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ABSTRACT

The microstructure and mechanical properties of pressure die cast components are influenced largely by the solidification and filling behavior of the alloy in the cavity during the injection phase. It is not uncommon to find very significant variations in the microstructure and properties of a given component from one region to another. This paper examines these variations in the A357 alloy die cast at different temperatures – from a temperature near the liquidus to one a little above the eutectic temperature. Reheated commercial thixotropic feedstock material of 76 mm diameter and 152 mm long was used. Specimens from the castings produced at various temperatures were cut and evaluated. Variations in mechanical properties at difficult locations are discussed and explained in terms of variations in the microstructure and the presence of casting defects in the alloy.

Key Word: Pressure Die Casting, Semi-Solid Casting, Microstructure, Mechanical Properties, A357 Alloy

INTRODUCTION

Aluminum-silicon alloys have excellent castability and mechanical properties when gravity or pressure die cast and are used extensively in the automotive industry. In applications where superior mechanical properties are desirable, parts are often heat-treated to the T5 or T6 condition to further enhance their properties. More recently, aluminum-silicon alloy components are also being produced from semi-solid billets or slurries, complementing traditional methods of producing components from liquid metal (1). Alloys most commonly employed for semi-solid casting have a nominal silicon content of 7% and a magnesium content of 0.35% (A356) and 0.55% (A357) respectively. The higher magnesium-containing alloy has higher tensile properties and is more responsive to heat-treatment (2).

Research on net-shape casting at Industrial Materials Institute over the past several years has focused on different aspects of semi-solid die casting of aluminum and magnesium alloys, using thixotropic bars produced either commercially or in a laboratory under controlled conditions. Activities include developing techniques to reheat billets by induction efficiently, characterizing flow and solidification in the die cavity by means of ultrasonic sensors and optimizing conditions to produce high-integrity components in a die casting machine (3-9). At the Materials Technology Laboratory, Canmet, activities on semi-solid forming are related to the production of thixotropic feedstock by electromagnetic stirring, reheating and forging of billets, and characterization of properties and microstructures (10-14).

In this paper, results of work by researchers from the two laboratories to investigate microstructures and mechanical properties of castings produced from A357 alloy at different alloy temperatures are presented. This study is important in that in past semi-solid casting experiments, small variations in the temperature of the feedstock (and thus fraction solid) have often been found to affect part quality significantly. By controlling the feedstock temperature accurately, it would be possible to establish systematically how the morphology and mechanical properties of a given part would differ when cast at different intervals between the solidus and liquidus temperatures.

EXPERIMENTAL

A Buhler 600T capacity SC N/53 die casting machine and an experimental die were employed to cast specimens for evaluation (3-4). The die contains features necessary to evaluate metal flow and solidification under typical production conditions and produces a 1.4 kg box-like component of 240 mm long, 138 mm wide and 90 mm deep, with a wall thickness that varies from 5 to 9 mm (Figure 1).

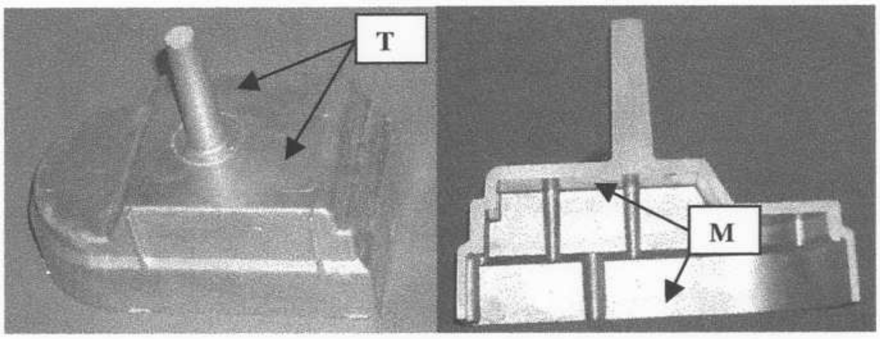


Figure 1: Casting showing locations where samples were taken for analyses (T: Tensile; M: Microstructure)

The experiments were conducted using 3-inch diameter A357 commercial billets with a non-dendritic microstructure generated by electromagnetic stirring. Each billet was contained in a ceramic fiber crucible and inductively heated to a preset temperature in the range of 565 ° C to 625 ° C just prior to injection at a pre-determined ram speed (3). An intensified metal pressure of at least 500 bars (50 MPa) and a ram speed of 1.0 m/s during the filling phase were used. The die was maintained at a temperature of 200 -250 ° C.

The liquid fraction of the A357 alloy as a function of temperature was obtained from thermal analysis by means of DSC (Differential Scanning Calorimetry) measurements. These measurements were performed in a Netzsch Model STA 449C Jupiter TG-DTA/TG-DSC system. Within the solidus-liquidus temperature range, liquid fraction at a given temperature is computed by a software program (Netzsch Proteus Thermal Analysis Software, Version 4.2) that calculates the ratio of the area under the energy-temperature curve associated with that temperature to the total area for the entire melting range.

Samples removed for microstructure evaluations were polished to a 1μm finish and etched with 0.5% HF solution. A Clemex image analysis system was used to measure the α particle size as well as the cross-sectional volume fraction of the eutectic phase at a selected microscopic field. At least six fields at locations near the center or the edge were analyzed at a magnification of 100X to obtain their respective average α sizes and eutectic fractions in percentages. The α particle measurements require that the particles have a well-defined boundary. Where it was difficult to delineate these particles as in samples cast at 565 ° C and 625 ° C respectively, measurements were not made

Sub-sized ASTM (E8-00b) tensile strip specimens were machined from the flat top region of box adjacent to the ingate. Around this region, material has been found to be most sound as conditions for feeding and solidification under an intensified pressure are most favorable.

RESULTS AND DISCUSSION

Solid Fractions and Morphologies at Various Alloy Temperatures

As shown in the percentage liquid versus temperature curve obtained from DSC measurements in Figure 2, the A357 alloy begins to melt at 550 ° C and attains a 0% solid fraction at just over 620 °C. At 565 °C, the lowest casting temperature practical, the material has a solid fraction of more than 90%. At such a high fraction solid level, it was found to be difficult to fill more than approximately 50% of the die cavity. The relatively steep rise in the curve between 570 ° C and 600 ° C indicates a rapid change in solid fraction with increasing temperature. Within a temperature range of 30 °C, the solid fraction varies from 30% to 90%. Past experiments (3,4) have showed that best results are obtained when the feedstock material is heated to 585 ° C, corresponding to a solid fraction of about 50%.

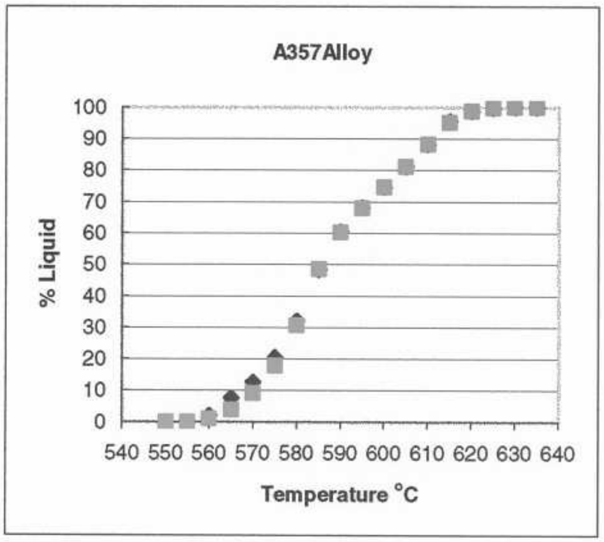
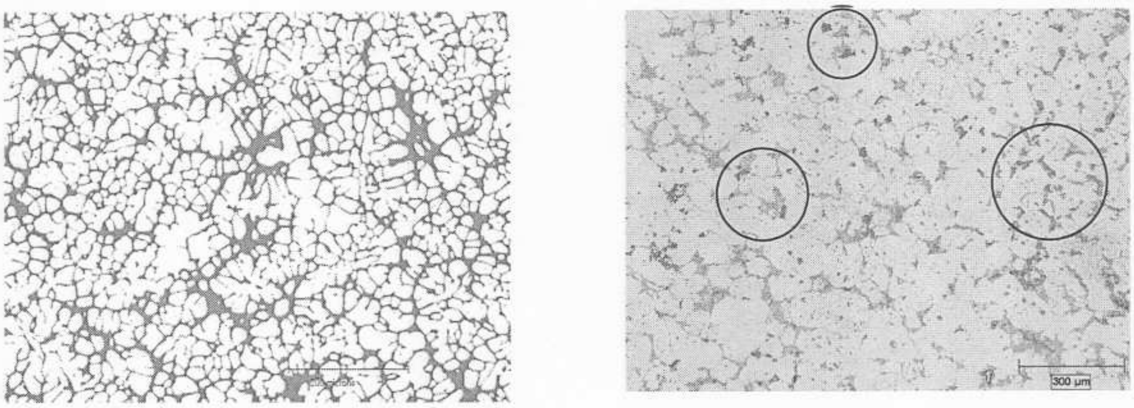


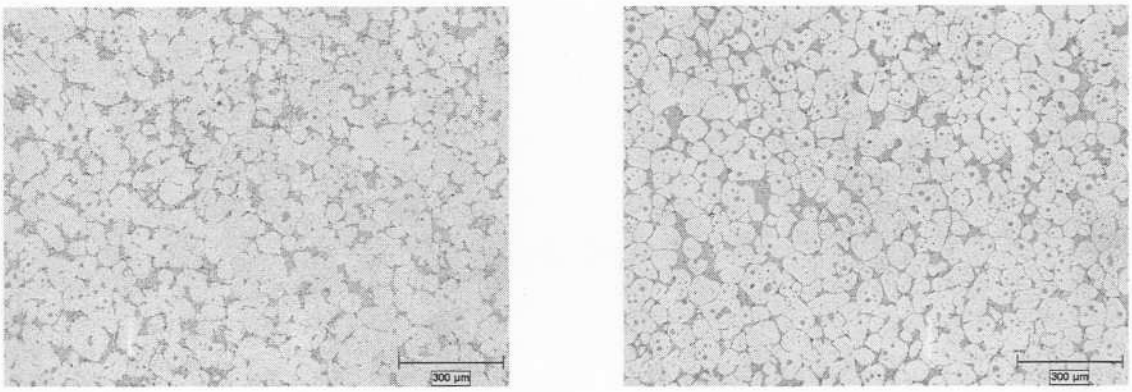
Figure 2: Liquid fraction as a function of temperature for the A357 alloy obtained from two test runs

Typical microstructures of samples cut from the flat region near the ingate of castings produced at various temperatures are shown in Figures 3. At 565 ° C, initial melting of the eutectic phase in the feedstock material is observed and agglomeration of the rosette and equiaxed α particles takes place. As melting of the eutectic phase could not be completed at this temperature, primary silicon crystals are produced. These relatively large crystals (see circled areas) are formed by the coalescence of smaller silicon particles between the α grains and have previously been observed in production parts (15). Micrographs from samples cast at higher temperatures do not contain primary



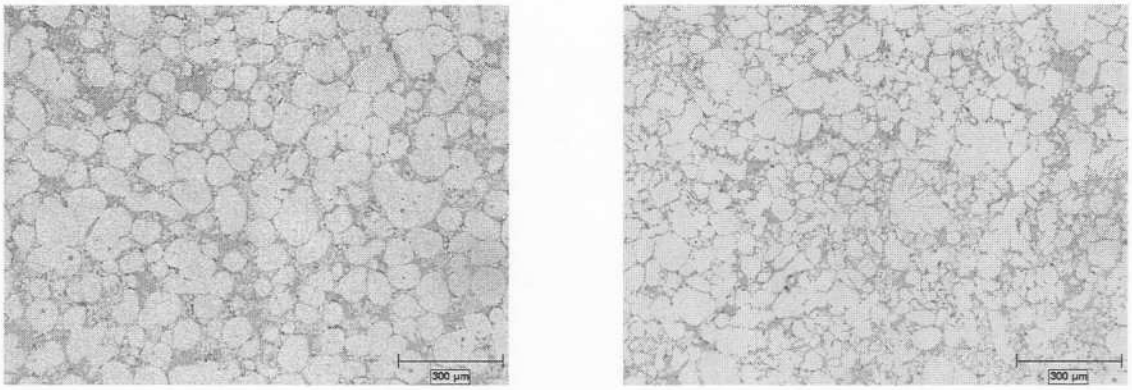
(a) Feedstock

(b) 565 C



(c) 575 C

(d) 585 C



(e) 600 C

(f) 625 C

Figure 3: Typical microstructures of A357 cast at various temperatures (samples taken from region near the gate). Note the presence of primary silicon particles (circled areas) and fine secondary α particles in the eutectic phase in (e) and (f).

silicon particles and the α and eutectic phases are more clearly defined. At 585 ° C, a globular α structure with entrapped eutectic liquid typical of A357 semi-solid castings produced from rheocast thixotropic billets is observed. When the liquid fraction increases further with increasing metal temperature, the sizes of the α particles become larger and are also less globular. In addition, finely dispersed secondary α particles not commonly present in samples cast at lower alloy temperatures appear in abundance in the eutectic liquid. Thus at 625 ° C, the α phase consists of a mixture of globular and equiaxed particles, a few dendrites and fine secondary α particles nucleated from the solidifying liquid.

Results of image analyses to estimate the different percentages of eutectic phase and the average sizes of α grains near the gate and edge regions of the castings at various temperatures are shown in Table 1. As expected, the percentage of eutectic phase generally increases with increasing temperature, though samples taken near the edge do not display as clear a trend as those taken near the gate. This may be due to the less orderly manner in which the metal is filled towards the end of the injection phase when several metal fronts meet. Depending on where a sample is taken, it is not uncommon to find regions rich or poor in eutectic, especially near the surface. Where it was possible to measure the average α particle size, its value increased with increasing casting temperature since growth rate would expect to be higher.

Table 1: Eutectic Percentage and α Particle Size versus Casting Temperature

	Casting Temperature °C				
	565	575	585	600	625
Eutectic phase at the edge (%)	32.40	42.49	34.07	38.5	35.7
Eutectic phase near gate (%)	15.20	22.51	25.26	31.5	32.3
Average α particle size near gate (micron)	NA*	NA*	81.23	98.8	NA*
Average α particle size near edge (micron)	NA*	74.55	82.67	99.3	NA*

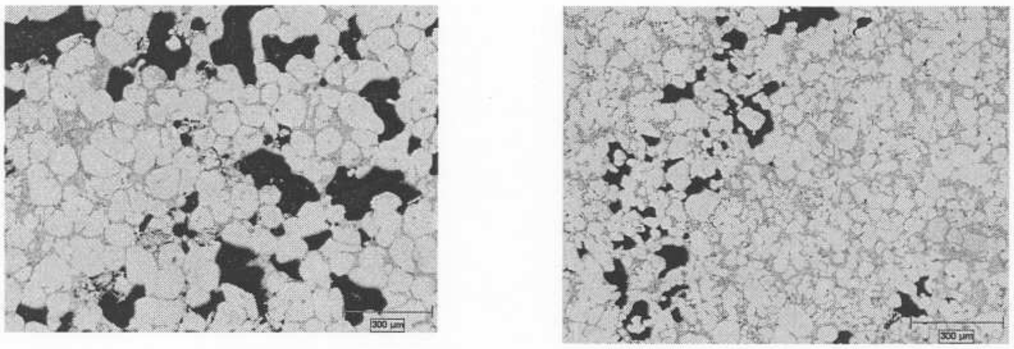
*NA : Not available due to difficulty in delineating alpha grains

Mechanical Properties and Defects

Results of tensile tests of as-cast samples cut from the flat region near the ingate are given in Table 2. It is evident that tensile strength and ductility increase with casting temperature, however these properties deteriorate significantly when the alloy approaches the fully liquid state. This deterioration in properties has been found to relate mostly to the higher level of defects seen in castings from feedstock containing little or no solid.

Table 2: Mechanical Properties of the Components at Various Casting Temperatures

Properties	Casting Temperature °C				
	565	575	585	600	625
Ultimate Tensile Strength, MPa	188 ± 16.8	192 ± 11.7	209 ± 10.5	154±18.4	160 ± 15.6
0.2% Yield Stress, MPa	119 ± 1.8	105 ± 3.9	106 ± 2.6	99 ± 3.0	92 ± 2.2
Elongation, %	3.2 ± 1.8	6.3 ± 1.7	8.0 ± 4.5	2.0 ± 1.1	3.1 ± 1.2



(a) (b)

Figure 4: Shrinkage voids observed in specimens cast at 600 °C (a) and 625 °C (b).

Examination of fractured surfaces of tensile specimens and other cross-sectional areas of castings away from the ingate showed that defects appeared mostly as shrinkage voids in the center of the wall or in regions that were difficult to feed. Although all samples examined had some shrinkage defects, they were found to be more numerous and larger in castings with a higher liquid fraction. Figure 4 shows some examples of shrinkage voids observed in samples cast at temperatures of 600 °C and 625 °C respectively. These voids between the α particles reduce not only the material thickness but also provide a convenient path for cracks to propagate. In test bars where optimal feeding can de achieved through proper control of parameters such as injection pressure, metal temperature and die temperature, properties significantly higher than those reported in Table 2 are usually obtained (16). Thus, in production components, it can be expected that mechanical properties would vary from one region to the next and reflect the material soundness of the particular region. It should also be mentioned that industrial castings could also contain other defects such as cold shuts, laps, gas porosity and inclusions (oxides and intermetallics) that might equally be detrimental to mechanical properties.

CONCLUSION

Microstructures of castings produced from commercial thixotropic A357 billets inductively heated to different solid fractions have been characterized, as follows:

- A poorly developed globular α phase containing primary silicon crystals at a sold fraction of 90% (565 °C)
- A well-developed globular α phase at a solid fraction of 50% suitable for semi-solid forming (585 °C)
- A mixed structure containing globules, equiaxed α particles, finely dispersed secondary α particles, and dendrites at 100% liquid fraction (625 °C)

Mechanical properties were found to be highest in samples cast at a fraction solid of approximately 50%. Shrinkage defects detrimental to mechanical properties were found to be less numerous in castings produced at this temperature compared those cast from liquid metal.

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