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Thixocasting of a A356 aluminium alloy demonstration part: microstructure, quality and tensile properties

E. de Freitas, M. Ferrante

Departamento de Engenharia de Materiais, Universidade Federal de São Carlos,
P.O. Box 676, 13565-905 São Carlos - Brasil

A small A356 demonstration part was thixocast at 580°C using three different ingate metal velocities: 2.4; 1.6 and 0.8 m s^{-1}. Good surface quality, absence of defects, low porosity and a relatively homogeneous solid/liquid ratio were observed throughout the part. The T6 tensile properties are of the same order of those reported in the literature for thixocast A356 samples.

1. INTRODUCTION

Semi-solid forming of metals and alloys, also called thixoforming, is a comparatively recent near net shape technology whose products exhibit a number of positive characteristics. For instance, the low injection temperatures mean a very low pore content with the consequence that for a given alloy, the tensile and fatigue properties of thixoformed parts are consistently higher than those of conventionally cast or forged A356 products [1]. Although a number of metallic materials are being considered, presently the aluminum alloys appear to be the most suitable choice for the process. However, to be successfully thixoformed, these materials must exhibit a non-dendritic microstructure, more precisely, one which is formed by a equiaxed primary phase (Al-α) well dispersed into a eutectic “liquid matrix”. This microstructure exhibits a favourable rheological behavior which gives good flow characteristics of the alloy into the mould cavity [2]. Among the processes employed for the production of non-dendritic microstructures, magnetic stirring of the liquid alloy (MHD) has already achieved commercial status, but many others competing processes exist [3].

This paper describes the thixocasting of a A356 aluminum alloy demonstration part in the shape of a small connecting rod, and reports on its quality and final tensile characteristics.

2. EXPERIMENTAL

A 9 kg commercial ingot of A356 (Al-7Si-0.4Mg) was re-melted, Sr-modified, inoculated with Ti-B and poured into a 52 x 46 x 250 mm^3 steel mould. The resulting plates were homogenized (540°C/24 h) and warm rolled to a thickness reduction of $\approx$ 30%. Cylindrical billets were machined out from the rolled plates; just before the forming operation they were partially re-melted at 580°C during 30 min and injected into a mould by a 30 T hydraulic press with a ram speed equal to 0.1 m s^{-1}. Three different gate cross-sections were employed in order to produce three different mould injection velocities. Part characterization included quantitative measurement of the following microstructural features: diameter (D), shape factor (F), contiguity (Q) and solid fraction (Fs) of the Al-α particles and also X-rays radiographs and tensile tests of T6 heat treated parts. The mould design was assisted by a FEM commercial software MAGMAThixo® whose output was validated by interrupted mould filling experiments. Tensile tests were performed on sub-size specimens extracted from the body of the part.

3. RESULTS AND DISCUSSION

Figure 1 depicts the thixocast demonstration part (total length equal to x mm) and a view of the three gates (G) employed in the experiments. Each gate exhibits a cross section to which corresponds a given metal flow: G1 = 60 mm^2 /2.4 m s^{-1}; G2 = 88 mm^2 /1.6 m s^{-1}, G3 = 173 mm^2 /0.8 m s^{-1} No filling defects were found and the surface quality was very good with R_a values in the range 0.85 - 1.20. The microstructure is shown in Figure 2; the part was obtained with gate 2 and three different positions are shown: (a) ring, (b) rib; (c) body.

Figure 1. Typical thixocast part and schematic of the three gates employed in the experiments

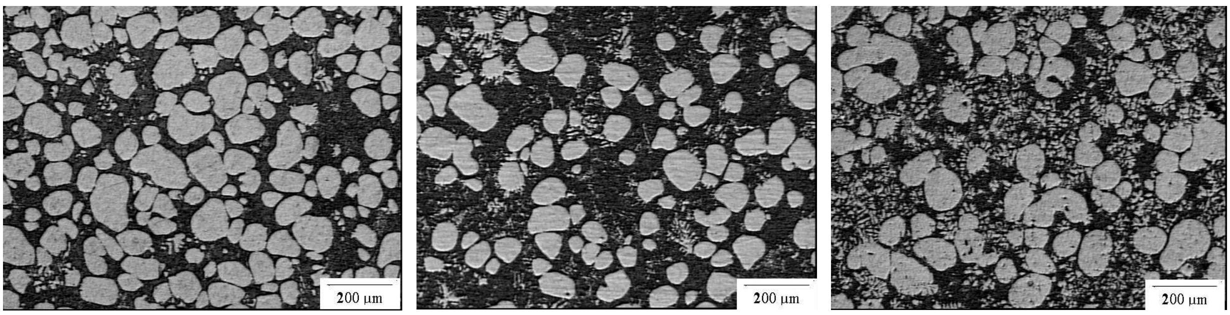

Figure 2. Typical microstructures of different locations of the part: (a) rings; (b) ribs; (c) body

This sequence of micrographs shows a relatively equiaxed solid phase well dispersed into a euctectic 'liquid'. It must be pointed out that the small dendrites are artifacts originated from the relatively slow cooling rate. As for the solid/liquid ratio within the part, a mild degree of liquid segregation is apparent from figure 2; it is more intense in the narrow ribs, see figure 2-

b, than throughout the rest of the part, but overall the solid/liquid distribution is relatively homogeneous. Therefore, metal inlet velocity does not appear to be very critical in terms of segregation. Microstructural parameters also do not change very much with that process parameter: Fs (0.41 - 0.47); D (73 - 85 μm); F (0.76 - 0.87) and Q (0.12 - 0,15), although C2 produced particles more equiaxed. Figure 3 compares liquid segregation (in terms of Fs) with porosity in different regions of the component and different metal injection velocities. It can be seen that gate three (C3) produced very sound parts and a homogeneous pore distribution. It must be pointed out that the narrowest gate (C1) produced the higher porosity level and the lowest solid fraction (probably because of prolonged filling time). This correlation is explained by the higher shrinkage deployed by material containing a higher proportion of liquid phase.

Finally, from the analysis of the radiograph shown in Figure 1 the part was classified as below Level 1 of the A-155 ASTM standard, indicating virtual absence of pores and defects.

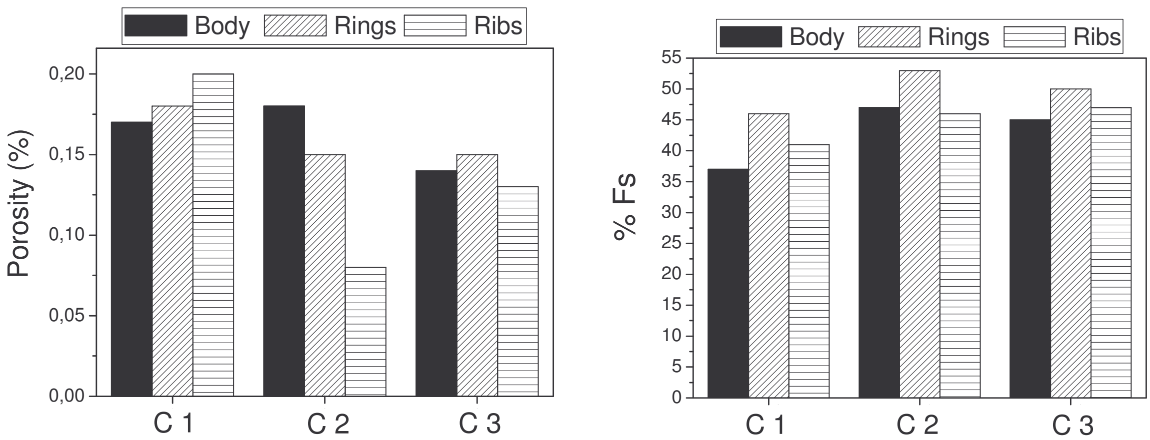

Figure 3. Distribution of porosity (a) and solid fraction (b) in different locations (body, ribs and rings) of parts produced with the three different inlet gates, C1, C2 and C3

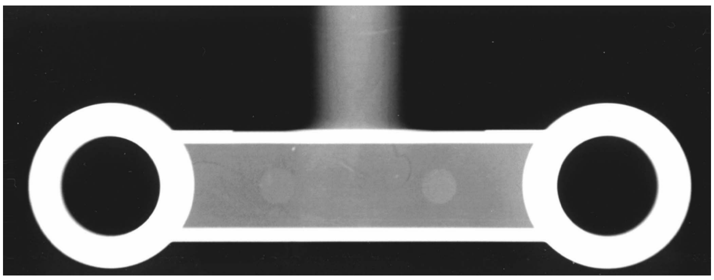

Figure 4. Radiograph of a typical thixocast part

In industrial practice, in order to avoid blisters thixocast parts are not normally subjected to the T6 precipitation heat treatment. However, the construction of the mould here employed prevented quick heat extraction of the part, thus ruling out T5. However, the low porosity here observed would probably permit the T6 heat treatment, and indeed no blisters were observed. The results of tensile tests performed on A356 specimens with different origins are in Table I. The following remarks can be made: (i) the mechanical strength of the thixocast demonstration part is much higher than that measured on specimens machined out from permanent mould cast plates; (ii) same comment can be made with regard to published data on A356 mechanical strength [4]; (iii) the present results are within the range of values obtained by a number of investigators dealing with tensile properties of thixoformed material [5].

Table I. Tensile properties of the thixocast samples, compared with literature data on conventionally cast and semi-solid formed A356 specimens

Process - gate	σ_y (MPa)	σ_r (MPa)	A (%)
Thixocasting - gate 1	233	298	8
Thixocasting - gate 2	226	296	8
Thixocasting - gate 3	217	319	14
A356 permanent mould - this work	201	265	5.0
A356 permanent mould - nominal [4]	186	262	5.0
Thixocasting - other investigators [5]	220-270	280-320	8-13

4. CONCLUSIONS

The thixoextruded demonstration part here produced exhibits a very good quality and a porosity level below 0.20%. Microstructural observation showed that the Al-α particle shape was relatively equiaxed, mainly when gate 2 was employed. Although three different metal injection velocities were tested, the quantitative microstructural parameters of the resulting parts were similar, thus almost insensitive to metal injection velocity, although C3 (lowest injection velocity) produced the lowest porosity level here observed.

Tensile test on T6 specimens showed that σ_r, σ_y and elongation are comparable with data obtained on the same alloy by other investigators.

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