EFFECT OF THE MICROPOROSITY ON THE FATIGUE RESISTANCE OF AN ALUMINUM ALLOY A356-T6

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ABSTRACT

The enhancement of the fatigue behavior of a widely Al-Si casting alloy (A356) by affecting solidification by pressure up to 20 atm was investigated. By applying pressures of 1, 10 and 20 atm during solidification, the formation of microporosity in castings was mitigated. This enhancement in the microstructure of the alloy, related with a lower porosity, gave a significant improvement of its fatigue behavior (5 x 10^6 cycles). The microstructure is determined by the cooling rate of the alloy affecting the secondary space arm (DAS), the Eutectic Silicon particles (morphology, size and distribution), and the porosity (morphology, maximum pore size, and distribution). Also the effect of the Strontium modification and the use of flux on the fatigue behavior of this aluminum alloy were investigated.

Keywords: Mechanical fatigue, A356-T6 Aluminum Alloy, Microporosity, DAS, Pressure Casting.

1. INTRODUCTION

Advances in melt degassing and fluxing, filtration, and casting design procedures have improved the ability to produce high quality aluminum castings, porosity and oxide inclusions are still the most nagging metallurgical aspects pertaining to the manufacture of structural castings. Both porosity and oxides in the casting impair the ductility (elongation) of the materials and thus the fatigue strength [1,2,3].

When aluminum alloys are solidified, as the temperature decreases, hydrogen is rejected from the solid into the intergranular liquid [4]. If the remaining liquid becomes saturated with hydrogen, porosity may nucleate. The application of 10 atm pressure during solidification of aluminum alloy castings has been reported. Cylinder blocks and cylinder heads for outboard and inboard marine engines are made by the “Pressurized lost foam” process [5]. The stated advantages of components made by this process are “reduced porosity to near undetectable levels; increased elongation properties; and increased fatigue life.”

In experimental work on the relation between fatigue life and microstructures in A356.2 [6,7] it was found that when the secondary dendrite arm spacing (DAS) was less than 30 μm and the pore sizes were below the critical value of approximately 80-100 μm, large eutectic constituents initiated the high-cycle fatigue cracks.

The use of strontium modification in aluminum alloys has been the target of numerous researches.[8,9,10,11,12,13,14] On one hand, modification of A356.2 changes the morphology of the silicon particles in the eutectic constituent from plate-like to fibrous form and results in rounder and finer silicon particles after solution heat treatment. Hence, modification can

improve the ultimate tensile strength and percent elongation [9,10,11,12]. On the other hand, the added porosity associated with Sr modification may nullify the beneficial effect of the improvement in the silicon morphology.
In this paper experiments were conducted at 4 different casting pressures (Vacuum, 1 atm, 10 atm, and 20 atm) with A356, a casting alloy that is often used in many applications. The casting were made in a Vacuum/pressure vessel that allowed both melting and casting to take place under a gas mixture of varying pressures and with hydrogen as one of the components. Also the effect of the DAS and strontium modification on the fatigue life of the aluminum alloy A356-T6 was evaluated.

2. MATERIALS AND METHODS

2.1 Casting

The alloy was melted in a fixed alumina crucible using a 175 kW induction power supply, where an alumina stopper rod at the bottom of the crucible allowed for the casting of metal into a ceramic mold below. The mold was designed to produce a casting 24.1 cm tall, 7.6 cm wide and 2.5 cm thick. The bottom of the mold was open and placed on a water cooled copper chill to effect directional solidification, and flexible heating tapes were wrapped around the mold for preheating. To minimize heat losses, the mold and heating tapes were enveloped with fine sand and covered with insulation. The temperatures during solidification and cooling were measured in some castings with a vertical array of six thermocouples. Table 1 shows the 16 ingots that were cast at 4 different pressures (Vacuum, 1 atm, 10 atm and 20 atm) obtaining 4 groups of 4 plates.

Table 1.- Features of the different cast plates.

Group N°	Characteristics of the cast alloy	Plate #	Casting Pressure
1	A356 without flux	4	Vacuum (0.0019 PSI)
	"	12	15 PSI
	"	13	150 PSI
	"	15	300 PSI
2	A356 + Sr without flux	5	Vacuum (0.0019 PSI)
	"	8	15 PSI
	"	9	150 PSI
	"	10	300 PSI
3	A356 with flux	7	Vacuum (0.0019 PSI)
	"	11	15 PSI
	"	14	150 PSI
	"	16	300 PSI
4	A356 + Sr with flux	6	Vacuum (0.0019 PSI)
	"	17	15 PSI
	"	18	150 PSI
	"	19	300 PSI

2.2 Heat treatment and machining

After the castings the ingots were cut into slices for the fatigue specimens at different distances from the chill, with the flat surfaces of each slice parallel to the face of bottom-chill. The plates were then heat treated under T6 conditions (538 ºC (1000 ºF) for 5 hours, water quenched at a temperature of 72 ºC (162 ºF), and aged within the next 2 hours at 160 ºC (320 ºF) for 4 hours. The heat treated slices were machined with a surface finishing of 16 micro-inches, in order to obtain the fatigue samples.

2.3 Axial fatigue testing

The high-cycle fatigue tests were conducted using a close-loop servo-hydraulic testing machine (MTS 810), in load control mode using sinusoidal loading at a frequency of 15Hz where there is not vibration in the servo-hydraulic machine. The stress ratio was R = 0.1, and the maximum/minimum stresses were set to 175/17.5 MPa.

2.4 Microstructural characterization

Quantitative metallographic examination was carried out under an optical microscope using an image analysis software package (Image-Pro). Reported porosity values (maximum size, minimum size, mean size and distribution) and other microstructural features are those measured on the plane of polish. Optical microscopy was conducted to examine the transverse section of the fatigue specimens to determine the secondary dendrite arm spacing (DAS), which was measured by the line-intercept method.

3. RESULTS DISCUSSION

3.1 Effect of porosity on the fatigue life

Figure 1 shows the effect of the Maximum pore size on the fatigue life, at a constant pressure, groups 3 and 4. The fatigue life increases as the Maximum pore size decreases in the microstructure for each group of plates. Also within each group of plates, the fatigue life increases as the casting pressure increases.

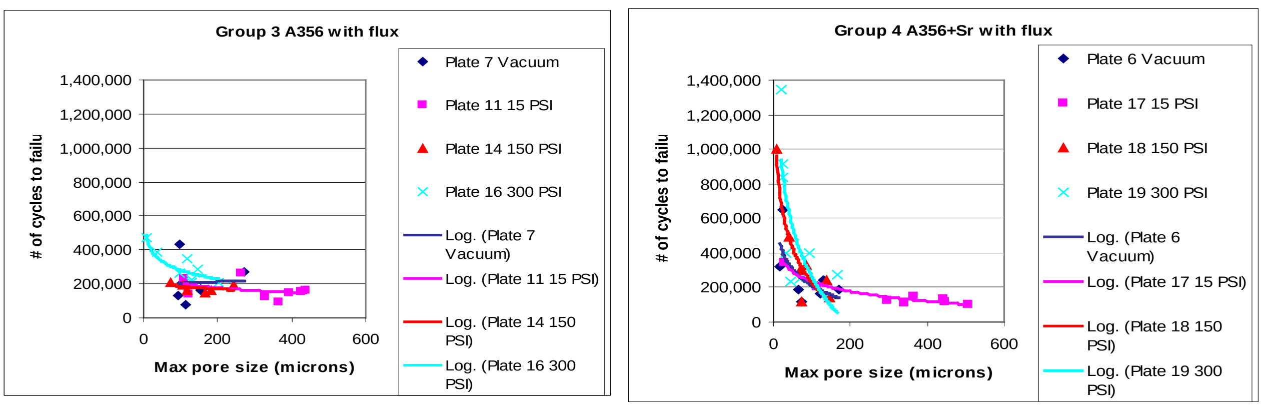

Figure 1.Effect of the porosity on the fatigue life

3.2 Effect of DAS on the fatigue life

The fatigue life increases as the DAS size decreases in the microstructure for each group of plates. Also within each group of plates, the fatigue life increases as the casting pressure increases.

CONCLUSIONS

The fatigue life increases as the Maximum pore size decreases in the microstructure for each group of plates. Also within each group of plates, the fatigue life increases as the casting pressure increases.

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