# ELEVATED TEMPERATURE MECHANICAL PROPERTIES OF A RAPIDLY QUENCHED Al - 8wt.%Fe ALLOY

G. Thursfield, H. Jones*, M. H. Burden**,
R. C. Dibling and M. J. Stowell
Tube Investments Research Laboratories,
Hinxton Hall, Saffron Walden, Essex, England.

* Now at Department of Metallurgy, University of Sheffield, Sheffield

** Now at Department of Metallurgy, University of Oxford, Oxford, England

## Introduction

The internal introduction of hard and stable intermetallic compounds into aluminium can be achieved by atomizing liquid alloys containing transition metals soluble in the liquid but highly insoluble in the solid. Towner (1) showed that extrusions of atomized powder of alloys based on Al - 7.6wt.% Fe have strength characteristics similar to SAP at temperatures up to 400°C but with increased ductility at high temperatures. The strength of these alloys was limited by the intermetallic spacing of about half a micron, deriving from the dendrite spacing within each atomized drop. Further increase in strength and ductility would be expected if the dendrite spacing were further reduced by imposing a higher freezing rate than can be obtained by atomization. Freezing rates up to $10^6$ deg/sec. can be obtained in very thin foils ($\leq$50μm thick) of Al - 8%Fe by splat cooling.

Individual splats of Al - 8%Fe prepared by the 'gun' technique (2) were shown by Jones (3) to exhibit marked structural variations when rapidly solidified from the melt. Jones showed that if a polished section, normal to the splat surface, is etched in Keller's reagent a transition in structure is revealed. The layers adjacent to each surface of the splat, which were characterised by only a slight response to etching, were designated Zone A (hardness ~260 kg/mm$^2$) and the strongly etched central layer was designated Zone B (hardness ~100 kg/mm$^2$). The microstructural features of each zone are described in detail by Jones and the effects of annealing at high temperatures on the microstructure are discussed further by Jacobs et al (4).

This paper describes two techniques which have been developed for the bulk preparation of splats of Al - 8%Fe containing a high volume fraction of Zone A.

Extruded bar is prepared from the splats by powder metallurgy techniques. The mechanical properties of the alloy in the as-extruded condition at ambient temperatures and at elevated temperatures will be discussed. The high temperature tensile properties are compared with those of established wrought aluminium alloys such as RR57 based on Al - 6%Cu and RR77 based on Al-Zn-Mg-Cu, and those of atomized powder extrusions of the Al - 7.6%Fe alloy described by Towner (1).

## Bulk Preparation of Splats of Al - 8wt.%Fe

### (a) Centrifugal Splat Quenching

Briefly, this method involves forcing the molten alloy by an applied gas pressure downwards through a capillary orifice in the base of a stationary reservoir into a heated graphite crucible which is rapidly rotating about a vertical axis. The molten material is flung centrifugally from the rim of the crucible on to a surrounding cooled cylindrical copper wall, making impact while still liquid. The splats are removed, almost as soon as they are formed, by a PTFE scraper which traverses the inner wall of the copper cylinder.

The experimental conditions were chosen so that the splats contained a high volume fraction of Zone A. Zone A is formed predominantly at the substrate side of the splat (3). It follows therefore that conditions for its formation must involve a rapid rate of heat removal from the splat and the deposition of very thin splats at a low deposition rate. To ensure a low splat deposition rate the maximum superheat given to the alloy is 150°C and the minimum gas pressure ($\simeq$30 $KNm^{-2}$) necessary to force the alloy through a 0.4mm diameter orifice is applied. The inner wall of the surrounding copper cylinder is grit blasted to promote near perfect thermal contact between the splat and the substrate and so ensure a rapid rate of heat extraction from the splat. The heated graphite crucible is rotated at 14,000 rpm to effect rapid ejection of the alloy on to the copper cylinder. Under these conditions splats containing >60% of Zone A are continuously produced. The experimental apparatus is capable of splat quenching up to 150g of alloy in each run.

(b) <u>Gas Atomisation Followed by Spray Quenching</u>

This process involves atomizing a stream of the molten alloy and then quenching the atomized droplets by a rotating water-cooled copper drum located at a predetermined distance vertically below the alloy reservoir crucible and the atomizing jets. Atomization is achieved by passing a fine molten alloy stream into a cone of high velocity gas formed by 36 gas jets directed downwards at 60°. The atomizing gas pressure employed was the minimum possible to achieve satisfactory atomization (i.e. ~350 $KNm^{-2}$). Too high a pressure resulted in some solidification of the droplets before they reached the drum and too low a pressure resulted in particles too large for the satisfactory formation of thin splats.

To ensure that the splats obtained contained a high volume fraction of Zone A, the copper drum was abraded with 60 mesh emery paper to improve thermal contact between the splats and the drum. A low deposition rate was achieved by restricting the diameter of the capillary orifice in the alloy reservoir crucible to 0.6mm diameter and by increasing the drum speed to the maximum possible (300 rpm). The maximum superheat was 150°C and the applied gas pressure to eject the alloy from the reservoir was restricted to a maximum of 40 $KNm^{-2}$ to ensure the lowest possible feed rate.

The optimum position of the drum was 13cm vertically below the jets. A nylon scraper, located at right angles to the vertical axis of the drum, and machined so as to fit along the circumference of the drum, ensured the continuous removal of the splats.

This technique is preferable to the centrifugal quenching process because larger quantities of material can be handled and the scale of the process can be increased more rapidly to industrial proportions.

Mechanical Properties

Hardness measurements on Al - 8%Fe carried out by Jones (3) showed that the hardness of Zone A and Zone B remains unchanged after prolonged exposure up to, and including, 300°C. Furthermore, the microstructure of Zone A showed no significant change after prolonged annealing at 300°C (c.f. Jacobs et al (4)). The stability of the microstructure in Zone A suggested that bulk material prepared from splats should possess reasonable strength even at elevated temperatures.

It has been found that Al - 8%Fe in the form of 0.63cm diameter bar extruded from splatted material possesses at ambient temperatures a minimum ultimate tensile strength of 570 $MNm^{-2}$ (57.5 $kg/mm^2$) and a minimum 0.1% proof strength of 500 $MNm^{-2}$ (51.3 $kg/mm^2$) with 5% elongation to fracture. The minimum ultimate tensile strength at 300°C after 100 hour exposure at that temperature is 232 $MNm^{-2}$ (23.6 $kg/mm^2$) and the minimum 0.1% proof stress is 216 $MNm^{-2}$ (21.8 $kg/mm^2$) with 9.5% elongation to fracture. Above 300°C a fairly rapid reduction in strength is observed with increasing temperature (see Fig. 1). This is attributed to the decomposition of the FeAl crystallites in Zone A to form needle-shaped $FeAl_3$ particles, which subsequently coarsen into spheroidal-shaped particles (c.f. reference (4)).

Table I describes the tensile strength, 0.1% proof stress, the modulus of elasticity and the ductility for the range 0°C to 450°C after an exposure of 100 hours at the test temperature. The 100 hour tensile strengths are only 5% below the 1 hour tensile strengths.

Fig. 1 compares the 100 hour ultimate tensile strength of Al - 8%Fe prepared from splat quenched material with the 100 hour ultimate tensile strengths of RR57, RR77 and the Al - 7.6% Fe alloy developed by Towner (1). It will be seen that the splat quenched alloy has greatly superior high temperature properties to both RR77, which has an equivalent room temp-

TABLE I

100 Hour Tensile Properties of Extruded Al - 8%Fe Alloy

| Test Temp. °C | UTS $MNm^{-2}$ | 0.1% Proof Stress $MNm^{-2}$ | % Elongation | Modulus of Elasticity $GNm^{-2}$ |
|---|---|---|---|---|
| Room Temp | 570 | 503 | 5.0 | 81.5 |
| 100 | 425 | 372 | 9.0 | 70.2 |
| 200 | 318 | 293 | 9.0 | 57.0 |
| 250 | 262 | 245 | 10.2 | 50.5 |
| 300 | 232 | 214 | 11.5 | 48.2 |
| 350 | 159 | 138 | 12.0 | 35.2 |
| 400 | 74 | 70 | 13.2 | 26.4 |
| 450 | 33 | 31 | 17.8 | - |

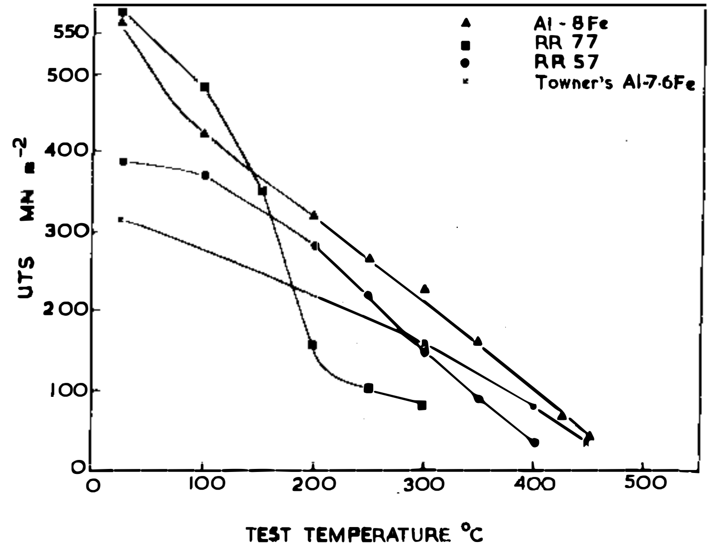


FIG. 1
Comparison of the Tensile Strengths of Al - 8wt.%Fe, RR77, RR57 and Towners Al - 7.6wt.%Fe

erature strength to Al - 8%Fe, and RR57, which possesses inferior room temperature properties.

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References

1) R. J. Towner, Metal Progress, 73, 70, (1958).
2) P. Duwez and R. H. Willens, Trans.AIME, 227, 362, (1963).
3) H. Jones, Mater.Sci.Eng., 5, 1, (1969/70).
4) M. H. Jacobs, A. G. Doggett and M. J. Stowell (this Conference).

DISCUSSION :

R. W. Cahn : I was interested to hear you say that grit blasting your copper substrate increased cooling rate by an order of magnitude. Can you say why blasting has such a notable effect ?

G. Thursfield : Grit blasting the cooper substrate improves thermal contact between the splat and the substrate. Grit blasting also enables the splats to mechanically stick to the substrate. If the substrate is polished the splats readily fall away from the substrate and the cooling rate falls.

M. Paić : And the length of the samples ?

G. Thursfield : The thickness of the splats obtained is ~ 50 μm, the length of the splats obtained under ideal conditions is 1 cm to 2 cm. However, if the deposition rate onto the copper drum is increased and the drum speed reduced to something like 20 rpm, extremely long samples can be obtained but with increased thickness ( 500 μm).

N.J. Grant : What were physical dimensions of your splats?

G. Thursfield : They were approximately 50 μm thick and 1 cm in the other dimensions.