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Investigation and prevention of the residues formed in melting furnaces and transfer ladles used in low-pressure Al-casting technologies

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ABSTRACT

Purpose: Refractory life, in Al-casting processes such as alloy wheel production, is obviously affected by the inclusions formed in the transfer ladles and holding/melting furnaces in which melting, fluxing and degassing operations are carried out. The short refractory life affects, adversely, the economical aspect of the process. Therefore, a study on the physical and chemical properties of the above mentioned inclusions has been started. The main purpose of the study is to understand the relationships among the metallurgical processes taking place during casting, properties of the refractories used and the formation of inclusions.

Design/methodology/approach: During this industry-university joint study, experimental studies using scanning electron microscopy (SEM), X-ray diffractometry (XRD) and optical microscopy were used to investigate the nature and properties of the inclusions. Also, corrosion behaviour of six different refractories was investigated by exposing them to molten aluminium.

Keywords: Aluminium alloy; A356; Residue; Corundum; Refractories

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MATERIALS

1. Introduction

A356 (Al7Si0.3Mg) one of the aluminium alloys is a casting alloy which has high elongation and tensile values, good machinability properties and heat treatment. It is widely used in automotive industry [2]. This alloy is produced by low pressure die casting method which is suitable in terms of many factors such as automation, ease of heat treatment, production of parts with relatively thin sections, casting at a pre-set temperature as a result of use of this method [3].

Residue formation is always observed as a result of interaction of molten metal with refractory used in low pressure die casting technology, in aluminium melting furnaces, in transfer and holding ladles which fluxing and degassing processes are carried out. This generally occurs in melting furnaces in wheel sector decreases the refractory life [5].

With the decrease in refractory life, the amount of refractory which is imported from abroad increases; accordingly, current account deficit increases.

Main purpose of this study is to minimize the residue formation problem which leads to refractory material and time loss, cleaning and labour cost, accordingly affects the number of targeted product number.

In this study, which was carried out with industry-university cooperation, residue samples which received from the alloy wheel manufacturer are investigated with various characterisation devices (SEM, XRD, Optical Microscope). Corrosion experiments were carried out in ladles made of having different composition refractory materials. Effects of refractory material selection and flux addition on residue formation are investigated with the results of applied corrosion experiments with and without flux addition.

2. Material and method

Within the scope of this study firstly, residue specimens were taken from the refractory wall of chip melting furnace of CMS Jant ve Makina Sanayi A.Ş. Çiğli factory. The specimens were placed into a polyester mould and grinded with 54 and 18 sized diamond abrasive papers, polished with diamond paste sized 3 µm to investigate with detail.

Microstructure and chemical composition of residue were investigated with JEOL JSM-6060 model scanning electron microscope which has secondary electron (SE) and backscattered electron (BE) detectors and energy dispersive spectrometry (EDS). Phases of the residue were analysed with Rigaku D/MAX-2200/RC X-ray diffractometer (XRD).

6 refractory ladles of different compositions were prepared to investigate the effect of refractory selection on residue formation (Table 1). Therefore, firstly polyamide moulds were prepared in accordance with the size that ALCOA applied as a standard for corrosion test (cup test). Material and water amounts required for preparing ladles are given in Table 2. E and F coded ladles were provided from abroad. Refractory mortar material that cast into the moulds was left at ambient temperature for 24 hours to remove the water in the structure.

Table 1.
Chemical and physical properties of refractories used in the experiment

	%Al_2O_3	%SiO_2	%CaO	%Fe_2O_3	%BaO	Phases (XRD results)	Density, kg/dm^3	Grain size, mm	Amount of mixture, %H_2O
A	60	35.8	-	0.8	-	Mullite-Al_2O_3	2.53	0-6	5-6.25
B	60	24	7.5	1	-	Mullite-Al_2O_3-Gehlenit	2.43	0-6	6.5-8.5
C	84	6.7	2.5	0.9	2.2	Anorthite-Al_2O_3	2.9	0-6	5.3-5.8
D	84	3.1	4.4	0.1	6	Celsian($BaAl_2Si_2O_8$)-Al_2O_3	3.05	0-6	5.2-6
E	64.9	0.3	24.3	0.1		Grossite ($CaAl_4O_7$) CA_2 ($CaO.2Al_2O_3$)	1.84	0-6	22
F	78.2	0.7	10.5	0.1		Hibonite ($CaO.(Al_2O_3)_6$)- CA_2 ($CaO.2Al_2O_3$)	2.69	0-6	8

Table 2.
Required mortar and water amounts to prepare the refractory materials

Material code	Water ratio, %	Mortar Amount, g	Water amount, g
A	5-6.25	1170	73
B	6.5-8.5	1040	88
C	5.3-5.8	1050	61
D	5.2-6	1085	65
E	22	-	-
F	8	-	-

After, refractory ladles were heat treated in the Protherm box type furnace at 150°C for 6 hours, at 250°C for 5 hours and at 350°C for 10.5 hours, respectively. Prepared ladles filled with molten A356 alloy and corrosion tests were carried out in furnace at 1000°C. For the purpose of investigating the effect of flux, 2 experiment set (10 days with flux addition, 7 days without flux addition) were prepared also. After the corrosion test, ladles were poured off molten metal and sectioned with the help of a diamond cutter to investigate infiltration depth. Infiltration depths were determined by an optical microscope. After the experiment microstructure of ladle section was investigated with SEM. Powder specimens were prepared from the internal surface of ladle to conduct phase analyses of residues formed inside the ladle.

3. Results

3.1. Results of XRD analysis of residue and SEM/EDS investigation

XRD analysis results of powder specimens taken from chip melting furnace residue are given in the Figure 1. According to the results, phases contained are identified in the residue; Metallic Aluminium, Corundum (Al_2O_3), and Spinel (Al_2MgO_4). Obtained data with the result of XRD analysis is compatible with the literature.

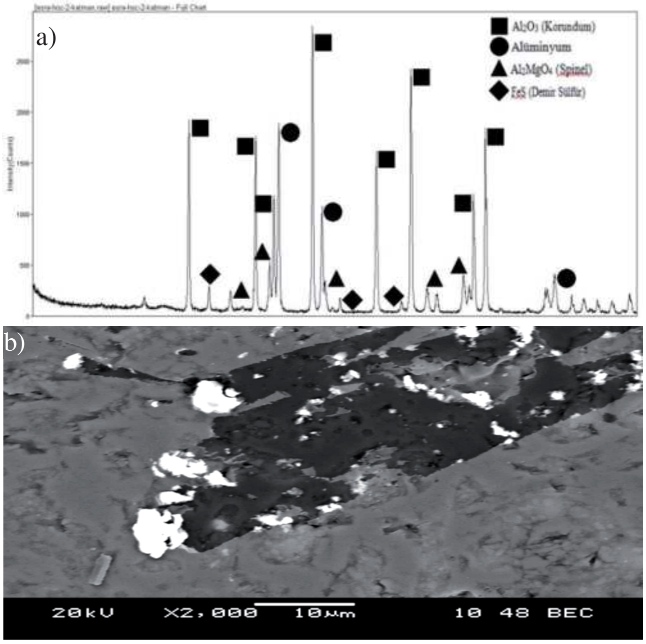

Fig. 1. Image of a) XRD analysis, b) SEM-BE of residue specimen

As is known alloy elements in molten metal are effecting residue formation and causes to the presence of different phases except corundum. Magnesium element in A356 alloy is aggressive element which has a property that accelerates corrosion rate and it forms the spinel (Al_2MgO_4) phase reacting with Al_2O_3 in the refractory structure [1]. We also encountered to this phase in the residues taken from chip melting furnace.

SEM-BE image of residue specimen is given at Fig. 1b. Regarding to the studies in literature, it was considered that bright parts are Mg containing spinel and darker parts are Al containing oxides (Al_2O_3).

3.2. Corrosion test results applied to investigate residue formation

After the corrosion tests with and without flux addition, images taken from refractory ladle sections are given in the Figures 2 and 3. The image could not be taken from sample B because of it was damaged after flux added test. Investigations at the macro level does not provide quantitative information about infiltration. Image of the A and C samples (Fig. 2a and 2c) it is observed that the formation of residue as a dark layer is more than the others. And also it can be said other samples are more strength because of residue formations are not at the level of visible in comparison with sample A and C.

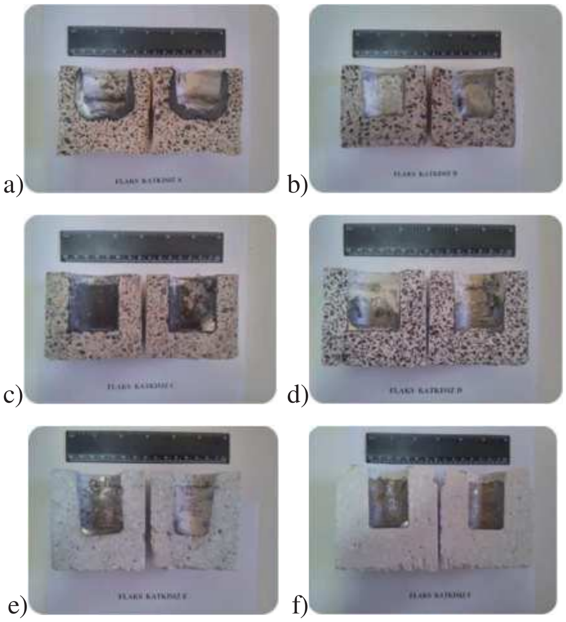

Fig. 2. Section photos of A, B, C, D, E and F ladles exposed to corrosion experiment for 7 days at 1000°C without flux addition

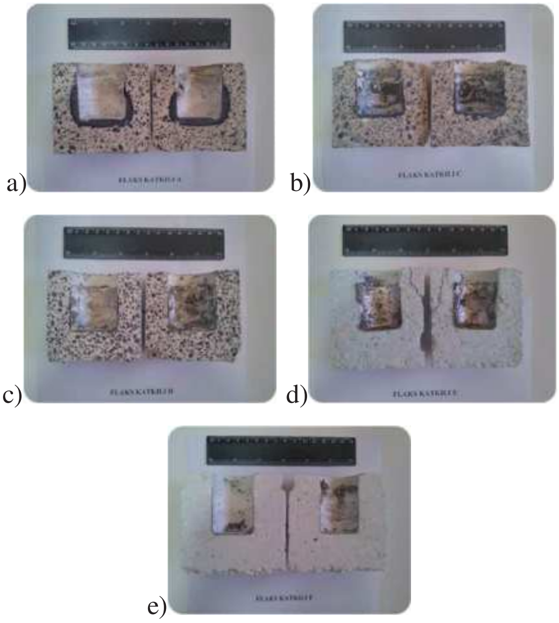

Fig. 3. Section photos of A, C, D, E ladles exposed to corrosion experiment for 10 days at 1000°C with flux addition

According to observations on macro level, it was determined that having low Al_2O_3 amount (%60) samples A and B are not resistant to the corrosion. A low amount of residue formation was observed for the sample D which has alumina amount %84 (Figs. 2d and 3c). But corrosion resistance is not only dependent on Al_2O_3 composition. It is also dependent on the composition of SiO_2 and CaO. For example; sample C (%84 Al_2O_3) which expected to be high corrosion resistance; it is thought to be corroded due to having high SiO_2 amount in the structure. Furthermore, having less Al_2O_3 amount comparing to other samples E (%64.9) and F (%78.2) refractory samples are more resistant to the corrosion due to having very low amount of SiO_2 (< %1) in the structure. Another important raw material in the structure is CaO increases the porosity and provides slowdown of the corrosion by repairing the protective oxide layer [1,4]

According to studies in the literature, refractory performances after corrosion experiment are graded according to specific criteria [1] Similar grading was also done in this study (Table 3).

Table 3.
Grading according to the results of the corrosion test

Preheating temperature			900°C/90 minutes	
Test temperature			1000°C/240 hours	
A356 (Al7Si0.3Mg)	Refractory type	Infiltration, µm	Grading[1]	
			Infiltration	Damage
With flux addition	A	7040	5	2
	B	Measurement failed	-	5
	C	2511	4	1
	D	780	2	1
	E	240	1	2
	F	352	1	1
Without flux addition	A	9440	5	2
	B	276	1	2
	C	2626	4	1
	D	831	2	1
	E	136	1	3
	F	53	1	1

[1] the highest performing refractory with "1" value, the lowest performing refractory with "5" value graded

4. Conclusions

Conclusions of the study can be listed as follows:

- XRD and SEM/EDS analyses were conducted on specimens taken from CMS Jant ve Makine Sanayi A.Ş. Çiğli factory chip melting furnace metal line and it was determined that the residues are α-Al_2O_3 (corundum).
- As a result of the experiments, it was determined that increase in the amount Al_2O_3 in refractory positively affected the corrosion resistance, but with increase of the amount SiO_2 in refractory structure negatively affects the corrosion resistance. Increase of the CaO and BaO amount increases the corrosion resistance up to a certain level with phases formed by but when used in large amounts, it has been found to cause reduction of the mechanical properties by increasing porosity. It was seen that every oxide in refractory composition has to be adjusted optimally and it was determined that D, E and F refractories are the most proper refractories to this optimisation.
- It was seen non wetting additives (BaO, $BaSO_4$, AlF_3) reduces the corrosion under favour of forming the phases with Al_2O_3 and SiO_2.
- During the corrosion experiments it was seen there is no noticeable effect of flux additive on residue formation. However as it is known that flux additive reduces the oxidation by providing a barrier between the metal and atmosphere. This conclusion may be attributed to the short duration of test.

According to the data obtained, it was decided to use the E coded sample applying in 1 low pressure die casting furnace. Refractory application has been completed by supplying material from abroad in Lodos Teknik company. After the application of olation of low pressure die casting furnace (Fig. 4), refractory mortar was prepared and casted between the mould and isolation bricks.


a) b)

Fig. 4. (a) Application of isolation LPD furnace and (b) casting process of refractory mortar

After the casting process completed, refractory was dried and removed from the mould and it was ready to use after sintering is completed (Fig. 5).

Fig. 5. Photo of the low pressure die casting furnace after the application

Furnace was ready to casting after refractory application done. Furnace outside temperature was compared with previous applications using thermal camera after 30 days of using in the production (Fig. 6). It was seen that it provides much better isolation than traditional refractories. Refractory performance will be determined and investigation will be done in order to determine corrosion resistance of refractory at least 1 year of usage.

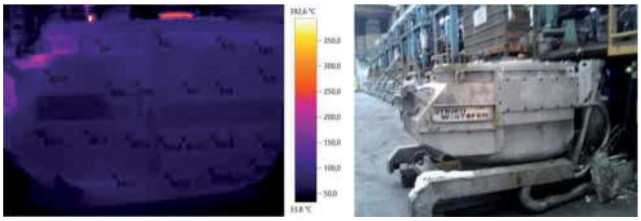

Fig. 6. Thermal camera measurements of low pressure die casting furnace

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References

[1] M. Çolak, R. ve Kayıkcı, The Effect of Electromagnetic Stirring on the Microstructural and

Mechanical Properties of A356 Casting Alloy, Sakarya Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi Cilt 15/3 (2009) 345-351.

[2] H. Hasırcı, F. Gül, Üretim Şartlarının Yerçekimine Ters Döküm Yöntemiyle Üretilen Parçaların Yapı Ve Mekanik Özelliklerine EtkileriGazi Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, Journal of the Faculty of Engineering and Architecture of Gazi University 21/2 (2006) 257-264.

[3] S. Quesnel, C. Allaire, S. Afshar, Criteria for Choosing Refractories In Aluminium Holding And Melting Furnace, TMS Proceedings, 1998, 1391-1402.

[4] C. Allaire, M. Guermazi, The Corrosion of Furnace Refractories by Molten Aluminum, Department of Engineering Physics and Materials Engineering Ecole Polytechnique of Montreal, Canada, 1998.

[5] R.W. Jackson, The Effect of Reactıon And Infıltratıon on the Degradatıon of Refractory Ceramıcs By Molten Metals, University of Pittsburgh, 2010.