Removal of Pollutants from Waste Foundry Sand by Chemical Washing Method

S. Balbay and C. Acikgoz

***Abstract*—The purpose of this research was to remove of metallic contaminant and other pollutants from waste foundry sand(WFS) by chemical washing method. Firstly, experimental investigation for removing of metallic contaminant and other pollutants from waste foundry sand(WFS) by using three different solutions 5 M HCl, 5 M H_2SO_4 and 5M NaOH. The extraction is carried out 3, 8 and 16 hours for each solution at 25 ^{0}C. After that, two - stage washing (successive washing with two different chemical) and triptych washing (successive washing with three different chemical) was applied to WFS. Functional group analysis of WFS and WFS after washing was done by using FT-IR. Results show the highest percentage of pollutant removal in H_2SO_4 – NaOH – HCl of triptych washing method.**

***Keywords*— chemical washing, metallic and other pollutants, waste foundry sand**

I. Introduction

Waste foundry sands represent the highest amount of solid wastes generated by foundries. Waste foundry sand (WFS) is a discarded material coming from ferrous and nonferrous metal-casting industry. Foundry sand typically consists of 85-95wt.% high-quality silica sand with uniform physical characteristics which is used by the foundry industry to create metal casting molds. Classification of foundry sands depends upon the type of binder systems used in metal casting. Two types of binder systems are generally used, and on the basis of that foundry sands are categorized as: clay-bonded sand (green sand) and chemically bonded sand[1]. Sodium silicate is used in foundries to bind sand grains by means of an appropriate acid, either directly such as CO_2, or indirectly with an organic ester, which hydrolyzes and subsequently gels the silicate sand mass. A gel network is prepared by acidifying concentrated sodium silicate (3.3ratio of SiO_2:Na_2O) solution. Sodium silicate solution, under acidic conditions is polymerized to silica and acts as an inorganic binder[2]. Foundries successfully recycle and reuse the sand many times. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as waste foundry sand. Additionally, chemical composition of the WFS also depends on the type of metal molded at the foundry. Several authors have reported the use of used-waste foundry sand in various civil engineering applications[3]. They have reported the use of used-waste foundry sand in various civil engineering applications such as highway applications, leaching aspect of usage of foundry sand, controlled low strength materials, concrete and concrete related products like bricks, blocks and paving stones, asphalt concrete[4]. In addition, the applications of waste foundry sand could be in following areas; barrier layers construction, embankments, flowable fills, road-way construction, agriculture, soil reinforcement/amendments, hot mix asphalt, portland cement manufacturing, mortars, traction material on snow and ice, vitrification of hazardous materials, smelting, rock wool manufacturing and fiberglass manufacturing[15]. However, the recycling of this waste is limited because its characteristics change significantly after use. This requirement poses a serious environmental problem due to not only the elevated volume produced but also the toxic substances found within the WFS, as the sand is contaminated by several dangerous chemical elements such as heavy metals (arsenic, cadmium, lead, and mercury) and organic compounds such as phenols [5].

The objective of this research is to remove of metallic contaminant and other pollutants from waste foundry sand(WFS) by chemical washing method.

II. Material and methods

Waste foundry sand used for the experimental work were supplied by Kibaroğlu Döküm Sanayi Ltd. Şti. in Turkey. The WFS is grayish in color with irregular shape. The particle size distribution of WFS was determined <1,18 mm. Firstly, the WFS was washed with distilled water and then dried overnight. 1 g of sample has been taken in beaker. Chemical washing studies of prepared WFS were performed at 25 ^{0}C. The dried WFS treated with 5 M hydrochloric acid (5 M HCl), 5 M sulphuric acid (5 M H_2SO_4), and 5 M sodium hydroxide (5 M NaOH) to remove of metallic contaminant and other pollutants, respectively. It has been well mixed by mechanical stirred at a speed of 300 rpm. Each experiment was carried out three times. The chemical treated WFS was washed with distilled water until the neutral pH was reached, and was filtered through over 0.45 µm membrane filters, then dried in an oven at 105 ^{0}C for 2

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hours. The removal percentage of contaminants was calculated as follows:

$$\text{Removal (\%)} = \frac{(Ai-Af)}{Ai}\ x\ 100$$

where A_i and A_f are the initial and final sample amounts, respectively. pH was measured using a pH meter (Hanna HI 991001). Waste foundry sand has low absorption capacity and is non-plastic[15]. The functional group compositional analysis of WFS and WFS after washing samples was investigated using FT-IR spectrophotmetry (Perkin Elmer, model spectrum 100**,** Bilecik, Turkey).

III. RESULTS AND DISCUSSION

The effect of washing time on the percentage of pollutant removal for 5 M HCl, 5 M H_2SO_4 and 5M NaOH solutions was studied. Chemical reactions involved in the washing studies by using three different solutions 5 M HCl, 5 M H_2SO_4 and 5M NaOH are grouped according to the following:

i) Reaction of sodium silicate with hydrochloric acid solution

$$SiO_3^{2-} + 2\ HCl \longrightarrow SiO_2 + 2\ Cl^- + H_2O \quad (1)$$
$$n[Si_7O_{18}H_4Na_4] + 4nHCl \longrightarrow n[Si_7O_{18}H_4] + 4nNaCl + nH_2O \quad (2)$$

Sodium silicate by adding dilute HCl, react through polycondensation reactions and lead to a silica gel by releasing water and NaCl (Eq. (1-2)) [16]-[17].

ii) Reaction of sodium silicate with sodium hydroxide solution

$$Na_{0.38}\ SiO_{2.19} + 1.62\ NaOH \longrightarrow 2Na^{2+} + H_2SiO_4^{2-} \quad (3)$$

Attack of the siloxane bridges and disintegration of the silica [17] – [18].

iii) Reaction of sodium silicate with sulphuric acid solution

$$n[Na_2SiO_3+(1-x)H_2O + H_2SO_4] \longrightarrow nNa_2SO_4 + [SiO_x(OH)_{4-2x}]_n \quad (4)$$

Acidification of the diluted sodium silicate solution via a reaction like the one below results in the formation of a semi solid network silicate gel (pH 10) as shown in Reaction (4) [19].

The washing times for HCl, H_2SO_4 and NaOH solutions were determined at 8 h, 16 h and 8 h, respectively (Fig.1). It was determined that the maximum removal percent as 13% with NaOH solution at 8 h washing time.

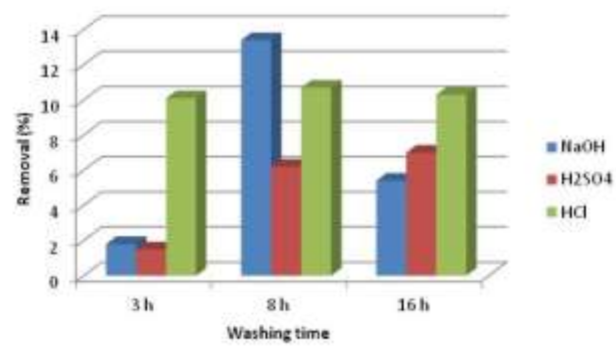

Fig 1. The effect of washing time of pollutant removal for per HCl, H_2SO_4 and NaOH (Solution concentration: 5 M, WFS amount: 1.0 g, Temperature: 25 ^{0}C)

The result of two - stage washing experimental studies were give in figure2. The highest removal percentage of pollutant was obtained in NaOH – HCl ambients of two - stage washing as 30%.

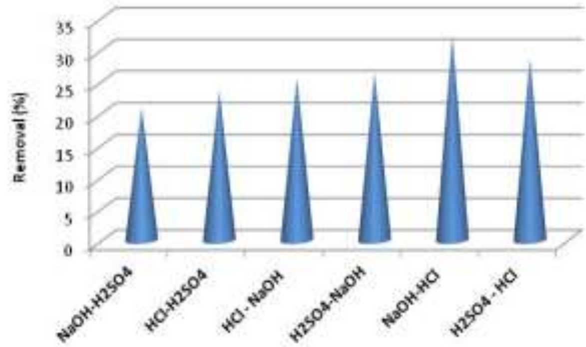

Fig 2. The effect of two - stage washing on pollutant removal (Solution concentration: 5 M, WFS amount: 1.0 g, Temperature: 25 ^{0}C)

Sodium silicate is very alkaline in nature having a pH ~12 [19]. Sodium silicate solution, under acidic conditions is polymerized to silica and acts as an inorganic binder [2]. According to reaction of sodium silicate with sulphuric acid solution, the silicate gel consists of a network of polymerized Si-O-Si-OH groups that traps water via solvation and hydrogen bonding forces (Eq. (4)). The structure of sodium silicate consists of silicate tetrahedral along with sodium that is not bonded into the structure and therefore can be washed out of the silicate gel that forms[19].

Silica is known to be more soluble in basic medium. A chemical reaction between the silica surface and the hydroxyl groups present in the basic solution could be consider by breaking the Si-O-Si leading to the formation of Si-OH and Si-O− groups (Eq. (3)) [17].

The result of three-stage washing experimental studies were give in figure3. The highest removal percentage of pollutant was obtained in H_2SO_4 - NaOH – HCl ambients of triptych washing as 40%.

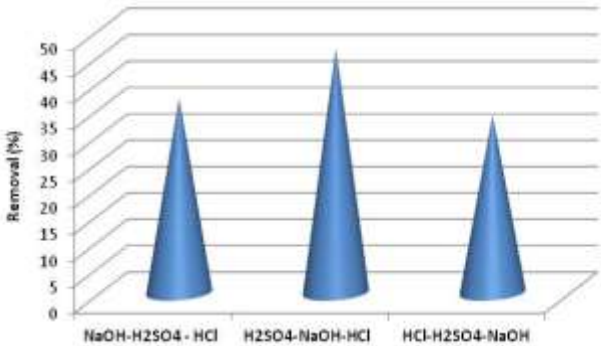

Fig 3. The effect of triptych washing on pollutant removal (Solution concentration: 5 M, WFS amount: 1.0 g. Temperature: 25 ^{0}C)

Chemical composition of the waste foundry sand depends on the type of metal molded at the foundry, type of binder and combustible used. The chemical composition of the foundry sand may influence its performance[1]. Silica sand is hydrophilic and consequently attracts water to its surface[15].

The effects of washing technique on chemical bonding in the WFS were studied using FTIR spectroscopy. Functional group analysis of used WFS and WFS after washing was done by using FT-IR. FTIR spectra of the WFS and WFS after washing samples are shown in Fig. 4-7. The peaks centered at 1070 and 495 cm^{-1} correspond to the Si–O–Si bonds and were the most informative of the silica network structure. In contrast, for the OD silica powder, a strong–OH peak (less stretched) at 3390 cm^{-1}, indicated that a significant fraction of the Si atoms existed on the surface of the silica network structure as hydroxylated species[20].

The presence of the anchored propyl group was confirmed by C–H stretching vibrations that appeared at 2933 and 2875 cm^{-1} [7]. Peaks in the spectral range at around of 1600 cm^{-1} and 2300 cm^{-1} are attributed to vibrations of carbon impurity atoms in the sample[8]. The presence of carbon in the WFS can be seen by two strong absorption bands at around 1619, 2921 and 2844 cm^{-1} (see Fig. 4 and Table.1).

In H_2SO_4 - NaOH – HCl ambients of triptych washing wasn't observed Si-O-Si and - OH ligand metal complex from 1400 to 1450 cm^{-1}(Table.1 and Fig 4-7).

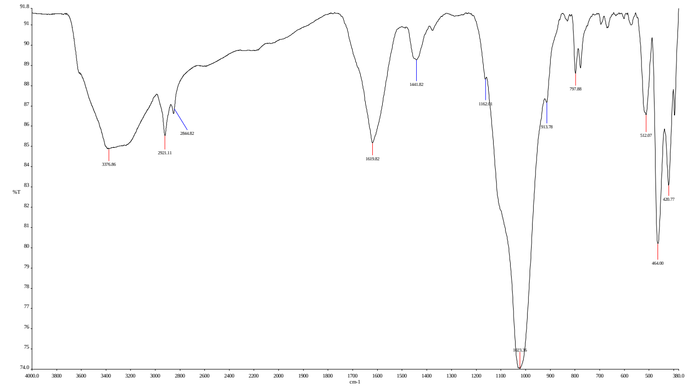

Fig 4. FT-IR spectrum of WFS

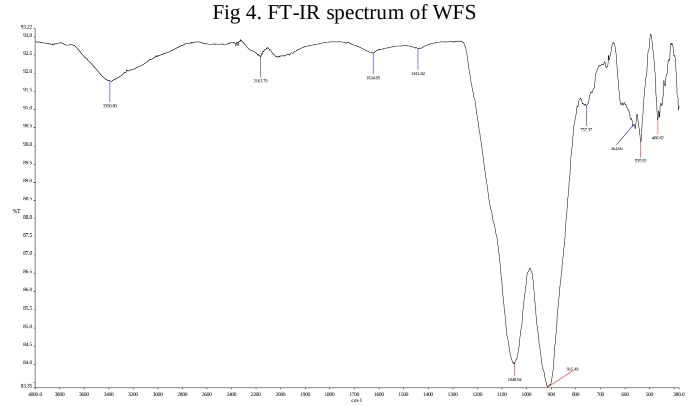

Fig 5. FT-IR spectrum of WFS in NaOH – HCl ambients of two - stage washing

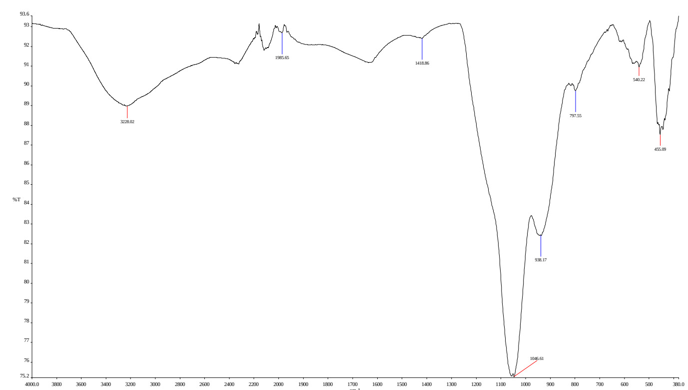

Fig 6. FT-IR spectrum of WFS in NaOH - H_2SO_4 – HCl ambients of triptych washing

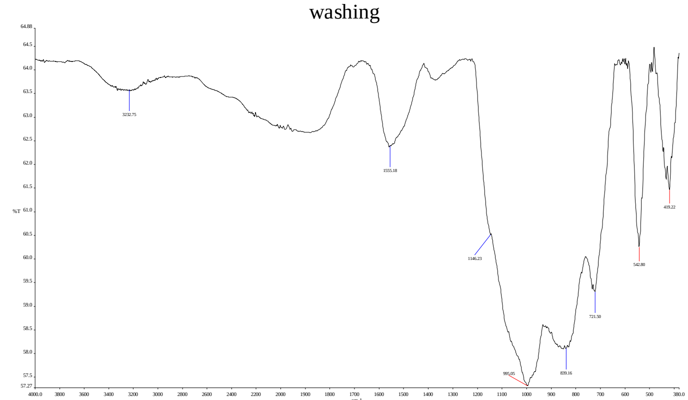

Fig 7. FT-IR spectrum of WFS in H_2SO_4 - NaOH – HCl ambients of triptych washing

Table 1. Attribution of FT-IR absorption for WFS and WFS after washing

Waste foundry sand (cm^{-1})	NaOH - HCl (cm^{-1})	NaOH - H_2SO_4 - HCl (cm^{-1})	H_2SO_4 - NaOH - HCl (cm^{-1})	Assignment
3376,86	3390,8			O-H stretching vibration of molecular water in the sample[6]
		3228,02	3232,75	Si - O - H bands [7]
2921,11				C–H stretching vibrations [7]
2844,82				C–H stretching vibrations [7]
	2163,79	1985,65		C $\equiv$ C bands
1619,82	1624,05			C - O bands [8]
			1555,18	C = C bands [9]
1441,82	1441,82	1418,86		Si-O-Si and - OH ligand metal complex [10]
1162,01			1146,23	Si–O–Si unti-asymmetric stretching of bridging oxygen atom within tetrahedra [11] - [12]
1023,36	1048,94	1046,61	995,05	
913,78	915,49	938,17		Si-OH bands [14] - [7]
			839,16	Si–O–Si symmetric stretch of bridging oxygen atoms between tetrahedra [13]
797,88		797,55		Si-C stretching vibration[9]
	757,37		721,5	Si–O–Si symmetric stretch of bridging oxygen atoms between tetrahedra [13]
	563,66			the rocking motion of Si–O–Si bridging oxygen which connects the various Qn species of silicates [8]
	535,92	540,22	542,8	
512,07				
464	466,62	455,09		
420,77			419,22	

IV. Conclusions

Removal of metallic contaminant and other pollutants from waste foundry sand (WFS) has been studied and experimental studies help to conclude reduction of metallic contaminant and other pollutants is much more better in case of H_2SO_4 - NaOH – HCl ambients of triptych washing and maximum reduction of metallic contaminant and other pollutants is 40%. The treated WFS may be reused in the foundry and various engineering applications such as rock wool manufacturing and fiberglass manufacturing.

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