47. W. N. SMITH, *ibid*, **11** (1967) 639.
48. H. E. PICKETT, M. J. R. CANTOW, and J. F. JOHNSON, *J. Polymer Sci.* C **21** (1968) 67.
49. A. A. LEACH and P. C. O'SHEA, *J. Chromatog.* **17** (1965) 245.
50. S. T. BALKE, A. E. HAMIELEC, B. P. LECLAIR, and S. L. PEARCE, *Ind. Eng. Chem. Prod. Res. Develop.* **8** (1969) 54.
51. M. J. R. CANTOW, R. S. PORTER, and J. F. JOHNSON, *J. Polymer Sci.* A-1 **5** (1967) 987.
52. T. WILLIAMS and I. M. WARD, *ibid*, B. **6** (1968) 621.
53. Z. GRUBISIC, P. REMPP, and H. BENOIT, *ibid*, B **5** (1967) 753.
54. C. TANFORD, "Physical Chemistry of Macromolecules" (J. Wiley and Sons, New York, 1961).
55. O. B. PTITZYN and YU. E. EIZNER, *Soviet Phys. Tech. Phys.* (English Transl.) **4** (1960) 1020.
56. J. V. DAWKINS, *J. Macromol. Sci. Phys.* B2 **4** (1968) 623.
57. G. MEYERHOFF, Communication at 7th International Seminar on GPC, Monaco (1969).
58. H. COLL and L. R. PRUSINOWSKI, *J. Polymer Sci.* B **5** (1967) 1153.
59. M. J. R. CANTOW, R. S. PORTER, and J. F. JOHNSON, *ibid* B **4** (1966) 707.
60. H. E. ADAMS, K. FARHAT, and B. L. JOHNSON, *Ind. Eng. Chem. Prod. Res. Develop.* **5** (1966) 126.
61. A. LAMBERT, *Polymer* **10** (1969) 213.
62. R. F. BOYER, Paper presented at 6th International Seminar on Gel Permeation Chromatography, Miami (1968).
63. M. L. MILLER, "The Structures of Polymers" (Reinhold Publishing Co, New York City, 1966).
64. H. W. MCCORMICK and W. R. NUMMY, US Patent 3,318,813, 9 May 1967 (assigned to the Dow Chemical Company).

Letters

Superplastic Behaviour of a Splat Cooled Al-17 wt % Cu Alloy

Al–Cu alloys near the eutectic composition (33 wt % Cu) have shown a superplastic behaviour within a wide temperature range [1–3]. In general, hot working or quenching from high temperatures is used to get a superplastic structure in such alloys. Independent of the fabrication method two main characteristics are required in order to obtain superplasticity: a small equiaxed grain structure and a high structural stability of the alloy at the test temperature. A small grain size can be obtained easily by splat cooling the molten material, resulting in a very high solidification rate since the heat is extracted rapidly by conduction through a cool substrate [4]. Nucleation and growth of the equilibrium phases can be prevented completely. New metastable phases and highly supersaturated solid solutions can be formed. In addition, large morphological modifications are always obtained, resulting in a refined structure. The necessary high structural stability at elevated temperature is an intrinsic property of a two phase mixture of equiaxed grains when the two phases have a large difference in chemical composition [5].

During the investigation of the mechanical properties of binary Al-alloys, prepared by splat cooling, a hypo-eutectic composition Al-17 wt % Cu showed superplastic behaviour in tensile tests. The foils suitable for mechanical tests were obtained from small amounts of the liquid alloy splat cooled between two copper plates. These plates were moved against each other with high speed, solidifying and deforming the drop of liquid alloy between them [6].

The tests were performed with an INSTRON machine at a constant cross head speed of 0.2 cm/min. The specimens were about 50 μm thick, 4 mm wide and had a gauge length of 7.2 mm. The test temperature was 400° C. The specimens were heat-treated at this temperature for about 3 h before applying the load. The total elongation was 600%. This value is impressive if we consider that the tensile specimens cut from the splat cooled foils were not perfectly sound and smooth, but exhibited surface irregularities and central cavities which could act as notches and so affect the ductility. In addition, these large elongations were obtained on tensile specimens with a larger length to thickness ratio than have standard samples for tensile tests. Such samples generally show elongation to fracture values smaller than the standard ones [7]. Experimental evidence of this fact was shown by measuring the total elongation of specimens having the same dimensions as the splat cooled samples which had been cut from rolled and fully annealed strips of

99.99 Al. Values about 20% less than those reported in the literature [8] were obtained.

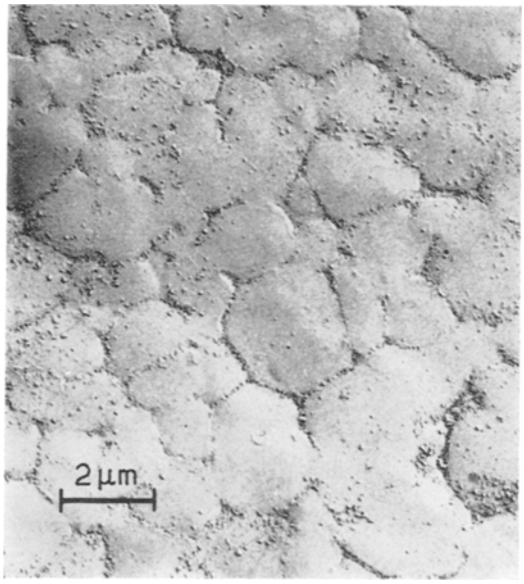

Figure 1 Replica electron micrograph of a splat-cooled Al–Cu alloy.

The microstructure of splat cooled foils, before any heat or mechanical treatment, is shown in fig. 1. It consists of very small equiaxed grains of aluminium-rich solid solution supersaturated in Cu and a precipitate of $CuAl_2$. The grain size varies from less than 1 μm up to about 10 μm. In some zones near the external surface of the foil which has been in contact with the copper plates, the grains were columnar and parallel to the thermal gradient. The $CuAl_2$ phase has been identified by X-rays and is present at the grain-boundaries as a very fine precipitate and also inside the larger grains. The lattice parameter of the aluminium solid solution determined by X-ray diffraction (Debye-Scherrer) is 4.039 Å. According to [9], this value corresponds to a concentration of copper atoms slightly smaller than that at the eutectic temperature.

After the high temperature deformation, the structure was changed considerably. Coarsening of the intermetallic had occurred and the structure consisted of a mixture of equiaxed grains of the two equilibrium phases (fig. 2). It was not possible to reveal grain-boundaries in the aluminium phase on the total microsection, even by heavy etching. X-ray back reflection did not reveal any remarkable change in grain size between the samples before and after deformation. The lattice parameter of the aluminium solid solution was now 4.046 Å. corresponding to the equilibrium concentration of copper atoms at room temperature. The $CuAl_2$ grains were smaller than those of the aluminium solid solution and were generally located at triple junctions.

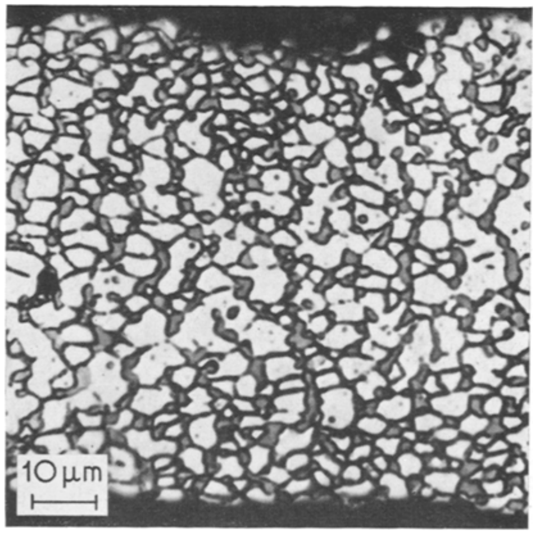

Figure 2 Longitudinal section of tensile specimen of an Al–Cu alloy after ~ 600% elongation. Al solid solution is light. $CuAl_2$ is dark.

Splat cooled foils heat-treated under the same conditions as those used for deformation (3 h at 400° C) revealed the same equiaxed grains two phase structure.

It can be concluded that the splat cooling technique is useful for the study of the superplastic behaviour by producing highly metastable microstructures which can generate after a simple heat-treatment, the structural conditions for the occurrence of this interesting phenomenon even in non-eutectic alloys.

References

1. A. A. PRESNYAKOV and V. V. CHERVYAKOVA, *Fiz. Metal. Metalloved.* **8** No. 1 (1959) 114.
2. E. R. PETTY, *J. Inst. Metals.* **91** (1962-63) 274.
3. D. L. HOLT and W. A. BACKOFEN, *Trans. ASM.* **59** (1966) 755.
4. P. DUWEZ, *ibid* **60** (1967) 606.
5. K. NUTTAL and R. B. NICHOLSON, *Phil. Mag.* **17** (1968) 1087.
6. G. BEGHI, R. MATERA, and G. PIATTI, *J. Nuclear Materials* **31** (1969) 259.

7. W. B. MORRISON, *Trans. AIME.* **242** (1968) 2221.
8. C. PANSERI, "L'alluminio e le sue leghe" (Hoepli, Milano, 1945).
9. YASUO FUJINAGA, SIGEMARO NAGAKURA and SHIGUEO OKETANI, *Nippon Kinzuku Gakkai,—Si*, **32** (1968) 1210.

Received 14 April
and accepted 6 July 1970

G. BEGHI
R. MATERA
G. PIATTI
Metallurgy and Ceramics Division
CCR, Euratom, Ispra, Italy

Czochralski-Type Crystal Growth in Transverse Magnetic Fields

The present communication is a preliminary report on single crystal growth from the melt in the presence of transverse magnetic fields. To our knowledge no experiments on this subject have been reported in the open literature.

The Czochralski type crystal puller used in our previous studies [1] was adopted to a 4 in. pole gap electromagnet (see fig. 1). An infrared heat shield (quartz tube coated on the inside with a 200 Å gold film) was placed outside the furnace to prevent over-heating of the magnet poles. Two stainless steel sheathed and carbon-coated thermocouples (0.020 in. o.d.) were introduced through the hollow pulling shaft and kept at two different positions about $\frac{1}{4}$ in. from the seed; one was immersed $\frac{1}{4}$ in. in the melt (prior to crystal pulling) whereas the other was $\frac{1}{4}$ in. above the melt. All experiments reported here were carried out at 4000 gauss. It was found, however, that

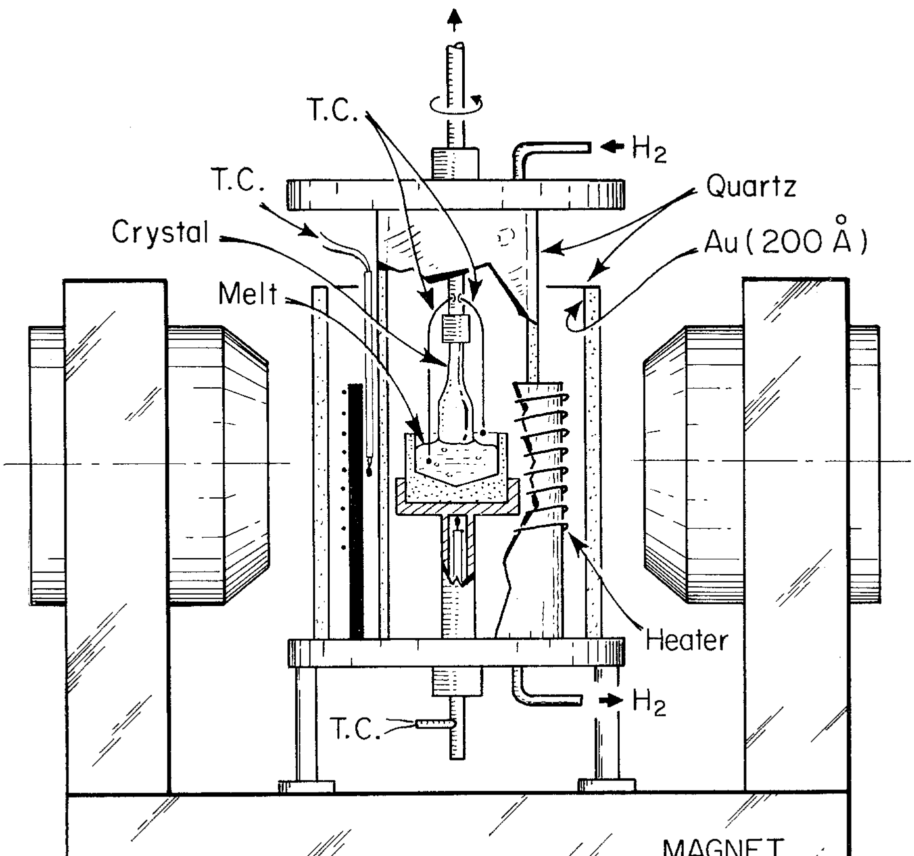

Figure 1 Schematic diagram of the Czochralski crystal puller adapted for the application of a transverse magnetic field.