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Short communication

Effects of heat treatment on the nanoscale precipitation behavior of 7055 aluminum alloy under dynamic shock

Ping Zhang*, Youqiang Wang

School of Mechanical Engineering, Qingdao University of Technology, Qingdao, Shandong, 266520, China

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ABSTRACT

This study is intended to examine the effects of heat treatment on the microstructural evolution of 7055 aluminum, an area rarely reached by previous studies. Considering that 7055 aluminum alloy belongs to the aging hardening type, the difference of heat treatment process will lead to a large difference in mechanical properties and microstructure of the materials. Dynamic shock test is conducted on the alloy after treated by T6 and T6I4 processes. The result demonstrates that before dynamic shock, the precipitates on the grain boundary of T4-state alloy are fine, straight and continuously, and the precipitation-free zones (PFZs) around the grain boundary are quite narrow; the precipitates on the grain boundary of T6I4-state alloy are spheroidized and discontinuous, and the PFZs around the grain boundary are quite broad. Under room temperature, the dispersed grains of T4-state alloy are large in size while those of T-6I4-state alloy are finer with concentrated, very dense dislocations around the dispersed grains. The dislocation density displays an obvious positive correlation to the strain rate: The larger the strain rate, the higher the dislocation density. After dynamic shock at 6000s-1, the dislocations are tangled into dislocation walls and the dislocation cells shrink in size. More dislocation cells form in T6I4-state alloy than in T4-state alloy. Under high temperatures, the dislocation density displays an obvious negative correlation to the dynamic shock temperature: As the dynamic shock temperature increases, the dislocation density in the alloy decreases significantly. Under 120 °C, the dislocation density in T4-state specimen increases. A lot of the dislocations are tangled into dislocation walls. Dislocation walls as well as cellular substructures occur in T6I4-state alloy. Under 320 °C, a lot of irregular dislocation networks appear in T6-state alloy, and these dislocations are obstructed by coarsening precipitates; the precipitates in the T6I4-tread alloy are dissolved. Only dislocations beamed into individual single-root structures are observed. The dislocation density is very low.

1. Introduction

7055 aluminum alloy is a new age-hardening ultrahigh-strength material whose microstructure and performance are highly sensitive to the ageing process applied. Given the service conditions of the material, examining its dynamic shock performance is particularly important [1–3]. Recently, many researchers have turned their eyes to the heat treatment and dynamic shock performance of 7055 aluminum alloy. Cai et al. [4]studied the mechanical performance and microstructure of 7050 aluminum alloy under dynamic shock and demonstrated that under the same temperature, the flow stress increases significantly with the strain rate, suggesting a strain rate hardening effect, especially under 220 °C. Molak, R. M. et al. [5]investigated the effects of solution treatment on the microstructure and performance of high-strength aluminum alloys and confirmed that the material performance reaches its optimum after solution-state under 475–480 °C for 2 h and then aged under 130 °C for 24 h. After heat treatment, the material's tensile strength increases by 5%–725 MPa and its elongation increases by 40%–13.0%. Karaaslan, A. et al. examined the effects of pre-deformation and ageing on the micirostructure and performance of 7055 aluminum alloy [6], and concluded that, if the material has been cold-deformed and then T6-aged, as the deformation increases, the strength increases slightly first and then decreases slowly. RRA-state alloy's strength decreases continuously as the deformation increases [7]. As the deformation increases, the electrical conductivity of cold-rolled 7055 aluminum alloy decreases gradually while that of the T6 and RRA-state alloy increases gradually [8]. Given the

* Corresponding author.
E-mail address: zp15200398517@126.com (P. Zhang).

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same amount of deformation, RRA-state alloy has the highest electrical conductivity. Despite increasing interest in the heat treatment and dynamic shock of 7055 aluminum alloy, however, little has been reported on the effects of heat treatment processes on the precipitation behavior of the material under dynamic shock. Hence we examined the microstructural evolution of the material under dynamic shock after treated by T6 and T6I4 processes. The result is expected to provide helpful reference for further studies on the shock resistance of the material.

2. Material, equipment and method

Table 1 gives the material composition of 7055 aluminum alloy. Heat treatment processes used include peak ageing (T6) and secondary ageing (T6I4). The former includes solution treatment under 460 °C for 1 h + ageing under 120 °C for 24 h; the latter includes solution treatment under 460 °C for 1 h + pre-ageing under 120 °C for 45min + ageing under 80 °C for 360 h. A split Hopkinson pressure bar (SHPB) was used for our dynamic shock test under temperatures 20 °C, 120 °C, 220 °C and 320 °C within strain rate rage of $10s^{-1}$~$7000s^{-1}$. Split Hopkinson pressure bar is shown in Fig. 1. After the test, the microstructure evolution of the dynamic shock specimens was observed under TEM.

3. Results

3.1. Microstructure of 7055 aluminum alloy treated by different thermal processes

Fig. 2 describes the TEM microstructures of T6 and T6I6-state alloy before dynamic shock. Fig. 2(a) and (b) show the TEM microstructure of intracrystalline precipitates in T6 and T6I4-states. Fig. 2(c) and (d) show the TEM microstructures of precipitates on the grain boundary of T6 and T6I4-states. Comparison of Fig. 2(a) and (b) demonstrates that precipitates in T6-state are coarse and scattered with relatively low precipitation density; those in T6I4-state are fine and dense with high precipitation density [9]. The reason should be: After pre-aged under 120 °C for 30min, T6-state is still undergoing high-temperature ageing under 120 °C. The high ageing temperature expedites the atomic diffusion and eventually leads to low nucleation density of the intracrystalline precipitates. As the ageing temperature is high, the intracrystalline precipitates in T6-state are coarse with low density. For T6I4-state, as there was an interruption between its pre-ageing and the secondary ageing under 80 °C for 36 h, and the ageing temperature is lower than that used for T6-state (120 °C), the growth rate of the atom clusters and GP zones formed during pre-ageing is reduced [10]. The precipitates become finer, and the nucleation density becomes larger. This explains why the precipitation density in T6I4 is higher than in T6, and the precipitates in T6I4-state are smaller than those in T6-state.

Furthermore, we can also see from Fig. 2(c) and (d) that the precipitates on the grain boundary of T6-state are fine, straight and continuous, and the precipitation-free zones (PFZs) around the grain boundary are very narrow; the precipitates on the grain boundary of T6I4-state are spheroidized and discontinuous, and the PFZs around the grain boundary are quite broad. The reason should be: As the grain boundary atoms in the crystals are poorly arranged and contains all sorts of defects, the atoms are in unbalanced positions with high potentials. This easily gives rise to new phase boundaries on the grain boundary. As the obstruction for the free energy of precipitate on the grain boundary is very modest, the solute segregation concentration at the grain boundary are higher than that in the crystal [11]; the diffusion and precipitate nucleation rate along the grain boundary is faster than that in the crystal. Hence, if the temperature is too low, the ageing should last a longer time. However, at the grain or phase boundary, as temperature levels do not make much difference to atom diffusion rate, even under a very low temperature, the atom diffusion rate will still be

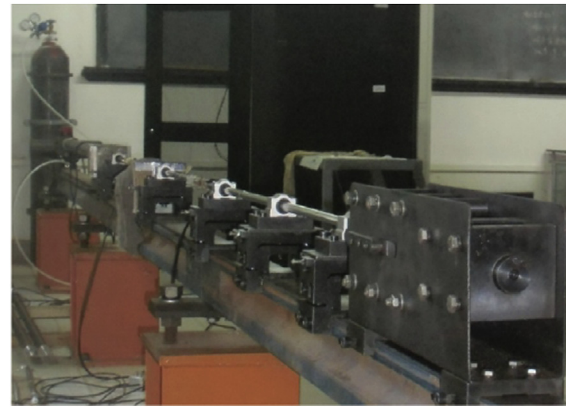

Fig. 1. Split Hopkinson pressure bar.

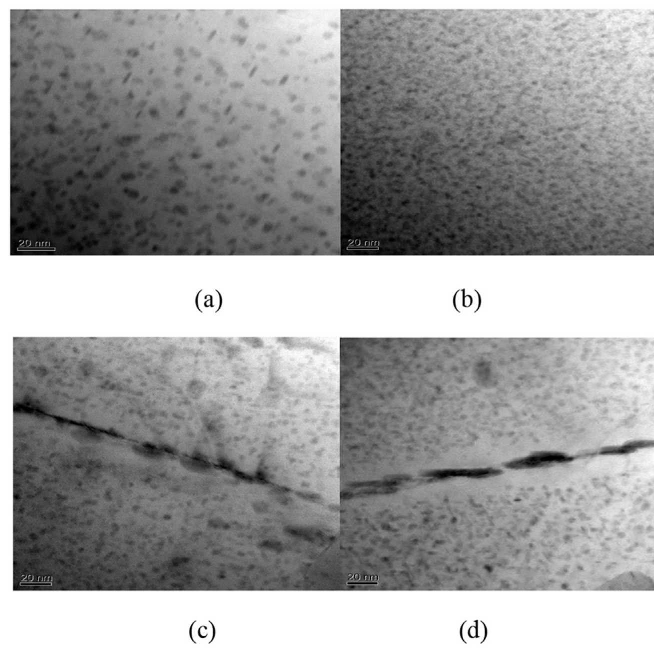

Fig. 2. TEM structure of 7055 aluminum alloy for T6 and T6I4 heat treatment before dynamic impact.

Table 1
The chemical composition of 7055 aluminum alloy(wt.%).

Element	Zn	Mg	Cu	Zr	Fe	Si	Cr	Mn	Al
Ture value	7.76	1.94	2.35	0.12	0.061	0.055	0.005	0.008	allowance
Nominal value	7.6–8.4	1.8–2.3	2.0–2.6	0.08–0.25	<0.15	0.10	<0.04	<0.05	allowance