Letters

On the Crane phenomenon in superplastic copper alloys

Crane [1] first suggested that an important factor in controlling the ductility of a microduplex superplastic aluminium bronze was the alpha:beta ratio. This idea was investigated in detail by Bright and Taplin [2] who showed that in a wide range of aluminium bronzes the maximum ductility occurred at 50:50 volume proportion of the two phases. The effect was observed in both binary alloys and ternary alloys containing a fine dispersion of precipitate particles which inhibit grain growth (Table I) and it seems to be related to the ease of sliding on the different types of boundary present. Work on superplastic alpha/beta brass suggested that the effect applied to other duplex alloys [3] and the present work was designed to further follow up the idea, in a range of binary alpha-beta brasses [4.] Superplastic copper alloys exhibit widespread cavitation during flow [3-6] and in an effort to limit cavitation, a study was also made of the influence of trace additions of cerium on the flow and fracture behaviour of alpha-beta brass. The purpose of the present letter is to make a preliminary report of the striking results thus obtained.

TABLE I The influence of alpha: beta ratio on the ductility of a range of microduplex aluminium-bronzes (grain size 25 μm) tested at 800° C and a strain-rate of 10^{-3} sec^{-1}

Alloy composition (wt %)	Alpha: beta ratio (vol %)	% elongation
Cu = balance	32:68	200
Al = 9.14	44:56	250
	55:45	300
	70:30	210
Cu = balance	35:65	250
Al = 9.57	42:58	320
	50:50	350
	60:40	300
	63:37	240
Cu = balance	33:67	310
Al = 9.5	42:58	600
	50:50	640
Fe = 4.0	60:40	330
Cu = balance	25:75	550
	55:45	680
Al = 9.0	60:40	580
Fe = 4.0	75:25	370

Table II records the influence of cerium on the ductility and strength: the elongation is increased by a factor of nearly three and the strength decreased similarly. This observation led to a sophisticated metallographic study of the influence of cerium on the stacking fault energy and grain-boundary structure involving X-ray line broadening and transmission microscopy to elucidate this apparently important effect [4].

Table III records the influence of alpha-beta ratio on the ductility and strength of a range of alpha-beta brasses of varying zinc content. Again a very marked effect is apparent: as the beta content changes from 30% to 70% the strength is reduced by an order of magnitude whilst a maximum in ductility is observed with 50% volume fraction of beta. The ductility is improved by a factor of four by changing the beta content from 30% to 50%.

These two sets of data (Tables II and III) are linked for it was found that the addition of cerium changed the alpha-beta ratio in a Cu–38.6% Zn alloy (Table II). From the results recorded in Table III it is clear that the influence

TABLE II The influence of cerium on the ductility and flow stress of a microduplex alpha-beta brass (Cu–38.6% Zn) at 600° C and a strain-rate of 1.7×10^{-3} sec^{-1}. Average grain size 32 μm

Alloy composition (wt %)	% elongation	Flow stress (MN m^{-2})	Alpha-beta ratio (vol %)
Cu balance, Zn = 38.6	8.0	19.8	70:30
Cu = balance Zn = 38.7, Ce = 0.07	230	6.3	55:45

TABLE III The influence of alpha-beta ratio on the ductility and strength of a range of binary alpha-beta brasses at 600° C and a strain-rate of 1.7×10^{-3} sec^{-1}. Average grain size 32 μm

Alpha:beta ratio (vol %)	% elongation	Flow stress (MN m^{-2})
70:30	80	19.8
62-38	215	11.8
48:52	320	2.3
30:70	170	1.7

of cerium on strength and ductility seems to be capable of explanation entirely in terms of the change in the alpha: beta ratio rather than by a more complicated theory. This presumably arises via a decrease in the solubility of zinc in the alpha phase. This brings in mind that beautiful section of Eliot's "Little Gidding" [7]:

"We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time."

We learn that the simplest explanation is again the most likely one (Occam's Razor) and the beauty of sophisticated explorations that lead us in a spiral to a profound simplicity. It is interesting to note that the addition of 0.07% cerium is equivalent in this case to a reduction in the copper content of the binary alloy by 1.6%: thus the effect has no practical significance since copper is more expensive than zinc. Jack Crane's original assertion is found to be justified from the practical point of view and this juxtaposition leads us to name the effect of phase proportions on superplasticity the *Crane phenomenon.*

References

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Effect of high temperature X-ray irradiation on the thermoluminescence of KCl crystals

Thermoluminescence induced by ionizing radiations in KCl single crystals, both pure and doped, has drawn the attention of several workers [1-4] and helped them in understanding the radiative recombinations and related electronic processes in solids. Although the reported glow peak temperatures show considerable disagreement depending on the nature of impurities, crystal growth conditions, heating rates and thermal histories of the crystals, the thermoluminescence glow peaks of KCl crystals irradiated by X-rays are well known and their origins have been explained [3] in terms of the impurities, deformations and the two types of F-centres. The existence of two types of F-centres has already been established by many authors [5-9]. However, all the reported works are mainly concerned with irradiation either at room temperature or at lower temperatures (liquid nitrogen or liquid helium temperature). It is known [10] that the mechanisms of colour centre formation at room temperature and at low temperature are quite different. But no work has been done so far on the thermoluminescence of KCl crystals irradiated at a temperature greater than room temperature. Ratman *et al.* [11] have reported, for CaF_2 crystal, the changes of thermoluminescence pattern with the rise of irradiation temperature.

The purpose of this communication is to show that the complexity of the thermoluminescence of X-ray irradiated (at room temperature) KCl crystal can be reduced by increasing the irradiation temperature, and that even for the crystal irradiated at a higher temperature, the thermal bleaching of F-centres is responsible for the thermoluminescence.

Several heat-treated (at 400° C, 1 h in vacuum and quenched to room temperature) KCl single crystals (grown in our laboratory by the kyropoulos technique from BDH Analar grade powder) of sizes 0.5 cm × 0.5 cm × 0.1 cm (all cut from the same bulk) were X-rayed at various temperatures ranging from 30 to 250° C for $\frac{1}{2}$ h in darkness using a Machlette Tube (Mo target, 30 kV, 10 mA). All the crystals (quenched to room temperature after irradiation) were found to exhibit reproducible glow patterns when heated in vacuum (10^{-3} mm Hg) at a constant rate (27° C min^{-1}); a typical set of thermoluminescence curves obtained for one sample is