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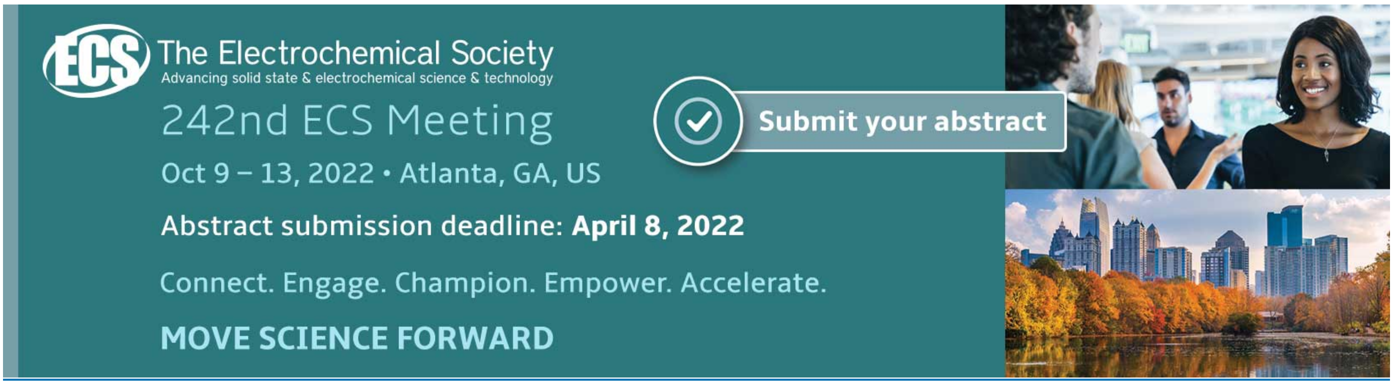

Effects of directional solidification on hardness and microstructure in Al–3wt.%Cu–1wt.%Li alloy

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Abstract. Solidification is probably one of most important phase transformations in materials manufacturing. Additionally, a wide range of solidification microstructural features is obtained depending on processing parameters. Mechanical properties of the cast are influenced by the microstructure obtained after solidification. The aim of this work is to investigate how solidification conditions affect solidification and the resulting microstructure of the Al–3wt.%Cu–1wt.%Li (ternary system) alloy. The alloy was solidified unidirectionally upward through a water-cooled steel plate. Results include secondary dendritic arm spacing (SDAS), hardness and microstructure analysis using optical microscopy. Results showed that SDAS values tended to increase as the distance from the heat-exchange surface increased (P). Conversely, hardness decreases as P increased.

1. Introduction

Properties such as low density and higher modulus of elasticity than conventional alloys make aluminum-lithium alloys attractive for aerospace applications. Li additions enable the formation of effective hardening precipitates and provide higher fatigue-crack growth resistance [1,2]. The addition of lithium and copper is promising as it allows for an attractive combination of properties, including a high strength-to-weight ratio, good machinability, environmental friendliness, and elevated fatigue strength, which determines the prospects of their application in aircraft structures [3,4].

Casting is an example of a manufacturing solidification process, and many variables must be. Thus, several authors addressed their studies on the resulting microstructure influence on the properties of engineering materials [5,6,7,8]. Generally, structures with more refined grains tend to increase the strength of the metallic material, as described by the well-known Hall-Petch equation [9,10]. However, for cast metals and alloys, this relationship is not always observed, as the effect of grain size can be overcome by increasing the number of imperfections (micro porosities), increasing the percentage volume fraction of the second phase or arm spacing dendritic [11].

The aim of the present work was to investigate how solidification conditions affect the microstructure of the Al–3wt.%Cu–1wt.%Li (ternary system) alloy. Solidification was carried out by heat extraction. This alloy was solidified unidirectional upward. Results include secondary dendritic arm spacing (SDAS), hardness, and microstructure analysis by optical microscopy.

2. Materials and Methods

Figure 1 shows the experimental apparatus. It can be observed that heat was extracted directionally through a low carbon steel plate (SAE 1020) with a thickness of 3 mm. A split ingot mold with an outer diameter of 70 mm, an inner diameter of 60 mm and a height of 157 mm was used. The internal surfaces of the ingot mold were coated with layers of alumina.

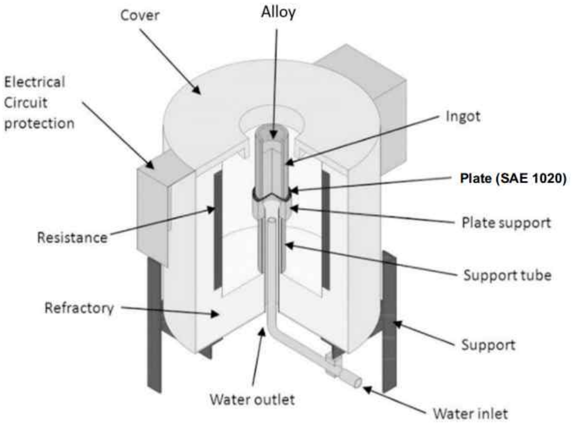

Figure 1. Unidirectional solidification furnace [12].

The aluminium alloy was prepared in a graphite–clay crucible placed in a muffle furnace using a commercial AA 2198 alloy. The alloy was heated to a temperature of 10°C above the liquidus temperature and then poured into the split ingot mold inside the solidification furnace [1]. Prior to casting, the solidification furnace was heated to reach the alloy-casting temperature. The heat-exchange surface was polished to decrease heat-transfer resistance. Type K thermocouples of 1.6 mm in diameter were placed at distances of 4, 8, 12, 22, 52, 68 and 88 mm from the plate from which the heat is extracted. All thermocouples were connected to a data logger interfaced with a computer, with a data acquisition interval equal to 1 s. The cooling system was activated after all thermocouples indicated temperatures of approximately 660 °C.

Selected cross sections (perpendicular to the heat extraction direction) were taken from the cast ingot at different distances from the heat-extraction plate, polished and etched. For metallography preparation, Tucker´s reagent was used (a solution of 45 mL HCl, 15 mL de HNO_3, 15 mL HF, and 25 mL distilled water). Image-processing system Zeiss AxioVert A1 microscope (Carl Zeiss, Gottingen, Germany) was used to measure SDAS (about 30 independent readings for each selected position) and their distribution range. The Zeiss AxioVert microscope (Carl Zeiss, Göttingen, Germany) was used to measure SDAS (about 30 independent readings for each transversal sample). Hardness values were obtained on a Wilson UH-930 hardness tester (Boehler, Lake Bluff, IL, USA) in accordance with ASTM E10-2012 [13]. A load of 62.5 kgf and a sphere 2.5 mm in diameter were used. Five hardness tests were performed on each sample. Graphs and experimental equations were obtained with the SciDAVis software version 1.25.

3. Results and Discussion

Figures 2 and 3 presents the mean experiment values of SDAS as a function of distance to P and as function of tip-growth rate (V_L). SDAS values tended to decrease to positions close to the heat-extraction plate. These positions had higher V_L values, suggesting that higher cooling rates imply a more refined microstructure.

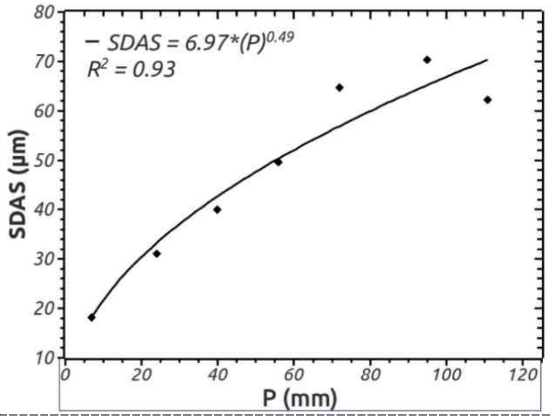

Figure 2. Correlation between secondary dendrite arm spacing (SDAS) and distance from heat-extraction plate (P).

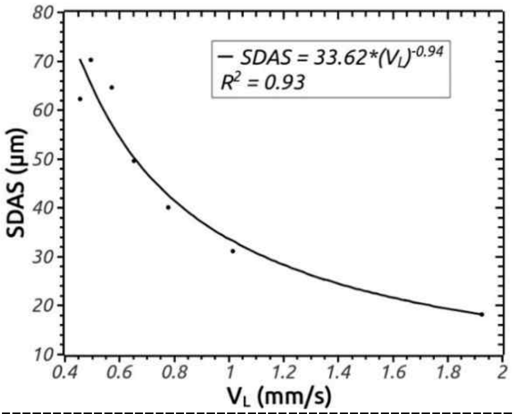

Figure 3. Correlation between secondary dendrite arm spacing (SDAS) and tip-growth rate (V_L).

Obtained microstructures along the longitudinal section of the Al-3wt.%Cu-1wt.%Li alloy are shown in figures 4, 5, 6 and 7. The microstructures were obtained by optical microscopy at positions 7, 24, 56 and 111 mm from the heat-extraction plate. It was observed that the size of the grains increases towards positions more distant from the heat exchange plate.

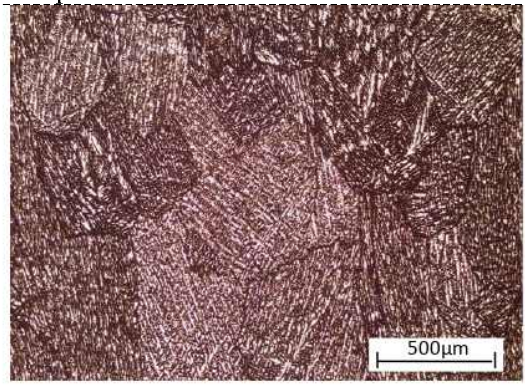

Figure 4. Micrograph of the sample taken from the 7 mm position as a function of the heat-extraction plate.

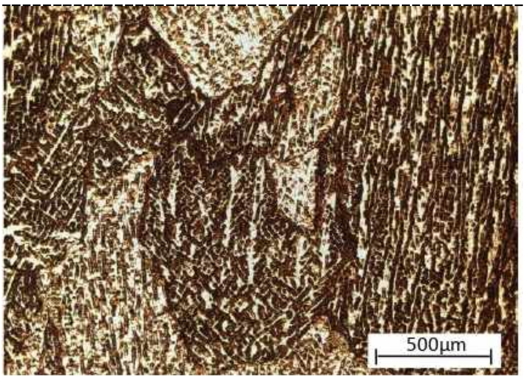

Figure 5. Micrograph of the sample taken from the 24 mm position as a function of the heat-extraction plate.

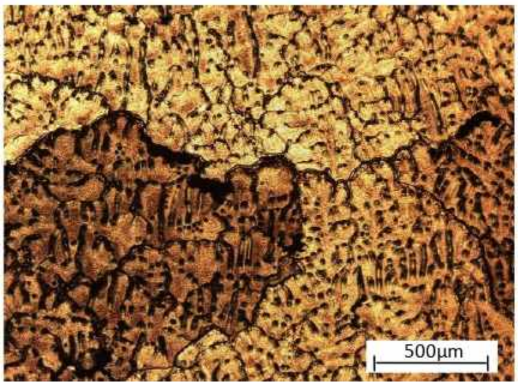

Figure 6. Micrograph of the sample taken from the 56 mm position as a function of the heat-extraction plate.

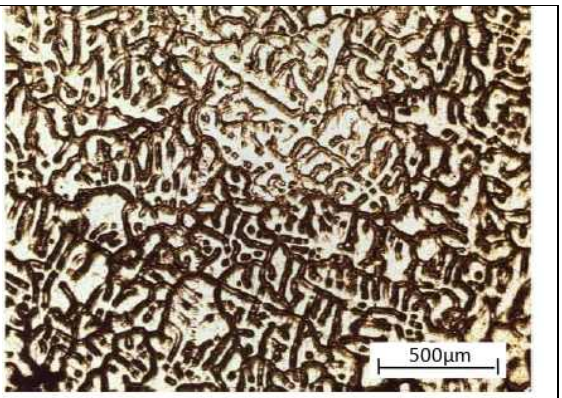

Figure 7. Micrograph of the sample taken from the 111 mm position as a function of the heat-extraction plate.

The data obtained in the hardness test are shown in figures 8 and 9. The hardness values (HB) were correlated with the values of distance from the heat exchange plate (P) and with the SDAS values. The experimental equations were obtained by the method of least squares. Error bars were defined by the standard deviation of the experimental data. The linear fit of the data suggests that HB values decrease with increasing distance from P and SDAS values.

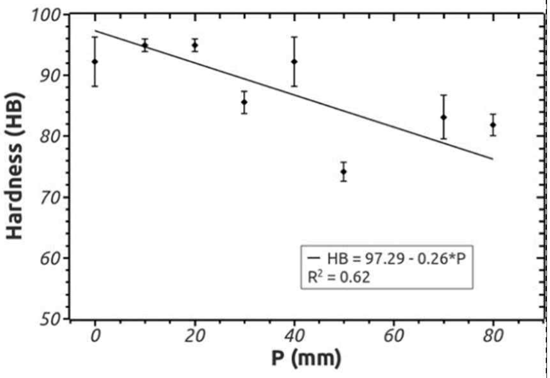

Figure 8. Correlation between hardness (HB) and distance P.

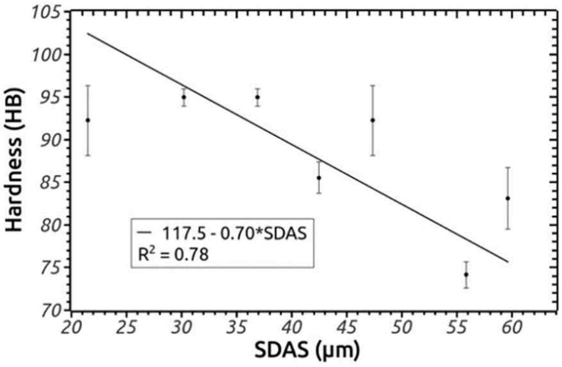

Figure 9. Correlation between hardness (HB) and SDAS.

4. Conclusions

We can draw the following conclusions:

(1) SDAS values decreased as distance from P increased.
(2) The structure is more refined in regions closer to the heat exchange surface.
(3) The experimental equations obtained indicate that HB decreases with increasing distance from the heat-extraction plate.
(4) The experimental equations obtained indicate that HB values decrease with increasing SDAS.

Acknowledgments

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