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Short communication

Low temperature superplasticity of ultrafine grained Mg–9.25Zn–1.66Y alloy with an icosahedral quasicrystalline phase

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ABSTRACT

The ultrafine grained Mg–9.25Zn–1.66Y alloy sheet with I-phase prepared by directly applying high-ratio differential speed rolling to the as-cast microstructure exhibited excellent low-temperature superplasticity (386–888% at 443–473 K) at a moderately high strain rate of 10^{-3} s^{-1}. A criterion for achieving low temperature superplasticity was proposed.

1. Introduction

The icosahedral quasicrystalline phase (I-phase, Mg_3YZn_6) in Mg–Zn–Y alloys has attracted researchers' attention because it has high thermal stability and forms a low interfacial energy and coherent interface with the matrix [1,2]. Researchers have tried to refine the cast microstructures of the I-phase containing Mg–Zn–Y alloys through various thermomechanical processing routes [1,2].

Superplasticity of the I-phase containing Mg–Zn–Y–(Zr) alloys with fine grains has been studied by several investigators [3–6]. There are, however, relatively limited studies on their superplastic behaviors at low temperatures below 473 K. Low temperature superplasticity (LTS), meaning superplasticity below $0.5T_m$ (where T_m is the melting temperature), is attractive for the application of superplasticity in industrial forming operations in terms of energy saving and prevention of the surface oxidation of products.

The purpose of this study is to explore the possibility of achieving LTS from the ultrafine grained (UFG) I-phase containing Mg–9.25Zn–1.66Y alloy, which was prepared by directly applying the high-ratio differential speed rolling (HRDSR) technique to a cast microstructure.

2. Materials and methods

The starting alloy used in the present study was as-cast Mg–9.25 wt% Zn–1.66 wt% Y alloy ($MgZn_{3.7}Y_{0.49}$). The as-cast slab with 4 mm was rolled using conventional rolling followed by high-ratio differential speed rolling (HRDSR, with a speed ratio of 3) to a final thickness of 0.63 mm. The detailed casting and rolling procedures are available elsewhere [7].

The microstructures of the HRDSRed alloy were examined by using a field-emission transmission electron microscope (JEM 2001F) operated at 200 kV. For TEM sample preparation, the HRDSRed alloy was mechanically polished and then thinned by jet polishing (using a solution composed of 60% methyl alcohol, 30% glycerin and 10% nitric acid), followed by ion milling (BAL-TEC RES 101).

For the tensile testing, tensile specimens with dog-bone geometries with a 5-mm gauge length, 4-mm width, 0.6-mm thickness and 4-mm shoulder radius were cut along the rolling direction. The strain rate change (SRC) tests were conducted at 443–653 K. The elongation-to-failure tests were conducted at 443–653 K using the initial strain rates of 5×10^{-4}–1×10^{-2} s^{-1}. The sample heating and holding time before tensile loading was 10 min.

3. Results and discussion

Fig. 1(a)–(d) show the TEM micrographs of the HRDSRed alloy. The HRDSRed alloy has fine and equiaxed grains with the sizes of

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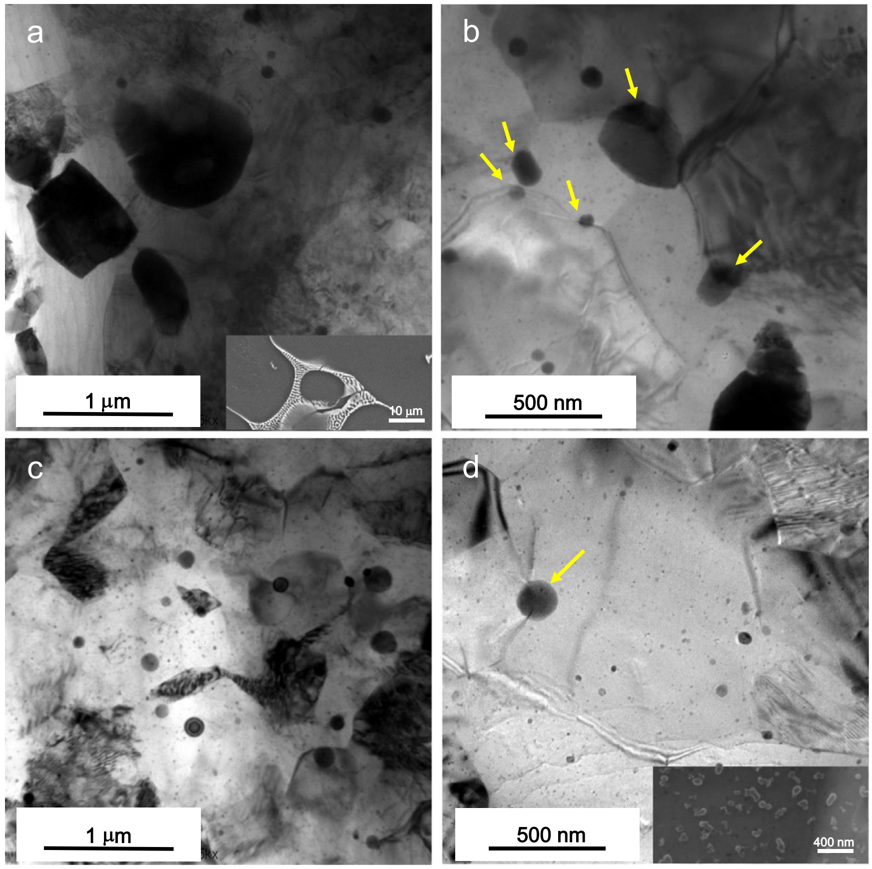

Fig. 1. (a)–(d) TEM images of the HRDSRed alloy at different locations. The inset in (a) and (d) show SEM images of the cast microstructure.

0.5–1.0 μm. In the microstructure, the irregular shaped particles with sizes of 0.1–1 μm (Fig. 1(a) and (b)) are the I-phase fragments broken and separated from the I-phase eutectic structure (inset of (a)), whereas the round or elliptical shaped particles with typical sizes of 100 nm (Fig. 1(c) and (d)) are I-phase particles formed during the casting (solidification) process (inset of (d)). Many particles with the sizes less than 50–150 nm interact with moving dislocations or grain boundaries (indicated by arrows in Fig. 1 (b) and (d)), indicating the potential of these size particles for stabilizing the fine-grained microstructure at elevated temperatures.

Fig. 2(a) shows the tensile elongation values of the HRDSRed alloy plotted as a function of the temperature at a given strain rate of $1\times10^{-3}\ s^{-1}$. The following is inferred. First, a tensile elongation of 386% is obtained at a temperature as low as 443 K ($0.48T_m$). At 473 K ($0.51T_m$), a large tensile elongation of 888% is obtained. At 523 K, a significant decrease of the tensile elongation (to 230%) is resulted. As the temperature further increases, however, the tensile elongation gradually increases (up to 350% at 653 K). This tensile elongation behavior indicates that the HRDSRed alloy exhibits excellent LTS, but its superplastic ability sharply degrades above 523 K. Fig. 2(b) shows the engineering stress–engineering strain curves of the HRDSRed alloy at different strain rates at a given temperature of 473 K. Compared at $1\times10^{-3}\ s^{-1}$, a slightly larger tensile elongation of 944% is obtained at a lower strain rate of $5\times10^{-4}\ s^{-1}$, but a notably smaller elongation of 263% is

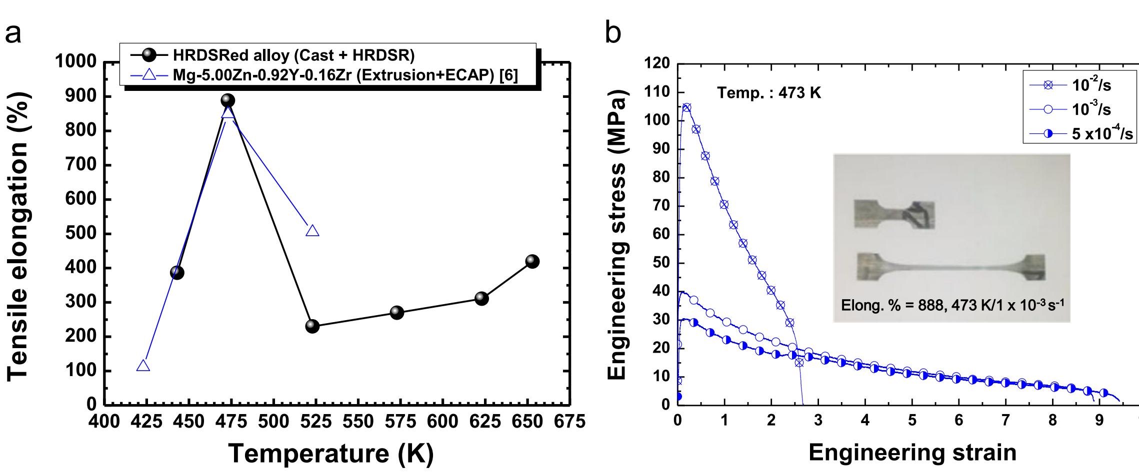

Fig. 2. (a) Tensile elongations of the HRDSRed alloy and the ECAPed Mg–5Zn–0.92Y–0.16Zr alloy [6] given as a function of testing temperature at $10^{-3}\ s^{-1}$. (b) Engineering stress–engineering strain curves of the HRDSRed alloy at different strains rates at 473 K.