Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi

Afyon Kocatepe University Journal of Science and Engineering

AKÜ FEMÜBİD **19** (2019) Özel Sayı (440-446) AKU J. Sci. Eng. **19** (2019) Special Issue (440-446)

Paslanmaz Çeliklerin Hassas Döküm Kumu Atıklarının Katılmasıyla Üretilen Beyaz Ergimiş Alümina Refrakterlerinin Mekanik Özellikleri ve Termal Şok Dayanımları

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Geliş Tarihi: 27.08.2019; Kabul Tarihi: 25.09.2019

Anahtar kelimeler
Beyaz ergitilmiş alümina refrakter; Paslanmaz çelik; Hassas döküm; Atık; Mekanik özellikler; Isıl şok

Öz

Bu çalışmada, paslanmaz çelik hassas döküm kum atıklarının ilaveleri ile üretilen beyaz ergitilmiş alümina (WFA) refrakterlerin mekanik davranışları ve ısıl şok dirençleri incelenmiştir. Refrakterlerin yoğunluk, açık gözeneklilik, soğuk basma dayanımı, 3 noktalı eğme ve ısıl şok direnci testleri yapılmıştır. Paslanmaz çeliklerin hassas döküm kumu atıklarının kullanılması, silis içeriği nedeniyle, mukavemet ve elastik modül gibi mekanik özellikleri azaltmıştır ancak, ancak silis varlığına rağmen, zirkon içerikleri ve mikro çatlak oluşumları nedeniyle katkısız WFA refrakterine yakın tokluk değerlerine ve termal şok testleri sonrasında katkısız refrakterden daha fazla mukavemet oranları değerlerine ulaşılmıştır.

Mechanical Properties and Thermal Shock Resistances of White Fused Alümina Refractories Produced by Incorporation of Precision Casting Sand Wastes of Stainless Steels

Keywords
White fused alumina refractory; Stainless steel; Precision casting; Waste; Mechanical properties, Thermal shock

Abstract

In this study, mechanical behaviours and thermal shock resistances of white fused alumina (WFA) refractories, that were produced by precision casting sand wastes of stainless steels additions, were investigated. Density, open porosity, cold crushing strength, 3-point bending and thermal shock resistance tests of refractories were performed. Incorporation of precision casting sand wastes of stainless steels decreased the mechanical properties such as strength and elastic modulus due to its silica content but despite the presence of silica, close toughness values to pure WFA rafractory and improved the strength ratios than that of pure refractory afer thermal shock tests were achieved due to their zircon contents and microcrack formations.

1. Introduction

Developments in high-temperature industries rely on the quality of their refractory materials. Alumina as a refractory material has the widest range of applications with its important refractory properties such as hot strength, thermal shock resistance, and corrosion resistance. Also, high alumina refractories are produced due to their stability in oxidizing and reducing atmospheres, considerable slag and metal corrosion resistances, extreme abrasion resistance and excellent refractoriness (Abbasian et al. 2019 , Gürel vd. 2009).

High-alumina refractories have continued to advance with their synthetic high purity alumina raw materials contents since 1965 (Gürel vd. 2009).

14-16 Ekim 2019 tarihleri arasında düzenlenen X. Uluslararası Katılımlı Seramik Kongresi'nde sunulan bildirilerden seçilen çalışmadır.

White Fused Alumina (WFA) is an important raw material for advanced refractories and abrasives due to its high alumina content, low impurities, and stability at high temperatures. White Fused Alumina is produced by fusing calcined alumina in an electric arc furnace under carefully controlled conditions at high temperature. The dense mineral has white color and low iron content, it's a very pure (Int Kyn 1).

In this study, the waste precision casting sands of stainless steels were incorporated into white fused alumina (WFA) refractory brick and its mechanical properties and thermal shock resistance were investigated.

In investment casting normally a number of wax patterns of the articles to be cast are made up by any convenient method, then connected by lugs to a central sump or sprue which eventually acts as a feeder, made also of wax (Int Kyn 2).

The ceramic mold process using inorganic binders has been developed recently in precision casting, especially in precision casting of thin stainless steel using a lost wax casting technique. However, the process for prevention of the reaction between ceramic mold and molten metal due to the high temperature of molten metal (above 1450 °C) and the high shrinkage of ceramic mold has lots of limiting factors to be applied (Kim et al. 2011).

Also a common problems for production of steel castings by the investment casting industry are high quality and surface finish. Surface pitting which has been a major cause of rejected castings. In conventional method, it is ditficult to control. Precision casting techniques provide high surface quality throughout the range of steel casting alloys and eliminate the condition of surface pitting (Int Kyn 3).

2. Materials and Methods

In this study i) white fused alumina (WFA) refractory materials, ii) precision casting sand wastes (PCSW) used for AISI 316 and AISI 420 stainless steel castingsiii) binding clay and totanin (2 %) as binders were used to produce WFA refractory composites.

Table 1. Recipes of alumina refractories.

	1-3 mm WFA %	0-1 mm WFA %	<63µm WFA %	<63µm PCSW %	Binding clay %
WFA	30	40	20	0	10
WFA+5% AISI 316	30	40	15	5	10
WFA+10% AISI 316	30	40	10	10	10
WFA+20% AISI 316	30	40	0	20	10
WFA+5% AISI 420	30	40	15	5	10
WFA+10% AISI 420	30	40	10	10	10
WFA+20% AISI 316	30	40	0	20	10

White fused alumina refractory recipies were mixed and then shaped as 50 mm^3 square prism by applying ∼20 bar pressure and also, 25 mm×25 mm×150 mm rod-bars WFA refractories were shaped by applying 30 bar pressure. All shaped samples were sintered at 1250 °C for 4 hours with 5°C/min heating rate.

Open porosities of samples were determined by Archimedes principles (ASTM C20). Cold crushing strength tests before thermal shock tests were applied to 50 mm^3 square prism samples by Liya compression testing machine (ASTM C133–97).

For thermal shock test, 25 mm×25 mm×150 mm bars of WFA and WFA+5% PCSW refractories were heated up to 1000 °C with 10 °C/min heating rate in the Nabertherm N11/R furnace. Thermal shock tests were performed by sudden cooling in water from 1000 °C to 25 °C room temperature.

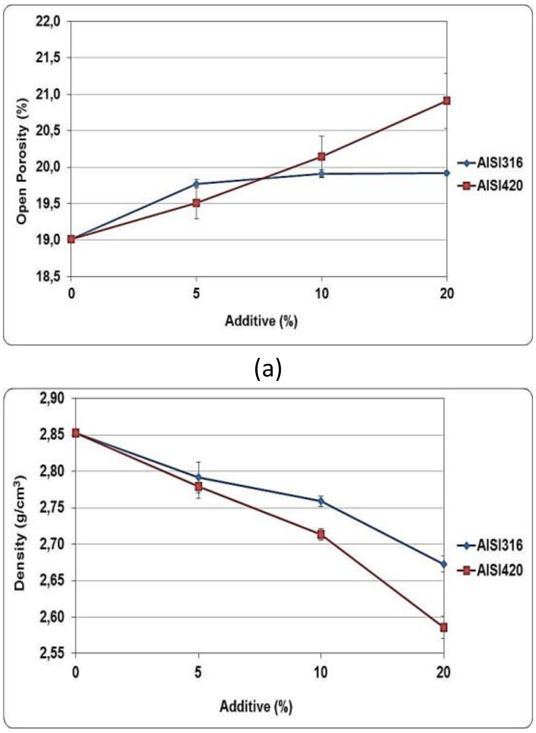
Before and after thermal shock tests, 3-point bending tests were performed for 25 mm×25 mm×150 mm bars by Shimadzu AGS-X machine (ASTM C1161-90). Also after thermal shock test, strength ratio values were determined.

The characterization of microstructures can be performed by the SEM with backscattered electron images at 1000x magnification.

Fracture surfaces of samples before and after thermal shock test were characterized by SEM with secondary electron images at 500x magnification.

3. Results and Discussions

WFA refractory materials produced with PCSW had higher open porosities (%), lower density (Figure 1), lower cold crushing strength (CCS) (Figure 2), lower 3-point bending strength and elastic modulus values than those of pure WFA refractory (Figure 3) and close toughness to pure WFA refractory (Figure 3).



(a)

(b)

Figure 1. Open porosity and density values of white fused alumina composite refractories.

The presence of SiO_2 in the PCSW reduced the refractoriness (T_m: SiO_2: 1710°C, T_m: Al_2O_3: 2030°C). Of WFA refractories, the bond strength of the silica material that was coming from PCSW is lower than pure alumina material that means lower bond strength of WFA refractories produced by incorporation of PCSW.

Also, microcrack formations due to thermal expansion coefficient mismatch (between main matrix alumina (Al_2O_3) phase and the phases such as Fe_2O_3, SiO_2 and ZrO_2 which were the main components of the additive materials) caused lower physical (Figure 1) and mechanical properties (Figure 2, 3) such as strength (CCS and 3- point bending) and elastic modulus before thermal shock test.

Elastic modulus values are related to bond strength, the elastic modulus of the waste-containing alumina refractory was lower than pure alumina refractory (Figure 3). Strength values decreased as density values decreased, thought that density was an effective parameter on the mechanical properties.

Table 2. XRF analysis of PCSW additions.

Oxides	Type of PCSW	
(% wt.)	AISI316	AISI420
Al_2O_3	28,000	27,870
SiO_2	70,571	66,845
ZrO_2	1,360	3,716
Cr_2O_3	0,003	0,048
MnO	0,002	0,022
Fe_2O_3	0,060	1,463
Co_2O_3	0,002	0,011
NiO	0,001	0,008
CuO	0,002	0,017

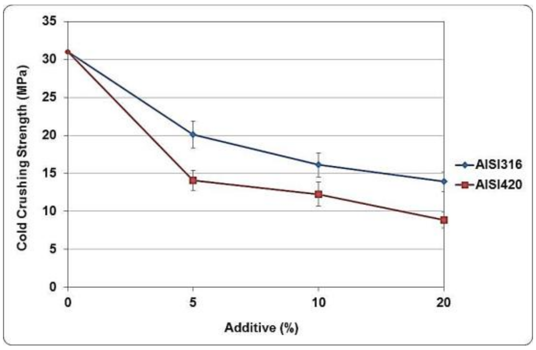
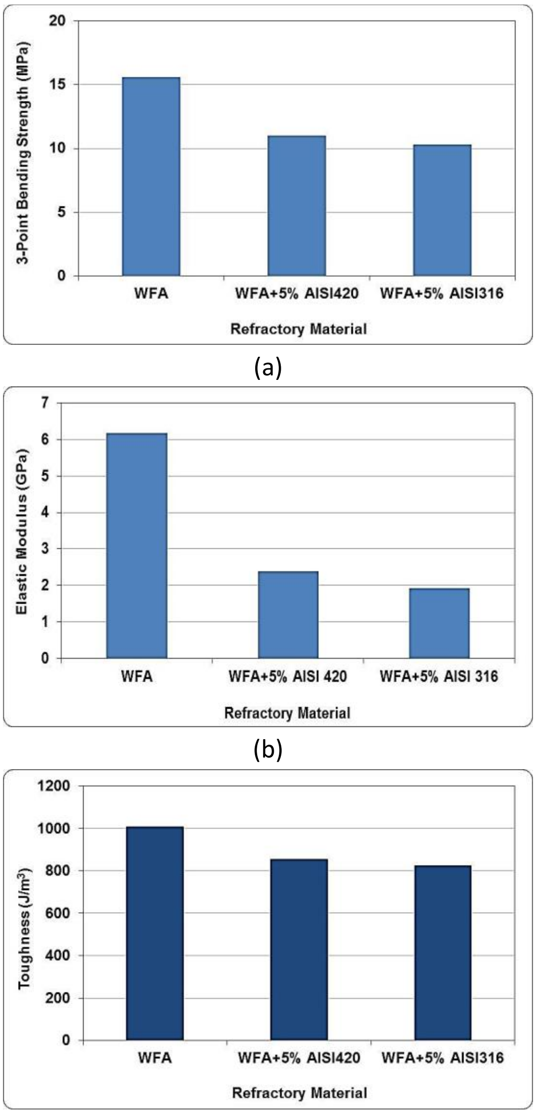


Figure 2. Cold crushing strength values of white fused alumina composite refractories.

Despite the presence of silica and the looser packing in the structure, refractories that were produced with PCSW additions had close touhness to pure WFA refractory due to zircon content of PCSW and microcrack formations. In other words, toughness didn't decrease too much even though PCSW had high silica content.



(a)

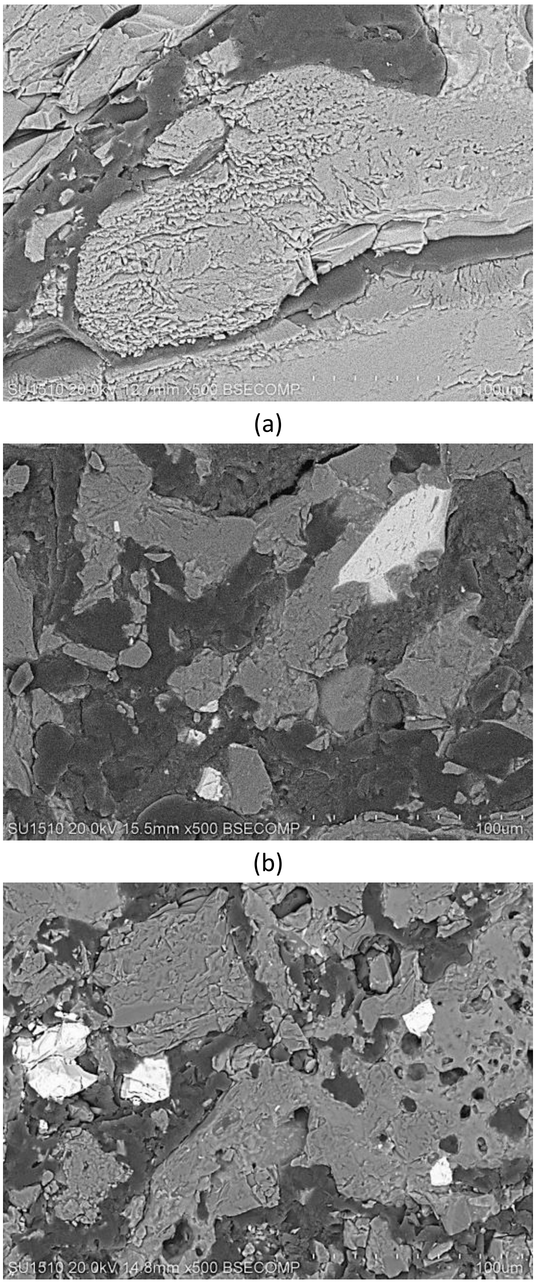
(b)

(c)

Figure 3. 3-point bending test values before thermal shock test a)strength, b) elastic modulus and c) toughness of white fused alumina composite refractories.

According to SEM images of refractories more compacted WFA grains seen as gray colour and then stronger bonding between particles was obtained in pure refractory (Figure 4-a).

In the microstructures of refractories that were produced with PCSW additions (Figure 4-b and 4-c), gray coloured alumina garins and white coloured ZrO_2 grains were seen dominantly in the structures. Also, larger and more amounts of microcracks and porosities were seen either in WFA and ZrO_2 grains or on the grain boundaries that indicated the decrease in mechanical and physical properties.

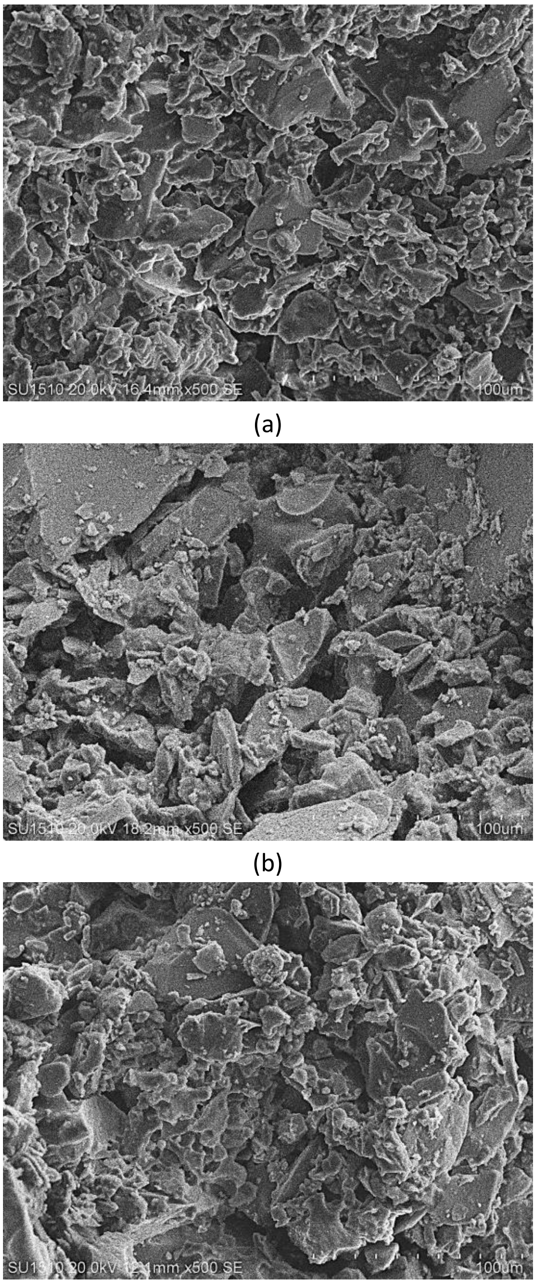


(a)

(b)

(c)

Figure 4. a) Microstructure images of a) WFA, b)WFA+5% AISI 420 and c) WFA+5% AISI 316



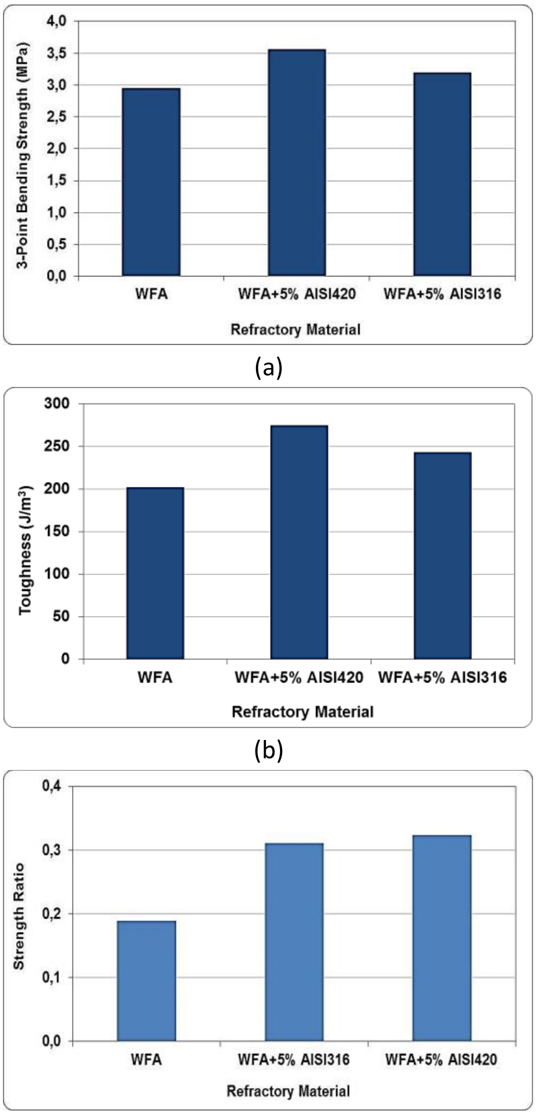
(a)

(b)

(c)

Figure 5. Fracture surface images of a) WFA, b)WFA+5% AISI 420 and c) WFA+5% AISI 316 refractory composite materials before thermal shock test

According to fracture surface images, in all refractory materials before thermal shock tests, both intergranular and transgranular fracture types were observed (Figure 5-a), Especillay refractories produced PCSW additions, transgranular fracture dominantly in coarse grains and also intergranular fracture in small grains were observed (Figure 5-b, 5-c).



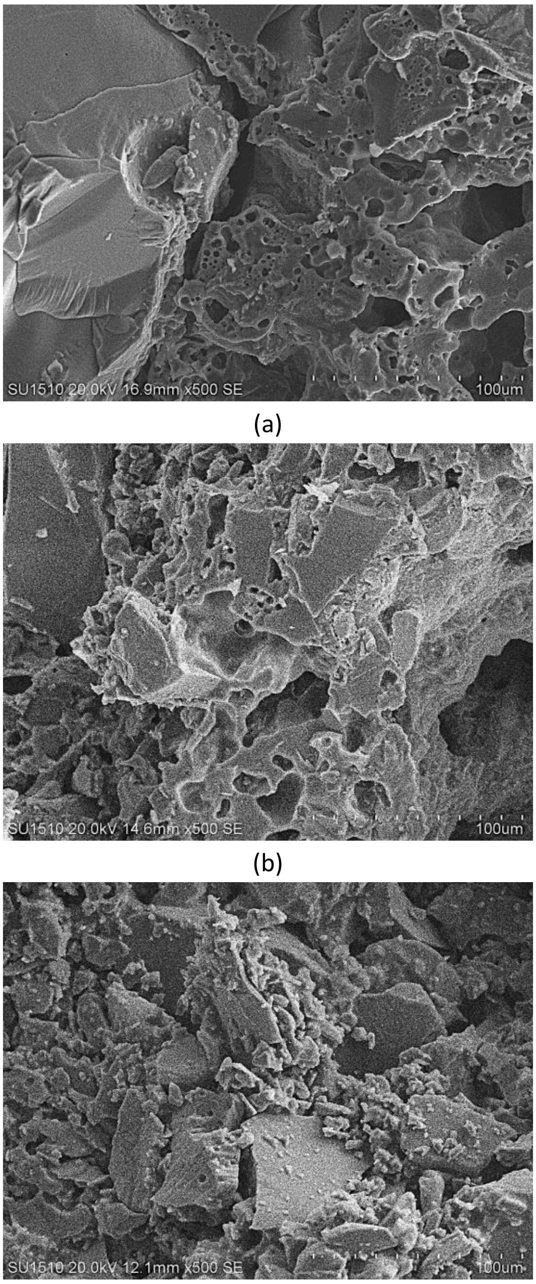
(a)

(b)

(b)

Figure 6. 3-point bending test values after thermal shock test a)strength, b) toughness and c) strength ratios of white fused alumina composite refractories.

According to thermal shock test results, the strength, toughness, strength ratio values of refractories incorporating of PCSW were higher than those of pure WFA refractory after thermal shock (Figure 6). It was thought that pre-existing microcracks propagated in the structure for a short distance by interlinking to each other, arresting or deviation of microcracks when reaching porosities, presence of ZrO_2 which is released due to decomposition of zircon due to transformation toughening mechanism and coexistence of intergranular and transgranular fractures (Figure 7-b and 7-c) increased those properties.



(a)

(b)

(c)

Figure 7. Fracture surface images of a) WFA, b)WFA+5% AISI 420 and c) WFA+5% AISI 316 refractory composite materials after thermal shock test

According to fracture surface images of refractory material after thermal shock tests, transgranular fracture type was dominant for pure WFA refractory. This change in the type of fracture decreased the mechanical properties. Also for this refractory, bigger grains with more amounts of porosities were observed.

For refractories produced by PCSW additions, either transgranular (for bigger grains) and intergranular (for smaller grains) fracture types were seen after thermal shock test.

Coexistence of intergranular and transgranular cracks, smaller grain size, microcrack formation and zircon content are the basic parameters that affected mechanical properties after thermal shock test and also thermal shock resistances of refractories produced with PCSW additions.

4. Coclusions

The presence of SiO_2 in the PCSW, microcrack formations caused lower physical and mechanical properties such as strength and elastic modulus before thermal shock test.

Interlinking of microcracks to each other, arresting or deviation of microcracks when reaching porosities, presence of presence of ZrO_2 which is released due to decomposition of zircon due to transformation toughening mechanism and coexistence of intergranular and transgranular fractures increased the strength, toughness, strength ratio values after thermal shock tests.

Acknowledgements

This study was supported by Necmettin Erbakan University Scientific Research Projects under projects no: 192819003 and 192819004.

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