be very important to understand the formation mechanism of LPSO structure, especially, why and how the in-plane and stacking orders of the impurity clusters are formed.

In this research, we calculate the pair-interaction energy (PIE) between two impurity elements, M-M, M-RE and RE-RE with M=Al, Zn and RE=Y, in Mg matrices with periodic stacking faults, namely, PIE through both hcp and fcc environments, by using first-principles calculation based on density functional theory (DFT). For the calculations, we use a unitcell, Mg1054i2 (i=M and/or RE), consisting of 22 layers of 4√3 aMg × 4√3 aMg rhombus to generate the stacking sequences of 10H, 14H, 18H and 22H in Ramsdell notation. Also, we investigate effects of the lattice distortion around the impurity elements in these stacking faulted structures. Through this work, we clarify the differences between impurity-impurity interactions in the Mg matrices with the periodic stacking fault and those in the pure hcp and/or fcc Mg. Finally, by comparing of the results in the cases of M=Zn and M=Al, we reveal how this difference contributes to the formation of long-range stacking order of LPSO structure and discuss the origin of the difference between the cluster ordering in Mg-Al-Y alloy and that in Mg-Zn-Y alloy.

C2-24: Corrosion Resistance and Super-Hydrophobicity of Poly(3-Aminopropyltrimethoxysilane)/Polypropylene Composite Coatings on AZ31 Magnesium Alloys(1235246)
Zhaoqi Zhang, Shandong University of Science and Technology, China / Luoyang Ship Material Research Institute, China; Rongchang Zeng, Shandong University of Science and Technology, China; Cunguo Lin, Luoyang Ship Material Research Institute, China

Recently, there has been increasing attention given to magnesium (Mg) and its alloys for a number of applications in the automotive, aerospace and electronics industries by virtue of their low density, high strength-to-weight ratio, good castability and recycling potential. However, the high susceptibility to corrosion of Mg alloys has so far limited their widespread applications.

A super-hydrophobic Mg alloy surface was successfully fabricated via amino-silane (PAPTMS) pretreatment, and subsequently covered with a polypropylene (PP) film. The surface morphologies, microstructures and chemical compositions were investigated using FE-SEM, XRD and FT-IR. The corrosion resistance of the composite coatings was evaluated using the electrochemical and hydrogen evolution tests. The results indicate that the PAPTMS/PP composite coatings exhibited a good super-hydrophobicity with a water contact angle (CA) of 162 ± 3.4°. The current density (Icorr) from 4.9 ± 0.06 × 10⁻⁸A·cm⁻² to 9.08 ± 0.09 × 10⁻⁸A·cm⁻², obviously, the Icorr of the PAPTMS/PP composite coatings decreased approximately three orders of magnitude compared to the substrate, suggesting that the PAPTMS/PP composite coatings can effectively protect the Mg alloy from corrosion. Additionally, a corrosion mechanism of the composite coatings was proposed and discussed.

C2-25: Microstructure and Deformation Behavior of Mg-9%Al Alloy Reinforced with in Situ Formed AlN Particles(1235810)
Alireza Maldar, Jie Wang, Leyun Wang, Xiaoxin Zeng, Shanghai Jiao Tong University, China

Between the various in-situ composites fabrications, the gas bubbling is considered a promising method that reactive gases are bubbled into the melt and the reinforced particulates are formed during the reaction between the gas or its decomposition product and the melt or its alloying elements. In the present study, Mg-AlN composite has been fabricated by bubbling nitrogen gas into a molten Mg-9%Al alloy. The in-situ synthesis was done in a furnace with SF6/CO2 protection and nitrogen gas with high purity (99.999%) bubbled into the melt through a rotating steel lancer for 1.5h. The molten alloy was then poured into a permanent mould. Mechanical properties were investigated by tensile and compression tests in as-cast, solutionized, and hot
regarded as potential structural materials for structure only slightly higher than many polymers. It is therefore stiffness as well as low density. The density of Mg is materials which possesses high specific strength, high Magnesium (Mg) is one of the lightest structural Hailong Shi, Xiaojun Wang, Harbin Institute of Composite(1386604)

Carbon Nanotube Reinforced Magnesium Matrix C2-27: A Melt Processing for Fabrication of beneficial for finer grains and better ductility. The lower extruding temperature was on the microstructures and mechanical properties. The secondary extrusion temperature has obvious effects 172MPa after secondary extrusion. Furthermore, The yield stress was declined from 218MPa to about slightly deteriorated the yield stress of the AZ80RE alloy. The yield stress was declined from 218MPa to about secondary extrusion was attributed to the lower yield stress at a higher pass number. The elongation was significantly prolonged from the initial 13.3% to 28.5% after secondary extrusion. The basal texture weakening slightly deteriorated the yield stress of the AZ80RE alloy. The yield stress was declined from 218MPa to about 172MPa after secondary extrusion. Furthermore, The secondary extrusion temperature has obvious effects on the microstructures and mechanical properties. The extrusion temperature is inversely proportional to the grain size and also inversely proportional to the elongation. The lower extruding temperature was beneficial for finer grains and better ductility.

C2-27: A Melt Processing for Fabrication of Carbon Nanotube Reinforced Magnesium Matrix Composite(1386604)

Hailong Shi, Xiaojun Wang, Harbin Institute of Technology, Chian

Magnesium (Mg) is one of the lightest structural materials which possesses high specific strength, high stiffness as well as low density. The density of Mg is only 2/3 of aluminium, 2/5 of titanium, 1/5 of steel and only slightly higher than many polymers. It is therefore regarded as potential structural materials for structure lightening. However, the poor mechanical behavior of Mg limited its application. Fabrication of Mg matrix composites provides us with a solution to strengthen Mg while maintaining its low density. Carbon nanotubes (CNTs) are regarded as the ideal reinforcement for metal matrix composites because of their extremely high elastic modulus and strength as well as good thermal and electrical properties. Because CNTs have good compatibility with magnesium even at high temperature. It is necessary to study the melt processing for CNTs reinforced magnesium matrix composites. In our work, a melt processing which consists of mechanical stirring and ultrasonic vibration process was developed to prepare CNTs reinforced magnesium matrix composites, which realized uniform distribution of CNTs in the composites and simultaneous strength and ductile improvement compared with the matrix. Grain refinement and load transfer of the CNTs were attributed to the improvement of the mechanical properties of the Mg/CNT composite.

C2-28: Strain Hardening Behavior of Mg-Y Alloys after Extrusion Process(1396562)

Chaoyue Zhao, Teng Tu, Chongqing University, China; Xianhua Chen, Fusheng Pan, Chongqing University, China / Chongqing Academy of Science and Technology, China; Zhu Luo, Chongqing University, China; Andrej Atrens, The University of Queensland, Australia

The strain hardening is an effective mode of enhancing mechanical properties in alloys. In this work, the strain hardening behaviors of Mg-X(Y (x = 1, 2, and 3wt.%) alloys after extrusion process was investigated and the strain hardening rate was obtained from true stress-true plastic strain curves testing by uniaxial tensile tests at 10^-6s^-1. Results suggest that the as-extruded Mg-Y alloys are mainly composed of α-Mg matrix and a little second phase Mg24Y5. The average grain size reduces from 19.8μm to 12.2μm with the Y content adds from 1wt.% to 2wt.%. Nevertheless, when Y content reaches 3 wt.%, the grain size of Mg-3Y is 12.9μm, which is close to that of Mg-2Y. The strain hardening rate decreases from 883MPa to 798MPa at (σ-σ_0) = 40MPa, and Mg-2Y and Mg-3Y have the similar strain hardening response. Moreover, Mg-1Y shows an obvious ascending stage after the steep decreasing stage, which is mainly caused by the activation of twinning. The strain hardening behavior of as-extruded Mg-Y alloys is explained based on understanding the roles of the deformation mechanisms via deformation microstructure analysis and Visco-Plastic Self Consistent (VPSC) model. The variation of strain hardening characteristics with increasing Y content is related to the effects of grain size and texture.
**C2-29: A High-Ductility Mg–Zn–Ca Magnesium Alloy (1435399)**

*Teng Tu, Chongqing University, China*

A new kind of Mg-2Zn-0.6Ca (wt%) alloy was fabricated by casting and hot extrusion as a high-ductility structural material. The as-extruded Mg-2Zn-0.6Ca alloy exhibits a superior elongation of ~30%, yield strength of 130MPa and ultimate tensile strength of 280MPa along the extrusion direction at room temperature. Microstructure, texture and tensile properties of the as-extruded Mg-2Zn-0.6Ca alloy were investigated in details. Hereinto, the fine and equiaxed grains was obtained in as-extruded Mg-2Zn-0.6Ca alloy and the average grain size was ~10μm in diameter. In addition, a small number of CaMg₆Zn₃ precipitates were formed in as-extruded Mg-2Zn-0.6Ca alloy with the average grain size of less than 1μm. Moreover, the as-extruded Mg-2Zn-0.6Ca alloy showed a texture intensity of 9.06, weaker than the texture intensity of 22.19 in as-extruded Mg-Zn alloy, because the addition of Ca to Mg-2Zn alloy can suppress the formation of basal texture by providing a random texture in the extrusion. The high ductility of as-extruded Mg-2Zn-0.6Ca alloy was attributed to three main reasons: the refined grains, a small number of CaMg₆Zn₃ precipitates and the weakened texture. Firstly, the refined grains of as-extruded Mg-2Zn-0.6Ca alloy lead to the increase in grain boundary and reduces the whole stress concentration, it is favorable for the activation of non-basal slip near the grain boundaries at room temperature and improve ductility. Secondly, the number of CaMg₆Zn₃ precipitates is limited and the inhibition of dislocation movement by the second phase is weakened hardly, which is beneficial to the process of plastic deformation and improves ductility. Finally, the weakened texture can be beneficial to the enhancement of ductility, because the majority of grains in the tilted texture have an orientation favorable for both basal slip and tensile twins. Our study shed lights on the design of new Mg alloys with high ductility.

**C2-30: Effect of Ultrasonic Melt Treatment on Corrosion of ZW61 Magnesium Alloy (1447555)**

*Xingrui Chen, Qichi Le, Shaochen Ning, Ruizhen Guo, Northeastern University, China*

Considering the excellent grain and phase refinement ability of dual-frequency ultrasonic field (DUF), this technology is employed to refine the quasicrystal-reinforced Mg-Zn-Y alloy (i.e. Mg-6%Zn-1%Y (ZW61)). Microstructural evolution, corrosion behavior and electrochemical behavior of cast ZW61 alloy with and without DUF treatment are investigated systematically. Results revealed that the DUF treatment can refine the α-Mg grain and the I-Mg₃Zn₆Y quasicrystals dramatically. The average grain size reduces from 568 ± 51μm to 89 ± 9μm after dual-frequency ultrasonic treatment. The I phase also become tiny and has a homogeneous distribution. Consequently, the corrosion resistance is improved as well, showing the decrease of corrosion rate from 5.29mg/cm²/day to 2.22mg/cm²/day after dual-frequency ultrasonic treatment. The corrosion potentials and corrosion current density are reduced after dual-frequency ultrasonic treatment. Based on the microstructure observation, the corrosion process of untreated ZW61 alloy can be divided into three stages, namely, the galvanic couple corrosion, the filiform corrosion and the pitting corrosion. However, the dual-frequency ultrasonic treatment can prohibit the filiform corrosion. It is also found that the dual-frequency ultrasonic treatment can increase the solid solubility in grain boundary of Mg matrix. Thus, the increase of segregation of solute Zn element at grain boundaries, the morphology change of I-phase and the prohibition of filiform corrosion should respond the promoting of corrosion resistance.
physical, chemical and mechanical properties by taking into account the characteristics of its member metal materials. The preparation of Mg/Al laminated composite plates with lightweight, high strength and corrosion resistance which has both advantages of components metals and achieves the complementary and optimum properties has attracted much attention. Explosive welding has high bonding strength, relatively thin diffusion layer, no porosity and other defects. But there is a little work reported on the dynamic behavior of Mg/Al composite plates especially the one fabricated by explosive welding. In this study, Mg/Al composite plate was prepared by explosive welding with good bonding strength. After explosive welding, Mg/Al composite is usually heat treated (annealing) to eliminate high residual stress from explosive wave, but this process will cause brittle intermetallic compounds between magnesium alloy and aluminum alloy and damaged the property of the composite plate. Continuous pulse current treatment is a useful way which could reduce the detriment according some researchers’ work. The magnesium plate and Mg/Al composite plate fabricated by explosive welding were treated by continuous pulsed current with different current density respectively, and their dynamic behavior under different strain rates were tested by Hopkinson pressure bar test system to indicate the effect of pulsed current treat. To clarify the mechanism of pulsed current treat, the microstructure change before and after continuous pulsed current treatment of magnesium and Mg/Al composites were observed by OM, SEM, EBSD. The results showed that Mg/Al composite plate by explosive welding has better response under dynamic condition compared with magnesium plate under both conditions, i.e. with and without continuous pulsed treatment. The results will help to widen the use of magnesium alloy in collision condition such as automobile buffer beam and weapons.

11:15-11:30(1234012)
Hot Forging Formability of Continuous Cast Mg-Al-Ca-Mn Alloys

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The movement that banning the sale of gasoline cars and diesel vehicles especially in Europe and allowing only electric cars for passenger’s cars has been accelerated. For examples, Germany’s federal council, the Bundesrat, has passed a resolution calling for a ban the sale of new cars with internal combustion engines by 2030. In Norway, until 2025 there is a movement to legislation prohibiting the registration of new cars for passenger car gasoline and diesel cars. Beginning in 2025 in the Netherlands, a bill to prohibit the sale of new cars for gasoline and diesel vehicles was submitted to ongress, ban the sale of new cars with internal combustion engines.

Recently, the European Union (EU) summarized a regulation to reduce carbon dioxide (CO₂) emissions of automobiles in 2030 by 37.5% from 2021 years. Although it is plan to decide concrete reduction width for each car manufacturer in the future, it is considered to be difficult to achieve by improving fuel economy of gasoline cars and hybrid cars. It is considered that manufacturers need to replace about one-third of new cars with electric vehicles (EV) . Under the circumstances, the growing demand for light weight products for automotive industries has been accelerated due to global trend of environmental preservation. Reducing to total weight of cars is one of the solution to achieve the regulation to reduce carbon dioxide (CO₂) emissions.

Reducing total weight of cars is one of the solution to achieve by replacing materials for car bodies from steel to lightweight materials, for examples, aluminum alloys, carbon fiber reinforced plastics (CFRP) and magnesium alloys.

In recent several years, although production of magnesium has risen dramatically, production of magnesium alloy sheet remains still at a very low level in practical use. The major barrier to greatly increased magnesium alloy use has been in still primarily high manufacturing cost as well as poor workability of magnesium alloys. Moreover, it has been recognized that higher strength as well as better corrosion resistance are needed for magnesium products when in practical use for car components. One of the author has been investigating into twin-roll casting (TRC) technology to adopt magnesium alloys into practical use, however detailed forming characteristics during hot forging of high aluminum content magnesium alloys has not been clarified.

The aim of the study is to confirm possibilities of practical use of cast magnesium alloy by continuous cast materials during hot forging with a servo press machine (SDE 1522 by AMADA Corp.) which can apply back pressure during forging. A simple compression test of continuous cast materials was performed to obtain exact stress strain relation in terms of forming temperatures. Double-ringed typed forming products were hot forged at 623K by using a servo press machine. Optical crystal observation as well as Vickers hardness test have been conducted to confirm the recrystallization and material flow. It has been found that manufacturing magnesium products could be possible when in selecting an appropriate manufacturing condition by using a servo press machine.