Presented at the Applied
Superconductivity Conf.
Oakbrook (Chicago),
October 1974

COMITATO NAZIONALE PER L'ENERGIA NUCLEARE
Laboratori Nazionali di Frascati

LNF-74/57(P)
30 Ottobre 1974

S. Ceresara, M. V. Ricci, N. Sacchetti and G. Sacerdoti: Nb_3Al FORMATION AT TEMPERATURES LOWER THAN 1000 °C.

Servizio Documentazione
dei Laboratori Nazionali di Frascati del CNEN
Casella Postale 70 - Frascati (Roma)

Nb_3Al FORMATION AT TEMPERATURES LOWER THAN 1000°C

S. Ceresara
I. S. M. L., Via del Lavoro 2, Novara (Italy)

M. V. Ricci, N. Sacchetti, G. Sacerdoti
Laboratori Nazionali del CNEN, C. P. 70, Frascati (Italy)

Presented at the Applied Superconductivity Conference, Oakbrook (Chicago), October 1974.

Abstract.

A study has been made of the possibility of making Nb_3Al wires by interdiffusion between Al and Nb at relatively low temperatures (lower than 1000°C). This method should allow the fabrication of a copper stabilized wire by coworking Nb and Al composites in a copper matrix before the diffusion treatment. Results concerning the diffusion temperature and time dependence of J_c and T_c are presented. While J_c(64 kG) is quite high, of the order of 1.5×10^5 A/cm^2, T_c is 15.56 °K, lower than the usually reported value. X-ray measurements of the lattice parameter are also reported and correlated with the measured value of T_c.

Introduction.

It is well known that the superconducting properties of the intermetallic compound Nb_3Al are such as to make it a possible candidate for large scale applications where high critical fields and high critical currents densities are required. Since Nb_3Al is an A15 compound like the well studied Nb_3Sn, it is logical to ask whether the fabrication methods of the latter can be extended to Nb_3Al. Actually it is reported that the temperatures required for the formation of this compound[1,2] (is high, ranging around 1400°C); this gives rise to a number of technical problems; e.g. the partial vapor pressure of aluminum at 1400°C is 10 mm Hg and strong evaporation of aluminum takes place. Furthermore, at these temperatures the recrystallisation of niobium is almost complete; this can lower the density of pinning centers and consequently the critical current.

In the present work we describe a fabrication process in which, by a suitable choice of experimental parameters, a stabilized single core cable of Nb_3Al can be obtained at temperatures lower than 1000°C. Experimental results on the most important superconducting properties will be presented and discussed.

Fabrication Method and Results.

Two thin foils of niobium (thickness t_{Nb}) and aluminum (thickness t_{Al}) were superimposed and then tightly wound round a small copper cylinder. The composite was inserted into a hollow copper cylinder and this specimen was rod rolled and drawn to a final diameter of 0.2 mm. The wire was then reacted at different temperatures and for several different times.

The reaction temperatures ranged from 750°C to 950°C and the reaction times varied from 30 minutes to 16 hours.

The experimental results are presented in Fig. 1 which shows the dependence of critical current J_c at 64 kG on the reaction time for different temperatures. In Fig. 2, J_c measured at 4.2°K, is plotted against the applied magnetic field. The data refer to the samples reacted at 850°C and the various curves correspond to different diffusion times. The field dependence of J_c is similar to that reported for other type II materials. The same behaviour has been found for samples reacted at 750°C and 950°C. The estimated maximum cross section of Nb_3Al_2 is about 5×10^{-5} cm^2 which gives a J_c(64 kG) = 1.8×10^5 A/cm for the sample diffused 6 hours at 850°C.

X-ray analysis were performed on some of the samples reacted at 850°C and showed that all the aluminum initially present was reacted and that only the A15 Nb_3Al phase together with unreacted niobium was present. The mean value of the lattice parameter a was found to be 5.20 Å.

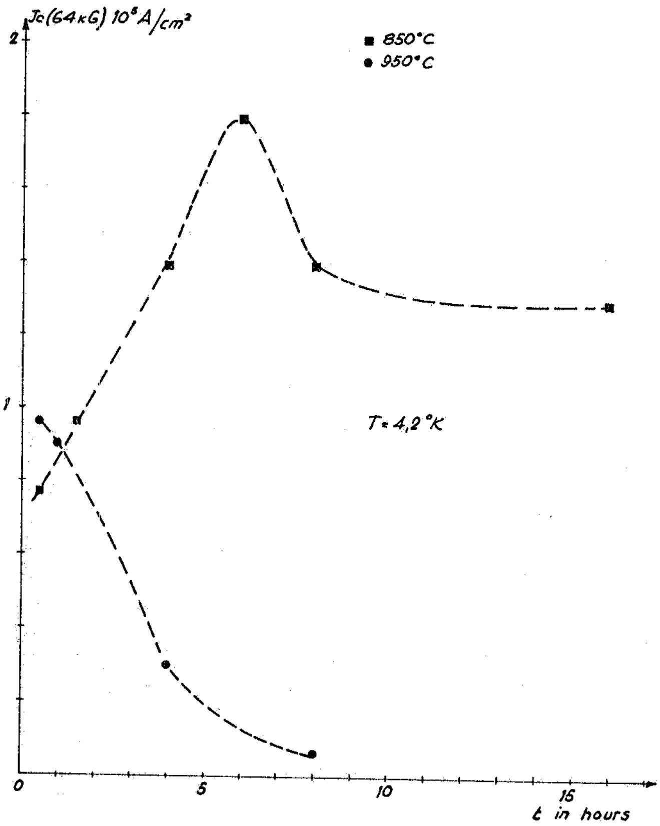

FIG. 1 - Critical current density J_c of Nb_3Al wires vs. time t, for two different reaction temperatures.

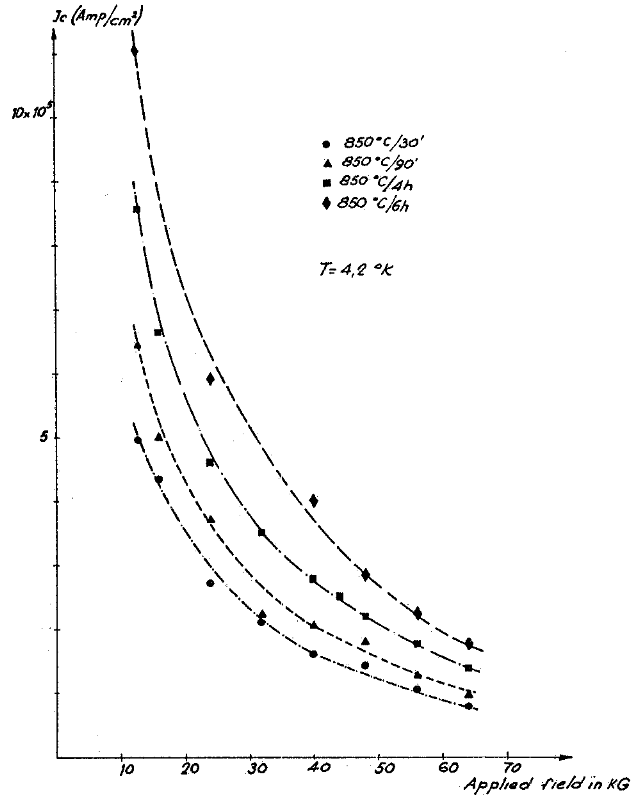

FIG. 2 - Critical current density J_c Nb_3Al wires vs applied magnetic field for samples reacted at 850°C for different times.

We have also measured the critical temperatures for all the samples reacted at 850°C, but no significant dependence of T_c on the reaction time has been found: T_c ranges from 15.48°K to 15.62°K.

The Al critical current density showed a strong dependence on the thickness t_{Al}. The data shown in Figs. 1 and 2 refer to samples for which t_{Al} was 0,2 μ and the average alloy composition of the diffusion couple was Nb-Al 14 at %. Higher values of the thickness t_{Al} gave lower critical current densities.

Discussion.

First, our measurements show that Nb_3Al is formed at relatively low temperatures provided the thickness in the diffusion couple is extremely low. The interest in this result lies in the fact that normally for diffusion experiments at such low temperatures only non superconducting phases richer in aluminum have been observed. A possible explanation of this result is the following. In the usual diffusion experiments in binary systems, the thickness of both components is much larger than that of the diffusion region i. d. one is concerned with semi-infinite diffusion couples. Under these conditions it is possible that one or more intermetallic phases do not form even if one would expect them on the basis of the phase diagram[3]. This happens e. g. when the kinetic constant for the growth of a particular phase is much smaller than those of other phases. So in the Nb-Al system, at low temperatures (800°C-900°C) only the $NbAl_3$ phase is practically found as its kinetic constant is the highest ref.(4). In our case the aluminum thickness t_{Al} is of the same order as the size of the diffusion region. When Al has completely reacted into $NbAl_3$, Nb_2Al will start to form at expenses of $NbAl_3$ and then Nb_3Al at expenses of Nb_2Al. A confirmation comes from the fact that by increasing the thickness t_{Al} the critical current density strongly decreases as other non superconducting phases are present.

Second, no direct measurements of the upper critical field H_{c2} has been made. However from the ratio between the measured value of T_c and the usually reported value of 18°K (ref. 5), using the relation $H_{c2}(0) \propto N\gamma T_c$, we can deduce a value for $H_{c2}(0)$ of about 260 kG. This large value of H_{c2} accounts for the very high critical current density at 64 kG. We also plotted the mean pinning force per unit volume $F_p = J_c x H$ versus the applied magnetic field; F_p, at least up to the field value of 64 kG, is quite independent of the applied field, showing a behaviour very similar to that reported for other high field A15 compounds (ref. 5) (e. g. Nb_3Sn diffused ribbon).

The dependence of J_c (64 kG) on the heat treatment time is rather complicated. The samples reacted at 850°C exhibit a maximum in J_c when $t \simeq 6$ hours; the maximum relative to the samples reacted at 950°C corresponds to t less than 30 minutes, while for those diffused at 750°C the presumed maximum arises for t larger than 16 hours. The existence of such a maximum can be explained on the basis of two competitive processes which are likely to occur by increasing the diffusione time: ordering of the superconducting phase and reduction in the density and/or in the efficiency of pinning; of course the first mechanism enhances J_c the second depresses it.

It is possible to correlate the measured value of the lattice parameter a with the observed value of T_c. Fig. 3 shows the dependence of T_c on a for

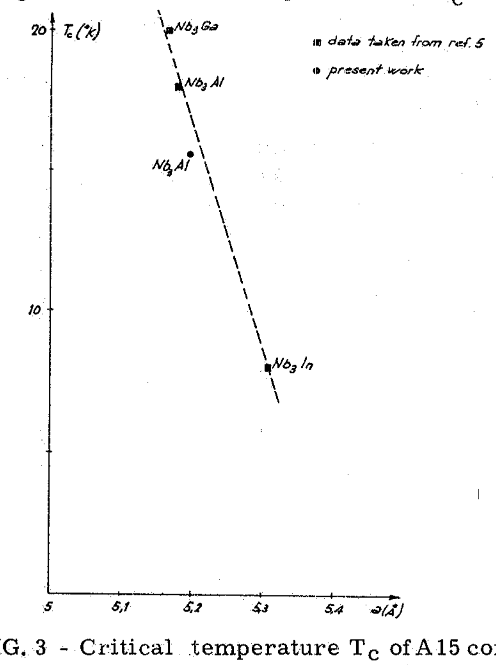

FIG. 3 - Critical temperature T_c of A15 compounds characterized by the same value of e/a = =4.5 vs. lattive parameter a.

the three A15 compounds Nb_3Ga, Nb_3Al and Nb_3In; all these materials have the same value of the electron concentration e/a, corresponding to the value e/a=4.5 electrons per atom. The correlation between T_c and a, as reported by J. M. Leger (ref. 7), is made by grouping the various A15 superconducting compounds in different series, each of which corresponds to a given value of e/a. The good agreement between our measured values of T_c and a and the curve reported in ref. 7 based on experimental data relative to materials obtained by quite different methods, confirms the validity of the analysis reported there. In this context it is likely that the reduction of T_c we observe is due to a slight mistif in the stoichiometry of the compound. Systematic measurements are in progress to investigate a possible correlation between the lattice parameter and the heat treatment time.

Some preliminary measurements of the dependence of the critical current density on the radius of curvature have been taken and results are shown in Fig. 4. No reduction of J_c if found for radii of curvature larger than 7. 5 cm; for smaller radii no conclusions can be drawn and further measurements are needed.

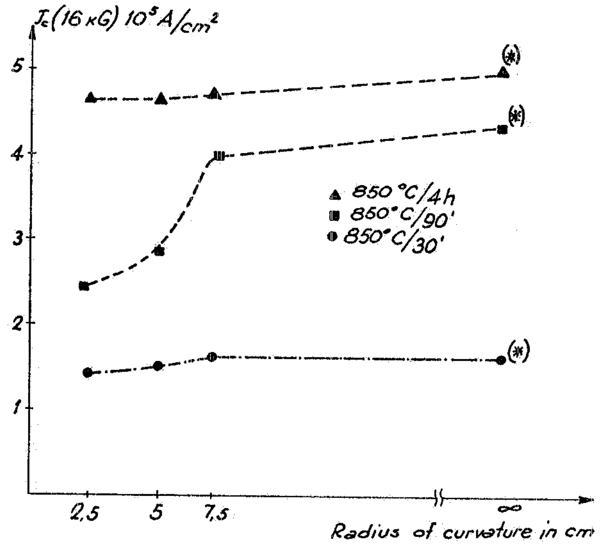

FIG. 4 - Critical current density J_c of some Nb_3Al wires as a function of radius of curvature. Data with (x) are relative to samples as received.

We can conclude that our method allows the fabrication of a copper stabilized Nb_3Al wire that promises to be a new tool for high field applications.

References.

1 - J. G. Kohr, T. W. Eagar and R. M. Rose, Met. Trans. 3, 1177 (1972).

2 - A. Isao, T. Noguchi, Y. Uchida and A. Kono, Journ. Vac. Technol. 7, 557 (1970).

3 - G. V. Kidson, Journ. Nuclear Mater. 3, 21 (1961).

4 - G. Slama and A. Vignes, J. Less. Comm. Metals, 29, 189 (1972).

5 - D. Dew-Hughes, Superconducting Machines and Devices, Proc. NATO Adv. Study Inst., Entreves (Italy), 1973, p. 88

6 - D. Bruce Montgomery and W. Sampson, Appl. Phys. Letters 6, 108 (1965).

7 - J. M. Leger, Journ. Low. Temp. Phys. 14, 297 (1974).