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The thermal stability of pre-strained Al-Al$_3$Ni eutectic

D. R. H. JONES, I. R. SARE, W. J. MORGAN, D.S.O. TINN
Department of Metallurgy and Materials Science, University of Cambridge, UK

A detailed study has been made of the thermal stability of aligned Al–Al$_3$Ni eutectic after prior compressive deformation at room temperature. Compressive strains of between 6% and 50% were imposed perpendicular to the axis of alignment of the eutectic. Annealing of deformed and undeformed material at 883 K led to spheroidization of the Al$_3$Ni rods at a rate which increased rapidly with increasing prestraining. Thus, for eutectic previously strained by 50%, almost complete spheroidization was observed after only 10 h at 883 K. The present behaviour was explained partly in terms of enhanced diffusion along matrix dislocations introduced during deformation.

1. Introduction

Much effort has recently been devoted to developing undirectionally grown eutectic alloys as high-temperature materials, e.g. [1]. Clearly, the production of finished components directly from the melt is likely to be expensive; and it is thus important to investigate to what extent aligned eutectics may be subjected to forming operations before incurring a significant decrease in thermal stability. In this direction, work on the Cd–Zn alloy [2] has shown that relatively small compressive strains can produce greatly enhanced spheroidization at high temperature; and preliminary work on cold-rolled Al–Al$_3$Ni [3] has given similar indications. It is the purpose of the present paper to carry out a more detailed study of the effect of prior deformation on the thermal stability of the aligned Al–Al$_3$Ni system.

2. Experimental

The Al–Al$_3$Ni eutectic was prepared from aluminium of 99.998% purity and nickel of 99.999% purity. Directional solidification was accomplished as described elsewhere [4], growth rates of either 100 or 200 mm h^{-1} being employed. Single-crystal specimens measuring 3.5 mm x 10 mm x 10 mm were removed from the grown bars by spark-erosion. Each specimen was divided carefully into three parts, the first serving as a reference specimen, the second as a control specimen, and the third as a specimen for deformation. The latter was in all cases finished to dimensions of 3.5 mm x 5 mm x 8 mm with the direction of alignment perpendicular to the face measuring 3.5 mm x 5 mm. The deformation specimens were subsequently strained in compression using lubricated plattens in contact with the faces measuring 8 mm x 5 mm. In this way nominal strains of approximately 6, 29, 42 and 50% (corresponding to nominal stresses of 49, 147, 245, and 392 MPa) were applied perpendicular to the growth direction.

Each compressed specimen was subsequently placed in a silica tube together with the appropriate control specimen; and the pairs of specimens were annealed at 883 ± 2 K for the appropriate lengths of time (either 10 h or 100 h). Annealed specimens were subsequently sectioned both parallel to, and transverse to, the growth direction. These sections, together with sections obtained from the reference (untreated) specimens, were prepared for optical and scanning-electron microscopy as described elsewhere [4].

Finally, several samples of as-grown alloy were deformed exactly as above, sectioned longitudinally, and examined in the scanning electron microscope. Longitudinal sections of the appropriate reference samples were examined in the same way.

3. Results

Fig. 1 shows typical optical micrographs of speci-

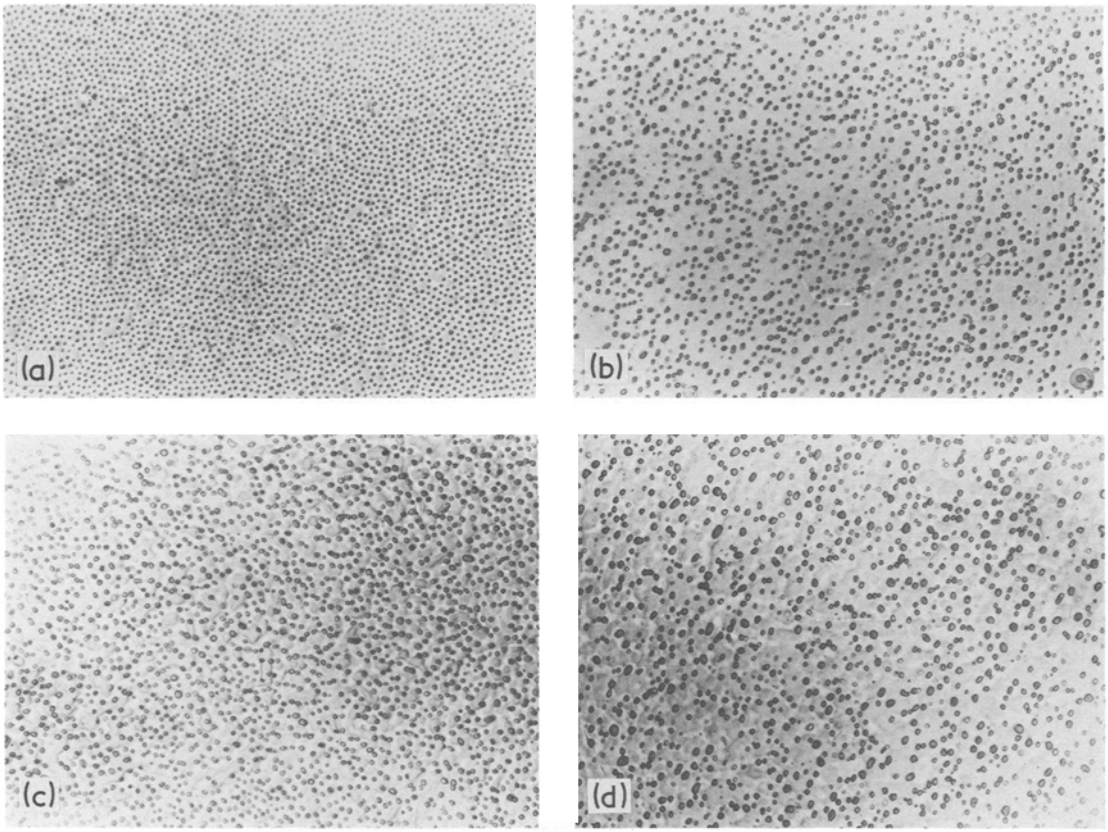
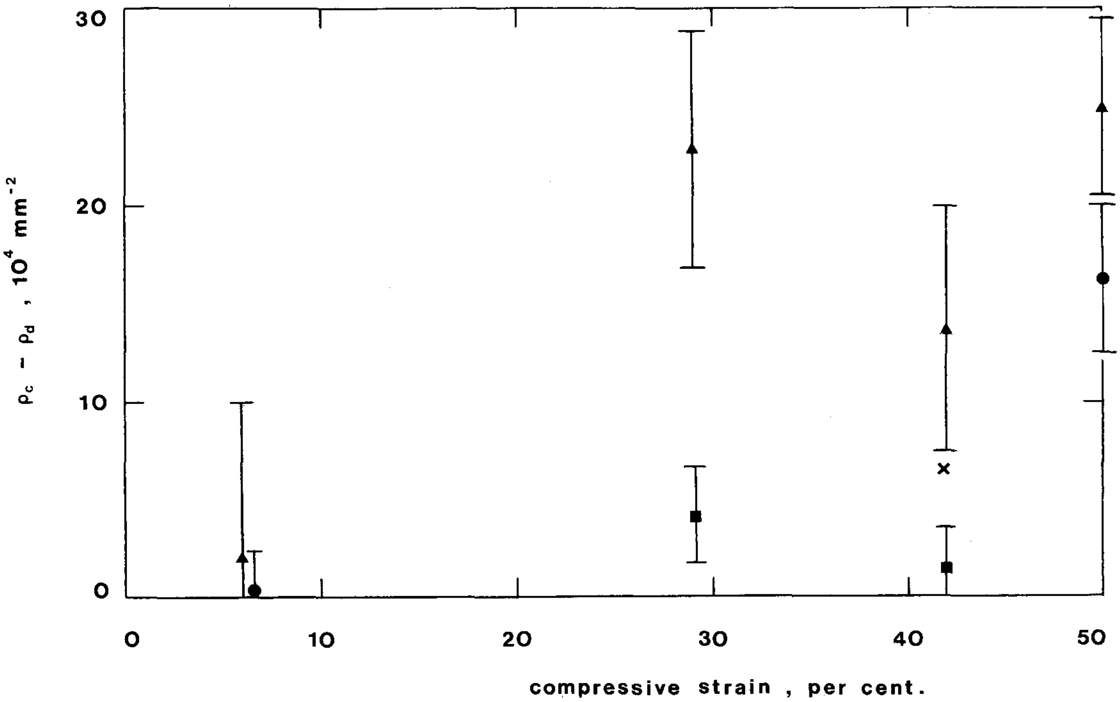
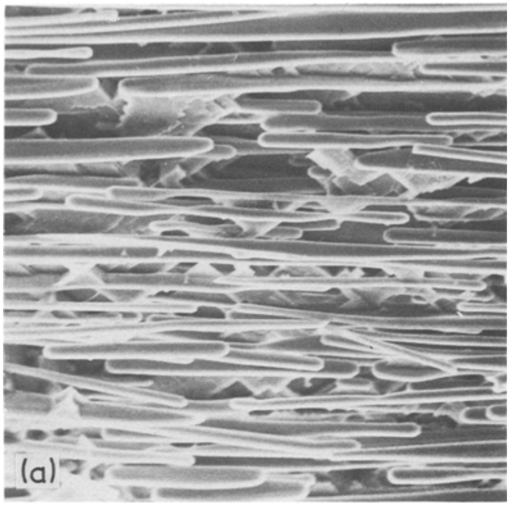
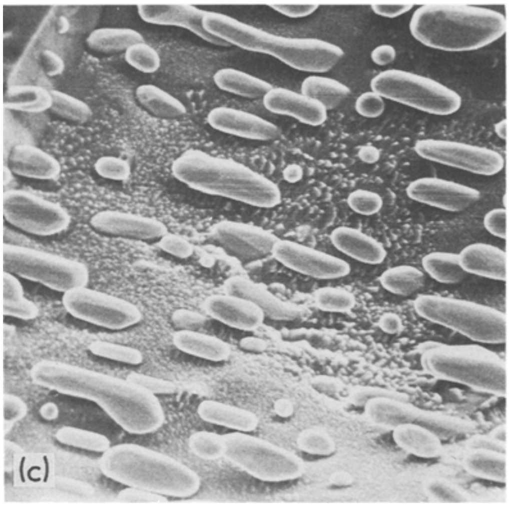


Figure 1 Typical optical micrographs of transverse sections of Al–Al_3Ni annealed at 883 K for 10 h after compressing by (a) 6%, (b) 29%, (c) 42%, (d) 50%. × 406.







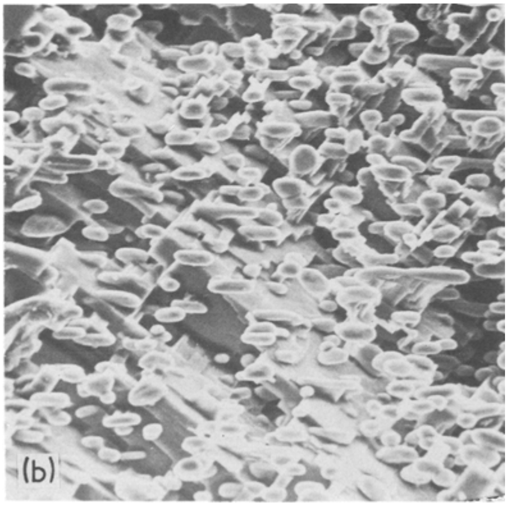


Figure 3 Typical scanning electron micrographs of deeply etched longitudinal sections of the fibrous Al–Al_3Ni eutectic; $\rho_i \sim 40 \times 10^4\,mm^{-2}$. (a) annealed at 883 K for 100 h without prior deformation; (b) annealed at 883 K for 10 h with 50% prior deformation; (c), annealed at 883 K for 100 h with 50% prior deformation. × 1510.

mens aged for 10 h after various degrees of prestraining. As is clear from the photographs, as the amount of prestraining increases so does the initial rate by which the microstructure coarsens at elevated temperature. This observation is expressed quantitatively in Fig. 2, where ρ_c—ρ_d is a measure of the increased breakdown at constant volume fraction due to prestraining. The values of ρ_c (defined in the caption to Fig. 2) were in close agreement with those obtained by Bayles *et al.* [5].

Scanning electron microscopy revealed that the undeformed annealed specimens (Fig. 3a) retained an essentially fibrous structure, in agreement with previous observations [6]. In contrast, specimens deformed by 50% before annealing showed an almost completely spheroidized microstructure after 10 h of heat-treatment (Fig. 3b). Further annealing of specimens deformed by 50% served only to coarsen the existing spheroidized structure (Fig. 3c).

Morphological comparison of as-grown and as-deformed material (Fig. 4) did not reveal any changes in the morphologies of the rod phase with deformation.

4. Discussion

As is clear from the above observations, the enhanced thermal instability of Al–Al_3Ni caused by prior deformation cannot be attributed to mechanically induced changes in rod morphology on the scale of the present electron-optical studies.

Figure 2 Plot of ρ_c—ρ_d measured on transverse sections for various compressive strains. ρ_d is the precipitate density for a specimen compressed at room temperature and then annealed at 883 K. ρ_c is the precipitate density for the appropriate control specimen annealed at 883 K for the same time but without prior deformation. The triangular datum points refer to alloys with an as-grown rod density (ρ_i) of approximately $40 \times 10^4\,mm^{-2}$ annealed for 10 h; the circles refer to alloys of similar ρ_i heated for 100 h; and the squares indicate samples with $\rho_i \sim 80 \times 10^4\,mm^{-2}$ heated for 100 h. The cross is derived from the data of Salkind *et al.* [3] for cold-rolled alloy, taken in conjunction with appropriate data for the thermal stability of undeformed Al–Al_3Ni [5].

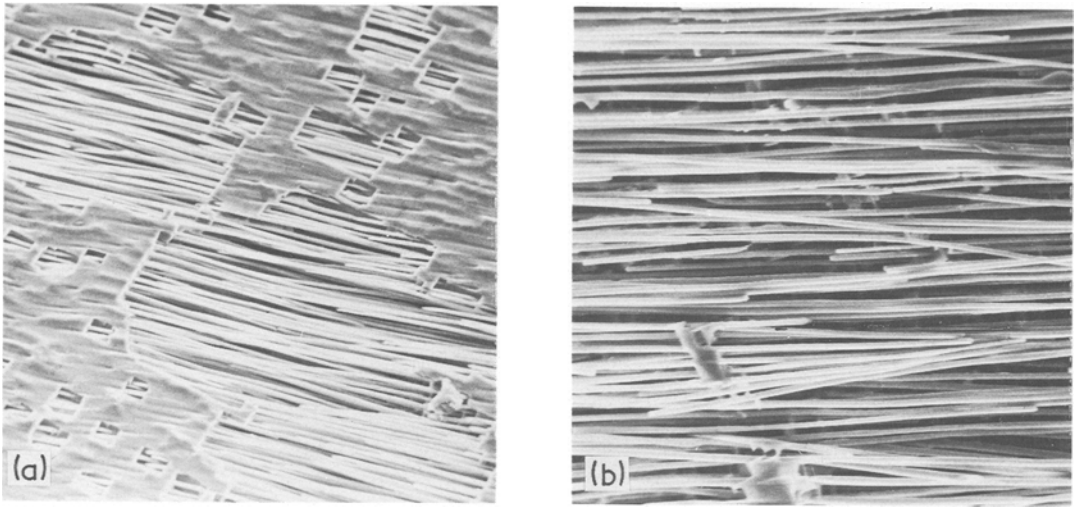


Figure 4 Typical scanning electron micrographs of deeply etched longitudinal sections of the Al–Al_3Ni eutectic. (a), as-grown structure; × 153; (b), after 50% deformation; × 1510.

In seeking alternative explanations for the present behaviour, it should be noted that compression of Al–Al_3Ni eutectic perpendicular to the growth direction by cold-rolling produces a significantly increased dislocation density in the matrix [3]; and it would be expected that the present mode of deformation would have a similar result. Unfortunately, no quantitative data were obtained [3] for the relevant dependence of dislocation density on strain. On a qualitative basis, however, dislocations generated by prestraining should lead to enhanced diffusion through the matrix during the present annealing treatments. This enhanced diffusivity is likely to contribute appreciably to the increased rate of coarsening observed in the present work (although, because of the short lifetimes of dislocations at the annealing temperature, dislocation-pipe diffusion may act mainly to catalyse the usual processes of spheroidization involving diffusion in the bulk phases or in the rod–matrix interface [7–10]). Finally, further contributions to the rate of coarsening may arise from the possible destruction of any preferred crystallography at the rod–matrix interface [3], and the possible formation of triple-point cusps at the interphase boundaries [11].

5. Conclusions

It has been shown that moderate compressive deformations of aligned Al–Al_3Ni eutectic at room temperature result in a catastrophic reduction in the stability of the fibrous microstructure at high temperature. The extremely rapid rate of spheroidization observed above indicates that, even at comparatively low operating temperatures, spheroidization should seriously shorten the working lifetime of the deformed eutectic. Such conclusions are highly relevant to aligned eutectics of commercial importance, and indicate that fabrication of components by mechanical forming may often prove quite undesirable in such systems.

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