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The Effect of Bifilm and Sr Modification on the Mechanical Properties of AlSi12Fe Alloy

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Abstract

The microstructure of Al-Si alloy has coarse silicon and this structure is known dangerous for mechanical properties due to its crack effect. Sr addition is preferred to modify the coarse silica during solidification. Additionally, bifilms (oxide structure) are known as a more dangerous defect which is frequently seen in light alloys. It is aimed at that negative effect of bifilms on the properties of the alloys tried to be removed by the degassing process and to regulate the microstructure of the alloy. In this study, the effect of degassing and Sr modification on the mechanical properties of AlSi12Fe alloy was investigated, extensively. Four different parameters (as-received, as-received + degassing, Sr addition, Sr addition + degassing) were studied under the same conditions environmentally. The microstructural analyses and mechanical tests were done on cast parts. All data obtained from the experimental study were analyzed statistically by using statistical analysis software. It was concluded from the results that Sr addition is very dangerous for AlSi12Fe alloy. It can be suggested that to reach high mechanical properties and low casting defects, the degassing process must be applied to all castings whereas Sr addition should not be preferred.

Keywords: Innovative foundry technologies and materials, Mechanical properties, AlSi12Fe alloy, Bifilm index, Sr modification

1. Introduction

Al and its alloys are preferred by many industries such as automobiles, aerospace, and aircraft because of their superior properties such as high specific strength, good formability, good machinability, and easy castability [1-3]. A413 alloy is an Al-Si alloy that used for the production of engine boxes, measuring box, cylinder, pump pieces, and thin-walled casting components [4, 5]. It is a material that needs to be developed constantly since it is used in critical applications. It is required to keep up the casting quality to improve the mechanical and microstructural properties of the alloy. In other words, it is very important to carry casting with optimum conditions to get the best result from the experiments. The microstructure of Al-Si alloy has coarse silicon and this structure is not preferred, because it decreases the mechanical properties of the alloy by giving brittleness. Sr addition is preferred to modify the coarse silicon during solidification [6, 7]. Sr modification also increases the castability (casting quality) of the A413 alloy. In the modification process, the orientation of the Si grains is restricted by Sr and a more ductile structure is achieved. The mechanical properties, therefore, are enhanced [8-10]. Improving the casting quality is a key point for a good casting [11-13]. Defects must be reduced from the structure before and during casting.

Bifilms are the defects seen in light alloys such as Al-Si alloy casts frequently [1, 14]. They occur from oxide films (Al_2O_3) that came from ingots or melts used before casting or that formed due to turbulence during casting [15]. It is aimed to remove bifilms by some applications such as degassing and grain refinement from the structure to increase mechanical properties and to regulate the microstructure of the alloy. The degassing process is vital to clean bifilms [4, 16, 17]. In this process, argon gas is given to the bottom of the crucible thanks to means of a rod immersed in the melt, and it is provided that while this low-density gas moves to the top of the crucible, it can clean bifilms, besides hydrogen [1].

The evolution of the results by using statistical analyses plays a vital role in scientific researches. The quality index, which is presented by Tiryakioğlu [18], is an index that helps researchers for determining melt quality before casting. If Q_T has a value between 0.25-0.70, there is still a considerable amount of young bifilms (oxides) in the melt. If this value is obtained above 0.70, it is understood that the melt has a sufficient property for casting. Q_T calculation is made with the formula as follow:

$$Q_T = \frac{e_F}{e_{F(max)}} = \frac{e_F}{\beta_0 - \beta_1 \sigma_Y}$$

In the current study, AlSi12Fe alloy was studied under the parameters of degassing and Sr addition to examining the relationship between the casting quality and the mechanical properties by supporting statistical analyses.

2. Experimental Work

The chemical composition of the AlSi12Fe alloy which was used in this study is given in Table 1.

Table 1.
The chemical composition (in wt. %) of the alloy used in the study.

	Alloy	Si	Fe	Cu	Mn	Mg	Zn	Ti	Sr	Al
Standard	AlSi12Fe	11,50-13,50	0,60	0,10	0,40	0,1	0,1	<0,001	0	Rem.
No degassing	As-Received	13,27	0,198	0,005	<0,001	0,005	0,014	0,006	0	Rem.
	Sr addition	13,47	0,209	0,122	0,001	0,131	0,013	0,007	0,0029	Rem.
Degassed	As-Received	12,95	0,199	0,005	<0,001	0,005	0,013	0,005	0	Rem.
	Sr addition	13,15	0,204	0,054	0,001	0,055	0,014	0,006	0,0032	Rem.

The alloy used in the study was obtained as the primary cast ingots. A resistance furnace that has 22 kg capacity was used to melt the alloy. Al15Sr master alloy was added at an amount of 30 ppm once the melt temperature had reached 670 °C. Castings were realized after 10 min of Sr addition. The degassing process was applied with Ar gas throughout 20 minutes with 4 l/min. The parts are cast into the tensile test molds which are 13 mm in diameter and 150 mm in length, given in Figure 1. Dimensions of RPT samples were used according to Dispinar et al. [16] used in their study. Silica-based sand was used in 60/65 AFS standard to product RPT molds. 100 mbar vacuum was selected to obtained RPT samples. Tensile test mold was produced by steel as a permanent mold. The tensile test mold was reached at 200 °C temperature while the RPT mold was at room temperature.

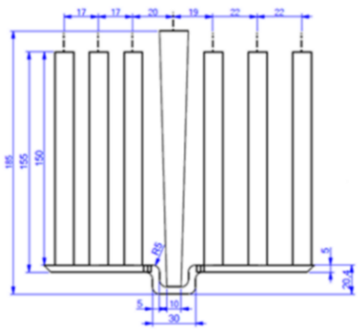

Fig. 1. Image and dimensions of tensile test mold used in the study

Castings were made firstly for an as-received condition when the alloy in the crucible is melted. The second and third casting was realized for Sr modification and degassing, respectively. Analysis of microstructure and mechanical properties were done on every parameter. The tensile samples were machine along with ASTM B557-15 and subject to tensile test at room temperature and with test velocity of 1m/s according to TS EN ISO 6892-1 standard. RPT samples were cut vertically and one of the pieces was prepared by metallographic methods. The surface of the sample scanned to create an image on a computer. Image of the samples was analyzed by image analysis software, i.e. SigmaScan, to calculate bifilm values.

Statistical analysis was done via statistical analysis software, i.e. Minitab, taking account every experimental sample which is obtained 10 samples from RPT casting and 18 samples from tensile test casting at least for each experiment.

3. Results and Discussion

Microstructural images of castings for Sr addition and as-received are given as a representative in Figure 2. It can be understood on the images that the microstructure of AlSi12Fe was changed by Sr addition. As known that AlSi12Fe alloy has 12 % Si and it displays eutectic morphology after the solidification (Figure 2). Silicon morphology was affected by Sr addition which is transformed the microstructure from coarse and long size to fine and short size [8, 19]. This effect of Sr can be observed on the microstructure images of the alloy. As can be seen in Figure 2c, Sr addition has a positive effect on the Si length both by increasing the similarity and decreasing average Si length (Table 2), which means that Si morphologies obtained has a similar property according to shape, length, and volume.

Table 2.
Changing in Si morphology by Sr addition

	Sphericity	Variance	Average	Variance

		(%)	Si length	(%)
As-received	0,46	36	10,63	-47
Sr addition	0,63		5,60	

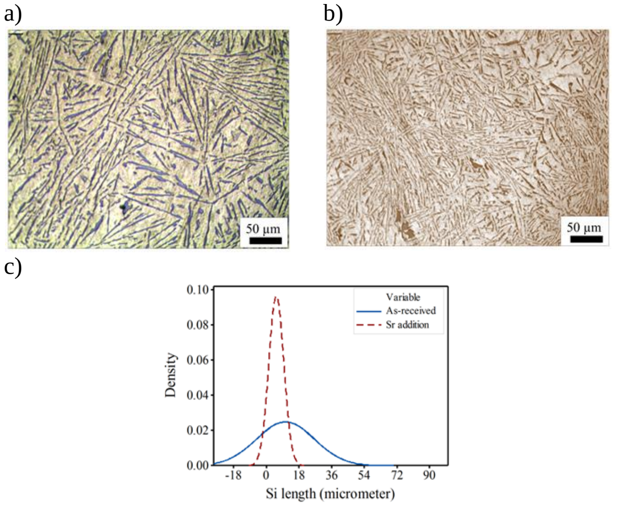

Fig. 2. Microstructure images of (a) as-received casting, (b) Sr addition casting, and (c) normal distribution of Si length

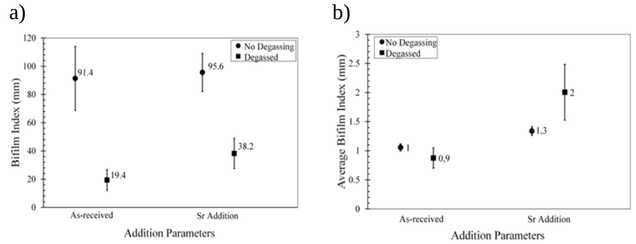

Fig. 3. Results of bifilm analysis:
(a) bifilm index calculation and (b) average bifilm index calculation

The relationship between melt processes and the bifilm index was examined, and results are shown in Figure 3. It is evident that degassing decreased the bifilm index by removing bifilms from the melt. While the negative effect of Sr addition on the melt quality, it was seen that there was no significant impact of Sr addition. At this point, the amount Sr used was an optimum value for this study.

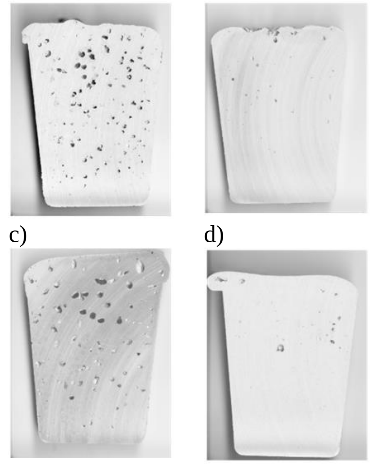

Fig. 4. Representative images of RPT samples:
(a) as-received and no degassing, (b) as received and degassed, (c) Sr addition and no degassing, and (d) Sr addition and degassed

Additionally, it can be said that while the bifilm index is decreased thanks to degassing, the number of bifilm is increased for Sr-added alloy because of the turbulence during degassing and addition of Sr. This result can be seen on Figure 4c by examining the average bifilm index. Whereas ABI value showed a slight fall for as-received, there was a huge gap between degassed and no degassed melts. These results were supported using representative images given in Figure 4 for all additional parameters. As can be seen with the macro-examination, there were large porosities before degassing and Sr addition. After Sr addition, there was no altering in the size of porosities. On the other hand, degassing declined the porosity size despite the increasing effect on the number of small porosities.

Table 3.
Quantitative results of Weibull analysis of bifilm length and bifilm area

	Bifilm Length (mm)		Bifilm Area (mm^2)	
Parameters	Weibull Modulus	Characteristic Alpha	Weibull Modulus	Characteristic Alpha
As-received	0,82	0,87	0,45	0,17
As-received + degassed	1,61	0,55	0,72	0,06
Sr addition	3,02	2,48	1,38	1,9
Sr addition + degassed	1,27	0,51	0,61	0,06

All quantitative results of the statistical analyses were numerically given in Table 3. Characteristic alpha value, which represents the possibility of the same results with 66 % when the experiment was done again, increased with Sr addition. However, degassing had a downward effect on this result of both bifilm area and length.

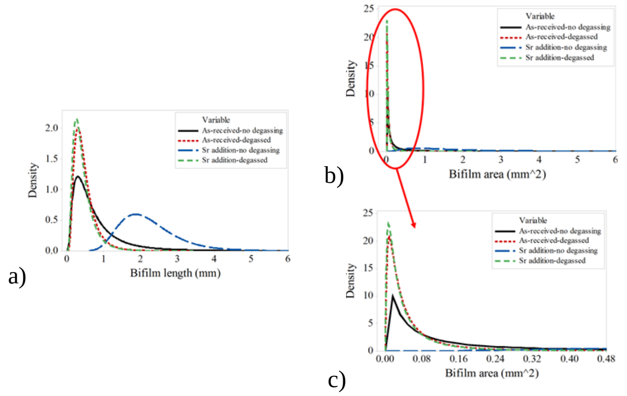

Fig. 5. Statistical analysis of bifilm values:
(a) lognormal distribution of bifilm length, (b) lognormal distribution of bifilm area, and (c) narrow scatter for lognormal distribution of bifilm area

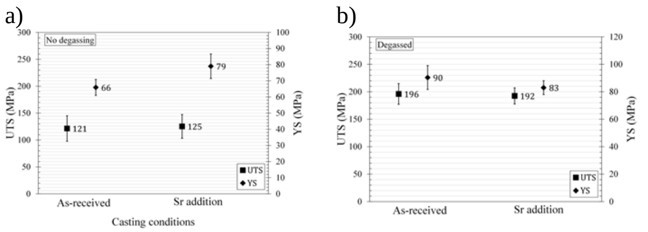

Fig. 6. UTS and YS results of the alloy for as-received and Sr addition casting:
(a) no degassing condition, and (b) degassed condition

Lognormal distributions, which give information about the stability of the results, of bifilm length and bifilm area, were drawn and presented in Figure 5a and Figure 5b, respectively. For both bifilm length and bifilm area, degassing and Sr addition improve the repeatability of the results when this experiment was made a few times. The results obtained are supported by the bifilm index calculations statistically.

UTS and YS results of the alloy for all conditions (degassed, no degassing, as-received, and Sr modified) were presented in Figure 6. This chart is quite explanatory to understand the effect of Sr modification and degassing process on the mechanical properties of the alloy. As shown in Figure 6, before degassing UTS values of the alloy for the as-received parameter are lower than UTS results of the alloy for the Sr modified parameter. It can be understood that Sr modification affects the UTS results, but this effect is quite low for no degassing condition. UTS results of as-received parts are the highest for the degassing condition. It can be said that the degassing process increases UTS and YS values of the alloys for all conditions. Similar effect with Sr modification and degassing was seen for YS values of the alloy. It was seen that Sr modification did not affect the results of UTS and YS for the degassed condition well but get worse the results of UTS and YS for the degassed condition. If the experiment parameters are investigated together, it can be understood that the best result was obtained from as-received and degassed conditions. However, if the results are examined in terms of stabilization, modified and degassed alloys are the best. Degassing is a crucial process to improve the mechanical properties of the alloys. As known in the literature [16, 20], Degassing is made to clean bifilms from the melt, and therefore, it increases the casting and liquid quality. This knowledge was promoted in this study.

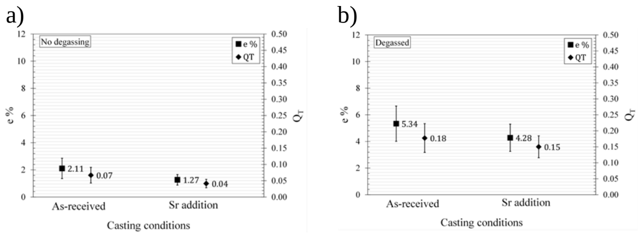

Fig. 7. e % and Q_T results of the alloy for as-received and Sr addition casting:
(a) no degassing condition, and (b) degassed condition

Table 4.
Weibull analysis results of UTS, yield stress, and elongation

	UTS (MPa)		YS (MPa)		e %	
Parameters	Weibull Modulus	Characteristic Alpha	Weibull Modulus	Characteristic Alpha	Weibull Modulus	Characteristic Alpha
As-received	10,21	153,2	17,95	73,13	2,82	2,97
As-received + degassed	6,67	214,9	4,98	97,20	2,69	6,37
Sr addition	5,99	167,3	6,86	92,91	2,72	1,94
Sr addition + degassed	8,55	204,4	9,23	87,43	2,30	4,85

Results of e % and Q_T were presented in Figure 7. To investigate Q_T of the alloy, 36 and 0.064 values were used for β_0 and β_1 respectively. It is seen on the chart that Sr addition decreases the e % value for no degassing and degassed conditions. If looking at the results in terms of stabilization, the results of Sr modified alloy are more stable. Similar to UTS and YS results mentioned above e % results were affected by the degassing process, positively. In general, degassing is a beneficial process to improve the mechanical properties, but it decreases the stabilization of e % results according to Figure 7b. If average results are examined, it can be said that degassed and non-modified parameters are optimum for this study. Q_T results are also affected by degassing and Sr modification similar to e %. Degassing improved Q_T value for both Sr modified and non-modified alloy. It can be thought about these results that the degassing process cleans the structure from bifilms and therefore casting and liquid metal quality can increase. The effect of this can be understood by comparing of degassed and non-degassed Q_T values.

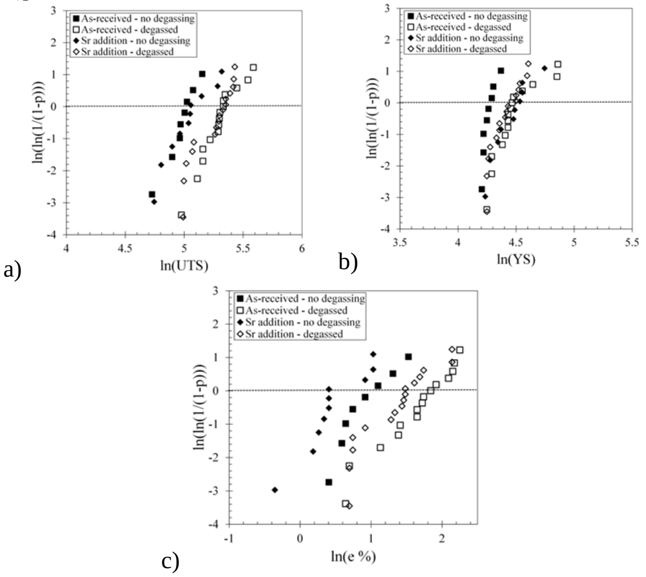

Fig. 8. Results of Weibull analysis of mechanical tests data: UTS (MPa), (b) yield stress (MPa), and (c) elongation (%)

To statistically support the results of the mechanical properties of the alloy, Weibull curves were drawn and given in Figure 8. Also, Weibull analysis results are given in Table 4. It is possible to say that if Weibull distributions, which show stability, reliability, and reproducibility that can be obtained from the experiments, are obtained much more upright and at the far right in the graph, results are more stable compare to others. When the distribution of UTS' results is examined, it is seen that degassing is a key factor to obtain better results, whereas there are negative effects with the addition of Sr. On the other hand, as can be seen on Figure 8b, Sr addition has no considerable effect on the stability of YS of the AlSi12Fe. However, similar to the results of UTS, YS is positively influenced by degassing. The first condition of the experiments (as-received and no degassed) showed the worst result for both UTS and YS because of the negative effect of coarse Si morphology and bifilms which are not cleaned from the melt. This result coincides with the literature [21, 22]. Additionally, similar results are achieved for elongation with which the most stables are degassed. It is seen that Sr addition degenerated the stability of the alloy which is produced under degassed and no degassing condition. Although there is a positive effect of Sr addition on Si morphology, melt quality is affected by it negatively. It can be understood that the effect of bifilm on the porosity formation and mechanical properties is more acceptable rather than current mechanisms claimed by researchers in the literature [23, 24] which is Sr addition increase the gas solubility in the melt and cause casting defects when the optimum amount of it cannot be arranged.

4. Conclusion

The effect of Sr modification and degassing process on the mechanical properties of AlSi12Fe alloy were investigated in this study and the conclusions of the study summarized below:

1. Not only silicon morphology is affected by Sr addition strongly but also porosity formation is affected by Sr addition. There is a good relationship between Sr addition and porosity formation because the change in Si morphology.
2. It was known that bifilms have an important role in the mechanical properties of aluminum alloys. It was found that the effect of bifilm on the mechanical properties of AlSi12Fe alloy is more than other alloys such as A356 and A380 alloy.
3. It was mentioned that the degassing process is an important way to decrease casting defects such as porosity. In the current study, it can be concluded that the degassing process must be applied to liquid AlSi12Fe alloy to decrease porosity and increase mechanical properties.
4. Sr addition affects mechanical properties negatively in AlSi12Fe alloy, so it is not suggested to improve the properties of cast parts for both scientific study and industrial applying. Also, the reliability and reproducibility of the alloy added Sr was found that the worst. The optimum condition for AlSi12Fe casting has been advised that it is with degassing and not added Sr.

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