ABSTRACT

A STUDY OF THE EFFECTS OF RARE-EARTH ELEMENTS ON THE MICROSTRUCTURAL EVOLUTION AND DEFORMATION BEHAVIOR OF MAGNESIUM ALLOYS AT TEMPERATURES UPTO 523K

By

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Due to their high specific strength, lightweight magnesium (Mg) alloys are being increasingly used for applications, such as the automotive industry, where weight savings are critical. In order to develop new alloys and processing methods to achieve higher strength and better formability to compete with currently used metal alloys, it is important to understand the effects of alloying elements, processing, and temperature on the microstructure, mechanical properties, and the deformation behavior.

In this dissertation, a systematic investigation on the effects of Nd additions (0-1wt.%) and temperature (298-523K) on the microstructure and the activity of different deformation modes in as-cast and cast-then-extruded Mg-1Mn (wt.%) alloys were performed. For this study, an in-situ testing technique which combines tension and compression testing inside a scanning electron microscope (SEM) with electron backscatter diffraction (EBSD) analysis was employed.

The main findings of this work were that the microstructure, strength, and the distribution of the deformation modes varied significantly as a function of Nd content, temperature, and processing. An increase in the Nd content resulted in a weaker texture after extrusion in Mg-1Mn alloys. A combination of slip and twinning mechanisms controlled the tensile deformation in the extruded alloys at ambient temperatures. With an increase in temperature, the twinning activity decreased, and slip mechanisms dominated the deformation. In the extruded Nd-containing alloys, basal \(<a> slip dominated the deformation, especially at elevated temperatures,
suggesting that Nd additions strengthen basal \( <a > \) slip. This resulted in excellent elevated-temperature strength retention in extruded Mg-1Mn-1Nd alloy, and a decrease in the Nd content to 0-0.3wt.% resulted in a decrease in the tensile strength at elevated temperatures. In extruded Mg-1Mn, contraction twinning dominated the tensile deformation and this alloy exhibited a lower elongation-to-failure (\( \varepsilon_f \)) than the other alloys at 323K. With an increase in strain, these twins evolved into \{10\overline{1}1\} \( \rightarrow \) \{10\overline{1}2\} double twins. Crystal plasticity modeling and simulation of the contraction twins and double twins showed that the activity of these twin modes is detrimental to the \( \varepsilon_f \) of Mg alloys due to the strain localization that happens within the twinned volume due to the enhanced activity of basal \( <a > \) slip. This agreed with the experimental observations. Compared to the extruded materials, the as-cast alloys exhibited significantly larger grain sizes and lower tensile strengths. The deformation in the as-cast alloys was dominated by a combination of basal \( <a > \) slip and extension twinning at all test temperatures.

A novel methodology which combines in-situ annealing inside a SEM with EBSD analysis was developed and employed to understand the effects of dilute Ce additions (0.2-0.6wt.% on the recrystallization behavior in Mg-2Zn (wt.%) alloys. Texture weakening in these alloys resulted from the formation of an enhanced number of grain boundaries with \( <hkl> \) rotation axis during recrystallization. The developed testing methodology will be valuable for future recrystallization studies on Mg and other alloy systems. Overall, the insights gained from this dissertation will have a broad impact on understanding the deformation behavior and microstructural evolution of RE-containing Mg alloys, and such insights can serve as guidance for the development of new alloys and processes. The information and data provided in this dissertation can also serve as inputs for the development of accurate crystal plasticity models.