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Component Production Using Casting Aluminum Alloys

Extended Abstract

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1. Introduction

This thesis is based on a study aimed at optimizing the production of bodies of air conditioning compressors for motor vehicles, by die casting of aluminum alloys. The work was developed in Halla Climate Control Portugal, in Palmela. In the production of these pieces, porosity was recurrently observed in the parts to a level which made them unsuitable for use. The aim of this work of Master's thesis in Materials Engineering, was to identify the causes for these abnormalities in production. The approach taken was to observe the entire production process, and select critical areas where samples of aluminum were made. Then, proceeding with a series of chemical and metallographic analysis (optical microscopy, SEM, EDS, Optical Emission Spectroscopy, X-rays Diffraction) and, based on the results, the causes were detected, and lines of action were proposed, to correct and control the variables of the process that produced metallurgical non-conformities in the parts.

The aluminum alloy used was the A383.1, an alloy that, besides aluminum as it’s main elements, has silicon, iron, copper, manganese, magnesium, zinc, nickel, lead, and, as residual elements, chromium, tin, titanium, bismuth, calcium, vanadium and cobalt. Halla worked with the aluminum of two suppliers, Alcasa and Befesa.

In aluminum injected foundries, an accumulation of residues occur at the bottom of the melting furnaces in the form of solid compounds of heavy elements, commonly called the "sludge". The "sludge" is composed of primary crystals containing aluminum and silicon, but which are also rich in iron, manganese and chromium. These crystals have high melting points, and high specific gravities, which causes them to accumulate in the bottom of the oven. These crystals appear only in alloys that have sufficiently large quantities of iron, manganese, and/or chromium, and also depending on the temperature of the furnace. The buildup of "sludge" may eventually reduce the effective area of the oven. It can also cause other adverse effects, such as "hard points" in parts (due to inclusions), the greater tendency of certain alloys to weld at the molding cavity, and restrict the flow of metal during casting. “Sludge” may consist of phases such as AlSiFe or AlSiFeMn(Cr).

Some authors have defined an empirical factor (the “Sludge Factor”), given by:

$$\text{Sludge Factor} = (1 \times \%Fe) + (2 \times \%Mn) + (3 \times \%Cr) \quad [1]$$

When this factor becomes larger than a certain critical value, then “sludge” may occur.

2. Results

After collecting samples of aluminum from both suppliers, from key points in the production line, namely Fusion Furnace, Holding Furnace and Lade, an observation was made, using a metallographic microscope. By observing the microstructure, it was possible to identify the formation of what appeared to be “sludge” precipitates. It was important to make further and more extensive observations and testing.

In a first approach, optical microscopy and Optical Emission Spectroscopy was made. In figure 1, bellow, we can see one of those micrographics corresponding to what is the ideal structure of the aluminum, with an lamellar eutectic phase present in a sparse primary aluminum matrix, from the Alcasa supplier, along the iron and silicon composition (an 200X magnification was used).

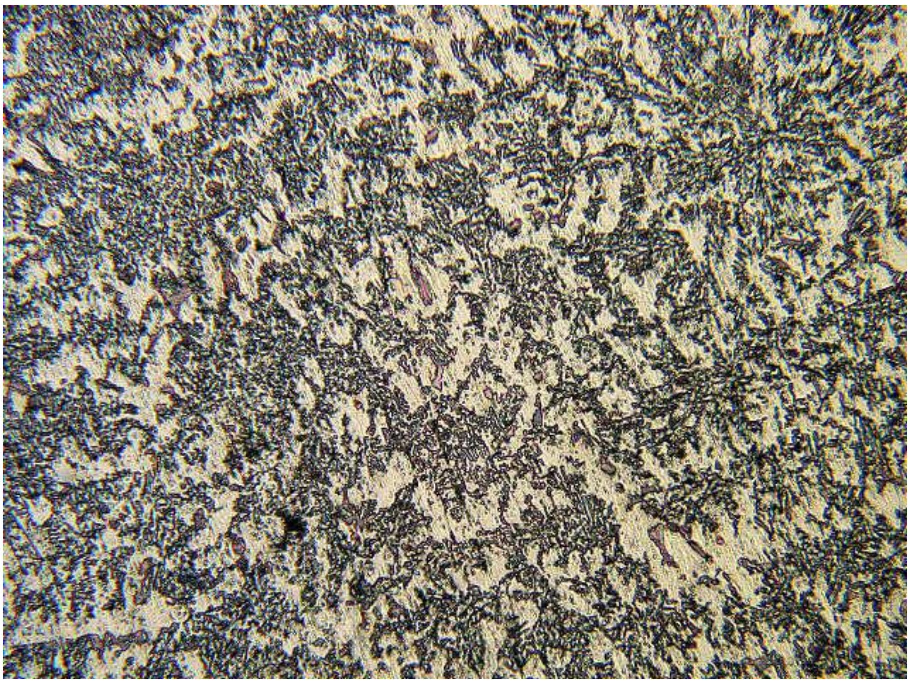

Fig. 1 - Alcasa (sample AL-10-W), Holding Furnace 0.873% Fe 1.110% Si.

Now, a non-ideal structure, also from an Alcasa sample, is show in figure 2, with no lamellar eutectic present, and several “sludge” precipitates in a large primary aluminum matrix.

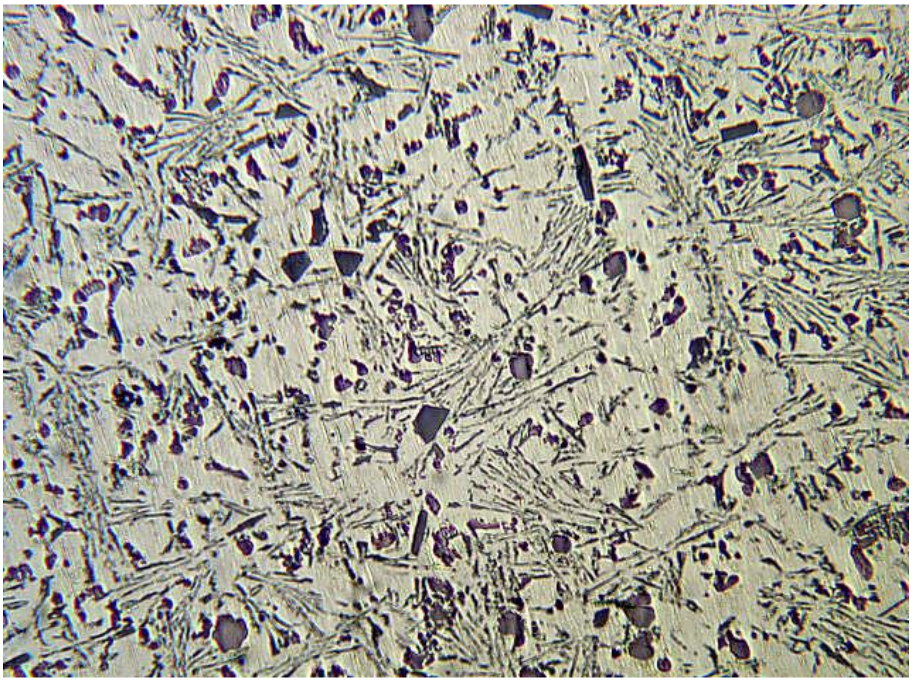

Fig. 2 - Alcasa (sample AL-5-W), a form of waiting, 0.790% Fe, 10.59% Si.

SEM-EDS analysis was also made, in order to further observe and indentify the several precipitates detected. As an example, it is showed, in figure 3, a picture of a Befesa sample, in which large hexagonal “sludge” crystals are observed in Befesa samples retrieved from the melting furnace.

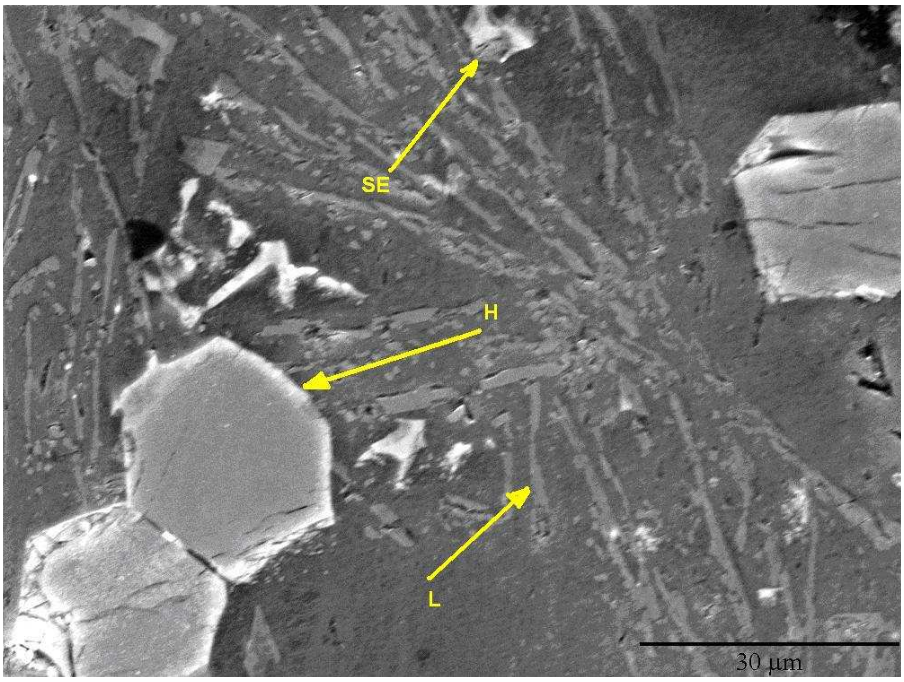

Fig. 3 - Befesa, Melting Furnace, (H - precipitate in the form of Hexagon, SE - Second Eutectic, L - Lamella)

The phases present in the samples were identified by X-ray diffraction. A difractogram of a sample is presented as an example, with the correspondent peak identification of the phases present in it.

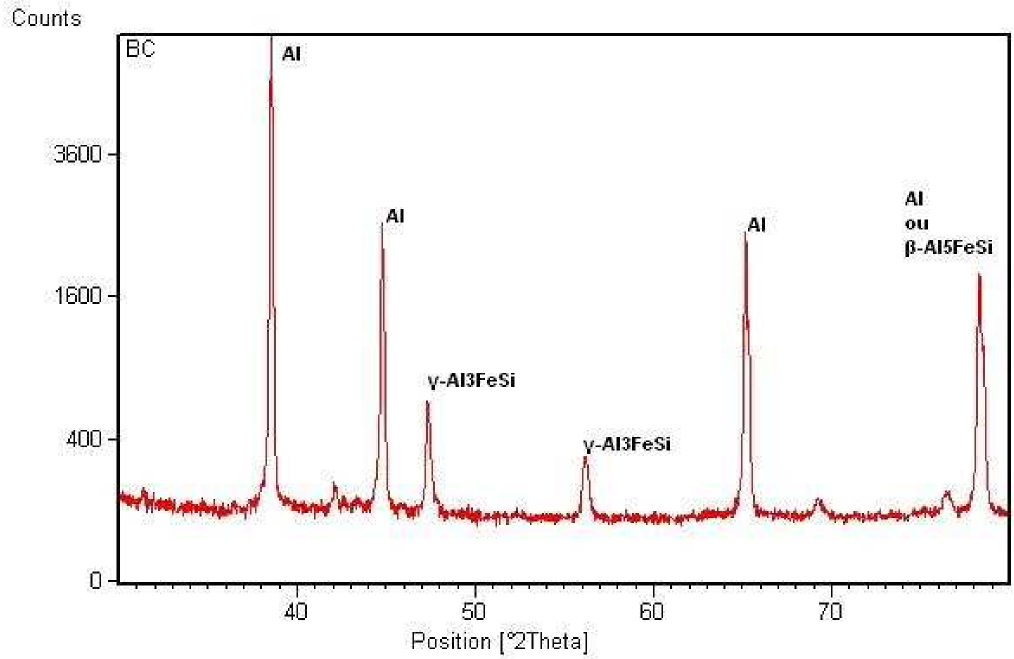

Fig. 4 - Befesa, Lade. Peaks 38.505 (111), 44.778 (200), 65.194 (220) – Aluminum. Peaks 47.061 (113) 55.020 (223) - γ-Al3FeSi. Peak 78.152 – β-Al5FeSi, or 78.305 (311) – Aluminum.

3. Conclusions and Recommendations

The results obtained during the eight months in which this work was carried out enabled to reach the following conclusions:

• It was not detected (by use of EDS) contamination by foreign elements in any of the alloys;

• The use of the Sludge Factor equation is not a sufficient criterion to determine whether or not "sludge" precipitation occurs;

• In Aluminum Befesa, some precipitates associated with the "sludge" appeared in the first step, next to the furnace. These precipitates remained essentially the same size, controlled during the later stages of the process. With Alcasa, the precipitates appeared with a considerable size in the holding furnace, and in the lade these precipitates grow further;

• There is, in the Alcasa aluminum, more formation of silicon precipitates than in the primary aluminum Befesa. These precipitates can lead to a lower fluidity of the molten aluminum in the molding cavity;

• The most relevant observation was that in the Alcasa aluminum, in the last two stages, it simply was not observed the presence of any lamellar eutectic phase. Moreover, in Befesa, the eutectic structure remained present, and with a considerable percentage, even after the end of the lade stage;

• Intersecting the chemical compositions of various samples, with the quality of the obtained microstructure, it was found that the most significant variation which leads to porosity was that of the iron, because when it was far from an ideal percentage (around 0.85 to 0.90%), there was loss of lamellar eutectic, and a growth in "sludge" precipitates;

• It was then concluded that the percentage of iron is the main factor, in the working conditions encountered in Halla Climate Control Portugal, which leads to the appearance of crystals of "sludge", and no formation of lamellar eutectic, and the consequent formation of an exaggerated quantity of primary grain of aluminum. All factors that contribute to the appearance of porosity in manufactured parts;

• Analysis of the set of all samples collected enabled to conclude that the ideal composition in terms of iron is between 0.83% and 0.90%, approximately. However, depending on the composition of silicon, this rule may allow less, or more, iron percentage. Example: in a sample of aluminum Befesa, with 1% Iron, there was good dispersion of primary aluminum, eutectic grain, and almost no "sludge". The percentage of silicon was slightly smaller than 10% (normally is 11%.) It would perhaps be allowed an upper limit of 1% iron, when the composition of silicon was lower (around 10%);

• Suppliers (at least Alcasa), ensure in their aluminum an iron percentage never inferior to 0.850%. However, in the specimens, the vast majority were below this value. It is concluded that this lack of control in the chemical composition occurs when the returns are mixed (sprue, rejected parts...) with the material "virgin" in ingots. Since these returns were added at a proportion of (approximately) 50% return, 50% "virgin" and that the returns were introduced into the furnace indiscriminately, without any prior selection (depending on supplier, lot, type of return...), there was often a variation of chemical composition sufficient to tip the percentage of iron to unacceptable values.

To control these deviations from the ideal conditions of composition and structure, it was presented to Halla Climate Control Portugal the following recommendations:

• Make a metallographic control through micrographs and chemical composition, frequently;

• Depending if the chemical composition of iron present is below the desired value, it might be possible to correct it, with the addition, in the Spoon or the Fusion Furnace, of iron: for example, ferroalloy, or mild steel (the latter presents, as possible problem, it's sulphur content.) This addition would be done by carefully calculating, in order to know the quantity to add to obtain the desired value;

• If the chemical composition of iron is excessive, it is recommended that the temperature in the Holding Furnace is increased to the highest that the process can allow, because it would allow to avoid the isothermal line of the phase diagram that occurs 650º C, which promotes the formation of one of the phases associated with the "sludge";

• The more "problematic" aluminum alloys should tend to be placed in the furnace during the weekend, when the oven is on, with no production, because being impossible to further increase the melting temperature to dissolve "sludge" crystals, they may dissolve at lower temperatures than the ideal, if the dissolution time is enough;

• Making a more careful separation of the parts that return rejected (by mechanical tests, etc.), from Visteon, plant which was the main destination of the parts produced in Halla, and that also had a self-control of the quality of parts shipped.

4. <u>References</u>

[1] Understanding Sludge, John L. Jorstad