O-32

Proceedings of the 72nd World Foundry Congress
21-25th May 2016, Nagoya, Japan

Description of Al-Si10-Mg1 Alloys By Advanced Thermal Analysis Based on Their Known Chemical Compositions

I.Vicario[1], M.B. Djurdjevic[2], G. Huber[2], E. Villanueva[2], A. Meléndez[2]
[1] Tecnalia Research & Innovation, Derio, Spain
[2] Nemak Linz, Linz, Austria

Thermal analysis is a quality control tool in aluminium casting plants. The cooling curve and its derivatives analysis offer parameters that can be used in simulation software programs to improve simulation accuracy and to control the metallurgical quality of cast parts. This paper shows the calculation of thermo-physical, solidification and precipitated phases characteristics of AlSi10Mg1 cast aluminium alloy. Minor alloying elements are included, comparing the results with the results obtained by using other methods as the Silicon Equivalent (SiEQ), showing a very good correlation with the different developed formula.

Keywords: *Thermal analysis, Aluminium-Silicon alloys, Silicon Equivalent.*

1. Introduction

In the last years new alloys have been developed in order to obtain aluminium structural parts by casting, especially High Pressure Die Casting (HPDC). Between the different alloys, the AlSi10Mg1 alloy has been one of the most studied, in order to obtain parts with improved ductility and crash performance.

Thermal analysis is a quality control tool in aluminium casting plants. Some methods have been developed to determinate solidification main temperatures. The results obtained by using the Silicon Equivalent (Si_{EQ}) method [1] are very accurate for the liquidus temperature (R^2=0.98) and more than other previous methods [2-4], but smaller for the Al-Si eutectic (R^2=0.88) and Al-Si-Cu eutectic (R^2=0.77).

This work demonstrates how the statistical analysis of the results obtained for a wide range of alloy chemical compositions shows a better correlation for the different eutectic temperatures.

2. Experimental conditions

The approach used in the present work has been based on the identification of the effect of 12 main alloying elements in solidification parameters through the Taguchi methodology. Two orthogonal matrices have been used, a L16 matrix and a modified L8 matrix. The former employs two levels that are related to the maximum and minimum amounts of the alloying element. Modified matrix incorporates intermediate values.

The base alloy for the developments has been chosen from the most common used alloys for HPDC. The selected alloy is the AlSi10Mg according to standard EN AC-43.400, included in the EN 1706:2010 standard. The obtained compositions are resumed in Table 1.

Table 1 Composition of base alloy (mass %).

Ref.	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Pb	Sn	Sr	Al
1	9,00	0,38	0,03	0,34	0,30	0,01	0,00	0,01	0,02	0,00	0,00	0,02	89,89
2	8,02	0,29	0,02	0,21	0,19	0,01	0,00	0,00	0,01	0,00	0,00	0,00	91,24
3	8,66	0,30	0,02	0,21	0,14	0,01	0,00	0,29	0,20	0,27	0,04	0,01	89,85
4	10,01	0,34	0,02	0,67	0,69	0,15	0,23	0,01	0,02	0,00	0,00	0,06	87,79
5	9,75	0,34	0,02	0,72	0,68	0,15	0,23	0,35	0,12	0,14	0,06	0,06	87,39
6	8,77	0,85	0,19	0,21	0,15	0,16	0,21	0,16	0,12	0,21	0,07	0,01	88,89
7	8,43	0,91	0,19	0,18	0,11	0,14	0,19	0,18	0,19	0,19	0,07	0,05	89,18
8	9,02	1,05	0,29	0,81	0,38	0,07	0,21	0,06	0,17	0,21	0,02	0,05	87,67
9	9,26	0,73	0,09	0,53	0,56	0,07	0,00	0,21	0,02	0,01	0,00	0,01	88,50
10	11,65	0,34	0,20	0,30	0,58	0,02	0,20	0,03	0,24	0,07	0,03	0,02	86,33
11	10,54	0,34	0,16	0,31	0,52	0,02	0,15	0,23	0,17	0,26	0,03	0,05	87,22
12	11,49	0,91	0,42	0,67	0,40	0,14	0,00	0,15	0,23	0,18	0,04	0,05	85,33
13	11,60	0,83	0,18	0,74	0,46	0,18	0,00	0,19	0,02	0,23	0,00	0,01	85,55
14	11,64	0,96	0,08	0,08	0,53	0,16	0,08	0,13	0,27	0,08	0,03	0,01	85,96
15	11,82	0,96	0,11	0,11	0,52	0,14	0,11	0,18	0,11	0,11	0,05	0,02	85,77
16	11,41	0,95	0,27	0,69	0,35	0,09	0,30	0,09	0,25	0,25	0,03	0,04	85,29
17	12,07	0,83	0,13	0,49	0,28	0,03	0,17	0,02	0,08	0,16	0,06	0,03	85,64
18	10,21	0,43	0,05	0,33	0,28	0,07	0,00	0,08	0,02	0,00	0,00	0,01	88,51
19	10,37	0,50	0,11	0,44	0,28	0,14	0,00	0,01	0,02	0,00	0,00	0,01	88,12
20	10,64	0,41	0,05	0,33	0,63	0,07	0,00	0,10	0,02	0,00	0,00	0,01	87,74
21	10,31	0,54	0,09	0,35	0,29	0,11	0,00	0,01	0,01	0,00	0,00	0,01	88,28
22	10,80	0,48	0,05	0,33	0,52	0,06	0,00	0,10	0,03	0,00	0,00	0,01	87,61
23	10,90	0,51	0,10	0,47	0,43	0,11	0,00	0,02	0,01	0,00	0,01	0,01	87,44
24	11,71	0,57	0,07	0,44	0,44	0,08	0,00	0,04	0,02	0,00	0,00	0,01	86,62
25	10,73	0,60	0,10	0,38	0,36	0,09	0,00	0,10	0,02	0,00	0,00	0,01	87,61

In order to obtain the Thermal Analysis (TA), samples with masses of approximately 300g ± 10g were poured into calibrates sand cups. Temperatures between 630 – 400 ºC were recorded. The data for TA was collected using a high-speed National Instruments Data Acquisition System linked to a personal computer. Each TA trial was repeated three times. The cooling rate was 3ºC/sec.

3. Results and discussion

From the solidification curves and derivatives were determined the Liquidus minimum and maximum (T_{Lmin}, T_{Lmax}), the Al-Si eutectic nucleation ($T_{AlSinuc}$), minimum ($T_{AlSimin}$) and maximum ($T_{AlSimax}$), the Mg_2Si precipitation (T_{Mg2Si}), and the Al-Si eutectic nucleation temperatures by the Si_{eq} method ($T_{AlSi\ Sieq}$), summarized on Table 2.

Table 2 Solidification Temperatures (ºC)

Ref.	TLmin	TLmax	TAlSi Si_{eq}	TAlSi nuc	TAlSi min	TAlSi max	TMg_2Si
1	590,38	591,67	593,75	586,56	563,59	565,31	552,73
2	604,43	605,94	601,65	596,05	564,79	569,15	550,26
3	600,01	600,06	596,09	590,50	564,14	565,36	549,92
4	586,55	588,09	584,00	582,76	561,70	563,53	549,47
5	584,11	584,11	584,71	571,11	555,74	560,10	546,68
6	594,82	595,07	590,42	587,13	562,57	567,17	539,26
7	597,61	598,45	593,74	591,10	563,40	564,72	541,13
8	593,64	593,72	584,97	585,73	558,64	560,10	543,58
9	592,16	592,33	589,08	588,51	561,60	562,14	548,25
10	577,18	577,18	575,15	570,89	561,55	564,19	549,62
11	584,00	584,00	580,84	575,49	561,08	563,66	549,04
12	576,80	576,80	570,85	571,55	564,11	565,33	543,36
13	572,79	573,39	568,88	570,47	562,51	563,50	549,63
14	575,46	575,46	575,34	569,22	560,73	563,92	548,99
15	570,82	572,16	571,97	567,85	562,16	564,63	547,33
16	576,60	576,60	569,43	571,96	563,00	564,12	540,32
17	568,71	570,62	567,02	568,18	564,27	565,81	541,33
18	583,20	583,97	585,05	578,81	563,71	566,42	552,37
19	584,53	584,99	582,61	576,63	563,35	564,61	548,88
20	579,20	580,55	582,55	575,31	561,34	563,48	553,05
21	586,03	587,68	583,48	582,89	564,72	567,86	553,59
22	578,67	579,62	581,03	574,73	563,59	565,50	553,42
23	580,97	581,91	578,91	576,42	563,11	565,95	552,75
24	575,04	575,55	573,47	572,00	564,78	567,34	551,21
25	580,92	581,74	580,15	576,34	563,19	565,71	552,09

By using linear regressions for the obtained values we obtain the equations from (1) to (6) in ºC. We can observe the linear regression coefficient (r^2) and the standard deviation (S_{ey}):

$$T_{Lmin}=665{,}72-7{,}65.Si-1{,}85.Mg-4{,}11.Fe+5{,}32.Cu-0{,}5.Ni+6{,}26.Cr-1{,}04.Mn+17{,}84.Ti-5{,}15.Zn+3{,}34.Pb-42{,}17Sn-32{,}79.Sr;\ r^2=0{,}978;\ S_{ey}=1{,}94 \quad (1)$$

$$T_{Lmax}=666{,}75-7{,}63.Si-1{,}29.Mg-3{,}4.Fe+2{,}66.Cu-2{,}58.Ni+5{,}54.Cr-1{,}95.Mn+11{,}99.Ti-10{,}34.Zn+5{,}95.Pb-30{,}75.Sn-16{,}05.Sr;\ r^2=0{,}978;\ S_{ey}=1{,}97 \quad (2)$$

$$T_{AlSiNuc}=649{,}16-6{,}54.Si-1{,}5.Mg+2{,}45.Fe+3{,}89.Cu-1{,}89Ni-5{,}79.Cr-4{,}1.Mn-1{,}15.Ti-11{,}68.Zn+7{,}08.Pb-59{,}0{,}Sn-5{,}7.Sr;\ r^2=0{,}947;\ S_{ey}=2{,}66 \quad (3)$$

$$T_{AlSimin}=561{,}16+0{,}73.Si-9{,}17.Mg-1{,}0.Fe+3{,}57.Cu-3{,}76.Ni-0{,}54.Cr-3{,}02.Mn-5{,}1.Ti-2{,}87.Zn+0{,}84.Pb-19{,}94.Sn+18{,}99.Sr;\ r^2=0{,}789;\ S_{ey}=1{,}33 \quad (4)$$

$$T_{AlSimax}=565{,}88+0{,}57.Si-7{,}56.Mg-3{,}19.Fe+4{,}91.Cu-0{,}53.Ni+4{,}06.Cr-4{,}0.Mn-6{,}69.Ti-5{,}14.Zn-0{,}32.Pb+7{,}5.Sn-8{,}47.Sr;\ r^2=0{,}794;\ S_{ey}=1{,}35 \quad (5)$$

$$T_{Mg2\ Si}=551{,}31+0{,}26.Si+5{,}22.Mg-5{,}47.Fe-8{,}84.Cu-15{,}94Ni+6{,}13.Cr-3{,}62.Mn+4{,}76.Ti-1{,}1.Zn+1{,}85.Pb-81{,}5Sn+8{,}05.Sr\ \ r^2=0{,}923;\ S_{ey}=1{,}72 \quad (6)$$

In order to determinate the accuracy of the Si_{eq} method, the obtained temperatures were plotted against calculated temperatures, as shown in figure 1:

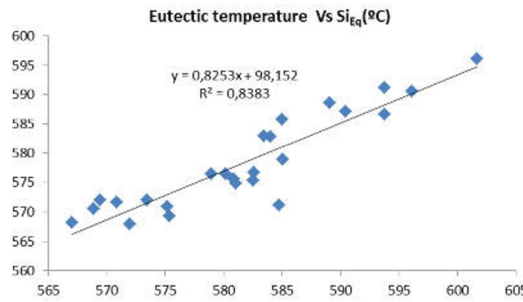

Fig. 1 Eutectic temperature vs. Si_{Eq} values

As it can be observed, the obtained values are less accurate than the obtained from developed equations.

4. Conclusions

A methodology based on Taguchi has been used to calculate the liquidus maximum and minimum, the eutectic and the Mg_2Si eutectic temperatures. The obtained results presented in this paper are more accurate than those found in the literature and the obtained by the Si_{Eq} method. The results show that the obtained equations allow to determinate with good accuracy the solidification parameters of any alloy.

Acknowledgements

This work has been partially funded by the Basque Government through the ETORGAI programme ER-2011/00002 and by the European Commission NIWE project (grant agreement 296024).

References

[1] M.B. Djurdjevic, I.Vicario. Rev. de metalurgia. 49 (2013) 161-171.

[2] G. Drossel. Giessereitechnik. 27 (1981) 7.

[3] R. Vijayaraghavan, N. Pelle, J. Boileau, J. Zindel, R. Beals: Scriptia Materalia. 35 (1996) 861.

[4] F.C. Robles, M.B. Djurdjevic, W.T. Kierkus, J.H. Sokolowski. Mat. Scien. and Eng. 396 (2005) 271-276.