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Emerging Mechanisms for Enhanced Plasticity in Magnesium

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Magnesium alloys offer an excellent lightweight alternative for increasing energy efficiency. To overcome the inadequate ductility, which often hinders the application of magnesium alloys, some new processing techniques, alloy systems, testing methods, and modeling approaches are addressed in this special topic. The scope is chosen to be inherently multi-scale, ranging from fundamental mechanisms at the crystal defect level to production techniques. Optimizing mechanical properties via microstructure and crystallographic texture modification is considered, while chemistry control and alloying, crystal plasticity finite element modeling, and thermomechanical processing are addressed.

AZ31 is one of the most common commercial wrought magnesium alloys. It is well understood and accepted for industrial use, but there is a need for enhanced formability. Seven papers within this special issue are centered on highlighting the challenges and presenting opportunities to improve the formability of AZ31. In the paper "Improving strength and formability of rolled AZ31 sheet by two-step twinning deformation" Q. Yang and his collaborators demonstrate the optimization of the stretch formability of AZ31 sheets by two-step twinning deformation. The first-step twinning deformation forms a strong *c* axis//rolling direction (RD) texture and generates profuse crossed twin lamellae within grains. Subsequent recrystallization annealing further enhances the twinned microstructure. Such a microstructure with *c* axis//RD texture remarkably enhances the Erichsen value (IE) while reducing the tensile yield strength along the RD and increasing the in-plane anisotropy. The second-step twinning deformation by tension along the RD induces activation of multiple twin variants while retaining the *c* axis//RD texture component. The existence of crossed twin lamellae generates a refinement hardening effect which contributes to a high stretch formability (IE = 7.1 mm) at room temperature.

In the paper, "Emerging hot topics and research questions in wrought magnesium alloy development" by Pérez-Prado et al., a large team of authors have put together a review on the research areas where they see the most potential for impact in the field. The focus of this timely review points out that the field of magnesium metallurgy is poised for significant advances. Access to synchrotron and neutron scattering techniques reveals new knowledge about deformation and fracture behavior, as well as the complex interaction between solutes, dislocations, interfaces, and disconnections. High-performance computing now makes it possible to use atomic-scale simulation techniques to make material calculations. Advanced techniques, such as atom probe tomography, are allowing us, for example, to examine the complex chemical nature of grain boundaries at the nano-scale. The review also provides a comprehensive analysis of areas ripe for further study, e.g., the nature of dislocation–shearable precipitate interaction and the relative resistance to shearing offered by the different dislocation types. Similarly, precipitate–twin interactions and their effects on strengthening, work-hardening, tension–compression asymmetry, and ductility leave room for deeper understanding. Any further research on the effect of solutes on deformation and work hardening, as well as on solute strengthening and texture development, will be of great benefit to the metallurgical community. The final points made concern rare earth (RE) free alloys and recycling issues. As the world's resources dwindle, eliminating high-cost and limited resources like RE elements from magnesium alloys will become necessary. In addition, narrowing the range of compositions on the market may also become a necessity to enable optimum alloy recycling at the end of component lifetime.

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Bong and his colleagues from South Korea prepared the paper, "A Study on Plastic Response Under Biaxial Tension and Their Correlation with Formability for Wrought Magnesium Alloys". The authors demonstrate the applicability of forming limit diagrams (FLD) of the two magnesium sheet alloys, ZE10 and AZ31. The plastic response at 200 °C at various strain rates under uniaxial and biaxial tension states is studied experimentally and numerically. For that, the FLD were further assessed by using the Marciniak–Kuczynski (M–K) model combined with two constitutive models: crystal plasticity finite element (CPFE) and phenomenological yield models. The predicted FLDs by the combined CPFE and M–K models were in excellent agreement with the experimental data. Finally, the authors show that the main sources of discrepancy between the experiments, and the predictions of phenomenological models calibrated using small plastic strain data, are the anisotropic strain-hardening during biaxial tension and significant *r*-value evolution during uniaxial tension.

In the paper by Wang et al. entitled, "Preparation Mechanism of Fine-Grained Magnesium Alloys by Accumulative Alternating Back Extrusion", the researchers from China demonstrate using AZ31, a novel and effective method for preparing high-performance magnesium alloys. Microscopy and electron backscatter diffraction show that accumulative alternating back extrusion (AABE) can effectively refine the microstructure and improve the uniformity in local areas of the sample. The authors summarize that, during AABE, a fan-shaped deformation flow area forms under the split stem and moves along with the stem in the same direction. The preferred orientation of the recrystallized grains and the deflection of the twin grains led to the segregation of the grain orientations toward the edge of the pole figure. The improved AABE process is a promising new method of severe plastic deformation. Through the alternate downward loading of the split stems on both sides, the metal underneath is subjected to continuous shearing and stirring, which provides a new idea for the preparation of high-performance fine-grained magnesium alloys.

Azghandi and his co-authors contributed the paper, "The Effect of Grain Size on the Bend Forming Limits in AZ31 Mg Alloy", presenting the bending behavior of coarse and fine-grained AZ31. The corresponding deformation mechanisms are ascertained via tensile, compression, and bending tests in combination with digital image correlation and electron backscatter diffraction. The authors show that grain refinement from 60 to 3 μm significantly improves tensile ductility, while forming limits in compression and bending show no obvious effect of grain size. Analysis revealed a high density of twin bands in the compression zones of the bent samples, where the fine-grained material experienced failure. The fracture strain in bending appears limited, both by the material ductility in tension and by compression. Bend failure was seen to be controlled by flow localization and, unlike tension testing, void formation appeared not to be involved in the formation of shear localizations. Thus, the impact of grain size on void size that appears to be important in tension tests does not manifest itself in bending.

In, "Microstructure Evolution and Mechanical Properties of Mg-1.5Zn-0.2Ca-0.2Ce Alloy Processed by Accumulated Extrusion Bonding", Han and his research team studied the microstructure and mechanical properties on samples corresponding to various process stages, which were taken from six locations parallel to the extrusion direction. Many twin boundaries were observed at the initial extrusion stage, and subsequently dynamic recrystallization (DRX), especially twin-assisted and continuous DRX, was activated. With increasing strain, the matrix grains were gradually transformed into new DRXed grains, and the grains were significantly refined to 0.55 μm, whereas the grains grew to 3.1 μm outside the die. As shown by the authors, after accumulated extrusion bonding (AEB), the sheet exhibited almost the same texture as that of an as-received sheet with basal poles tilted to the extrusion direction by $\sim \pm 30°$. The tensile test results revealed that, compared with the as-received sheet, the yield strength of the AEBed sheets was improved by 50 MPa, resulting mainly from the grain refinement.

In the last contribution to this collection, "Isothermal Continuous Equal Channel Angular Pressing Processing of Magnesium Alloy AZ31", Davis and his team describe a commercially viable continuous equal channel angular pressing (ECAP-C) method to manufacture UFG AZ31 Mg for bioabsorbable stents, with a coil-to-coil processing strategy to enhance scaling efficiency. The optimum processing parameters were obtained by isothermally processing a coarse-grained (> 100 μm) extruded AZ31-B rod by 2-pass, 4-pass, and 8-pass ECAP-C, between 423 and 523 K, with feed rates between 1 and 8 mm/s, under no additional backpressure. Their study revealed that the feed rate has a minimal impact, whereas the temperature and the number of passes (i.e., the effective strain) have a significant impact on the grain size distribution and, consequently, the mechanical properties. The best combination of tensile strength and ductility (UTS = 333.5 MPa, elongation-to-failure = 28%) was achieved via the 4-pass route ECAP-C at 423 K with 1 mm/s feed rate.

To read or download any of the papers in this special topic, follow the URL: https://link.springer.com/journal/11837/72/7/page/1 to the table of contents page for the July 2020 issue (vol. 72, no. 7) of JOM.

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