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RECOVERY APPLICATIONS OF WASTE FOUNDRY SAND

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1. INTRODUCTION

One of the biggest problems in foundry facilities is foundry sand problem. Sand, which is the raw material of the casting industry, is easily obtained, easily removed and not easily processed. Foundry sand is used primarily in the metallurgical industry, automotive industry, ship industry, iron and steel production and many other industries. Developing the beneficial use of industrial materials, such as foundry sands, provides cost reductions and significant opportunities for a sustainable future.

1.1. Foundry Industry

As the first process in casting, pig iron, steel scrap and ferro alloys are heated at melting temperature in induction, arc or cupola furnaces to become melted. After the melting stage, metal, ceramic or sand is poured into the cavities of the molds, shaped and solidified. After solidification, pig, steel, ductile iron and temper products are obtained (Kepez, 2007). Obtaining the desired product is also called casting. Casting industry is a very dirty, dusty, dangerous and difficult sector (Gönüllü, 2007).

Turkey has an important place in the casting industry in Europe and the world. According to the report prepared by TÜDOKSAD in 2013, Turkey's casting production ranked 4th in Europe in 2012 after Germany, France and Italy. It is in the 13th place in the world ranking. China, India, USA and Germany are among the top countries in the world ranking.

When we look at the number of companies in the casting sector in Turkey in 2012, 1119 companies out of 1127 are private sector companies and 8 are public or military companies. The companies in the foundry industry are very diverse. Iron, aluminum, steel casting enterprises are the enterprises with the highest number. Again, according to the report prepared by TÜDOKSAD in 2013, 780 companies in iron-steel castings, 350 companies in non-ferrous castings and 171 companies in aluminum castings were active in 2012. The leading facilities of the sector are located in cities such as Istanbul, Bursa, Adapazarı, Eskişehir, Konya, İzmir, Samsun, Bilecik, Gebze, Ankara, Adana and Gaziantep. Pig and steel scrap are the most important and widely used raw materials for the foundry industry. Supply of raw materials is provided both domestically and abroad. In Turkey, foundry companies worked up to 63% capacity in 2012. The highest capacity utilization was in non-ferrous iron with 83%, followed by iron with 64% and steel casting with 47% (TÜDOKSAD, 2013).

According to the 2016 World Casting Production statistics of the American Foundry Association (AFS), the total casting production was 104,378,000 tons. Turkey, on the other hand, produced a total of 1,900,000 tons of castings (TÜDOKSAD, 2017).

1.2. Physical and Chemical Properties of Foundry Sand

Foundry sand has different physical and chemical properties depending on the sector in which it is formed and the casting process used (Siddique et al., 2009). Foundry sands are generally composed of 85-95% high quality silica sand, 4-10% bentonite or kaolinite clay added binder, 2-10% coal dust (carbonaceous additive) to smooth the surface and water for easy binding of the binder. They are grains at a sintering (heat treatment) temperature of °C (Yalçın et al., 2003). The specific gravity is between 2.39 and 2.55. Its water absorption capacity is low due to its specific gravity (Siddique et al., 2010). Foundry sands are free and loose. It has a black color due to its carbon content. In terms of structure, they are round or semi-angular sands, the majority of which are between 0.15-0.6 mm in size (Javed et al., 1994a; Kaur et al., 2012).

Table 1. Chemical composition of foundry sand (analysis results of a foundry factory in Bilecik/Bozuyuk)

Component	%	Component	%
SiO_2	86.20	Al_2O_3	4.02
Fe_2O_3	1.07	K_2O	0.41
Na_2O	0.83	TiO_2	0.25
CaO	0.75	MgO	0.45
Glow loss	6.02		

As Başar (2012) stated, although foundry sand is a non-hazardous waste due to the high silica (compound containing oxygen and silicon) it contains, the presence of dissolved organic carbon puts the foundry sand in the hazardous waste class.

2. WASTE FOUNDRY SAND

Although ceramic or metal molds can be used as mold material in casting processes, sand molds are the most used. Casting methods vary according to the type of sand mold used. Sand casting; shell molds, core molds, molds prepared using CO_2 gas, green sand molds, dry sand molds (Hawaman, 2009). Automotive industry and sub-industry are the leading sectors in which foundry sand is formed the most after casting (Siddique et al., 2010).

As a result of the production of one ton of casting material, 0.6-0.8 tons of waste is generated. The largest amount of this is 0.4-0.6 tons of used sand. According to the report prepared by TÜDOKSAD in 2015, 1750000 tons of castings were produced in Turkey in 2014. As a result, 500000 tons of waste was generated. 65% of this is foundry sand, 15% is dust-sludge, 10% is slag, and the remaining percentage is waste such as oil, stone, refractory, paint, barrels. The production points that cause the formation of foundry sand in foundries are shown in Figure 1.

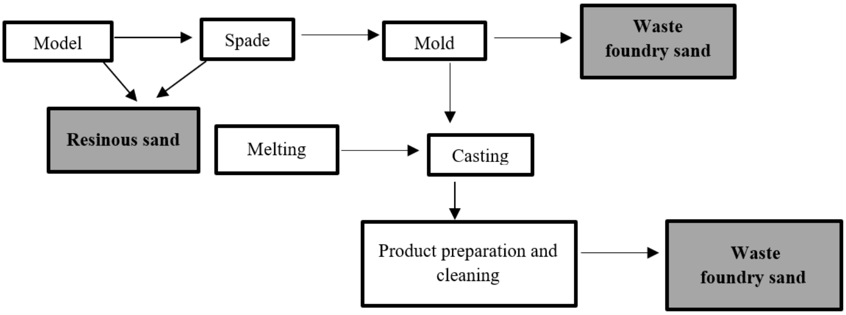

Figure 1. Foundry sand formation points in foundries

There are many factors that cause the foundry sand to become unusable after casting and become waste. It undergoes physical and chemical changes during the casting process, being treated with metal at a temperature of 1500°C, reduced grain size, spherical shape, decreased gas permeability in the cavities of the grains, decreased heat resistance feature, loss of binding material, inability to bind sand grains with each other, and With the decrease in the durability of the mold, the casting sand becomes waste. Foundry sands that become waste should be disposed of (Başar, 2012).

2.1. Disposal Methods of Waste Foundry Sands

More regular storage is applied in the disposal of waste casting sands formed as a result of casting. Apart from this, sand regeneration is also carried out (Solmaz et al., 2007).

2.1.1. Landfill

Waste foundry sand has been disposed of by being stored in landfills since 2005. Waste foundry sand was used as a surface cover in municipal landfills before landfill (Başar, 2012). Waste foundry sand is stored in Class I storage facilities where 2-C hazardous wastes can be stored, according to the waste acceptance criteria table in Annex 2 of the Regulation on Landfilling of Wastes. Waste foundry sand is disposed of by being stored in landfills in nearly 40 cities in Turkey. The regular storage of waste casting sand is mostly carried out in cities such as Istanbul, Kocaeli, İzmir, Konya, where the casting industry is concentrated.

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2.1.2. Sand Regeneration

Foundries use sand as a primary material. Green sand (chemically bonded sands) can be recycled after use. Regeneration is done in two stages. Primary regeneration involves breaking up the sand and returning it to its original size. In addition, it ensures the sieving of sand, removal of metals, and the destruction of fine particles. With the secondary regeneration process, the remaining binders on the sand are removed (Hawaman, 2009). Sand regeneration is not widely used in Turkey.

2.2. Alternative Methods for Disposal of Waste Foundry Sands

As a result of the increase in storage costs, the narrow and small storage areas, and the gradual decrease in the number of landfills, the necessity of disposal / reuse / evaluation in other areas has emerged. For this reason, suitable and alternative methods are sought for the reuse/recovery of waste foundry sand formed in the foundry industry (Gedik et al., 2010).

Ensuring the reuse/recovery of waste foundry sand using alternative methods will reduce production and disposal costs to a large extent. Four practices regarding the recovery of waste foundry sand are given in Table 2. (AFS, 2006; US EPA, 2006; Lawrence and Mavroulidou, 2009). The applications of waste foundry sand in other areas are also indicated in the other applications section in Table 2.

Table 2. Recovery applications of waste foundry sand

Geotechnical Applications	Highway Applications	Production Applications	Agricultural Applications	Other Applications
Set/Bend Structural fill Landfill fill/cover	Underground foundation material Road pavement Bituminous asphalt mix Anti-slip material on snowy-icy roads	Cement Grouting, mortar Asphalt concrete Concrete and concrete products	Soil improver Compost production Land surface cover	Adsorbent production Vitrification material

Siddique and Noumowe (2008); Siddique and Singh (2011) investigated the usability of waste foundry sand in embankment/dam construction. Abichou et al., (1998; 2000); Goodhue et al., (2001) as structural fill and fluid fill in sports fields, playgrounds and hydraulic barriers; Kunes and Smith (1983) conducted an experimental study on its usability as a filling material. Kunes and Smith stated that the sample obtained as a result of their study can be used in impermeability systems.

Bhat and Lovell (1996); Dingando et al., (2004) investigated the usability of waste foundry sand in flowable fillings. Arulrajah et al., (2016) stated that it can be used as a filling material and in pipe laying applications. Deng and Tikalsky (2008) stated that it can be used in fluid fills by performing physical, geotechnical and infiltration experiments. Ham et al., (1986); Regan et al., (1997); Siddique and Singh (2011) investigated the use of waste foundry sand in the landfill.

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Solmaz (2008) investigated the use of waste foundry sand as an impermeable curtain by compressing it with the addition of bentonite. Solmaz, in his study, examined the physical and index properties of waste casting sand and stated that it would be appropriate to use it as an impermeable curtain in the landfill.

Güney and Koyuncu (2002) and Güney et al., (2006) investigated the use of waste casting sand as filling material and base layer in road infrastructure and superstructure. Güney and Koyuncu stated that the waste foundry sand, which they observed to comply with the criteria in the Turkish Highways Standard, will be used in road materials. Yazoghli-Marzouk et al., (2013) also found it suitable for use as a road base material.

Gedik (2008) conducted a study on the use of waste dump sand as road material and stated that waste dump sand can be used in road construction. Gedik et al., (2010) stated in their other study that it can be applied on the highway as a filling material or a road sub-base material. Javed and Lovell (1994a); Abichou and Edil (1998); Kirk (1998); Kleven et al., (2000); Abichou et al., (2004) stated that waste dump sand can be added in the construction of the highway embankment. Mast and Fox (1998), on the other hand, used waste casting sand in the construction of the highway embankment after their study.

Yalçın et al., (2003), on the use of waste casting sand as cement mortar in concrete; Siddique et al., (2009); Khatib et al. (2010); Monosi et al., (2010) concluded in their studies that it is suitable for cement mortar. Perairaa et al., (2006); Korac et al., (2006) mentioned its use in mortars. Yalçın et al., (2003) investigated the usability of waste casting sand in Portland cement added concrete. Instead of standard sand, casting sand and mixtures with different water/cement ratios as binders were prepared and their effects on the physical and chemical properties of concrete were investigated. As a result of the experiment, they concluded that waste casting sand cannot be used in reinforced concrete, but can be used in filled concrete.

Başar (2013) investigated the usability of waste casting sand in ready mixed concrete. Başar carried out experimental studies of the new concrete he prepared by mixing waste casting sand with silica sand instead of aggregate in concrete. He performed this experiment with the application of solidification/stabilization. As a result of the experiment, he stated that the use of waste casting sand could meet the aggregate requirement for ready-mixed concrete.

Bakis et al., (2006); Lawrence and Mavroulidou (2009); Güney et al., (2010); Khatib et al., (2010) observed that the mechanical properties of concrete change by using fine aggregate in concrete. Siddique and Sing (2012); Bhardwaj and

Kumar (2017) concluded that the strength and compressive strength of the concrete they designed by using casting sand instead of natural sand increased. In the study of Güney et al., (2010), it was observed that the slump and workability of fresh concrete decreased with the increase in the waste casting sand ratio. Siddique and Kaur (2011); Mastella et al., (2013) conducted a study on the use of mushroom added waste foundry sand as a concrete material. Siddique and Kaur concluded that the use of cork in concrete accelerated the reaction of cement and waste casting sand. Gurumoorthy and Arunachalam (2016) also investigated the effect on concrete by mixing waste casting sand with silica instead of the cork used by Siddique and Kaur in their study.

Javed et al., (1994b); Güney et al., (2006); Bakis et al., (2006); Fiore and Zanetti (2007); Monosi et al., (2010) waste casting sands as bricks, briquettes, road stones in the manufacture of concrete and concrete products; Naik et al., (2004); Siddique et al., (2009) studied its usability in civil engineering fields. Naga and Al-Maghraby (2003); Seung-Whee and Woo-Keun (2006); Raupp-Perairaa et al., (2006); Mymrin et al., (2015) conducted research on its addition in ceramics. According to AFS (2006), waste casting sands are also used as briquettes, blocks, paving stones. Doğan (2010) revealed in his study that waste foundry sands can be used as paving stones. Alonso-Santurde et al. (2011) stated that waste foundry sand can be recycled in clay bricks. It has been understood from the study of Siddique and Sing (2011) that it can also be used in the production of stone wool and glass wool.

Kunes and Smith (1983) stated in their study that some foundry sands can be applied as vegetable soil by mixing them with the ground they use as filling material. Lindsay and Logan (2005) conducted a study on the use of waste foundry sand as compost material. Dayton et al., (2010) stated that waste foundry sand has soil-like properties and can be used in agricultural applications since it also contains nutrients (K, N, P, S) and trace elements (Cu, Mn, Zn, Mo, Co) found in the soil. According to US EPA (2006), waste foundry sand can be used as soil conditioner, compost, production soil and surface cover.

Gürkan (2017) examined the effect of waste foundry sand on cationic dyestuff removal by adsorption method in textile wastewater. In the study, it was concluded that the efficiency of cationic dyestuff removal from aqueous solutions was high by using waste casting sand with bentonite binder. Yerlikaya (2001) previously conducted a study on the organic and inorganic character of waste foundry sand and observed the effect of pollutants on groundwater. Siddique and Noumowe (2008) mentioned its use as a vitrification material in their study. Volunteer

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(2007) also participated in the study of Siddique and Noumowe and said that waste foundry sand is suitable for vitrification due to its high silica content.

3. RESULTS AND DISCUSSION

Waste foundry sand originating from the foundry industry is evaluated in Europe and the USA with applications for recycling / reuse with environmentally friendly methods instead of disposal. Waste foundry sand is mostly disposed of in regular landfills in our country. It can be reused as a warehouse cover and as a raw material in cement factories. Related applications should be developed. Regulations should be issued for the use of waste casting sands as building material in construction, as filling material in highways, and as compost in agriculture, and these applications should be encouraged. Constructive incentives for its use as raw materials for other industrial sectors should be prepared. Recovery / reuse of waste foundry sand in accordance with standards; It will reduce sand costs, reduce the waste accumulated in the environment, prevent the depletion of natural resources, reduce the raw material costs of other industrial sectors, and contribute to the protection of the environment.

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