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Tensile-stress-induced decomposition of β_s'-phase in Zn–Al-based alloy

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As a part of a systematic research program on external-stress-induced phase transformation and microstructural change, structural evolution in cast, furnace-cooled and extruded eutectoid Zn–Al-based alloys during tensile and creep deformations have been studied [1–6]. It was reported that the stress induced by tensile and creep deformations resulted in decompositions of both metastable phases η_T' and ε, accompanied by microstructural change from a coarse lamellar structure into a fine-grained structure. The coarse lamellar structure was deduced from decomposition of the β_s'-phase, a zinc-rich supersaturated phase of face-centred cubic structure. Because of this microstructural change the elongation and ductility of the alloy were very much enhanced. It was elucidated that the decomposition of the β_s'-phase played an important part in improving the plasticity of the alloy. Also it was reported that over 70% of the η_T' and ε were from the decomposition of the supersaturated β_s'-phase in a solution-treated-and-quenched eutectoid Zn–Al-based alloy [7, 8].

Therefore the decomposition of the supersaturated β_s'-phase is essential with regard to the mechanism of structural evolution and the mechanical properties of the eutectoid Zn–Al-based alloy.

The supersaturated β_s'-phase is unstable even at room temperature and decomposes into three metastable phases: α_T', ε and η in the cellular reaction $\beta_s' \rightarrow \alpha_T' + \varepsilon + \eta$, during the early stage of ageing in the quenched eutectoid Zn–Al-based alloy [7–9]. The decomposition of the β_s'-phase is very rapid and is complete on ageing at 100 °C for about 45 s [7, 8]. It would be rather difficult to determine the effect of the tensile stress on the decomposition of the β_s' phase.

The present work will deal with the tensile-stress-induced decomposition of the β_s'-phase in a solution treated-and-quenched eutectoid Zn–Al-based alloy (Zn–22 wt % Al–2 wt % Cu).

Cast ingots of the eutectoid Zn–Al-based alloy were extruded at 250 °C for homogenization of the material being tested and then machined into standard tensile specimens of 6 mm diameter with 20 mm gauge length for tensile testing. The specimens were solution treated at 350 °C for 4 days and then quenched into ice–water. Immediately after quenching, the specimens were tensile tested on an Instron machine at a cross-head speed of 7.00×10^{-3} mm s^{-1} at room temperature. The stress–strain curve is plotted in Fig. 1. The ultimate tensile stress and 0.2% proof stress of the quenched specimen were found to be 276.0 MPa and 130.5 MPa, respectively. The specimen broke as the strain reached 38.47% with a breaking stress of 100.9 MPa. The displacements at peak and at breaking point were 3.68 mm and 6.73 mm, respectively. The tensile test lasted 16 min.

The quenched specimens were examined by X-ray diffraction, optical microscopy and scanning electron microscopy techniques as described in previous publications [1–7] to identify the stress-induced phase transformation and microstructural change before and immediately after tensile testing at room temperature. The X-ray diffractogram of the as-quenched specimen before tensile testing is shown in Fig. 2a. It was found that the as-quenched specimen consisted of mainly the β_s'-phase in addition to a small amount of ε-phase. The supersaturated β_s'-phase appeared as the matrix and the ε-phase existed as particles, as shown in the scanning electron micrograph in Fig. 3.

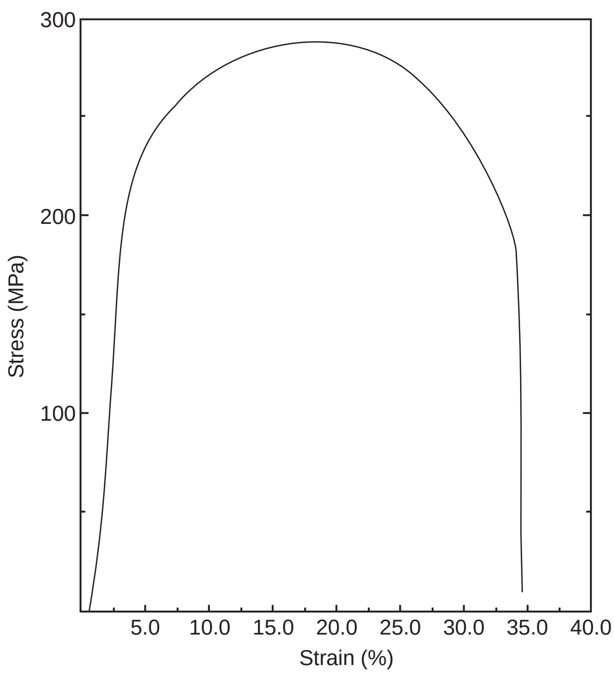

Figure 1 Stress–strain curve of the quenched eutectoid Zn–Al-based alloy.

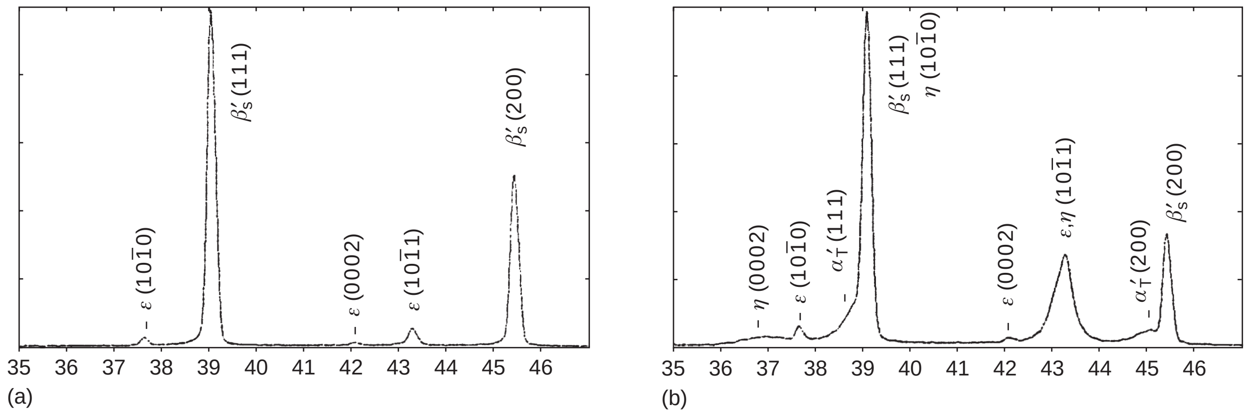

Figure 2 X-ray diffractograms of the eutectoid specimens (a) as quenched and (b) after ageing at room temperature for 16 min without external tension.

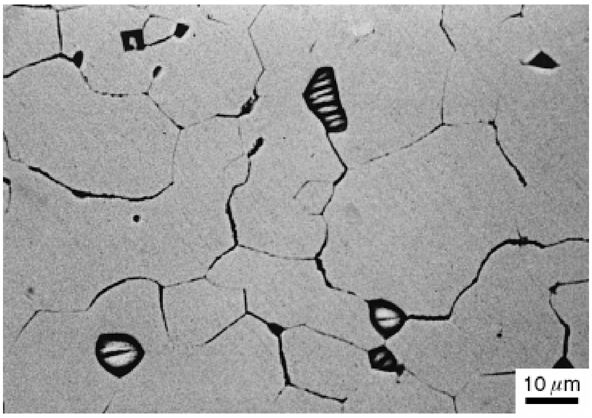

Figure 3 Scanning electron micrograph of the as-quenched eutectoid Zn–Al-based alloy.

Shown in Fig. 4 are the X-ray diffractograms of various parts of the specimen after tensile testing at room temperature: the bulk part, neck zone and rupture part. It was clearly observed that the β'_s-phase in both the bulk and the rupture parts decomposed during tensile testing at room temperature. By comparing the X-ray diffractograms of the specimen before tensile testing, the heights of the X-ray diffraction peaks of the β'_s-phase decreased in the bulk part of the specimen, whilst three sets of the diffraction peaks of α'_T, ε and η phases appeared, as indexed in Fig. 4a. As the tensile test was in fact a process of both ageing and tensile deformation, the as-quenched specimen underwent ageing at room temperature in addition to the tension. Shown in Fig. 2b is the X-ray diffractogram of the quenched

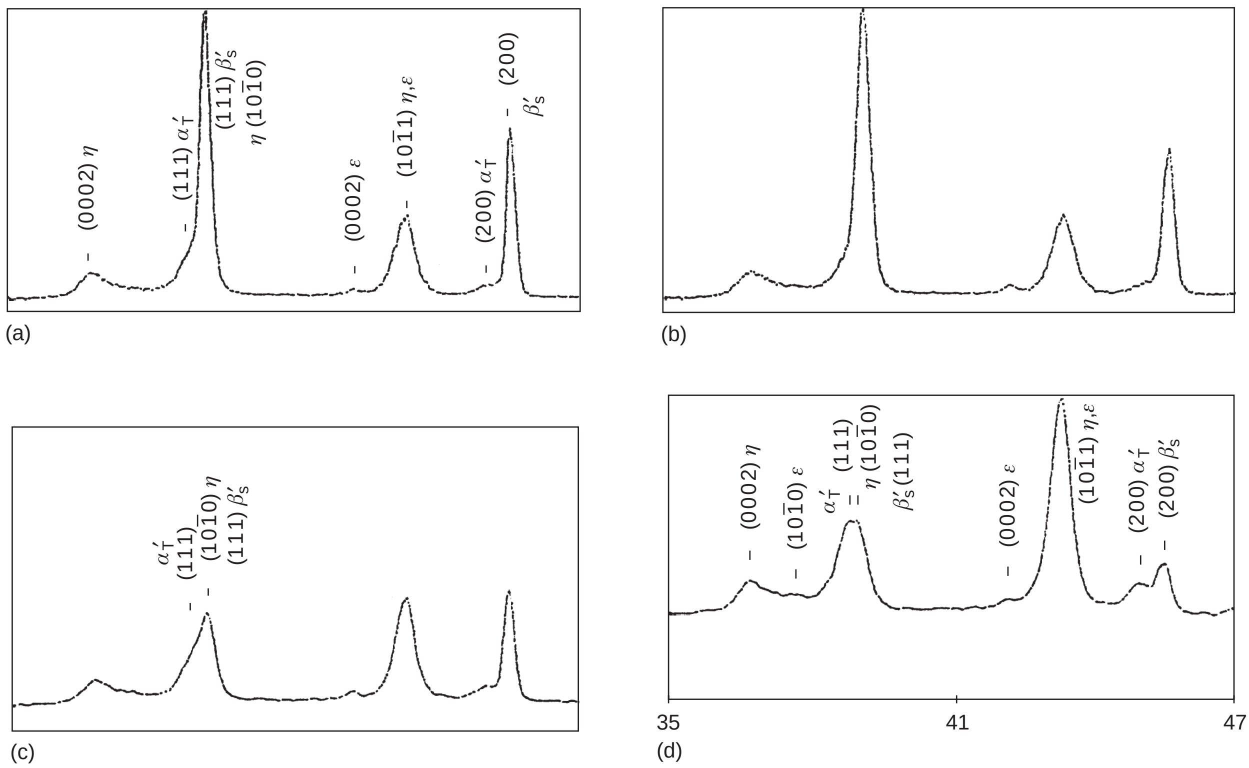

Figure 4 X-ray diffractograms of various parts of the specimen after tensile testing at room temperature: (a) bulk part; (b) neck zone; (c) rupture part.

specimen after ageing at room temperature for 16 min, the time of tensile testing, without external tension. Comparing Fig. 2b with Fig. 4a, it was found that the β_s'-phase decomposed in both the aged specimen (without external tension) and the bulk part of the tensile-tested specimen, and the diffraction intensities of the decomposed β_s'-phase and the three metastable phases, α_T', ε and η were identical. Obviously the decomposition of the β_s'-phase in the bulk part of the specimen was due to the ageing at room temperature, but not to the external tensile stress. Discontinuous precipitation occurred along the grain boundaries inside the β_s'-phase, as shown in both the optical micrograph (Fig. 5a) and the scanning electron micrograph (Fig. 6a).

In the neck zone and the rupture part of the specimen, plastic deformation occurred, and accordingly the decomposition of the β_s'-phase started to develop. As shown in Fig. 4, the (1 1 1) and (2 0 0)

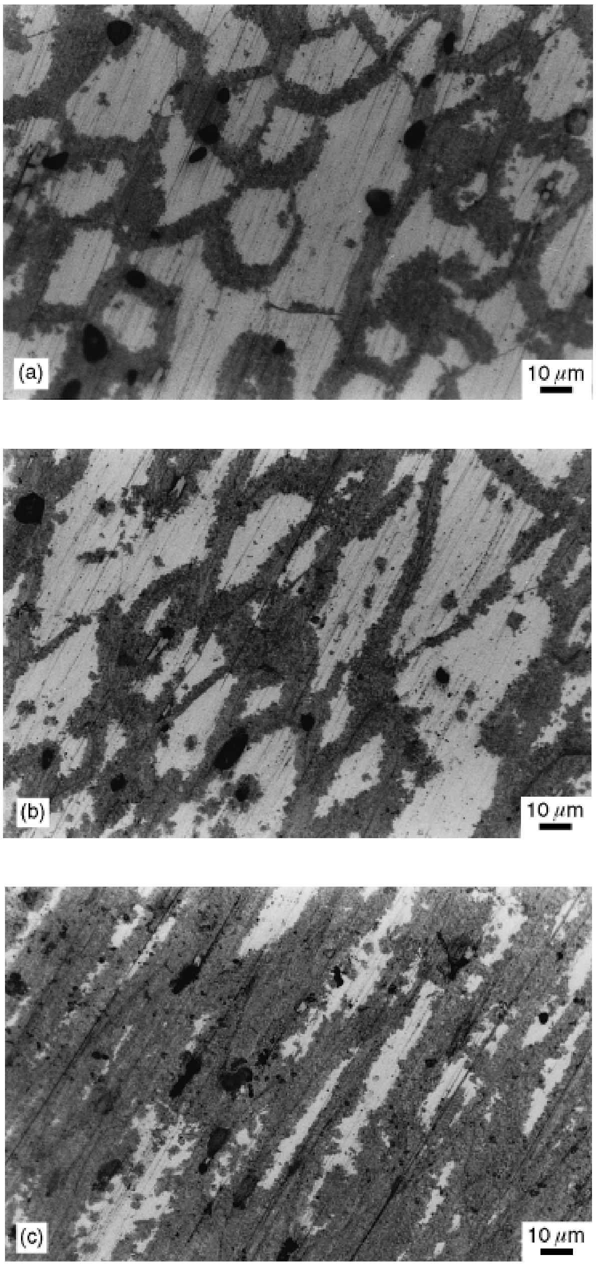

Figure 5 Optical micrographs of various parts of the specimen after tensile testing at room temperature: (a) bulk part; (b) neck zone; (c) rupture part.

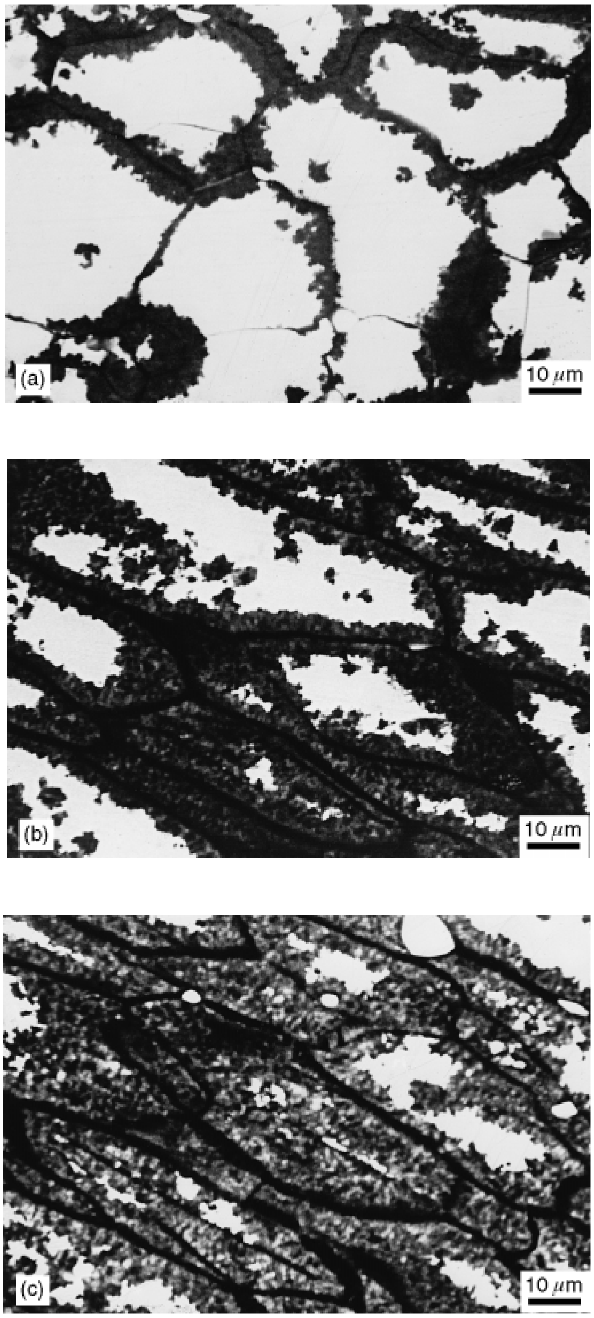

Figure 6 Scanning electron micrographs of various parts of the specimen after tensile testing at room temperature: (a) bulk part; (b) neck zone; (c) rupture part.

diffraction intensities of the β_s'-phase decreased, with accompanying increases in the diffraction intensities of the three metastable phases: α_T', ε and η. As the distance from the rupture frontier was decreased, the discontinuous precipitation of the β_s'-phase apparently developed, as shown in both the optical micrographs (Fig. 5) and scanning micrographs (Fig. 6). Because of the high concentrated strain due to necking, the decomposition of the β_s'-phase was greatly accelerated in the rupture part of the specimen, as shown in Fig. 4d.

Accompanying the tensile-stress-induced decomposition of the β_s'-phase, the grains inside the β_s'-phase were elongated along the tensile direction, as shown in Figs 5 and 6.

It was concluded that the external stress induced by tensile deformation accelerated the decomposition

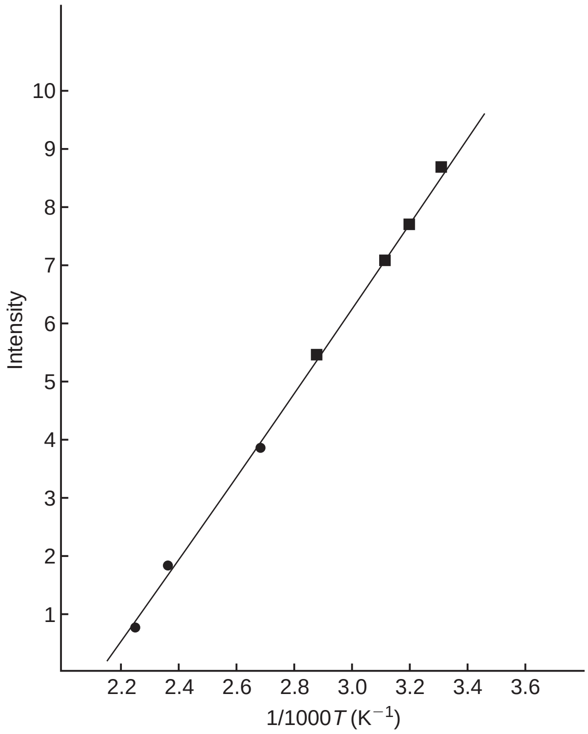

Figure 7 Arrhenius plot for determination of activation energy of decomposition of the β'_s-phase in eutectoid Zn–Al-based alloy: $\beta'_s \rightarrow \alpha'_T + \varepsilon + \eta$. (●), deduced from X-ray diffraction; (■), deduced from exothermic measurements.

of the β'_s-phase and resulted in grain elongation. The activation energy of the decomposition of the β'_s-phase was 60.6 J mol^{-1}, obtained by calculating the slope of an Arrhenius plot deduced from both X-ray diffraction and exothermic measurements, as shown in Fig. 7 [10]. The driving force for the decomposition of the β'_s-phase was sufficient for the activation energy in the as-quenched specimens and the β'_s-phase decomposed in both the bulk part and the rupture part of the quenched specimens. With the additional strain induced by plastic deformation, the probability that an atom reaches the activation state was increased greatly and the decomposition of the β'_s-phase was apparently accelerated in the rupture part of the specimen.

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