An Investigation on the Microstructure and Impression Creep Behavior of the Magnesium Alloys

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Abstract

Magnesium alloys are important materials in industries because of their low densities. But the problem with these alloys is their lack of creep resistance at high temperatures. In this research, the creep behavior of cast ZE63 and ZE41 magnesium alloys were studied by using the impression creep method. The tests of impression creep were carried out at a temperature of 473 Kelvin and constant punching stress range of 175MPa to 500MPa. Microstructural investigation of magnesium alloys was performed using an optical microscope and X-ray diffraction (XRD). The results of XRD analysis indicated that the structures of both alloys were composed of α-Mg matrix phase accompanied by Mg_7Zn_3, $Mg_{12}RE$, and $Mg_{17}RE_2$ intermetallic compounds. Besides, the analysis of the microstructure of deformation zones showed that the creep resistance of ZE63 was higher than ZE41. The higher creep resistance of ZE63 was attributed to the existence of more continuous phases of Mg_7Zn_3, $Mg_{12}RE$, and $Mg_{17}RE_2$.

Keywords

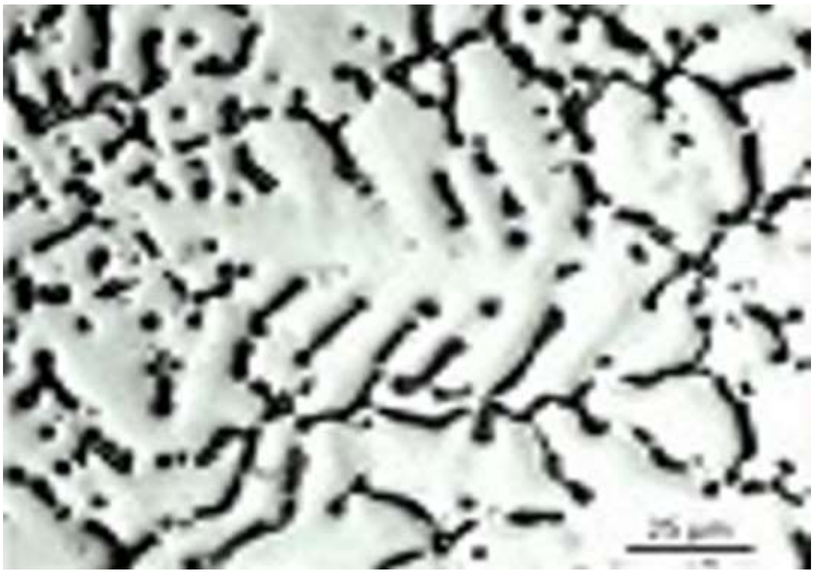
Impression Creep, ZE63, ZE41, Microstructure

1. Introduction

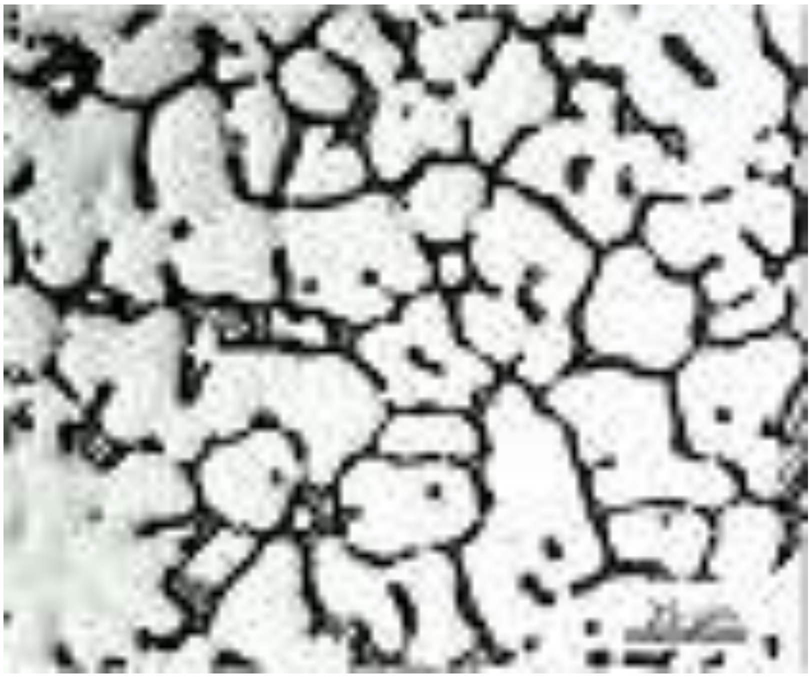
Due to their low densities, magnesium alloys have received considerable attention from the automotive and aerospace industries [1]. However, poor creep resistance of magnesium alloys at higher temperatures is a barrier on a way of expansion of these alloys. The creep behavior of different magnesium alloys has been investigated by localized creep test methods [2,3]. For example, the impression creeps behavior of an Mg-4Al-RE-0.8Ca-0.2Sr has been studied using a flat-ended cylindrical indenter [4]. Creep properties of Mg–Sn–La alloys have been also examined through compressive creep methods [5]. Impression creep technique has been developed by modifying the indentation creep test in which a conical or ball indenter is replaced with a flat-ended cylindrical punch. In this method, the depth of the punch impression in a material is recorded versus creep time. Impression creep method presents several advantages over conventional creep tests, which include needing a small quantity of material for the test, constant stress at a constant load, absence of tertiary stage, etc. [2,6]. Mg–Zn–RE alloys have attracted much attention, in which the icosahedral quasicrystalline phase (I-phase) is found, and the precipitation of the I-phase is effective to improve the mechanical properties including high hardness, high thermal stability, high corrosion resistance and low-surface energy [7]. A few investigations have been carried out on impression creep properties of Mg–Zn–RE alloys. Thus, this study aimed to investigate the creep properties of ZE63 and ZE41 magnesium alloys using the impression creep technique.

2. Method and procedure

Chemical compositions of the alloys used in the present study are Mg-4Zn-1RE (in wt.%) and Mg-6Zn-3RE (in wt.%). The alloys were prepared by melting pure 99.9 wt.% Mg at the temperature of 750°C for 30 minutes in a graphite crucible in an electrical resistance furnace under the protection of an atmosphere of high-purity argon gas. Pure 99.9 wt.% Zn and Mischmetal including 50.2 wt.% Ce, 24.2 wt.% La, 19.2 wt.% Nd, and 6.4 wt.% Pr, were added to the melt at 750°C. It was then poured into a preheated steel mold with a diameter of 35mm and a height of 180mm. The casting was carried out using a tilt-casting technique for minimizing the melt turbulence and the quick emergence of entrapped air. The specimens of impression creep testing were prepared as slices with the dimensions of 3 ×10 ×10 mm^3 from the as-cast sample by an electro-discharge wire cut machine. For obtaining parallel surfaces, two surfaces of the slices were mechanically ground and polished. Creep test was carried out using impression creep technique, in which a flat-ended cylindrical punch with a diameter of 2 mm was impressed on the samples. The tests were performed at a temperature of 423K and applied to a punch stress range of 175-500 MPa for 4000 s. After the application of the load, the impression depth was measured automatically as a function of time with the resolution of 1μm. Moreover, the load applied to the punch was measured by a load cell with the accuracy of ±1N.



a)



b)

Figure1. Optical micrographs of a) ZE41 and b) ZE63

3. Result and discussion

The optical microstructures of ZE41 and ZE63 are shown in Figure 1. Both alloys have dendritic cast structures with interphases at interdendritic regions. As it is seen in Figure 1, there are more dendritic structure regions in Mg-6Zn-3RE in comparison with Mg-4Zn-1RE. This is due to the existence of more element alloys in the chemical composition of Mg-6Zn-3RE. X-ray diffraction (XRD) patterns of the alloys in Figure 2 indicate that both alloys have been composed of α-Mg matrix phase accompanied by Mg_7Zn_3, $Mg_{12}RE$, and $Mg_{17}RE_2$ intermetallic compounds. It should be noted that the intensity of intermetallic compound peaks increases with increasing RE addition in the alloy of Mg-6Zn-3RE.

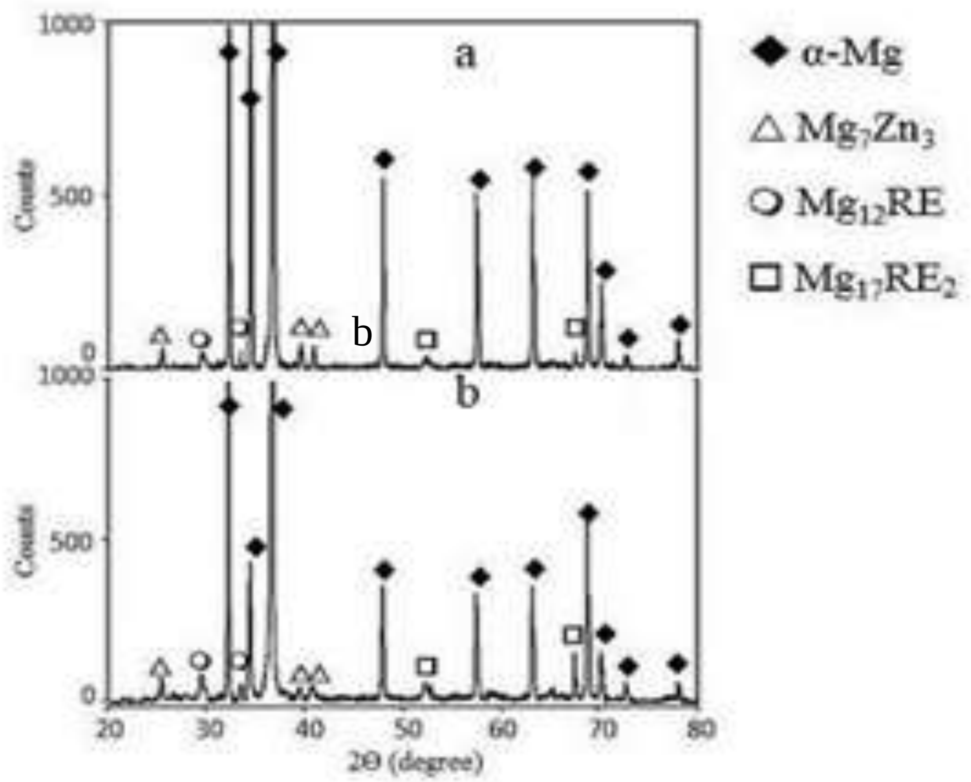


Figure2. XRD patterns of a) ZE41 and b) ZE63

Figure 3 shows the creep curves demonstrated as impression depth versus creep time at a temperature of 473K. Almost all the curves have a primary creep regime followed by a steady-state creep. It is obvious that increasing the stress at the constant temperature results in higher penetration rates, and thus the steady-state region occurs at shorter periods. Another feature of the curves depicted in Figure 3 is that the RE addition causes more increase in creep resistance of Mg-6Zn-3RE at all test temperatures in comparison with Mg-4Zn-1RE alloy. The higher creep resistance of Mg-6Zn-3RE is attributed to the changes in the morphology of the eutectic structure from a lamellar to the continuous phase.

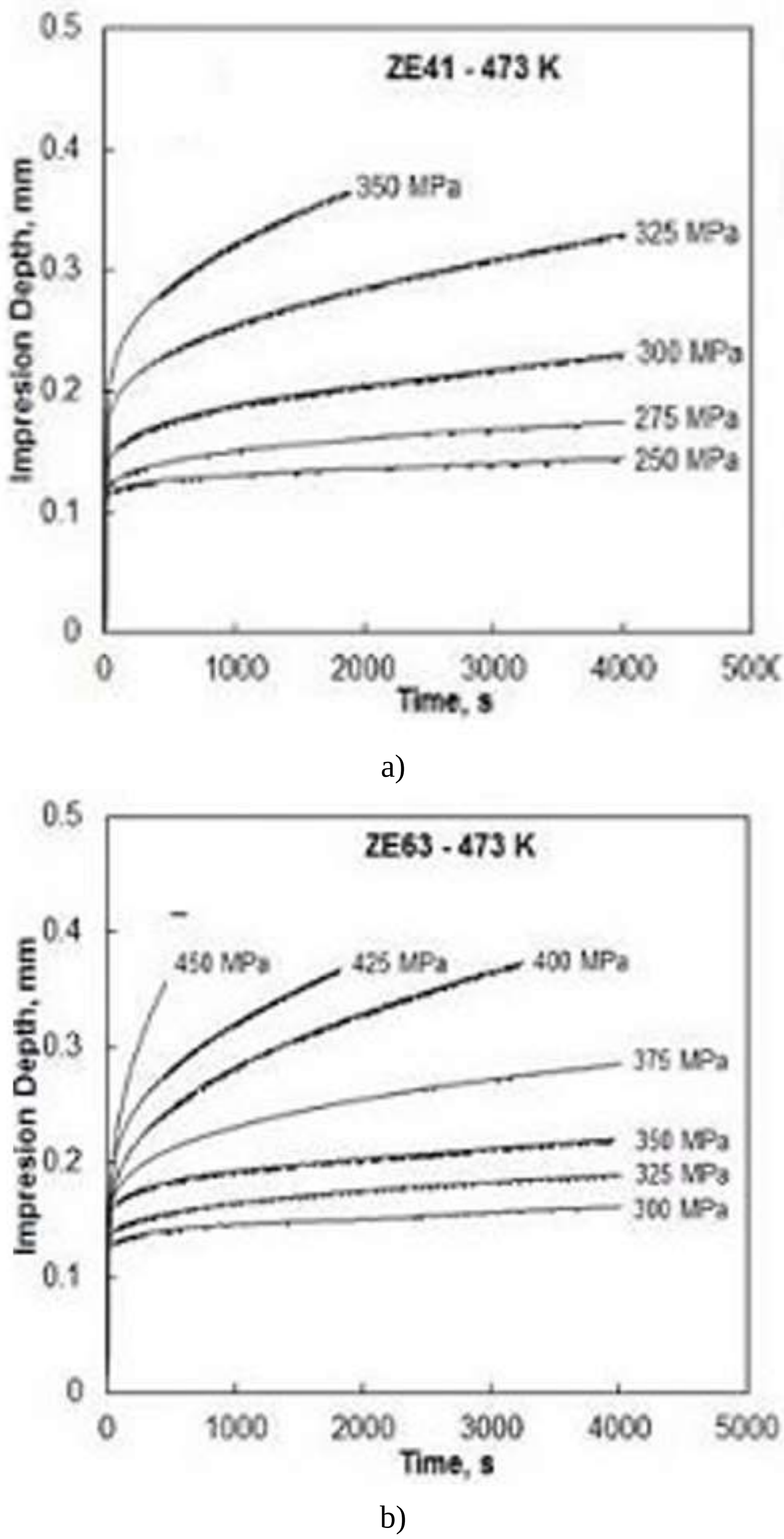


Figure3. Comparison of the creep behavior of a) ZE41 and b) ZE63 at T = 473 K

Figure 4 shows the microstructure of the alloys after creep testing at 473 K under 350 MPa. Three distinct areas are observed in the microstructure separated from each other by curved lines named 1, 2, and 3 regions. In region1 and 3, there are no microstructural changes, whereas, in region 2, microstructural changes are detectable. According to Figure 4 (b), high creep resistance of ZE63 leads to less microstructural changes in region 2 rather than ZE41 alloy. This may be ascribed to the increased number density of intermetallic compounds in ZE63 alloy.

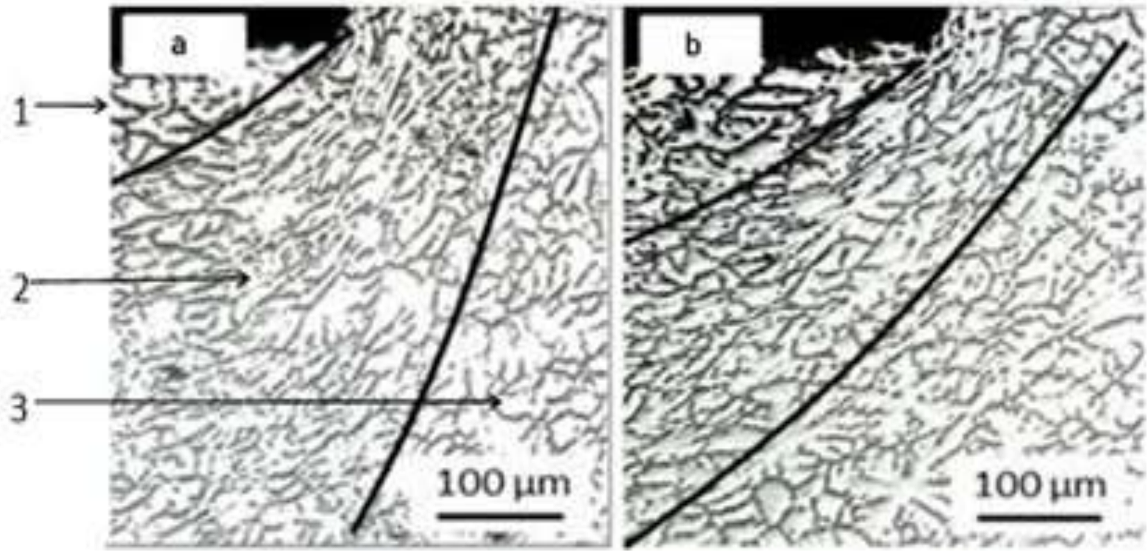


Figure4. Microstructure of the alloys after the creep test at 473 K under 350 MPa: a) ZE41 and b) ZE63

5. Conclusion

Applying the impression creep method on Tilt-casted ZE63 and ZE41 magnesium alloys at the temperature of 473K and constant punching stress range of 175-500MPa resulted in that:

1. The creep resistance of ZE63 is higher than the ZE41 alloy.
2. Structures of both alloys are composed of the α-Mg matrix phase accompanied by Mg_7Zn_3, $Mg_{12}RE$, and $Mg_{17}RE_2$ intermetallic compounds.
3. The higher creep resistance of ZE63 is related to the existence of more continuous phases of Mg_7Zn_3, $Mg_{12}RE$, and $Mg_{17}RE_2$.

6. References

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