Solute Effects on Deformation and Fracture of Beta Brass

M. M. Shea and N. S. Stoloff
Rensselaer Polytechnic Institute
Troy, N. Y. 12181 U. S. A.

Introduction

The purpose of this paper is to show that the ductility of several ternary beta brass alloys in air and in several liquid metals can be related to the operative slip and grain boundary relaxation processes. Nickel and manganese were chosen as alloying elements on the basis that they are expected to respectively enhance and suppress cross slip in beta brass.

Experimental Procedure

Single-phase binary and ternary beta brass alloys were used in both polycrystalline and single crystal form; see Table 1 for compositions and critical ordering temperatures, T_c.

Table 1

Compositions and Critical Ordering Temperatures

Polycrystals Alloy	T_c(°C)	Single Crystals Alloy	T_c(°C)
45Zn	457	48Zn	468
48Zn	468	48Zn-2Mn	454
45Zn-5Mn	429	50Zn-2Ni	---
48Zn-2Mn	451		
48Zn-2Ni	488		

Ingots were cast under argon from 99.999% copper and zinc and 99.98% nickel and manganese. Polycrystalline grain sizes of 120μ were obtained in sheet samples of all alloys by annealing in the range 480-520°C for up to 4 min, and water quenching. Tensile tests were conducted at a strain rate of 0.02 min^{-1}, under an argon blanket for elevated temperatures. Tests in liquid metal environments were made by applying liquid to only one surface of the polycrystals, and to the entire circumference of cylindrical single crystals.

Results

Fig. 1 shows the effect of test temperature, measured as a fraction of T_c, on the ductility of polycrystalline beta brass alloys in air. Increasing zinc content increased ductility. Nickel slightly lowered ductility at all temperatures, but manganese decreased ductility significantly. Stable intergranular cracks were formed in each alloy during deformation up to about 200°C, depending on alloy composition, but final failure was always transgranular. Manganese increased both the degree of cracking and the maximum temperature of occurrence. Intergranular cracking was observed up to 250°C in manganese alloys, and to 200°C in binary and ternary nickel alloys.

Fig. 2 shows the effect of gallium on total elongation for four of the same alloys. A distinct ductile to brittle transition was induced in each case. Manganese increased severity of embrittlement, while nickel additions had the opposite effect. The failure mode in gallium was primarily transgranular for binary and nickel ternary alloys, although slight evidence for intergranular cracking was found. Secondary cracking was seldom observed. Failures in manganese ternary alloys were exclusively transgranular with substantial secondary cracking, see Fig. 3.

Environments of liquid indium or Hg-70%In produced solely intergranular fracture, with considerable penetration of grain boundaries. All alloys failed at or shortly after yielding. The transition temperature was independent of composition, falling between 225°C and 250°C for all alloys. Prolonged exposure of unstressed alloys to In and

Hg-70%In had no effect on ductility in subsequent tests.

Single crystals embrittled with gallium or Ga-16.5%In showed the same effects of alloy composition on ductility and transition temperature as did the polycrystals. Failure occurred on {100} planes, independent of alloy composition, crystal orientation or test temperature. For tests in Hg-70%In, although fractures occurred within the liquid metal zone, brittle cleavage was not observed. All compositions were considerably more ductile in this environment than in pure gallium. The separation plane was close to either {321} or {320} except for orientations near <100>, where {100} fracture was identified. No failures occurred in liquid metal above 50°C for any composition.

Surface slip traces showed that manganese additions increased the occurrence of planar slip, while nickel had the opposite effect. Also, slip became slightly more wavy in binary alloys at higher zinc contents. Manganese also increased the temperature at which slip-induced jogging of grain boundaries occurred, as well as the recrystallization temperature. It appears, then, that grain boundary relaxation processes are suppressed by manganese additions; nickel had the opposite effect.

Discussion

Manganese raises T_c and therefore the ordering energy of beta brass, leading to more planar glide, while nickel has the opposite effect on T_c and case of cross slip. These solutes do not markedly alter the ductility of beta brass alloys in air, but in the presence of liquid metals they assume greater importance. Manganese, by suppressing cross slip, causes stress concentrations to build up at grain boundaries, eventually leading to premature failure in the presence of liquid gallium.

Intergranular embrittlement in Hg, In and their amalgams is, on the other hand, a consequence of stress-assisted penetration along grain boundaries. This is substantiated by the lack of (solid) composition and temperature dependence of the degree of embrittlement, and the lack of embrittlement above 50°C, when stress concentrations are less likely to be present.

Acknowledgement

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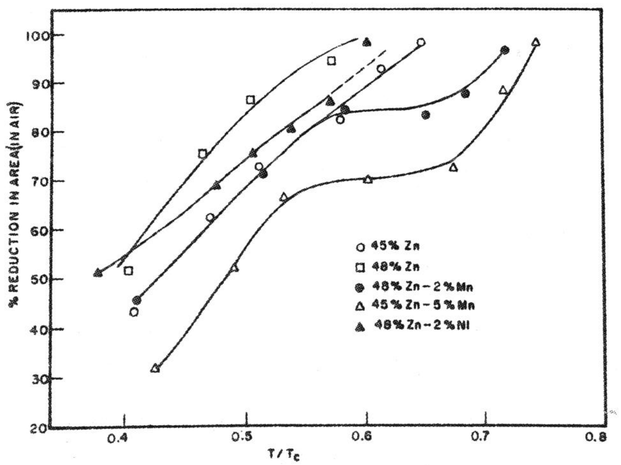

Fig. 1 Effect of test temperature, relative to T_c, on ductility of beta brass in air

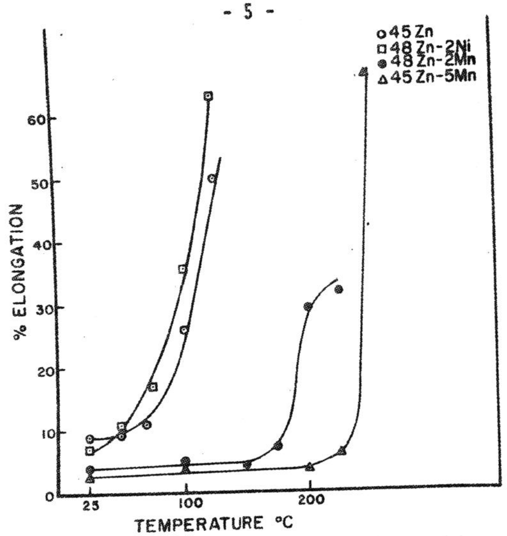

Fig. 2 Effect of test temperature on ductility of beta brass in gallium

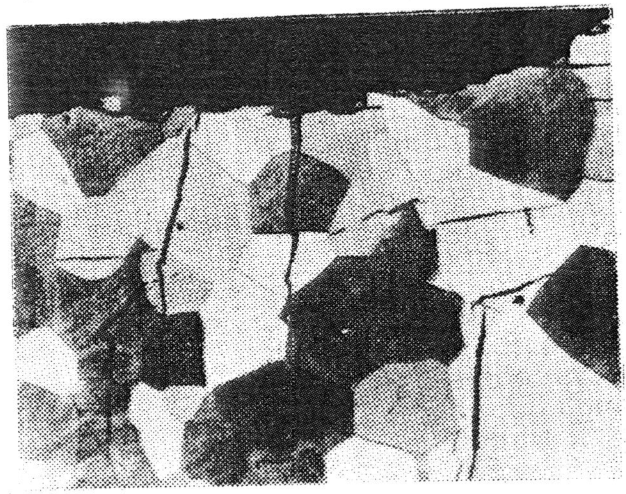

Fig. 3 Transgranular cracks in Cu-45%Zn-5%Mn, tested in gallium at 200°C, x100