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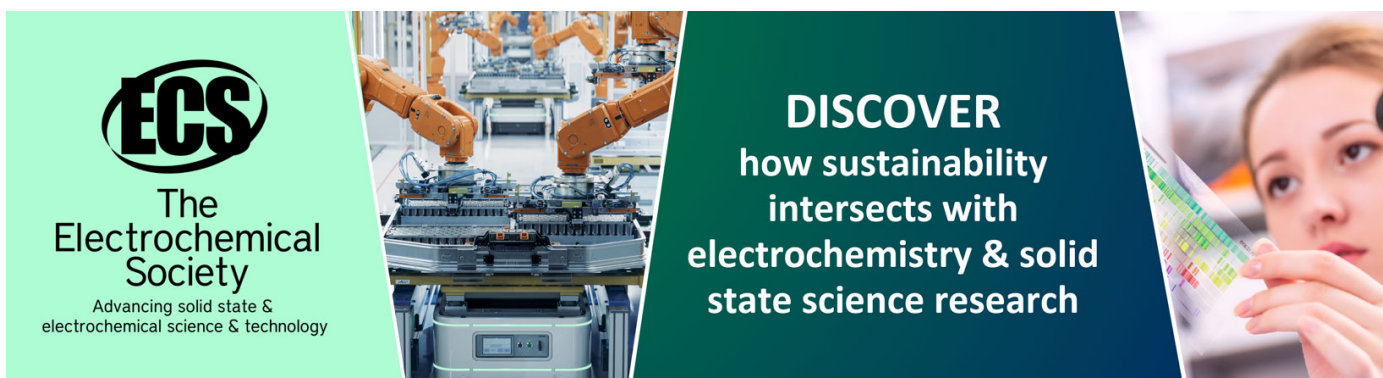
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Influence of microstructure on creep strength of MRI 230D Mg alloy

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Abstract. The low density of magnesium alloys makes them attractive for lightweight constructions. However, creep remains an important limitation of Mg alloys. To gain a more detailed understanding of the correlation between microstructure and creep properties in Mg alloys, creep tests have been performed on MRI 230D samples featuring various microstructures. For this purpose, the MRI 230D Mg alloy has been thixomolded into a plate with four steps of different height, which gives different microstructures in each step due to different cooling rates. With an increase in cooling rate (e.g., a decrease in step height) the interconnectivity of the eutectic phase increases at virtually constant volume fraction. The creep strength is found to decrease with decreasing interconnectivity of the eutectic phase. This implies that a eutectic phase morphology, which is highly interconnected, benefits the creep properties and should therefore be one goal in further developments for creep resistant Mg alloys.

1. Introduction

Magnesium, due to its low density, is attractive for lightweight constructions. However, next to other issues, the rather poor creep resistance of the most commonly used alloy AZ91 remains an important limitation to its widespread application. To overcome this issue, a series of creep resistant and cost competitive alloys has been developed. In many cases, Sr, Ca or rare earth elements (RE) have been added to improve the creep strength [1, 2, 3].

However, little is known about the correlation between microstructure and creep and on the mechanisms responsible for the improved creep behavior of those newly developed alloys. The difficulty in gaining an insight into these reasons lies in the fact that with an introduction of new alloying elements (for example Ca or Sr) several microstructural features change simultaneously and the effects of these changes on the mechanical properties are hard to separate. For Mg-Al-based alloys like AZ91 or AM60, with the introduction of, for example, Ca, the precipitate phase changes from $\text{Mg}_{17}\text{Al}_{12}$ to Al_2Ca , which is harder than $\text{Mg}_{17}\text{Al}_{12}$ (up to testing temperatures of about 200°C, [4]). Furthermore, not only the hardness and the chemistry of the second (intermetallic) phase changes, but also its morphology. The divorced eutectic, which is typical for AZ91 [5, 6] and shows rather isolated particles, changes into a network-like morphology of the eutectic phase [7, 8, 9]. Another effect is that the al-

teration of the elements and their concentrations in the α -Mg solid solution causes differences in solid solution strengthening.

In order to separate the above-mentioned influences on the creep strength we employ different cooling rates by means of casting stepped plates, which result in different morphology of the eutectic phase without significant changes in the chemistry.

2. Experimental

MRI 230D alloy was prepared by thixomolding at a melt temperature of 605°C (that means, in fully liquid state) by Neue Materialien Fürth GmbH (NMF, process details can be found, e.g., in [9, 10]). To produce different microstructures as a result of varying cooling rates, the alloy was thixomolded into stepped plates having a base area of 110 × 120 mm² and step heights of 2, 6, 10 and 14 mm (see also Figure 2). For the investigations, only the 6, 10 and 14 mm steps were used, due to geometrical restrictions of the sample size.

The concentration of alloying elements remains constant for all step heights (compare [11]), which is in accordance with the expectations as cooling rates in thixomolding are too high to allow for diffusion over macroscopic distances.

Microstructural investigation on polished and etched (0.5% HNO₃ in ethanol for 5 s) samples have been performed with a light microscope (LM, Leica DmRm 200) and a scanning electron microscope (SEM, Zeiss CrossBeam 1540 EsB) at 5 kV acceleration voltage. Precipitate volume fraction was measured as linear fraction from a set of parallel test lines superimposed onto the SEM images of the microstructure, i.e., by line intercept method.

Creep tests were performed at constant stress (= force per current cross section) and temperature in compression. Compressive stresses and strains conventionally have negative sign but are reported here in absolute values. Details of the creep test conduction can be found in [7, 11].

3. Results and Discussion

3.1. Microstructure

Light optical images (Fig. 1) of the investigated step heights reveal that all share a similar microstructure: a network of eutectic phase is enclosing the α -Mg solid solution.

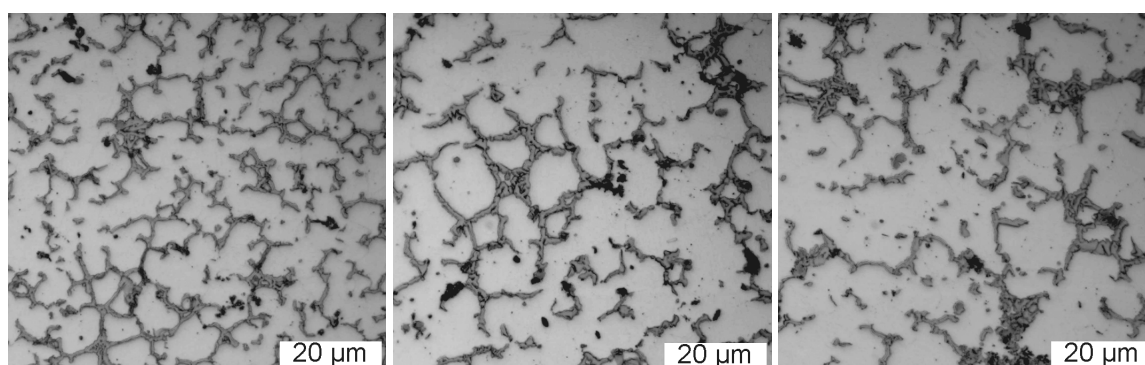


Figure 1: LM images of MRI 230D alloy at 6, 10, and 14 mm step (left to right)

However, a closer look shows that the network of the eutectic phase in the 6 mm step is finer and also seems to be more closed than the network of the other two steps. Between the 10 and the 14 mm steps a slight decrease in interconnectivity of the skeleton can be identified from the LM pictures (see

also [11]). It can be concluded that the connectivity of the network of the eutectic phase increases with decreasing step height (increasing cooling rate), although no exact quantification of this connectivity is presently available.

The volume fraction of the eutectic phase, measured by the line intercept method and shown in Figure 2 remains constant within the margin of error among all step heights.

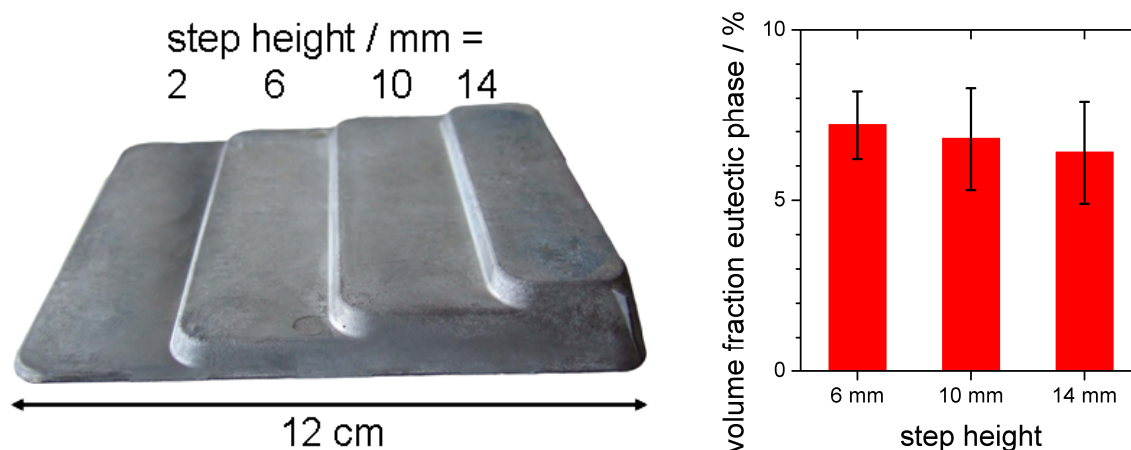


Figure 2: Stepped casting plate and volume fraction of the eutectic phase for the different step heights

Therefore differences in creep properties cannot be rationalized from different volume fractions of the eutectic phase. With regard to the fact that the chemical composition does not vary for the different steps [11] one can also conclude that the chemical composition of the eutectic phase as well as of the solid solution remains constant. Differences in solid solution hardening as well as hardness differences of the eutectic phase can thus be excluded – the differences in mechanical properties seem solely linked to the different morphology of the eutectic phase as seen in the LM images.

3.2. Creep properties

Figure 3 shows the creep curves (creep rate vs. creep strain) for all three steps tested at a temperature of 200°C and a compressive stress of 100 MPa.

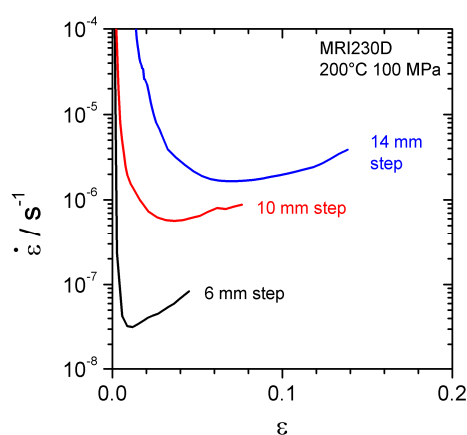


Figure 3: Compressive creep rate vs. creep strain for the different step heights of MRI 230D alloy measured at 200°C and 100 MPa

The 6 mm step exhibits by far the lowest creep rate of all tested step heights, its creep rate lying more than one order of magnitude lower than the creep rate of the 10 mm step and almost two orders of magnitude lower than the creep rate of the 14 mm step. The differences in creep rate between the 10 and the 14 mm step are far less pronounced, as the minimum creep rate of the 14 mm step is approximately a factor of 2 to 3 higher than the minimum creep rate of the 10 mm step.

Observing the chemical and microstructural results reported above, the lower creep strength is predominantly connected to the lower interconnectivity of the eutectic phase (resulting from lower cooling rate in thicker steps). Independently, a similar correlation has been reported [12] between the local room-temperature strength measured on cross-sections of AZ91 high-pressure die castings and the corresponding degree of eutectic phase interconnectivity observed in three-dimensional reconstructions of the microstructure. In line with both such results it was shown [7] that a destruction (by low-temperature prestraining) of the highly interconnected eutectic phase network leads to a massive deterioration of the creep strength.

4. Summary and Conclusion

The creep behavior of as-cast MRI 230D Mg alloy strongly depends on the structure of its eutectic phase network solidifying in the inter-dendritic channels. When this is highly interconnected a significantly higher creep strength results. The eutectic phase acts as a scaffold similar in structure to an embedded open-cell ceramic foam and thus provides strengthening in line with the expected behavior of such foams. Therefore, a conclusion with regard to further developments of creep-resistant Mg alloys would be to produce a highly interconnected network of second and harder phase within the soft α -Mg matrix.

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