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The quench rate-dependent formation of lamellae of the metastable rhombohedral R phase in an aluminium-29 at.% zinc alloy

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The precipitate morphology developed by room temperature ageing of an aluminium 29 at. % zinc alloy has been found to depend on quenching rate. For slow quenches there is a slow development of fine R phase laths together with large precipitates of zinc, but for fast quenches well-defined colonies of lamellae of R phase form rapidly. The results are rationalized in terms of the strain field interaction between R phase precipitates.

1. Introduction

Much research has recently been devoted to a study of the decomposition of quenched aluminium zinc alloys, and for compositions containing up to approximately 15 at. % zinc the ageing sequence

$$\text{spherical GP zones} \rightarrow \text{ellipsoidal GP zones} \rightarrow \text{R phase} \rightarrow \alpha' \rightarrow \text{zinc}$$

has been well documented [1-6]. However, in more concentrated alloys, R phase is present in as-quenched material [7, 8] and there is some evidence that, during ageing at low temperatures, the above sequence is not followed. In particular, lamellar arrays of R phase have been reported [9] but there has not been any systematic study of the factors influencing this transformation. The present paper reports an investigation of the influence of quench rate on the growth of R phase at room temperature in an aluminium-29 at. % zinc alloy.

2. Experimental

An aluminium-29 at. % zinc alloy (50 wt % zinc) was prepared by melting under argon and chill casting 99.999% aluminium and 99.995% zinc. The ingot was rolled at 400°C to 2 mm strip and subsequently cold rolled to 0.2 mm thickness. Spectrographic analysis of the final product showed the total impurity content to be ~ 10 ppm by weight. Prior to ageing, the material was solution treated at 440°C for 1 h. Different quench rates were obtained by quenching into iced brine at −5°C and silicone oil at 20°C. After ageing for different times at room temperature (20°C) thin foils suitable for transmission electron microscopy were prepared by electropolishing at −60°C in an electrolyte of 15% perchloric acid in methanol.

3. Results and discussion

Both the as-quenched microstructure and that obtained after short ageing times were relatively independent of quench rate. A quantitative comparison of structures was not possible for ageing times of less than 12 h because the thin foils were very metastable and the microstructure changed during examination in the electron microscope. A typical as-quenched microstructure is shown in Fig. 1a and consists of ellipsoids of the metastable R phase. It has been suggested [10] that this phase forms spinodally and it is possible that these ellipsoids nucleated during the quench. The R phase was identified by comparison of interplanar spacings, determined from both X-ray diffractometry and electron diffraction, with the published data of Krishna Rao, *et al* [7]. Agreement was obtained to within 5% (electron diffraction) and 2% (X-rays) In addition, the distribution of R phase diffraction spots in the vicinity of the {111}, {200} and {220} matrix spots in electron

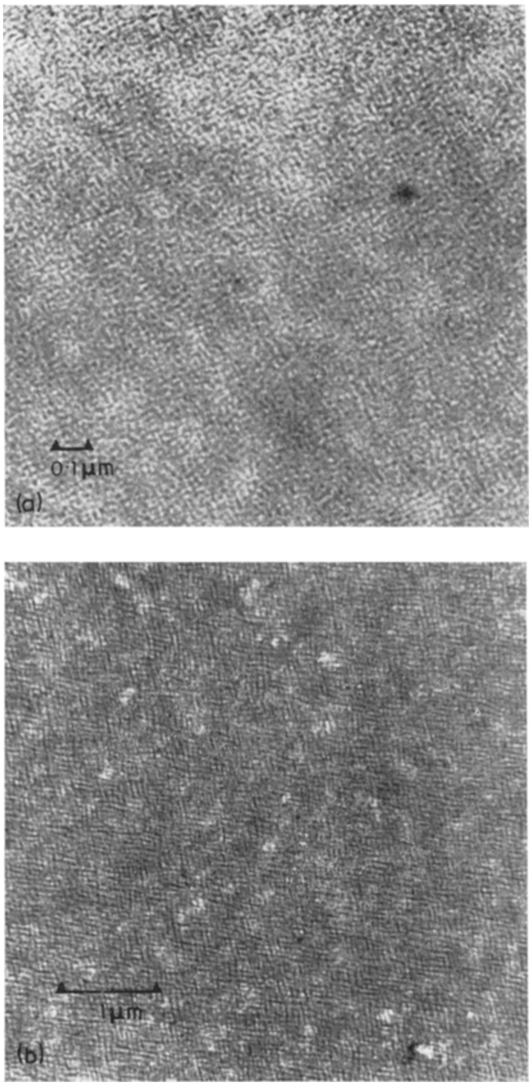


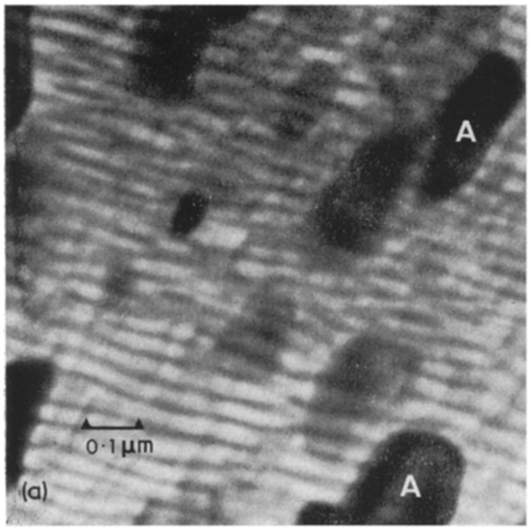
Figure 1 (a) Microstructure after quenching into silicone oil, consisting of ellipsoids of the metastable R phase. (b) Platelets of R phase on {1 1 1} planes in a silicone oil quenched specimen aged for 2 days.

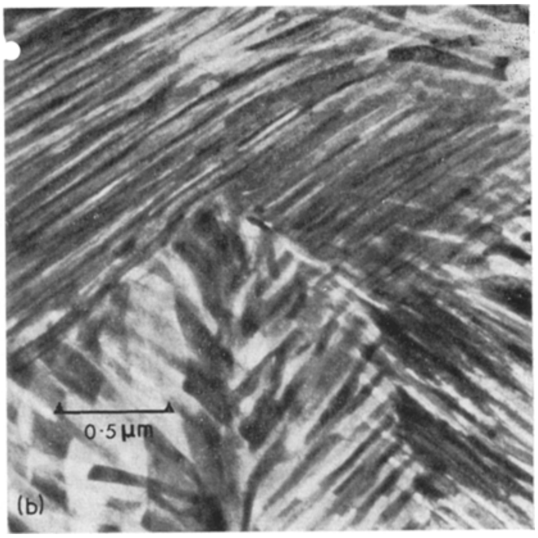
diffraction patterns agreed with that reported by Dobromyslov [11]. After short ageing times at room temperature, platelets of R phase were observed on {1 1 1} matrix planes (Fig. 1b). The habit plane was determined from trace analysis using three low index beam directions, and agrees with that previously reported for this phase [4, 6].

The rate of coarsening on ageing and the resulting precipitate morphology depend upon the rate of quenching from the solution treatment temperature. At slow (oil) quenches, colonies of laths of R phase were observed after 7 days. Within each colony the laths tended to lie along the same [1 1 0] direction in the same (1 1 1) plane (Fig. 2a). In general, large precipitates of zinc were also present, e.g. at A in Fig. 2a. However, at high quench rates (iced brine), colonies of lamellae of R phase formed after only 2 days (Fig. 2b). These R phase lamellae did not nucleate at grain boundaries because the equilibrium hexagonal zinc rich phase was the only precipitate ever formed there. The lamellae lie approximately along ⟨1 1 0⟩ directions in {1 1 1} planes as reported by Dutkiewicz [9]. Selected area electron diffraction showed that there was a slight misorientation between adjacent colonies (Fig. 2c).

The importance of quench rate is perhaps not surprising because it has previously been reported [12] to influence the rate of the room temperature cellular reaction which forms aluminium and zinc. In the present case, the quench-rate effect can be interpreted as follows. At low quench rates, the initial structure transforms to colonies of laths of R phase on a (1 1 1) plane, which are stabilized by the co-existing equilibrium zinc particles. However, at high quench rates, the coarsening of R phase is more rapid so that laths are formed before any precipitation of zinc to stabilize them. The lath colonies then rapidly grow to form the observed colonies of R phase lamellae. During the growth of the lamellae to form the colonies shown in Fig. 2b it is reasonable to expect that the dislocation networks always observed in annealed material would become incorporated in the moving colony/matrix interface to produce the observed small misorientation between colonies, Fig. 2c.

There is no clear explanation for the transition from plates of R phase on {1 1 1} planes to colonies of laths on a particular (1 1 1) plane, as observed on ageing in the slow quenched material. However, it is possible that it may arise from some form of complex co-operative strain field interaction. It can be shown that as the R phase precipitates grow and impinge, it would be expected that elastic interactions would give rise to an instability. Carpenter and Garwood [3] have calculated the elastic moduli of the matrix and R phase precipitate for the 11 at.% zinc alloy. They showed that the ⟨1 0 0⟩ precipitate directions are of high Young's modulus, E, and concluded that the {1 1 1} habit plane is adopted as this involves least strain in the high E pre-





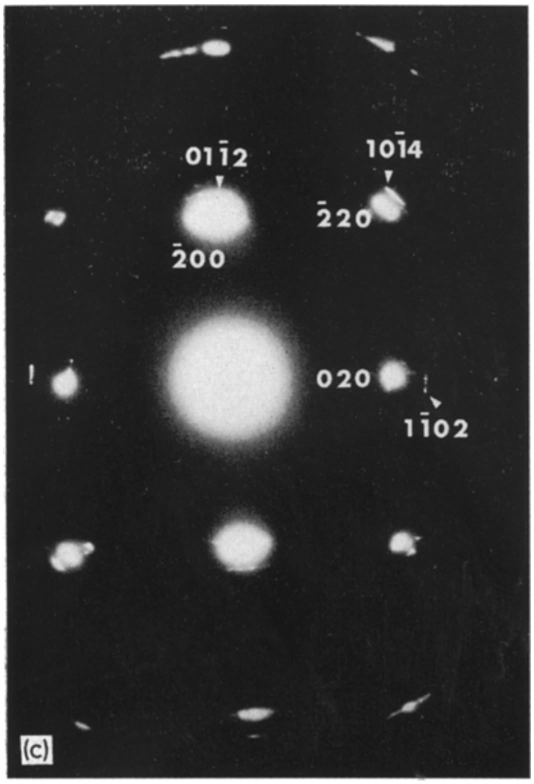


Figure 2 (a) Laths of R phase after ageing a silicone oil quenched specimen for 7 days. Larger precipitates of zinc are present at A. (b) Colonies of lamellae of R phase formed on ageing iced brine quenched material for 2 days. (c) Selected area electron diffraction pattern from several adjacent lamellae colonies, showing "arcing" of matrix spots as a result of small misorientations between the colonies. Beam direction near $\langle 002 \rangle$. The apparent different displacement of $\{01\bar{1}2\}$ and $\{1\bar{1}02\}$ R phase sites from those of the $\{\bar{2}00\}$ and $\{020\}$ matrix sites is an effect due to the sectioning of reciprocal space, the R phase sites being displaced out of the (002) plane along $\langle 111 \rangle$ directions [10]. The indices of the R phase refer to the non-primitive hexagonal unit cell [7].

cipitate directions, the elastic properties of the matrix being of secondary importance. In their model for the distortions around an R phase platelet, much of the coherency strain is accommodated in the matrix adjacent to the precipitate. Thus once a situation is reached in which the R phase platelets nearly impinge, the strain field in the matrix around a platelet on one of the four $\{111\}$ planes will strain a platelet on another habit plane along elastically hard directions. Such an array of platelets has a higher energy, because of this elastic interaction, than an array on one (111) plane only. Therefore, an array of parallel plates is more stable than a multiplanar array, and once formed can rapidly coalesce and grow to form the observed colonies of laths or lamellae.

The above discussion is also consistent with the observation of Carpenter and Garwood [3] that in a water quenched 11 at.% zinc alloy aged at 200°, the R phase precipitated on a limited number of $\{111\}$ planes. In contrast, specimens directly quenched to 200° C and aged for similar times were found to contain R phase platelets on all $\{111\}$ planes. It is known that water quenching gives a high nucleation rate of GP zones compared with direct quenching [13]. Consequently, in water quenched and aged material the GP zones rapidly transform to produce a higher density of R phase platelets than obtained from direct quenching. As a result, the interaction between the strain fields around these precipitates would occur at earlier ageing times and produce a reduced number of habit planes, as observed.

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