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Spheroidal microstructure suitable for thixoforming obtained by low temperature pouring and controlled solidification of a A356 aluminium alloy

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Spheroidal, non-dendritic microstructures are a strong requirement for the success of thixoforming processes. Initially, from a 'V' shaped ingot having the A356 composition and poured at temperatures lower than the usual practice, a suitable microstructure was identified and related to its cooling rate. This rate was reproduced in a copper mould designed by making use of a FEM commercial software, and the resulting ingots were partially re-melted at 580^{o}C. Metallographic characterisation of these samples indicated that the method is suitable for producing a spheroidal microstructure exhibiting good rheological behaviour.

1. INTRODUCTION

Studies by Fleming and co-workers [1] led to development of a new technology called thixoforming, directed to the production of premium structural parts, mainly based on Al alloys. This technology has a number of technical advantages over conventional forming processes but a higher cost due to an additional step named *microstructural conditioning,* which produces the non-dendritic spheroidal microstructure required by the process. Two groups of techniques are employed for this purpose [2]: (i) mechanical or magnetic (MHD) stirring of the liquid alloy, and (ii) a thermomechanical process followed by partial melting (TTM). However, cost reduction still calls for new alternatives and low temperature pouring associated to controlled solidification (LTP) appears to be very promising [2], although rheological data are still lacking.

This wok presents microstructural and rheological studies performed on a LTP-conditioned A356 alloy and compares data with those of the same alloy conditioned by MHD and TTM.

2. EXPERIMENTAL

A commercial A356 ingot (Al-7Si0.3Mg) was melted, degassed modified and inoculated with Sr and Ti-B, respectively. The melt was poured at 700 and 625^{o}C into a 'V'shaped mould in the upright position. In it, four equally spaced thermocouples (position 1 to 4, from top to bottom) were employed to correlate pouring temperature and cooling rate (CR) with the microstructure of samples taken from the same four positions. Once found a suitable microstructure a cylindrical Cu mould was designed using a commercial FEM software

(MAGMAsoft®) in such a way as to replicate the V-shaped ingot CR corresponding to the chosen microstructure. Microstructural features (particle size and shape, contiguity, solid fraction and trapped liquid volume fraction - *f*si) of samples partially re-melted at 580^{o}C and held for 20, 30 and 40 min were characterised and compared with those obtained by the TTM and MHD processes. Finally, the rheological behaviour of LTP samples was analysed by the back extrusion technique [4].

3. RESULTS AND DISCUSSION

The microstructure of V-ingots poured at 700 and 625^{o}C are in Figure 1. It can be seen that

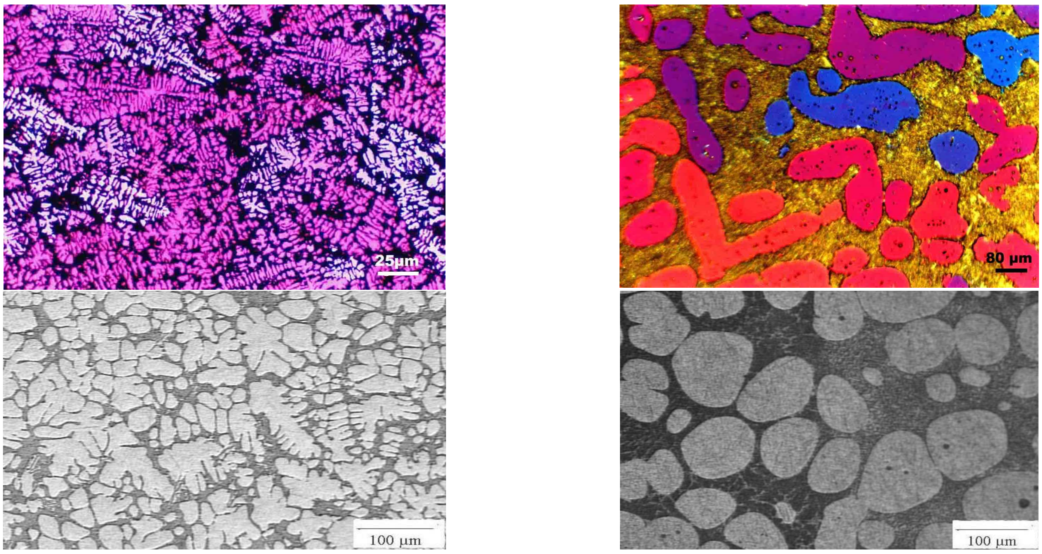

Figure 1. Microstructures of 'V'- shaped ingots poured at 700^{o}C (a: as-cast; b: partially re-melted at 580^{o}C/30 min) and 625^{o}C (c: as-cast; d: partially re-melted, same conditions)

for the lower temperature in the as-cast condition, the dendrites are not fully developed but resemble the rosette morphology described by Flemings [1]. After partial re-melting the microstructure appears quite suitable for thixoforming, see Figure 1-d. The results of the V-mould experiments are in Figure 2. At pouring temperature equal to 625^{o}C the as-cast microstructural unit is the rosette instead of the dendrite[1], obtained at 700^{o}C. Therefore, the following remarks are relevant: (i) 625^{o}C, that is, a superheat of only 12^{o}C, is the optimal pouring temperature; (ii) the higher CR the more spheroidal the Al-α particles, but above 5^{o}C s^{-1} this correlation ceases to be significant. Hence, 5^{o}C s^{-1} was chosen as the minimum CR, which was replicated by the Cu mould (actual value equal to 6.7^{o}C^{-1}) as explained in section 2. Figure 3 compares data from microstructural observation of LTP samples (poured in the Cu mould at 625^{o}C and partially re-melted at 580^{o}C) with those of TTM and MHD samples. The shape factor is slightly less favourable for the LTP samples, but is still satisfactory. Although the fraction of entrapped liquid appears to be quite high when that sample is compared with

[1] The graph shows secondary dendrite spacing (λ) and rosette diameter ($\varnothing$) for partially re-melted ingots. Of course $\varnothing >> \lambda$ but the purpose of presenting together these two samples is to correlate their size dependence with cooling rate and not to compare their absolute dimensions

TTM and MHD, it must be considered that in absolute terms f_{Li} is always very low and in practice it does not affect the value of intergranular fs.

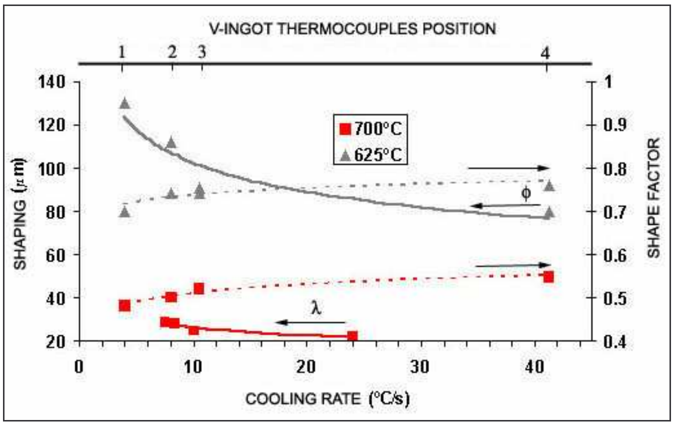

Figure 2. Shape factor and microstructural unit size (λ and∅) of V-shaped ingots in the as-cast condition, as a function of pouring temperature and CR

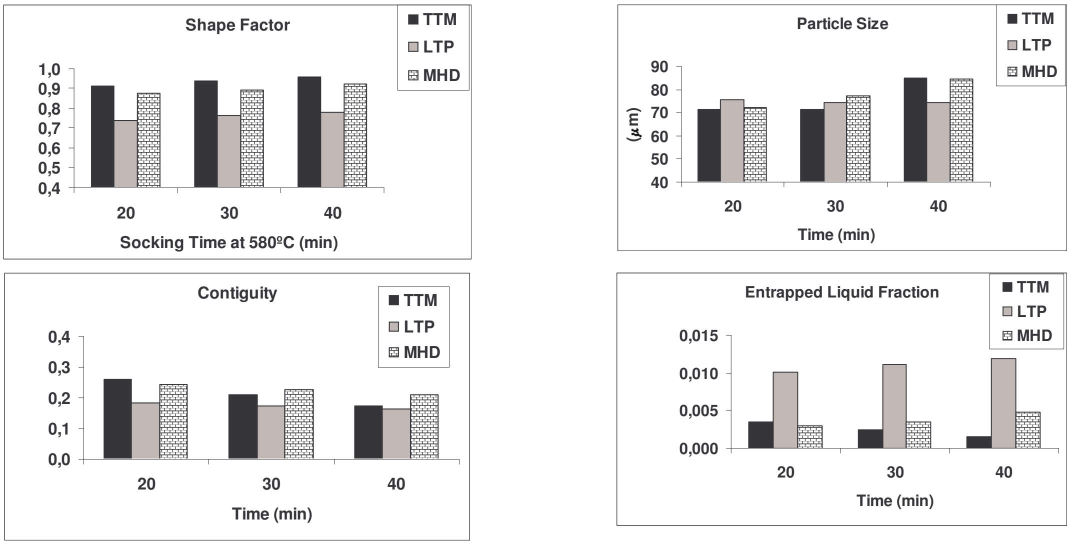

Figure 3. Microstructural features of semi-solid samples held at 580°C during 20, 30 and 40 min. Copper mould, pouring temperature and CR are equal to 615°C and 6.7°C s^{-1}. Results are compared with those of TTM and MHD A356 semi-solid samples

Finally, Figure 4 shows results of the back-extrusion experiments, which express the semi-solid rheological behaviour of LTP, TTM and MHD samples. It can be seen that the Load against Displacement curve of the LTP sample coincides almost entirely with that of the TTM-conditioned sample and is lower than that of the MHD sample. Using the formula [4]:

$$\eta = \frac{dF/dt}{2\pi \lambda C_1 V}$$

where dF/dt is the slope of the force versus time plot, λ and C_1 are geometrical constants and V is the plunger velocity, one obtains, in Pa.s: MHD = 298; TTM = 184 and LPT = 148. Therefore, the viscosity obtained with the LTP is similar to those obtained by more conventional techniques.

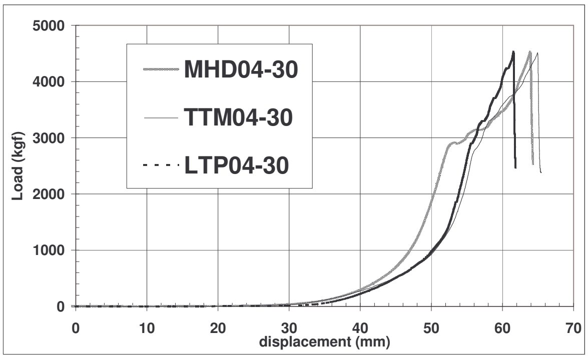

Figure 4. Rheological measurements by the back-extrusion technique: Load against displacement curves comparing LTP, MHD and TTM-conditioned samples. Partial re-melting conditions are 590°C (*f*s = 0.4) and 30 min soaking time

4. CONCLUSIONS

Microstructural conditioning by LTP, employing a superheat of only 12°C and a CR equal to 6.7°C s^{-1} appears to be a viable process to produce a non-dendritic, spheroidal microstructure, suitable for thixoforming. Comparison of the microstructure and rheological behaviour of semi-solid LTP-conditioned samples with MHD and TTM materials was favourable in almost all respects.

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