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ENHANCEMENT OF SUPERCONDUCTIVITY IN RAPIDLY QUENCHED SAMPLES OF ALUMINIUM ALLOYS

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Abstract

The process of ultrarapid quenching has been found to effect the transition temperature of a number of alloys. Transition temperatures T_c of up to 2.95°K have been obtained in bulk samples of aluminium-copper alloy (containing 0.85 at% of copper) that had been subjected to the process of ultrarapid quenching in a rotating mill device. This method of quenching has been found suitable as it secures large thin samples that had undergone cooling rates from the melt of about 10^6 °Ks^{-1}. At the same time conventionally prepared alloys (from the same melt) showed normal behaviour expected from such an alloy. The rise in T_c is linked to the quenching speed and is proportional to the residual resistance observed, A possible explanation of the phenomenon is offered by evoking phonon surface modes mechanism.

Introduction

Experimental results in superconductivity have generally been explained in terms set out in BCS theory. An expression for T_c often quoted (and given by McMillan) is derived from the strong coupling theory and is written as

$$T_c = \frac{\Theta}{1{,}45} \exp - \left\{ \frac{1{,}04\,(1+\lambda)}{\lambda - \mu^* (1+0{,}62\lambda)} \right\}$$

where μ^* is the Coulomb pseudeopotential taken to be of the order of 0.1; λ is a quantity that involves the phonon frequency spectrum and the electronic matrix elements. Written down it looks like this:

$$\lambda = 2 \int \alpha^2(\omega) F(\omega) \frac{d\omega}{\omega} \approx \frac{N_0 \langle g^2 \rangle}{M \langle \omega^2 \rangle}$$

N_o is the electronic density of states at the Fermi surface, M is the nuclear mass, $\langle g^2 \rangle$ is the Fermi surface momentum average over the electronic matrix elements and $\langle \omega^2 \rangle$ is an average over the phonon frequencies. If an increase in T_c is observed for a given material it will be due to the increase in λ owing to the lowering of $\langle \omega^2 \rangle$ since for a given material

$$\lambda = \frac{\text{const.}}{M \langle \omega^2 \rangle}$$

Experiment and Results

We have achieved a drastic increase in T_c on samples of rapidly quenched aluminium contaning 0.85 % (at) Cu. The samples were produced using the device just described and were on the average 15 mm long, about 1 mm wide and up to 20 μm thick.

There is no time in this short talk to describe how the alloy was prepared, but we may say that it was prepared with all the usual care indicated for such applications. Strips of dimensions similar to those of quenched samples were prepared starting with exactly the same alloy, but prepared conventionally and rolled down to the required thickness.

All rapidly quenched samples showed large residual resistance ratios, almost an order of magnitude higher than ratios exibited by a conventionally prepared alloy. While the strips of conventionally prepared alloy show no deviation from Matthiessen's rule down to the lowest temperature reached in our cryostat (1.48°K), the quenched samples exibit superconducting transitions at temperatures which are a good deal higher. No transition was observed in the conventionally prepared alloy down to 1.48°K. Some of the transition curves obtained are shown in Fig.1.

One would reasonably expect that these transition temperatures would bear some simple relationship to the electronic mean free path ℓ which we can calculate from a simple relation:

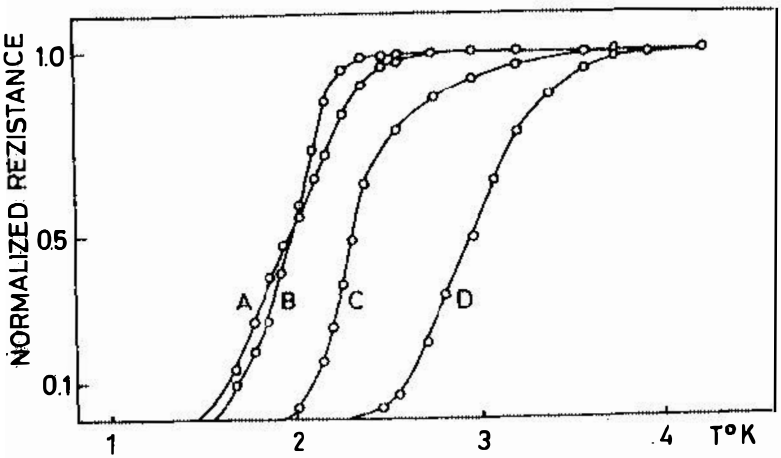

FIG. 1

$$\frac{1}{l} = 0.62 \times 10^6 \rho \qquad \text{where} \quad \rho = \frac{R_{4.2}}{R_{293}-R_{4.2}}$$

As expected, the values of ρ or $\frac{1}{l}$ plotted as a function of T_c fall on a straight line (Fig.2).

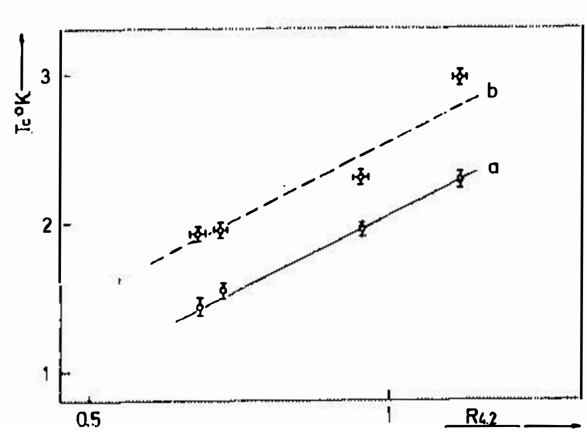

FIG. 2

Since the only variable parameter in this experiment was the quenching speed, we may conclude that the shift in T_c was due to changes in the alloy structure due to rapid quenching. We made Debye-Sherrer diagrams of our samples and these suggest a highly distorted alloy structure.

We offer a tentative explanation of this phenomenon, based on evidence that a quenched sample of such an alloy would contain very small narrow and long crystals oriented perpendicularly to the quenching surface.

We may recall that Dickey and Paskin have considered in detail a mechanism where $\langle \omega^2 \rangle$ is lowered in material consisting of small platelet - like particles where low frequency modes result in a shift of the phonon frequency spectrum large enough to account for the shift in T_c observed, for example, in films. We have applied this line of reasoning to our case and find that we too could obtain a shift in T_c of the correct magnitude by assuming platelet-like structures to exist in our samples.

Whatever the mechanism involved, we can still calculate the λ for each of our samples using the expression.

$$\frac{T_c}{T_{c\,max}} = \left(\frac{2}{\lambda}\right)^{1/2} \exp\left(\frac{1}{2} - \frac{1}{\lambda}\right)$$

where T_c is the observed value while $T_{c\,max}$ is the highest T_c theoretically possible on the basis of the strong coupling theory. These values together with other relevant quantities are shown in Table I.

One last question may be raised. Why the Al-Cu samples show the effect while pure Al samples similarly prepared do not. Again we may invoke the existence of grains or platelets in Al-Cu alloy and not present in pure Al. Work on films indicates that Cu-doped Al films crystallize in smaller grains than when pure metal is used.

This question will have to be settled by further investigation which is in progress.

TABLE I

Sample	T_c (K)	ρ	$\frac{1}{l} \cdot 10^{-6} (cm^{-1})$	λ
A	1,48-1,95	0,68	0,42	0,43
B	1,56-1,97	0,72	0,45	0,43
C	1,96-2,30	0,95	0,59	0,50
D	2,30-2,95	1,12	0,69	0,56

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DISCUSSION :

B.K. Chakraverty : Soft modes due to internal surfaces need not be the only mechanism of Tc enhancement. One must consider change i.e. increase of density of electronic states at the Fermi surface due to rapid quenching or possible amorphicity.

B. Leontić : If one tries to calculate this effect the resulting shift in T_c is too small.

K. Mukherjee : Have you studied the annealing kinetics of the effect mentioned in your paper? At what temperature and time of annealing does the T_c come back to the normal T_c of a slowly cooled alloy of the same composition ?

B. Leontić : The comparison with the conventionally prepared alloy was considered sufficient. We have kept the samples in the lab at room temperature to see if they age. They do not age perceptibly in the period of one month.