Cooling Rate Effect Study on the Microstructure and Hardness of Hypereutectic Aluminum Al-18%Si Elaborated by V-process

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Abstract— **The solidification process significantly affects the microstructure and mechanical properties of molding workpiece, and there are numerous factors that affect this process. Much progress has been made in the research on the solidification effect on microstructure and mechanical properties. This study deals with the solidification in V-process, the main studied parameter is the massively cooling rate effect on the microstructure and hardness. The experimental study shows that when the surface is small, the solidification rate is higher and the microstructure is more refined than when the surface is large. However, the cooling rate is very important in the case of small section; it reaches a maximum value that equals to 5°C / s; with this rate, the average hardness value rises to 51.97 (HRA).**

Keywords— **hypereutectic Al-Si, primary silicon, cooling rate, hardness, V-process, microstructure.**

I. INTRODUCTION

Aluminum is considered as a suitable metal for sustainable development because it combines both light Weight and good physical and mechanical characteristics [1-2]. This fosters its use to reduce cars and aeronautic equipment's weight and other automotive applications [3-7].

In Al-Si alloys that contain more than 12 wt%, Si exhibits hypereutectic microstructure, normally consisting of the primary silicon phase in the eutectic matrix [8,9]. α-Fe formation can also be affected by the superheating and cooling rate. For instance, when the melt is superheated up to 200–300∘C above the liquid temperature, the iron compound crystallizes in the form of α -Fe at a high cooling rate with no Mn presence [10-14]. Furthermore, increasing the cooling rate increases the critical content of Fe at which β-Fe first appears. When the cooling rate is 1°C/s, the critical Fe content is 0.75 wt%, but when the cooling rate is 10∘Cs−1, the critical Fe content increases to 1.0 wt% [15]. The parameter that exerts the highest influence on the strength levels and the required

internal quality is the solidification rate; as the material microstructure is refined, solidification proceeds at a higher rate [16–19].

Recently, hypereutectic Al-Si alloys have been widely used in automotive applications, especially in the piston industry due to their excellent properties, including low coefficient of thermal expansion, low density, good corrosion resistance, high wear resistance, and so on[20-21]. However, the use of this alloy in-process V is being extended.

In the present study, the temperature effect and cooling rate on the microstructure and the characteristics of aluminum hypereutectic Al-18%Si is considered, using the V-process), as will be shown, the two parameters directly affect the primary silicon and hardness grain size .

II. EXPERIMENTAL PROCEDURE:

The hypereutectic Al-Si alloys used in the experiments were produced by melting reflow the ingot in electrical resistance furnace. The experimental alloys chemical compositions are shown in Table 1 (all quoted compositions in this work are in wt%).

TABLE1: COMPOSITION OF ALUMINUM ALLOY

Element	Si	Cu	Mg	Mn	Fe	Al
content	18	0.5	0.8	0.5	0.01	Bal

The moulding technique V-process was then processed with depression sand was 6 bars. The part dimensions are as follows:

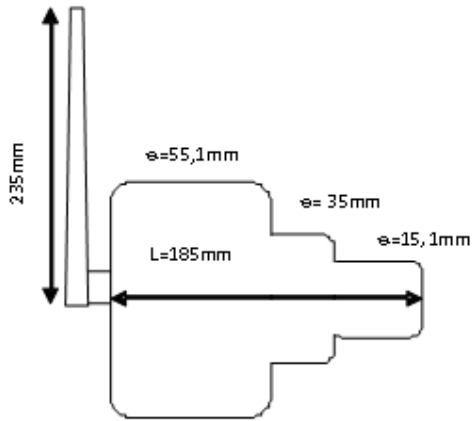Fig1: schematic dimensions of part for casting experiments

The liquid metal was poured into a mold whose size is $500 \times 500 \times 300$, based on the sand whose fineness index is equal to 52AFA, three K-type thermocouples were stuck in three areas of different sections to record the temperature as a function of time during the solidification. The three thermocouples were connected to a data acquisition and recording system.
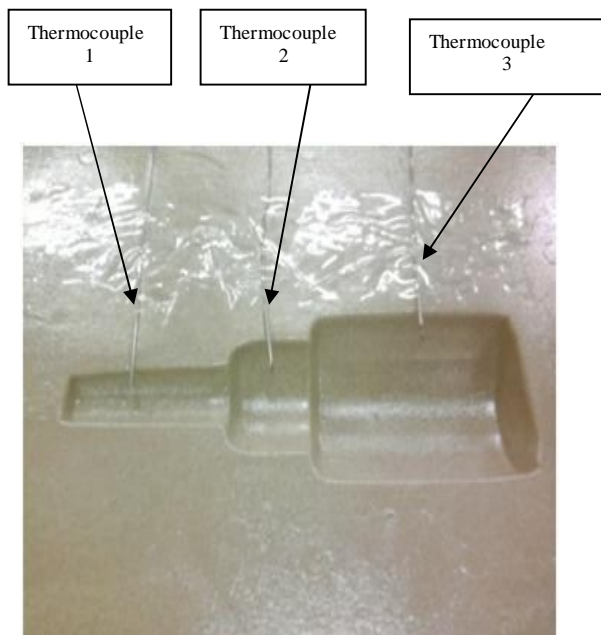

Fig 2 : Shot of lower mold half with three position thermocouples

Fig3: photo of the drag and the cope thermocouples

After collecting the molded part, a surface treatment was proceded by taking the following these steps:

After the recorded data was made in tabular form, temperature variation was plotted with time and a derivative of this curve was performed by using the original software.

The corresponding curve for cooling rate was obtained. Hypersilicié aluminum alloy Part was cut with an electric saw, and polishing was carried out on a range of sandpaper for 200 to 1000 with a grain finish by diamond pasta. Etching is made by Keller reagent (2.5 ml HNO3 and HCl 1.5 ml, 0.5 ml HF) for 3 min. Microstructure observation is made by using an optical microscope and numurisation is performed by LCD camera with a 10 Megapixel resolution,

Our experimental work is splitted into two parts:

First part: Study the effect of cross section massivity on the microstructure and hardness. Two areas were compared: a small area (zone 1) and a large one (Zone 2)
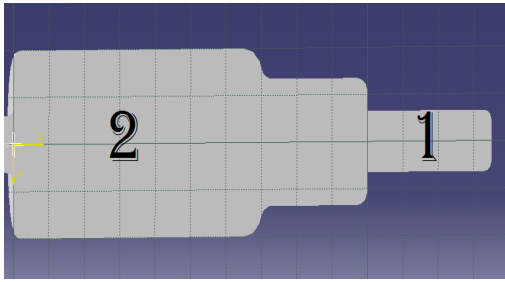
Fig4: position of zone 1 and zone 2 in the casting part.

Second part: Study the effect of pouring temperature, (730 ° C, 750 ° C and 780 ° C), setting the zone 2 as reference.

III. RESULTS AND DISCUSSION

1- The cross section effect on the microstructure and hardness

Melt temperature equals 750° C, the results below present the microstructures and cooling curves, and then the derivatives of these curves are calculated to plot the cooling rate. This work is done for both zones 1 and 2 that are shown in the fig5:
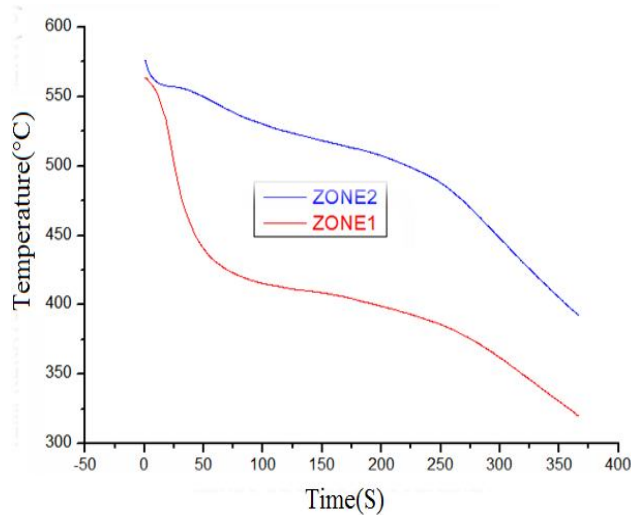

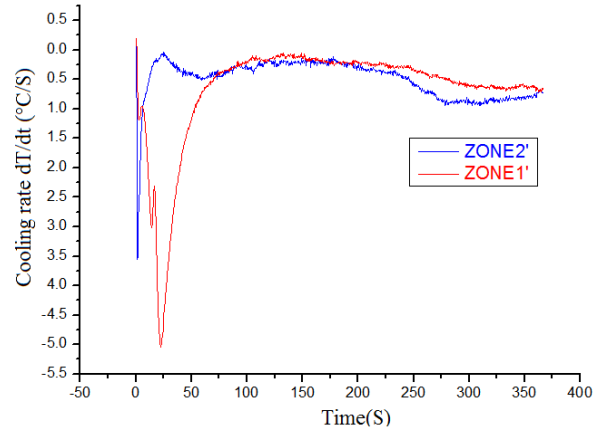Fig5: Temperature curves of cooling during solidification for both zones 1 and 2

Fig 6: the red and blue curves represent respectively the cooling rates versus time for zone 1 and 2.

It can be deduced from these two curves that the small section area rapidly solidifies, especially in the first 25 seconds and can reach a maximum cooling rate that equals to $5°C / s$.
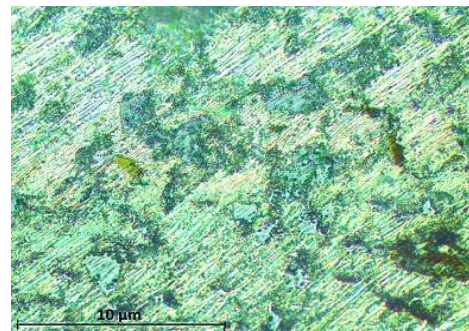

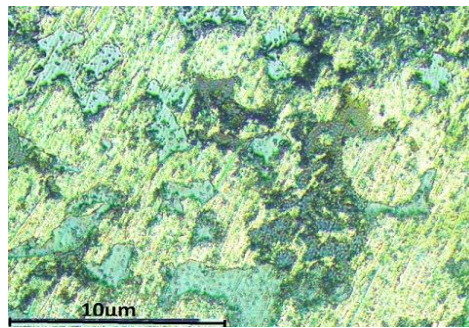Fig .7.1: Microstructure of small section part zone 1

Fig. 7.2: Microstructure of large section part zone 2

Hardness values are measured at both areas, the table below gives the obtained values.

TABLE 2

HARDNESS VALUES MEASURED AND CALCULATED AS MEAN VALUE

measure number	1	2	3	4	average hardness (HRA)
zone 1	50.7	53.5	43.8	59.9	**51.97**
zone 2	52.8	49.1	46.7	32.6	**45.3**

By using ImageJ software, it was possible to calculate the primary silicon surfaces. Table below shows the obtained values:

TABLE 3

AVERAGE PRIMARY GRAIN SURFACE SILICON

	number of silicon surface	total area (mm^2)	average area (mm^2)	silicon fraction
Zone 1	27	28.254	1.046	**7.5**
Zone 2	17	73.541	4.326	**20.7**

It can be deduced from fig8 that during the solidification process in v-process like other methods, the areas having a small section solidify first with a very high solidification rate, which directly influences on microstructure. It was also noted that in areas of small sections, primary silicone is refined over areas of large sections; this directly and positively influences on the mechanical characteristics, as table 2 shows the average hardness of the small section area is larger than the large-sectional.

2- Study of the effect of pouring temperature on v-process

In this experiment, the zone 2 (large section) is set as study area, and the effect of pouring temperatures will be studied. In our case, three temperatures 730°C, 750°C and 780°C were chosen. In this section, the cooling curves were ploted for the three temperature of the bath; it was observed here that the bath temperatures are different from the indicated values in the curves made to the cooling metal during the casting operation.
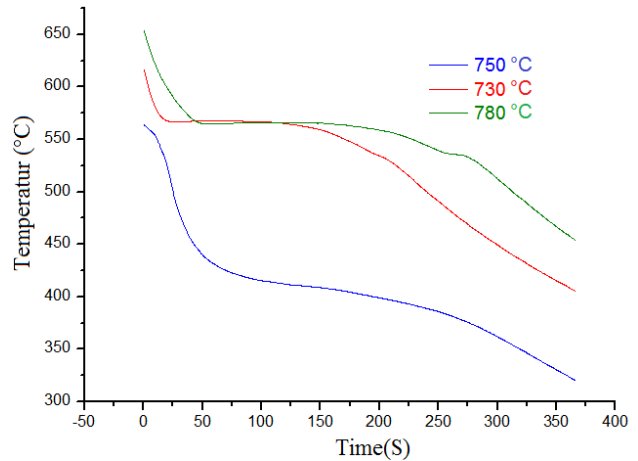

Fig 9: cooling curve for three bath temperature 730°C 750°C and 780°C.
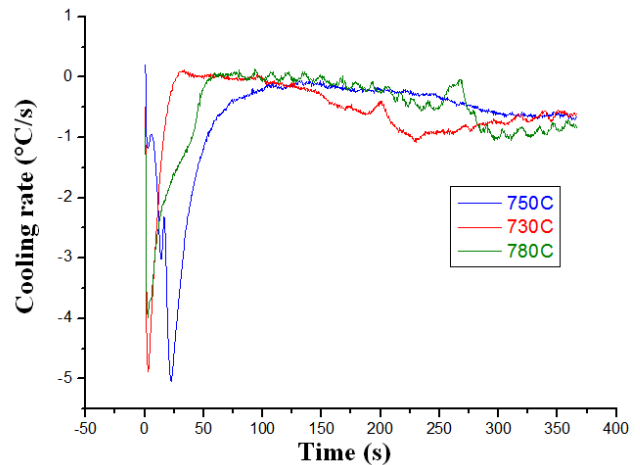

Fig 10: the red blue and green curves represent respectively the cooling rates versus time for 750°C, 730°C and 780°C
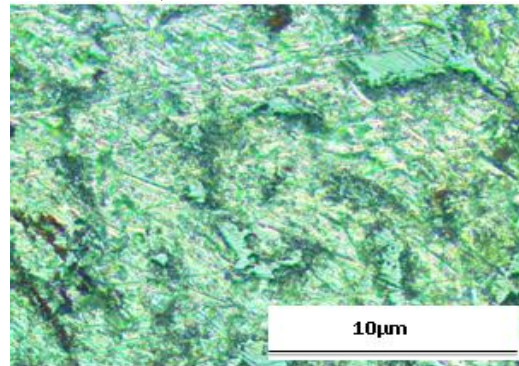

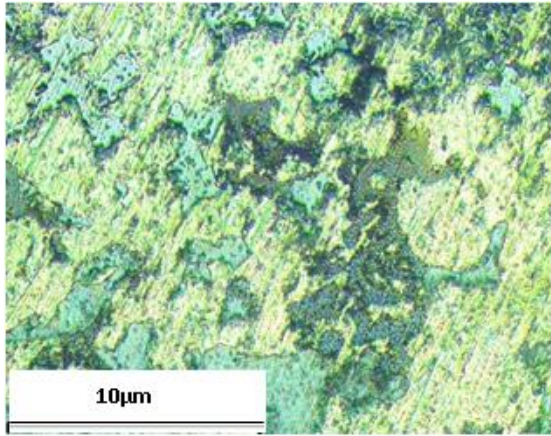Fig 11.1: Microstructures of the simples zone 2 / T$_1$=730°C
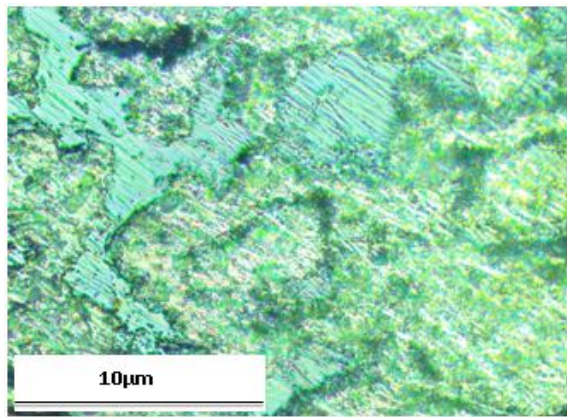
Fig 11.2: Microstructures of the simples zone 2 / T$_2$=750℃

Fig 11.3: Microstructures of the simples zone 2 at temperature T$_3$=780°C.

The obtained curves show that the pouring temperature has a direct effect on the microstructure, such as when the temperature increases the casting microstructure continuously varies as the found optimum temperature for a fine microstructure is 730°C. It was deduced that when the pouring temperature decreases the grains are refined, which provides a good mechanical characteristic. It was deduced that when the bath temperature decreases the grains are refined, which provides good mechanical characteristic. The table below is consistent with the microstructure, like what hardness measurement shows when the high value of hardness is obtained for a 730°C bath temperature.

TABLE 4: MEASURING THE HARDNESS (HRA) FOR VARIOUS VALUES OF TEMPERATURE OF THE BATH.

measure number	1	2	3	4	average hardness (HRA)
Zone 2/ T=730°C	44	50.3	47.7	43.8	**46.45**
Zone 2/ T=750°C	52.8	49.1	46.7	32.6	**45.3**
Zone 2/ T=780°C	40	38.6	36	12.2	**31.7**

IV. CONCLUSIONS

A stepped mold casting experiment in v-process about area 1 zone and area 2 was carried out, and the following conclusions were obtained.

(1) The v-solidification process of vertical surfaces of a part is directly influenced by the sections surfaces. Solidification for a small area is faster than a large area

(2) For both areas under study, a difference in cooling rate of 1.5 ° C/S results in the hardness variation of 6.67 (HRA)

(3) A pre-rafined is made with the high cooling rate. A histogram grain distribution size shows that the area small section is refining.

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