Magnesium: Applications and Advanced Processing in the Automotive Industry

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One of the most significant design challenges within the automotive industry is improving fuel economy, through reduction of gross vehicle weight, without compromising safety. This is a particularly effective strategy since the benefits of weight reduction are compounded by a lighter body requiring a less massive suspension, drive train, etc.[1] Magnesium alloys are a prime example of the advanced materials that are being developed to meet this challenge. This issue features a series of articles spotlighting strategies under consideration to utilize the attractive properties of magnesium alloys.

Several key issues must be addressed before magnesium alloys can be used extensively in the automotive body. At present, wrought magnesium sheet is primarily a niche material due to limited availability, high production costs, and undesirable corrosion properties. Wrought magnesium sheet also demonstrates poor room-temperature formability, making production of even simple shapes by conventional forming processes difficult. Conversely, the consistent properties and low overall component production costs have made cold-rolled mild steel sheet the material of choice in the automotive industry for decades. More importantly, mild steel has been used extensively throughout the last century so the technical knowledge base that has been developed for forming traditional sheet steels far exceeds that of wrought magnesium sheet. The combination of higher production costs, limited technical and practical forming experience, and problematic properties impede the widespread use of magnesium alloys.

Incorporation of magnesium into the automotive body is not a simple drop-in substitution of one alloy for another. Conventional sheet steels have a fine grain size and a body-centered cubic crystal structure that facilitates plastic deformation, whereas most magnesium alloys are hexagonal closed-packed (hcp) with considerably larger grain sizes than steel. Of the three commonly occurring crystal structures in engineering alloys, hcp alloys have the fewest available primary slip systems, and only the basal plane of the hcp unit cell is close-packed. This confines slip to the basal planes, exacerbating the influence of initial crystal orientation on room-temperature deformation. The limited slip systems in the hcp structure also produce more pronounced grain-to-grain inhomogeneity.

Magnesium is prone to twinning, which greatly complicates numeric predictions of the forming behavior since the mechanical properties during tension and compression can be quite different. At room temperature, the propensity for deformation by mechanical twinning strongly depends upon the initial crystallographic texture of the sheet, and deformation by twinning is highly localized. As a result, wrought magnesium sheet often fails at much lower strains than what are normally required to form steel and aluminum alloys. Even though the lower densities of magnesium alloys make magnesium alloys highly attractive from a weight-savings perspective, the forming issues arising from the hcp crystal structure must be resolved before these alloys can be incorporated into the automobile body on a large scale.

Forming at elevated temperatures is a practical approach for wrought magnesium sheet, because raising the ambient temperature activates additional slip systems and substantially enhances the overall formability. As such, strategies such as quick plastic forming are being developed to take advantage of the improved plastic flow.

Thixotropic molding and other semi-solid forming techniques are also attractive routes to produce complex shapes from magnesium alloys. Since at least one of the components in the feedstock used for these processes is not entirely in solid form, the mechanical behavior is generally not affected by the hcp crystal structure. In addition, semi-solid forming can potentially produce components from a wider range of alloy compositions.

The joining of magnesium components is another major concern. Since magnesium is extremely active electrochemically, strong corrosion reactions are likely wherever magnesium contacts other metallic components unless special measures are introduced to prevent galvanic contact. For this reason, special coatings are also being developed to isolate magnesium components from the service environment; however, even a simple scratch could expose the chemically reactive magnesium to road salts, etc. and severely degrade the integrity of the components.

References

1. F.R. Field and J.P. Clark, "A Practical Road to Lightweight Cars," *Technology Review* (January 1997).

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