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Sensitivity of different Al–Si alloys to centrifugal casting effect

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ABSTRACT

This paper is concerned with the sensitivity of different Al–Si alloys to centrifugal effect of the vertical centrifugal casting technique on castings as compared to the traditional gravity casting technique.

A comparison of mechanical properties of specimens obtained by both centrifugal casting technique and gravity casting technique is made on three different Al–Si alloys (from a hypoeutectic to a hypereutectic alloy). A microstructure analysis, in order to quantify the phase/constituent distribution along the gradation axis, is made to understand the relationship between constituents and mechanical properties for both casting techniques.

It was verified that the centrifugal effect is very alloy dependent and may be substantially well correlated with the eutectic volume fraction of the alloy. It was also found that the centrifugal effect on mechanical properties is more is more pronounced in alloys with high eutectic contents.

1. Introduction

Al–Si alloys are increasingly used in many applications due to its high tensile strength in relation to density compared to other cast alloys, such as ductile cast iron or cast steel.

As the properties of a specific Al–Si alloys (hypoeutectic, eutectic or hypereutectic) can be attributed to the individual physical properties of its main phase constituents (α-aluminium solid solution and silicon crystals) and to their volume fraction and morphology [1], different approaches have been used to control the micro structural features of Al–Si alloys such as adding some alloying elements [2,3] in order to refine the grain. However the most common way to improve mechanical properties of cast Al–Si alloys is by changing the casting technology [4]. Each technology has particular aspects that interfere on microstructure and consequently on mechanical properties.

On a previous paper by Chirita et al. [5] it is shown that the vertical centrifugal technique has some particular processing characteristics namely: fluid dynamics inside the mould; inherent vibration of the system; and centrifugal pressure; that may interfere on the metallurgical features of the obtained castings. On that paper an explanation about how the previous processing characteristics may affect the metallurgical features of the castings is provided. That study was performed on a specific Al18Si alloy.

The aim of the present paper is to quantitatively assess the sensitivity of different Al–Si alloys, from hypoeutectic to hypereutectic alloys, to the vertical centrifugal casting technique on mechanical properties of the castings based on changes in microstructure. Moreover it is intended to establish a global correlation that can be used for a range of Al–Si alloys, between metallurgical features and mechanical properties.

1.1. Microstructural–mechanical properties relations

In order to understand the relation between microstructure and mechanical properties some investigations are found in literature trying to clarify the relation between micro structural features such as secondary dendrite arm spacing (SDAS), eutectic constituent, Si and Fe intermetallics, Si particles size and shape [1,6–11], alloy composition [3], and respective mechanical properties. In Ref. [6] it is discussed the relationship between secondary dendrite arm spacing (SDAS) and tensile properties of both unmodified and Sr-modified A356 aluminium alloys. It is also discussed the micro structural effects on tensile and fatigue behaviour. Results show an increase of the ultimate tensile strength and strain to failure of both A356 and A357 (ASTM) alloys with the decrease of the secondary dendrite arm spacing (SDAS). The ductility of the Sr-modified alloy was reported to be higher than that of the unmodified alloys over the range of SDAS [6]. Other studies performed with an unmodified sand cast A356-T6 obtained by hot isostatic pressing revealed also an increase of ultimate tensile strength and of ductility with a decrease of secondary dendrite arm spacing (SDAS) [7]. Other experiments performed on an Al–7%Si–Mg alloy showed also an increase of the ultimate tensile strength and of the elongation with a decrease of dendrite arm spacing (DAS) [12]. The yield strength was found to be less influenced by the

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Table 1
Chemical composition of the alloys as obtained by SEM/EDS.

	Si	Fe	Co	Mg	Ni	Mn	Zn	Ti	Sb
Alloy A	6.80	0.12	–	0.61	–	0.01	0.02	0.12	0.14
Alloy B	12.09	0.27	0.58	1.34	1.26	0.09	0.04	0.06	0.05
Alloy C	18.89	0.90	0.52	1.20	1.37	0.12	0.24	0.04	0.11

SDAS. In Ref. [2] there is a correlation between the amount of dendritic α-Al phase and mechanical properties of the Sr-modified alloy. In Ref. [9] it is reported that an increase of the silicon content of the Al–Si cast alloy causes a decrease of casting density and an increase of Young's modulus. In another study [8], an increase in the strain to failure was attributed to the increase in the amount of eutectic.

Most of the previous studies are concerned with single alloys. However some companies, although working with a single class of aluminium alloys (e.g., Al–Si alloys – series 4000), they use different grades of those alloys (for e.g., 7% Si, 12% Si and 18% Si, etc.). This paper intends to, besides of quantifying the centrifugal effect on those alloys, establish a global denominator, for Al–Si alloys, that could be used with some accuracy for the prediction of mechanical properties of those alloys, as obtained by the two different casting processes.

In this study, a comparison between the effects of the centrifugal casting technique, as compared to the conventional gravity casting technique, on the microstructure (and consequently on mechanical properties) is made for different Al–Si alloys. It will be shown that a strong correlation between amount of eutectic constituent and mechanical properties, namely ultimate tensile strength, Young's modulus, and mainly strain to failure, exists for all alloys. It will also be shown that this correlation is very alloy dependent and is more pronounced for alloys with higher Si contents. Additionally it will be shown that the centrifugal effect may strongly increase the mechanical properties of different Al–Si alloy castings.

2. Experimental methods

Three commercial Al–Si alloys with different Si contents were selected and will be referred in this study as alloys A (≈7% Si), B (≈12% Si) and C (≈18% Si) (Table 1). It must be highlighted that alloy C is known commercially as an 18% Si alloy but it has almost 19% of silicon. Notwithstanding in this work it will be referred with its commercial designation namely 18% Si alloy.

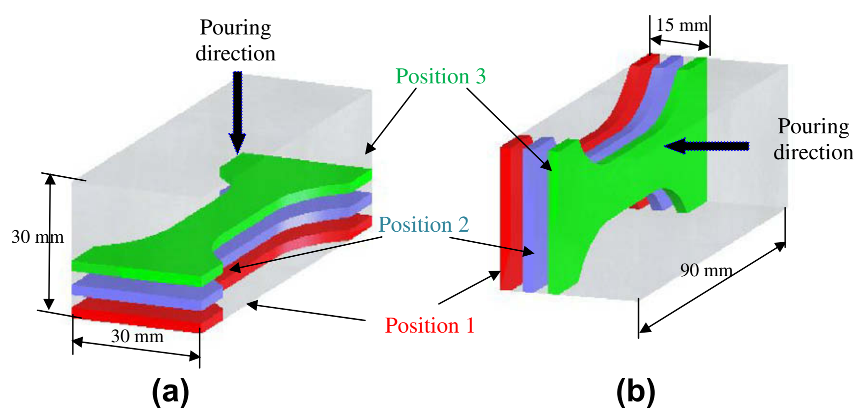

Fig. 1. Position from where tensile test specimens were taken: (a) gravity castings and (b) vertical centrifugal castings.

Table 2
Mechanical properties, chemical composition and volume fraction of constituents for alloy A under gravity and centrifugal castings.

7% Si	Pos.	Mechanical properties			Chemical comp.	Volume fraction (%)					
		σ (MPa)	ε (%)	E (MPa)	Si (wt.%)	(Al) dendrites	Eutectic	Si particles	Intermetalics	Pores	Hardness (HV)
Gravity	1	283	7.1	84,194	7.5	58.3	41.3	–	0.0	0.4	111 ± 1.3
	2	267	4.7	71,399	6.6	61.3	38.6	–	0.0	0.1	107 ± 0.6
	3	282	3.3	71,227	6.6	68.1	31.7	–	0.0	0.1	103 ± 2.3
Centrifugal	1	321	10.2	71,557	12.0	51.4	48.4	–	0.0	0.1	127 ± 1.3
	2	298	8.0	74,837	12.5	63.3	36.4	–	0.1	0.2	120 ± 1.9
	3	285	4.0	66,620	12.6	66.3	33.5	–	0.2	<0.1	115 ± 2.3

Table 3
Mechanical properties, chemical composition and volume fraction of constituents for alloy B under gravity and centrifugal castings.

12% Si	Pos.	Mechanical properties			Chemical comp.	Volume fraction (%)					
		σ (MPa)	ε (%)	E (MPa)	Si (wt.%)	(Al) dendrites	Eutectic	(Si) particles	Intermetallics	Pores	Hardness (HV)
Gravity	1	226	0.9	82,946	12.0	37.0	56.2	0.4	6.4	<0.1	109 ± 1.2
	2	208	0.7	82,780	12.5	35.4	56.1	1.1	7.3	0.1	106 ± 1.0
	3	202	0.70	58,790	12.6	38.6	51.9	1.8	7.7	<0.1	105 ± 1.3
Centrifugal	1	264	1.52	80,652	12.2	25.6	68.5	0.0	5.7	<0.1	121 ± 3.3
	2	249	1.30	62,510	11.8	27.9	64.7	0.1	6.8	0.1	116 ± 1.2
	3	227	0.91	70,170	11.6	34.8	58.1	0.0	6.7	<0.1	114 ± 1.2