INFLUENCE OF MICROSTRUCTURE IN MECHANICAL PROPERTIES OF DIRECTIONALLY SOLIDIFIED HYPEREUTECTIC Al-15wt%Si AND Al-18wt%Si ALLOYS

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Aluminum alloys are worldwide applied due to their relatively good properties such as fluidity, low melting temperature, short foundry cycles, good surface finishing, and others. Among these alloys, the alloys that have silicon in their composition are widely used in the automotive industries because of the good fluidity and the wide variety of possible properties. The purpose of this research work is to perform directional solidification experiments with two Al-Si alloys containing 15wt% and 18wt% of Si so that the influence of cooling thermal parameters, and of microstructures, in the tensile mechanical properties could be examined through functional experimental interrelations between microstructure and properties. In conclusion, tensile strength and elongation-to-fracture decrease with increasing alloy silicon content.

Key words: unidirectional solidification; microstructure; mechanical properties; Al-Si alloys.

Introduction

Aluminum alloys offer several advantages, such as good fluidity, low melting temperature, short foundry cycles, relatively low tendency to hot fracture, good superficial finishing after foundry process and good chemical stability. Among the foundry aluminum alloys, Al-Si alloys are the most widely used, particularly in the automotive industries. The silicon provides a good fluidity and wide variety of possible properties that can be reached considering alloys from this family[1].

Hypereutectic alloys are those in which the content of Si is over than 13wt.%. These alloys are widely used and studied in the transportation sector due to low density, high specific stiffness, resistance at high temperatures, wear resistance, and low thermal expansion coefficient. Those properties allow Al-SI hypereutectic alloys to be used as substitute for cast iron in automotive engines components such as piston, cylinders, oscillating arms, and retention valves[2-4].

Although the effects of eutectic and primary silicon modifiers such as Na, Ca, Sr, Sb, and P in microstructures of these alloys are relatively well-known, the effect of cooling rate in the morphology, distribution, and size of the eutectic and of the primary phase are not fully studied according to the literature. In addition, the influences of Si morphology in the mechanical properties of Al-Si hypereutectic alloys were not studied so far. The processes involving solidification of metals have as goals the production of parts able to reach certain project requirements. In the case of Al-Si hypereutectic alloy, such requirements are linked with the microstructural aspects. Enough mechanical-and-surface properties (wear resistance, for example) to a specific application may be reached only if optimized microstructures are developed [5, 6].

According to the state of art, the properties of Al-Si hypereutectic alloys are directly linked to morphologies and distribution of primary Si in the matrix alloy, which are directly dependent on chemical composition, melting, and solidification conditions. Furthermore, the main constituent of these alloys is the eutectic, which also affects the properties. Despite the higher proportion of eutectic, only few researches devoted to the eutectic microstructures and their effects in the mechanical properties can be found[5-8].

Materials and Methods

This research work has as purpose to correlate the eutectic spacing, λ, with the mechanical properties measured in the uniaxial tensile test and in the Brinell hardness test for the Al-15 and 18 wt.%Si alloys. In order to obtain these measurements, several specimens were extracted from the directionally solidified Al-15wt%Si and Al-18wt%Si alloys castings obtained through unidirectional solidification under transient heat flow condition. Both alloys were prepared in an induction furnace with superheat of approximately 23% over the *liquidus* temperature, which are 618ºC and 664ºC for the alloys containing 15wt% and 18wt% of Si, respectively. Then, such alloys were submitted to the unidirectional solidification experiments connected with a system for acquiring thermal data during solidification, as shown in the Figure 1.

A water-cooled directional solidification setup was used in which the transient solidification takes place vertically upwards. The alloy was melted in situ by radial electrical wiring positioned around a cylindrical stainless steel container. For a given melt temperature (23% above *liquidus* temperature of each alloy), the electric heaters were disconnected and at the same time the water flow at the bottom of the container was initiated, thus permitting the onset of solidification. Fine K-type thermocouples (0.2 mm diameter wire) were placed in the geometrical center of the cylindrical mold cavity along its length (at the positions 5mm, 10mm, 15mm, 20mm, 38mm, 52mm, 68mm, and 98mm from the metal/mold interface). All the thermocouples were connected by coaxial cables to a data logger interfaced with a computer, capable of automatically recording temperature data at a frequency of 1Hz.

The samples obtained at the positions 3mm, 5mm, 10mm, 14mm, 20mm, 25mm, 30mm, 40mm, 60mm, 70mm, 90mm, 105mm, 120mm, and 135mm from cooled casting surface were sanded from 120 *mesh* to 1500 *mesh* and then polished with 0.3μm alumina. The optical micrographs in longitudinal sections were obtained through an Olympus optical microscope with the INFINITY1 camera considering magnification from 50x to 1,000x. The eutectic spacings (λ_E) were measured on longitudinal sections of the castings. The intercept method was adopted to determine such microstructural spacing as reported by Gündüz and Çadirli[9].

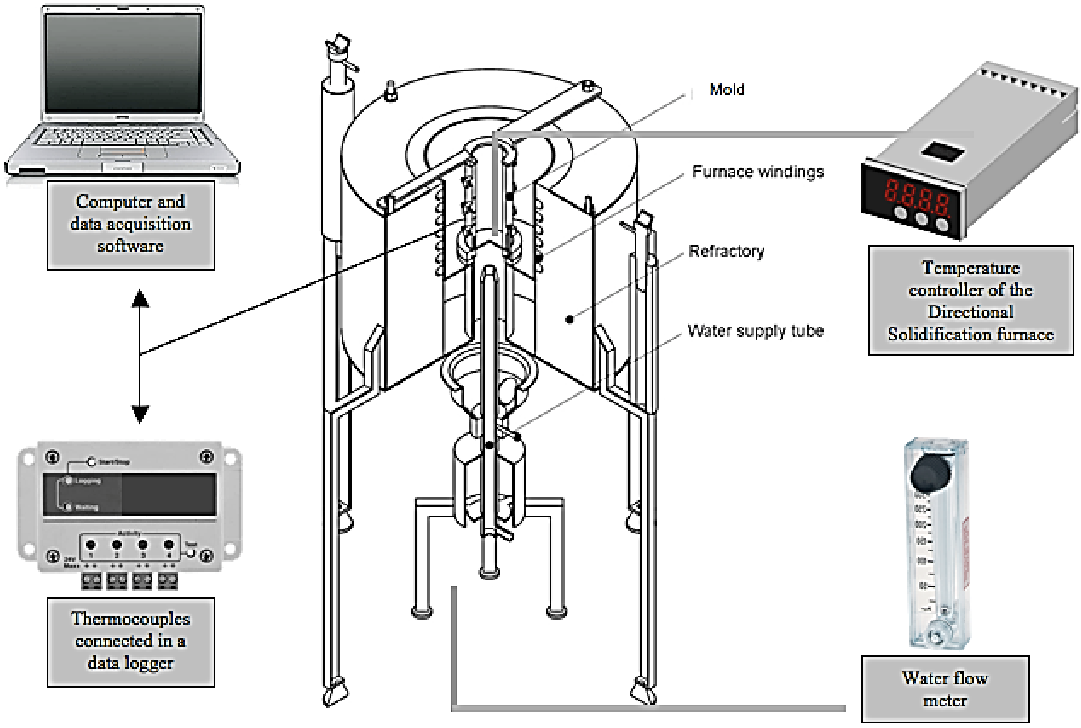

Figure 1. Unidirectional solidification system for transient heat flow extraction coupled with the necessary devices.

In order to perform tensile tests, the samples were extracted at the the positions 6mm, 20mm, 34mm, 48mm, 62mm, 76mm, and 90mm from metal/mold interface. These specimens were subjected to tensile tests at a strain rate of about 3 × 10^{-3} s^{-1}. In the case of the Brinell hardness tests, a load of 31.25kgf and a sphere of 2.5mm of diameter have been adopted for the same positions regarding the tensile test samples as described above.

Results and Discussions

According to the obtained findings, as the solidification advances in relation to the bottom of the casting, a deceleration of the growth rate is perceived due to the presence of solidified layers which become thicker. Under such conditions, heat extraction is inhibited leading to decrease on eutectic growth rate, V_E, cooling rate, $\dot{T}$, and thermal gradient, G, along the length of the solidified alloy casting. Figures 2a to 2d show the solidification thermal parameters obtained from the experiments of transient unidirectional solidification with the hypereutectic alloys Al-15wt%Si and Al-18wt%Si alloys.

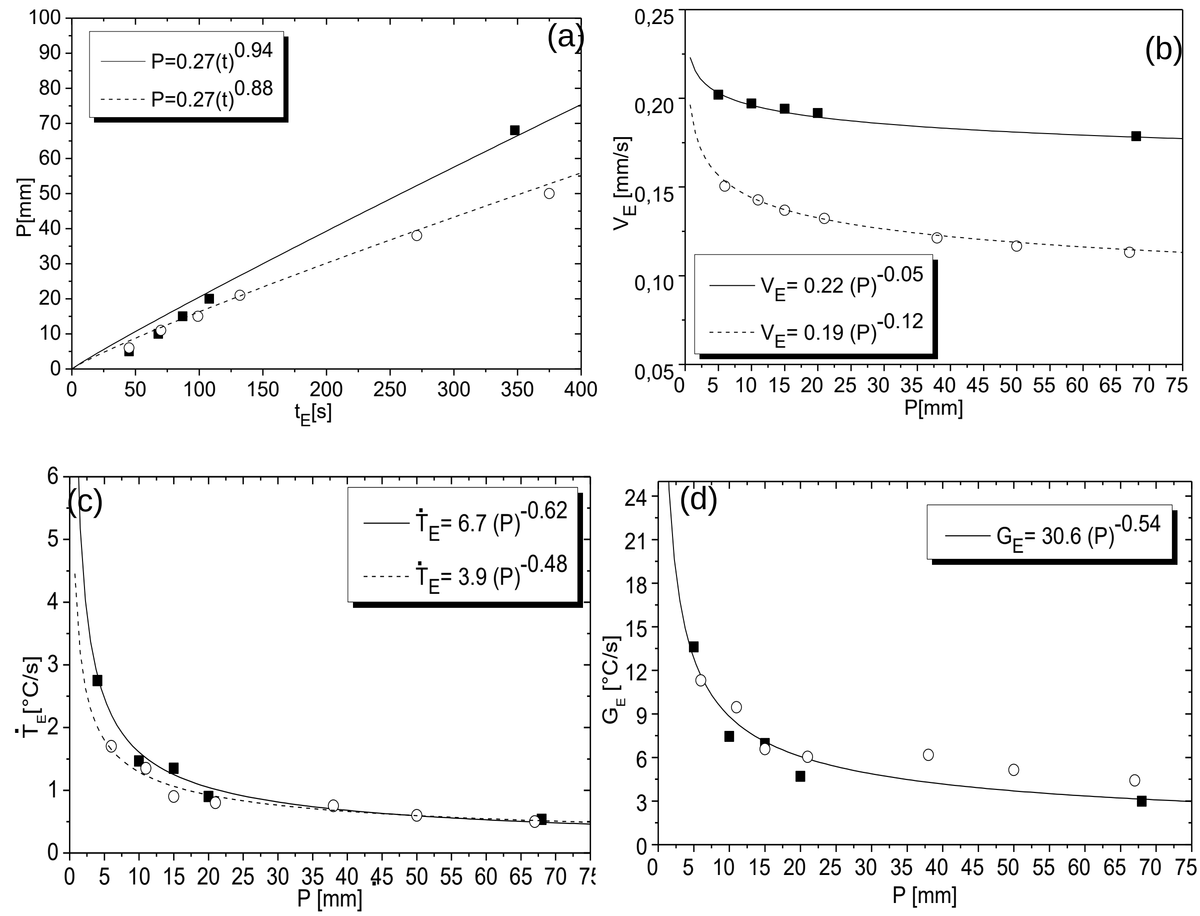

Figure 2. Graphs showing (a) Displacement of eutectic front; (b) eutectic growth rate; (c) eutectic cooling rate; and (d) thermal gradient along the Al-15wt.%Si and Al-18wt.%Si alloys. ■Al-15wt.%Si; ○Al-18wt.%Si.

Figure 2(b) shows that just a small variation on growth rate may happen along the length of the Al-Si alloys castings. This can be associated with the very high superheat temperature adopted during the experiments, i.e., the temperature corresponding to the cooling system starting during the unidirectional solidification. Comparing the experimental profiles obtained for both alloys, it is possible to notice that the cooling rate, the eutectic growth rate, and the thermal gradient profiles of the Al-18wt%Si alloy are lower than those obtained for the Al-15wt%Si alloy. In sum, the increase in the Si content tends to decrease the efficiency of heat extraction during the directional solidification.

As mentioned before, considering the positions monitored along the length of the casting, growth rate shows only a slight variation, which justifies a non-expressive difference of the eutectic spacing value obtained for both alloys as can be seen in Figure 3. The eutectic spacing of the Al-15wt%Si alloy varies from 2.5µm to 5µm between the positions 3mm and 137mm from the cooled surface of the alloy casting;

and in the case of the Al-18wt%Si alloy λ varies from 3.4μm to 5.20μm in the same interval of positions. These variations can be observed in the Figure 3.

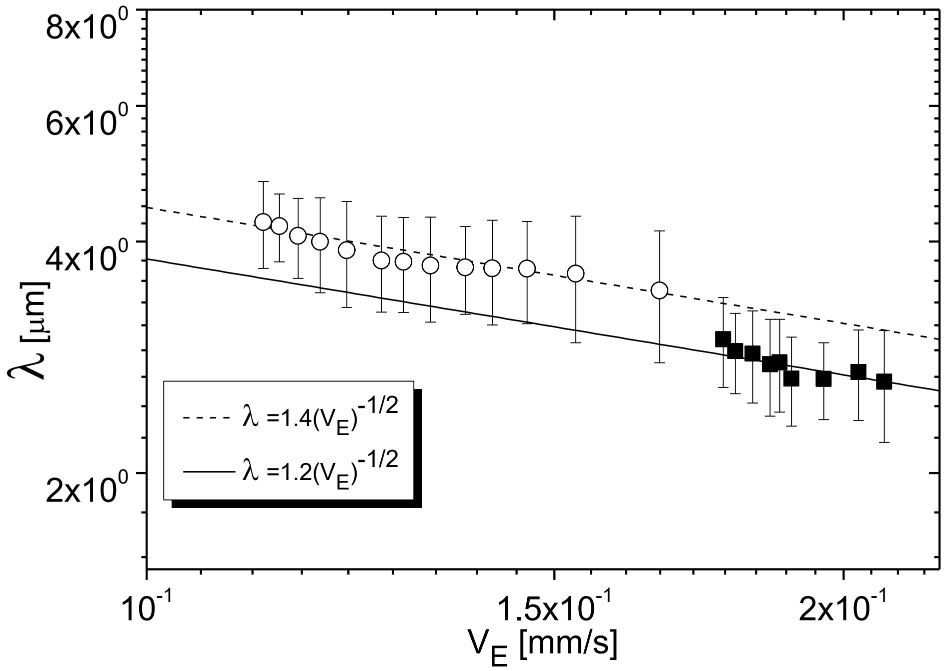

Figure 3. Eutectic spacing along the directionally solidified Al-15wt%Si and Al-18wt%Si alloys as a function of the eutectic growth rate. ■Al-15%Si; ○Al-18%Si.

The eutectic spacings were correlated with the eutectic growth rate in Figure 3. The relation λ x V_E generated an exponent of -1/2 for both examined alloys, which is in agreement with the traditional growth relation proposed by Jackson and Hunt to eutectic alloys[10-12]. Both correlations shown in Figure 3 prove that the eutectic spacing of the Al-18wt%Si alloy is higher than the eutectic spacing of the Al-15wt%Si alloy when considered the same V_E. In addition, the increase in the V_E results in a slight refinement of the microstructure.

In relation to the mechanical properties, Brinell hardness, tensile strength and elongation-to-fracture from tensile tests were obtained for both Al-Si alloys. In both cases, the mechanical properties were associated with the microstructure of the alloys through the eutectic spacing along the length of the alloy casting, as showed in the graphics of Figure 4.

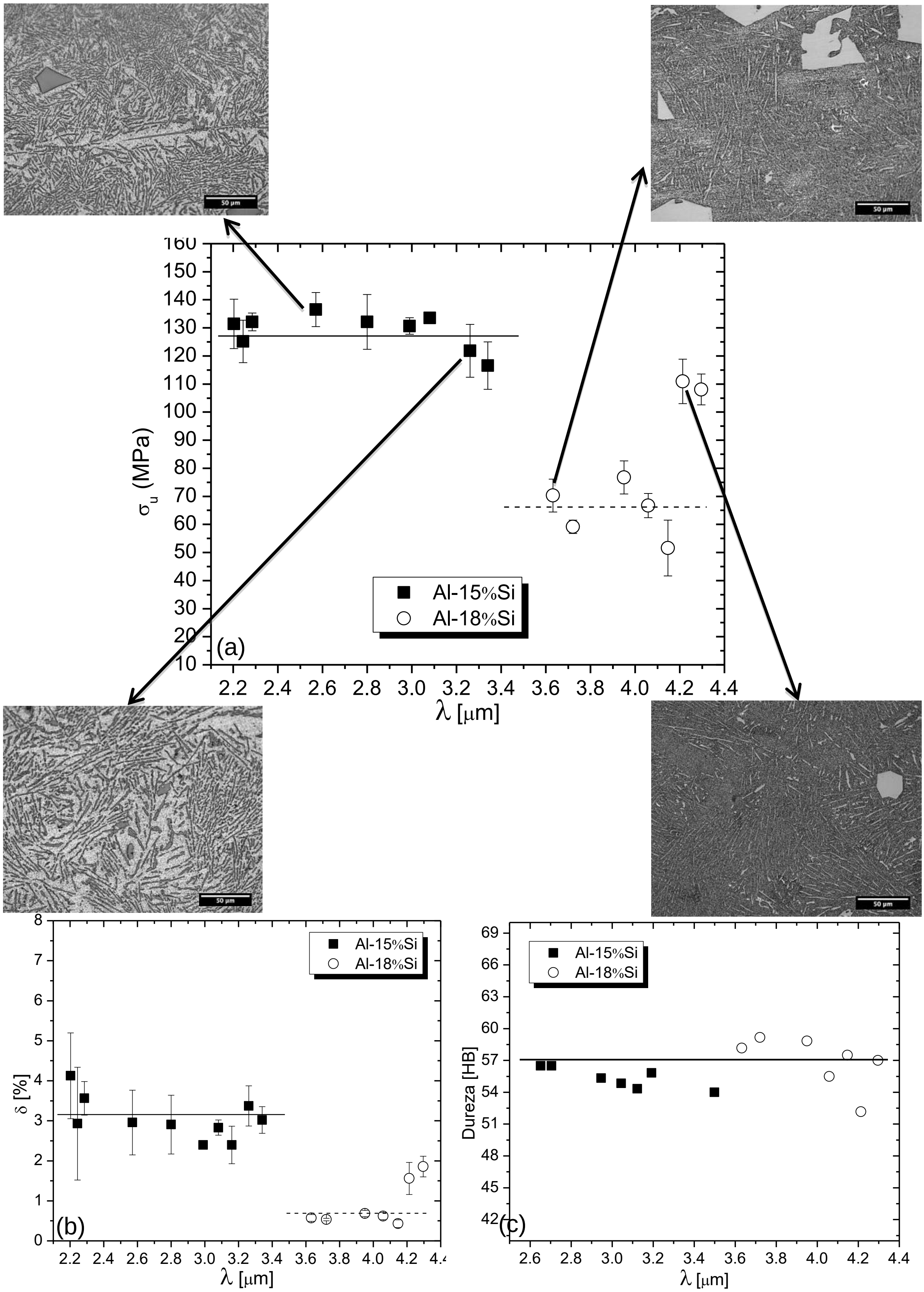

Figure 4. Tensile mechanical properties of the Al-15wt%Si and Al-18wt%Si alloys: (a) tensile strength; (b) elongation-to-fracture; and (c) Brinell Hardness as a function of the eutectic spacing (λ) ■Al-15%Si; ○Al-18%Si.

The tensile strength and elongation-to-fracture of the Al-15wt%Si alloy are higher than those found for the Al-18wt%Si alloy, and have an inconsiderable variation as a function of eutectic spacing, λ, for both alloys. The Brinell hardness maintained around 57HB, remaining roughly unaltered as function of both Si content and λ.

Conclusions

The results considering transient unidirectional solidification of Al-15wt%Si and Ali-18wt%Si alloys allow the following conclusions to be drawn:

1. In general, the present morphologies in the microstructures of the Al-15wt%Si and Al-18wt%Si alloys were a mixture of the eutectic phase, particles of primary Si, and the Al-rich dendrites. It seems to exist a dependency of the formation/permanency of one of these phases in relation to the others as a function of the solidification thermal parameters, which will be verified opportunely;

2. It was verified that the increase in the Si content of the hypereutectic Al-Si alloy causes lower eutectic growth rates and lower cooling rates to happen along the length of the casting. In other words, the solidification thermal parameters associated with the Al-18wt%Si alloy are lower than those regarding to the Al-15wt%Si alloy;

3. The experimental interval of eutectic spacing is from 2.5µm to 5µm for the directionally solidified Al-15wt%Si alloy; and from 3.4µm to 5.20µm for the Al-18wt%Si alloy. In sum, the increase in Si content causes an increase on the scale of the eutectic microstructures;

4. In both alloys it was possible to correlate the growth of the eutectic spacing λ with the eutectic growth rate through the traditional growth low proposed by Jackson and Hunt to eutectic alloys ($\lambda = k(V_E)^{-1/2}$);

5. The increase on the alloy Si content leads to decrease on tensile properties. The hardness did not suffer any considerable variation as a function of the Si content.

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