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SOLIDIFICATION CHARACTERISTICS OF MODEL 356 Al-7Si ALLOY

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ABSTRACT

Cooling curve analysis (CCA) was conducted in a graphite crucible using K-type thermocouples. Solidification temperatures of the basic phases were identified based on past literature techniques; and curves were plotted in conjunction to collected Microsoft Office-Excel raw data. Start of solidification, dendrite coherency temperature (DCT), Al-Si, Al-Si-Cu, and end of solidification temperatures were identified. Optimal solution heat treatment temperature of these alloys was recommended to be 500^{o}C.

Keywords: Al-Si alloys, solution heat treatment, solidification characteristics.

1. INTRODUCTION

Al-Si alloys are taking the lead among the commercial aluminium foundry alloys because they possess many desirable properties including: high corrosion resistance, excellent castability, low thermal expansion, excellent thermal conductivity, high strength to weight ratio, low density, good wear resistance, and are recyclable and relatively inexpensive [1], [2]. For these reasons, they find numerous applications in the automotive, aerospace, construction, and general engineering applications industries [1], [3], [4].

Recycling of aluminium alloys has been on a global increase due to the numerous advantages associated with it such as: energy saving and pollution reduction. Therefore, there is a likely increase in the uptake of secondary cast aluminium alloys in automotive and structural applications. High demand for excellent performing automotive engines has increased the need for continuous development of improved cast aluminium alloys for power-train components that possess desirable properties such as high fatigue performance. The aluminium industry is characterized by lack of informed knowledge on optimal heat treatment parameters necessary to ensure precipitation of sufficient quantities of strengthening precipitates.

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Simulation applications are on the increase since they improve production process of cast products in addition to speeding up design and acting as inexpensive prototypes for testing of various parameters that influence desired performance [7]. Therefore, as new model Al-Si alloys come up, there is a need to determine their solidification characteristic temperatures and unique fatigue strengths at a desired number of cycles. The results can then be used as databases to simulation applications which are widely used for design in this age in the aluminum industry.

Better control of the production process leads to improved product quality. The analysis of cooling curve analysis (CCA) finds its basis on the fact that any event that occurs during cooling affects the shape of the cooling curve (slopes and inflection points) and of its derivatives. This has been attributed to the heat released in the course of solidification and the accompanying microstructure transformation during the solidification process [7].

The most important parameters considered during solution treatment of Al-Si alloys are temperature and time. Generally, the temperature must be lower than the melting point of the Cu-rich phases but at the same time, it should be able to facilitate dissolution of the Cu phase and spheroidisation of the Si phase. Therefore, TA results are paramount in providing a deep understanding of the changes that occur during melting of castings. CCA tests can be conducted to obtain reliable CCA data and to use the obtained data to propose informed optimum solution heat treatment parameters.

2. METHODOLOGY

One laboratory tests were performed i.e. CCA tests. The alloy investigated in this research is a variant of alloy 356 obtained by alloying using transition elements. The following master alloys were used: Al-50 wt. % Cu, Al- 15 wt. % Ti, Al-5 wt. % V, Al-10 wt. % Zr, and Al-10 wt. % Cr in form of briquettes and Al-10 wt. % Sr in form of rods. Alloying was done to give the alloy investigated the desired microstructure. Optical emission spectroscopy was used to characterize the chemical composition of the alloy tested (356M) whose compositions are shown in Table I.

Table I: Chemical composition of alloy investigated

Alloy code	Experimental alloy with the total composition of each additive element in the alloy (wt. %).
356M	356 + 0.5% Cu + 0.15% Ti + 0.15% Zr + 0.25% V +0.015% Sr+ 0.15%Cr

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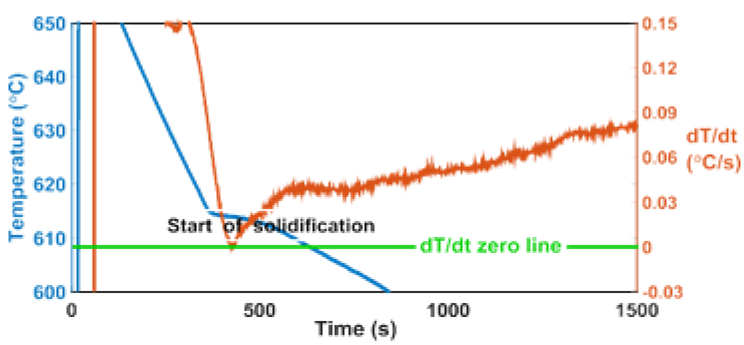
Alloy 356M was melted in an ELSKLO s.r.o. electric resistance furnace to a temperature of 735°C. Tempered K-type thermocouples (5mm outside sheath diameter and 50mm probe length) were calibrated several times using 99.999% pure aluminium before any measurement was taken. The molten metal was then poured inside a graphite crucible (60 mm internal diameter and 65 mm height), preheated to 400°C, which was placed on top of a 6 mm thick ceramic insulation material. Two appropriately clamped calibrated thermocouples were simultaneously dipped in the molten metal, one at the centre and the other near the wall, each at a height of 22 mm from the bottom of the crucible. The crucible was also insulated at the top using a 6 mm thick ceramic insulation material before any measurements were taken. The thermocouples were connected to a high acquisition data logger which was connected to a laptop installed with DATAQ Instruments Software Manager. This way, temperature decrease with time was recorded. Two CCA tests were conducted to ensure reproducibility of results.

3. RESULTS AND DISCUSSION

Various criteria are used to identify various solidification temperatures: start of solidification, dendrite coherency temperature (DCT), Al-Si, Al-Si-Cu, and end of solidification [5], [6], [8]–[13]. The solidification characteristic temperatures of alloy 356M-A are shown in Table IV. The plots used to obtain the temperatures are shown in Fig. 4 (a) - 4(d).

The cooling rate of the aluminium melt in the graphite crucibles was approximately 0.10 $^{o}Cs^{-1}$. This was due to the small sample size. This low cooling rate was used because when the cooling rate is too high, there is very fast heat release leading to difficulty in recording initial solidification steps and inability of the first derivative of temperature versus time (dT/dt) curve to arrest released latent heat during phase solidification.



(a)

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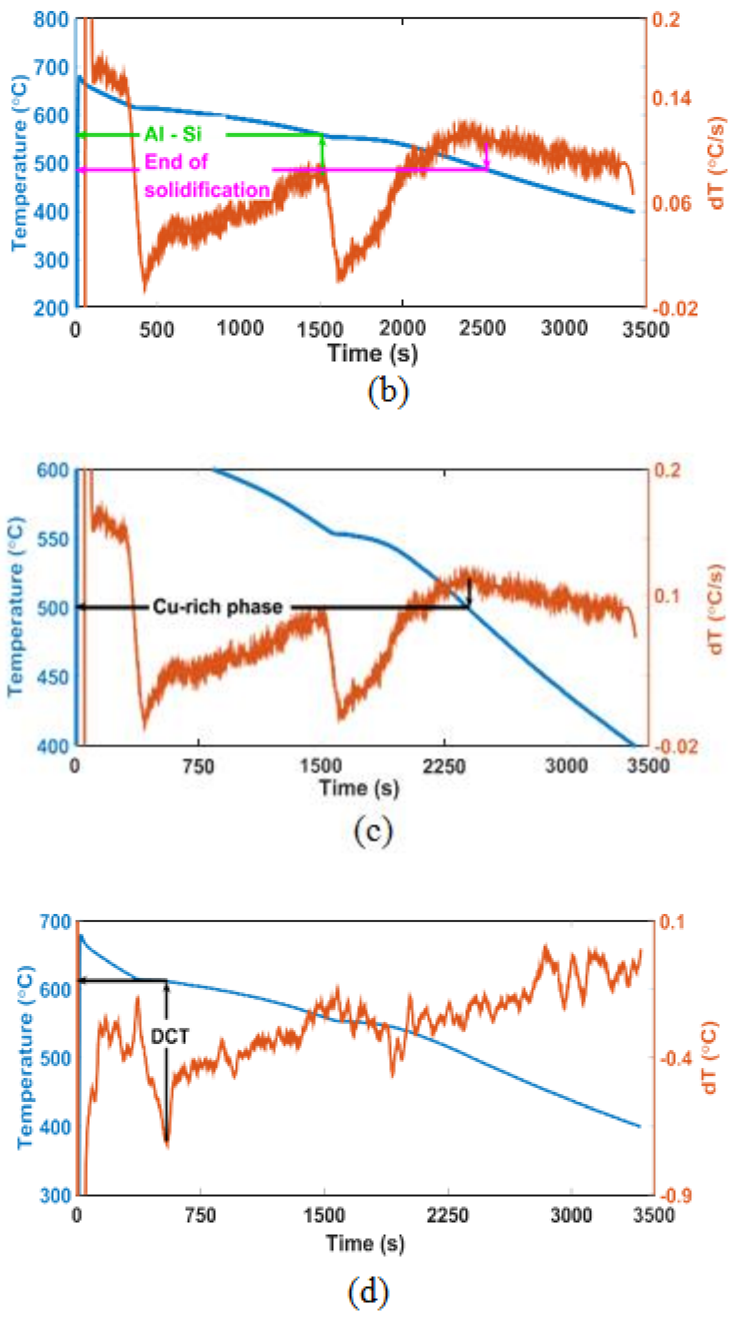

Fig. 4: Identification of phases' solidification températures: (a) Start of solidification; (b) Al-Si and end of solidification; (c) Cu-rich phases; (d) DCT

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Table IV: Phases' solidification temperatures

Solidification phases	Solidification temperature (°C)
α-Al dendrite nucleation	613.0
DCT	611.0
Al-Si	558.5
Al-Si-Cu	500.5
Solidus	487.8

The start of solidification, DCT, Al-Si, Al-Si-Cu, and end of solidification temperatures were found to be: 613.0 °C, 611.0 °C, 558.5 °C, 500.5 °C, and 487.8°C respectively as shown in Table IV. At least one peak of the Cu-rich phase was identified. Some peaks were present in the vicinity of the identified peak but they were least suspected to be associated with the Cu-rich phase since they were not very distinct. The inability to identify all Cu-rich phases is associated with weak latent heats that characterize solidification of 356 alloys. The identified solidification temperature of the Cu-rich phase indicated that the maximum temperature at which alloy 356M-A can be subjected to solution heat treatment while minimizing incipient melting is 500°C.

Table V: Chemical composition in wt. % of some sample alloys subjected to CCA tests in literature

	1 [12]	2 [12]	3 [12]	4 [12]	5 [12]	6 [12]
Si	5.91	5.90	5.82	5.78	8.03	8.14
Fe	0.07	0.11	0.06	0.07	0.136	0.123
Cu	1.07	1.83	3.03	3.96	1.09	1.93
Mg	0.14	0.15	0.15	0.13	0.0006	0.0007
Mn	0.01	0.01	0.01	0.01	0.0029	0.0028
Ti	-	-	-	-	-	-
Sr	-	-	-	-	-	-
Other	0.01-Zn	0.01-Zn	0.01-Zn	0.01-Zn	0.003-Zn	0.0025 - Zn
	7 [12]	8 [12]	9[13]# 10[13]*	11[13]# 12[13]*	13[13]# 14[13]*	15[13]# 16[13]*
Si	8.03	7.84	7.13	7.05	6.95	6.75
Fe	0.141	0.138	0.12	0.13	0.14	0.12
Cu	2.96	4.31	0.96	1.98	3.05	4.38
Mg	0.0009	0.0008	0.28	0.28	0.26	0.29
Mn Ti	0.0032	0.0031	0.01	0.01	0.01	0.01
Sr	-	-	0.056	0.079	0.081	0.091
Other	-	-	0.0041	0.004	0.0031	0.0042

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	0.003-Zn	0.003-Zn	0.01-Zn	0.01 -Zn	0.007-Ni	0.01-Zn

Table VI: Solidification characteristic temperatures of the alloys in Table V

Serial No. [Reference]	Solidification temperatures 1	2	3	4	5
1 [12]	622.4	616.1	573.7	518.7	501.7
2 [12]	618.9	615.0	570.5	518.3	502.2
3 [12]	614.8	611.7	569.3	522.0	502.7
4 [12]	610.3	608.3	566.9	522.9	501.8
5 [12]	600.7	598.7	575.0	517.4	501.8
6 [12]	601.7	597.9	572.2	517.2	499.4
7 [12]	600.5	591.0	569.3	517.7	494.5
8 [12]	596.8	587.8	565.9	516.3	495.7
9 [13]- #	613.3	611.1	570.3	526.2	482.3
10 [13]-*	611.4	NA	571.8	533.7	509.9
11 [13]- #	610.3	606.1	569.0	508.5	480.4
12 [13]-*	608.5	NA	569.2	518.7	509.9
13 [13]- #	607.4	602.6	562.2	507.4	482.1
14 [13]-*	605.6	NA	566.6	512.9	509.9
15 [13]- #	604.6	600.2	558.9	509.6	481.9
16 [13]-*	602.4	NA	563.2	515.2	509.9

Note: Number 1 to 5 represent various temperatures as follows: 1 - α-Al dendritic network, 2 - DCT, 3 - Eutectic Si (Al-Si), 4 - Cu-rich phases, 5 – Solidus ; * represents Pandat Program in Scheil Mode and # represents CCA

It can be seen in Table V and VI that the obtained results compare well with the typical solidification characteristic temperature values of Al-Si alloys in literature. However, as much as the solidification characteristic temperatures can be obtained using the criteria stated in literature, these methods cannot be entirely independent due to errors such as those arising from smoothing of the curves and inaccurate reading of the temperatures.

4. CONCLUSIONS

The aim of this particular research was to identify the characteristics of the solidification path of as-cast and heat treated Al-7SiMgCu alloy with an aim to propose optimal solution heat treatment temperatures. The following conclusions were made from this study:

1. The start of solidification, DCT, Al-Si, Al-Si-Cu, and end of solidification temperatures of alloy 356M-A were found to be: 613.0 ^{o}C, 611.0 ^{o}C, 558.5 ^{o}C, 500.5 ^{o}C, and 487.8^{o}C respectively from CCA experiments.

2. The lowest recommended solution heat treatment temperature for alloy

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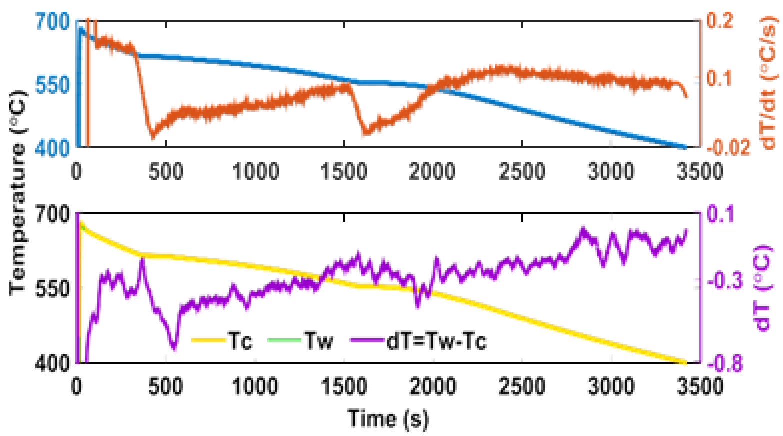
356M-A is 500^{o}C for both single or two-step solution heat treatment.

3. Further CCA research should be carried out on alloy 356M-A while combining the methods presented in literature, metallography, and solid fraction evaluations in the identification of phase solidification temperatures.

4. More experimental work should be done to complement the simulation databases for design of efficient systems.

Appendix



Appendix 1 Combined plot of Temperature (s) vs time, first derivative curve of temperature vs time, change in temperature between the wall and centre thermocouple vs time -

Where: Tc is the centre thermocouple température and Tw is the near wall thermocouple température

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