THE EFFECT OF WASTE FOUNDRY SAND AS PARTIAL SAND REPLACEMENT TOWARDS POROSITY AND CHLORIDE RESISTANCE IN MORTAR

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ABSTRACT

Waste foundry sand (WFS) is high quality silica sand that is a byproduct from the production of both ferrous and nonferrous metal casting. In metal casting process, molding sand which is foundry sand is recycled and re-used for several times until it no longer can be used. The large amount of waste foundry sand demand more landfill space. The research should be continuously done to investigate about the potential of waste foundry sand to be reused in various types of field such as construction, highway and geotechnical applications. For this research, the properties of mortar containing different percentage of waste foundry sand (0%,10%,20% and 30%) as partial replacement of naturals sand were investigated towards porosity and chloride resistance. The type of waste foundry sand used was silica sand with sodium silicate as a binder. Vacuum saturation test was done to determine the porosity and two tests for chloride resistance which were open circuit potential (OCP) test and impressed voltage test. From the result, it was found that the waste foundry sand has a potential to be used in mortar to reduce the porosity and increase the resistance towards chloride attack. The waste foundry sand can be used as a partial sand replacement in mortar and the optimum percentage of partial sand replacement was up to 10% of waste foundry sand in mortar.

ABSTRAK

Sisa pasir foundri ialah pasir silika yang berkualiti tinggi dan merupakan hasil sampingan daripada proses pembentukan logam ferus dan bukan ferus. Semasa proses pembentukan logam, pasir foundri akan dikitar semula dan digunakan semula untuk beberapa kali sehingga ianya tidak boleh digunakan lagi. Pertambahan jumlah sisa pasir foundri memerlukan tapak pelupusan yang lebih besar. Lebih banyak penyelidikan perlu dilakukan bagi mengkaji mengenai potensi sisa pasir foundri untuk digunakan semula dalam pelbagai bidang seperti pembinaan, jalan raya dan aplikasi dalam geoteknik. Dalam kajian ini, sifat-sifat mortar yang mengandungi sisa pasir foundri yang berbeza peratusan (0%,10%,20% dan 30%) digunakan sebagai pengganti sebahagian pasir semulajadi dikaji daripada segi keliangan dan rintangan klorida. Jenis sisa pasir foundri yang digunakan adalah pasir silika dengan "sodium silicate" sebagai pengikat. Ujian "vacuum saturation" dijalankan untuk menguji kesan terhadap keliangan dan dua ujian untuk rintangan klorida iaitu ujian "open circuit potential (OCP)" dan ujian "Impressed voltage". Dari hasil kajian, didapati bahawa sisa pasir faundri mempunyai potensi untuk digunakan dalam mortar bagi mengurangkan keliangan dan meningkatkan rintangan terhadap serangan klorida. Sisa pasir faundri boleh digunakan sebagai pengganti sebahagian pasir semulajadi dalam mortar dan peratusan optimum penggantian sebahagian pasir adalah sehingga 10% sisa pasir faundri dalam mortar.

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CHAPTER 1

INTRODUCTION

1.1 Background study

Metal casting is one of the important industries in the world. The metal demand is increasing over the year due to the development of various industries which are using metals as main material such automotive and machines production. Sand casting is the oldest, most basic, and the cheapest method of casting ferrous and non-ferrous materials. Foundry functions as a manufacturing facility that produces metal castings by pouring molten metal into a performed mould to yield the resulting hardened cast. Each year foundries produce million of tones of foundry sand that not suitable for used continuously in the mould or core making process. This is because the sand loss its characteristics especially the cleanliness and uniformity ones.

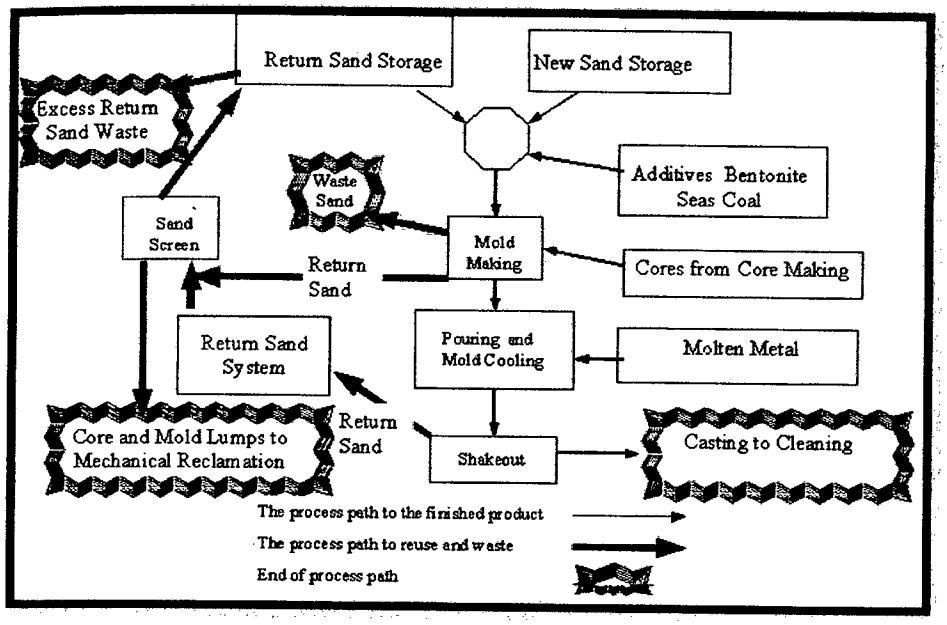

Figure 1.1: Simplified schematic figure of green sand mold system (American Foundrymen's Society, 1991)

The sand is by product from foundry is high quality silica sand which is called waste foundry sand. Only the small amount of waste foundry sand is beneficially reused outside of foundry. The remainder is discarded in municipal or industrial landfills despite of the fact that the waste foundry sand is actually non hazardous and has potential to be used in various applications.

Now days, the environmental aspect is one of the main elements in industrial activity that need to be concerned. Even though most of the waste foundry sand is non hazardous by product, the large amount of this waste still can give thread to the environment and public. For example the potential of various constituents to leach from the sand becomes a concern because the possibility to contaminate the soil. Besides that, the large amount of waste foundry sand generated by foundry over a year is increasing due to the higher demand for metal product. More landfill need to be built in order to satisfy the requirement of waste foundry sand dumping. Many researches are done in various fields such as concrete materials, highway, geotechnical and many more to find solution to reduce the problem.

For waste foundry sand, properties such as physical characteristics, physical properties, chemical composition and mechanical properties. These properties are important to ensure the viability of waste foundry sand to be used in various applications. A mortar is a material resulting of intimate mixture of sand, binder which is cement and water. Sand is the common ingredient for mortar and it constitutes bulk of the mortar volume. The composition of sand and its grading can influent the properties of mortar in fresh as well as in hardened state. The properties of mortar such as compressive strength, durability which are permeability and porosity, and chloride resistance can be determined by the series of tests.

The research about partial replacement material in mortar is done to study about the possibility to reduce the cost, to increase the strength, durability and chloride resistance, and in the same time to make it more environmental friendly. Waste foundry sand is one of the by product that has high potential to be a partial replacement of sand in mortar.

1.2 Problem statement

For many years, foundries are successfully in recycling the sand for several times until it cannot be reused and it will be disposed at the landfill. The byproduct then will be called as waste foundry sand. The rapid development in metal industries produce more amount of byproduct which is waste foundry sand and the demand of space for the waste is higher. Larger landfill is constructing and the cost for the construction is increasing years by years.

Due to ever increasing quantities of waste materials and industrial by-products, solid waste management is the prime concern in the world. Shortage of land-filling

space and because of its ever increasing cost, recycling and utilization of industrial by-products and waste materials has become an attractive proposition to disposal (Rafat Siddique et al., 2011).

By referring to American Foundry Society (AFS), industry estimates are that approximately 100 million tons of sand is used in production annually. In fact, four to seven million tons are discarded annually and are available to be recycled into other products and industries. This amount is still small to compare with the total amount of waste that increases by the time being. Actually waste foundry sand is like other waste that can be applied in other industry for example in civil engineering field. This includes application such as embankments, flow able fill, hot mix asphalt (HMA) and Portland cement concrete (PCC). In PCC, the usage of waste foundry sand is to replace natural fine aggregate.

The conscious about the important of protecting the environment is increasing for concrete industry. Many approaches are proposed in order to produce concrete that more environmental friendly. Special term for example "green concrete" start to be used to show the concern about environment matter. The U.S EPA estimates that the current level of waste foundry sand use in construction application and manufactured soil results in the prevention of 20,000 tons of CO_2 emissions and the saving of more than 200 billion BTU_S. The number of data is increasing year by year parallel with the increasing of metal manufactured.

1.3 Research objectives

The objectives of this research are:

i. To investigate the effect of waste foundry sand as partial sand replacement in mortar toward porosity properties.
ii. To investigate the effect of waste foundry sand as partial sand replacement in mortar towards chloride resistance properties.
iii. To investigate the optimum percentage of waste foundry sand as partial sand replacement in mortar.

1.4 Scope of work

Laboratory tests are done to study the potential of waste foundry sand to partially replace sand in mortar. The type of mortar is Portland cement mortar that consist cement, natural sand, foundry sand and water as the elements. This research is focus on determining porosity properties and chloride resistance properties of mortar contain foundry sand of 0%, 10%, 20% and 30%. Sieve analysis, particle size analysis and chemical content test for chloride are done to ensure the foundry sand pass the standard required for partial replacement of sand in mortar. Hardened mortar tests in term of porosity and chloride resistance are done. For chloride resistance two tests are involved which is Open Circuit Potential test (OCP) and Impressed Voltage test. Then for porosity determination Vacuum Saturation test is done. The standard used for the laboratory test is ASTM standard and Malaysian Standard. The foundry sand sample is collected from Hunta Foundry Sdn. Bhd. at Kapar, Klang. The waste foundry sand contains silica sand and sodium silicate as the binder. For porosity test, the test is done

28, 60 and 90 days after curing day. Then for Open Circuit Potential (OCP) the test is done at 0 and 90 days after curing and for impressed voltage the test is done after 28 days of curing day.

1.5 Research Significant

In today world, the reused and recycle process becomes important issues. More research must be done to investigate the effectiveness of waste foundry sand in various industries. The outcome of the research is able to solve environmental and landfill problem. In this research, waste foundry sand is used as a partial replacement of sand in mortar. Various tests are done in order to investigate the effectiveness of waste foundry sand toward the porosity and chloride resistance properties.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A mortar is used since a long time ago as a constructive material and it has two main purposes which is to act as bonding agent between material and fill the gap between them for example in construction when brick and rocks are applied. Mortar is also applied as protector and construction material to cover the column, wall and other surface. Mortar helps to produce smoother surface for the structures. Mortar is different from concrete especially in term of material because mortar is the material result of mixing of well graded sand, cement and water (Venkatarama Reddy et al., 2007). On the contrary, concrete is a man-made composite the major constituent of which is natural aggregate, such as gravel and sand or crushed rock. Concrete is composed mainly of three materials which are cement water and both course and fines aggregates (Neil Jackson et al, 1996:163).

Stefanidou Maria (2010) stated in the research that mortar is counted among the oldest building materials and mortar plays an important role to connect masonry elements such as stones and bricks. Mortar is also applied to render surfaces for protective and aesthetics purposes, as substratum for frescoes, floors, roofs, and mosaics. Besides that mortar is also has different technological characteristics in term of binder combination, type and size of sand, different compaction degree and water/cement ratio in order to meet the specific construction demands.

By referring to book of Foundry Sand Facts for Civil Engineer (Foundry Industry Recycling Starts Today (FIRST), 2004:13), Foundry sand is basically is a fine aggregate. It can be used in various applications such as concrete and mortar and can be applied the same ways as natural or manufactured sands.

Rafat Siddique et al. (2008) in the research stated that waste foundry sand is high quality silica sand with uniform physical characteristics. It is a byproduct of ferrous and nonferrous metal casting industries. The sand casting is one of the oldest methods of metal casting and it has been used for centuries because of its thermal conductivity.

2.2 Overview of foundry sand and waste foundry sand

By referring to book of Foundry Sand Facts for Civil Engineer (Foundry Industry Recycling Starts Today (FIRST), 2004:11), a foundry is a manufacturing facility that produces metal castings by pouring molten metal into preformed mold to yield the resulting hardened cast. There are various type of metals cast include steel and iron from the ferrous family and copper, brass, aluminum and bronze from nonferrous family.

Through the summary of report of Beneficial Reuse of Spent Foundry Sand, all foundries produce castings by pouring molten metal into molds. The characteristics of the residuals vary from foundry from foundry, and it depend on type of metal being poured which are iron, steel, aluminum, brass or bronze, the type of casting process such as sand casting and investment casting, and the technology applied. The technology employed are including the type of furnace such as induction, electric arc and cupola and the type of finishing process for example grinding, blast cleaning and coating (Clean Washington Centre (CWC), 1996) .

By referring the summary of report of Beneficial Reuse of Spent Foundry Sand, the most common casting process used in the foundry industry is the sand cast system. Sand casting involves making a pattern of the component to be cast, and packing sand around the pattern to produce a hollow mold. Sand casting generates residuals from metal melting and pouring, and molding processes. The residuals consists of waste foundry sand from molding and core making, slag, and wastes from cleaning rooms, dust collectors or scrubbers waste. Some of them may be hazardous (Clean Washington Centre (CWC), 1996).

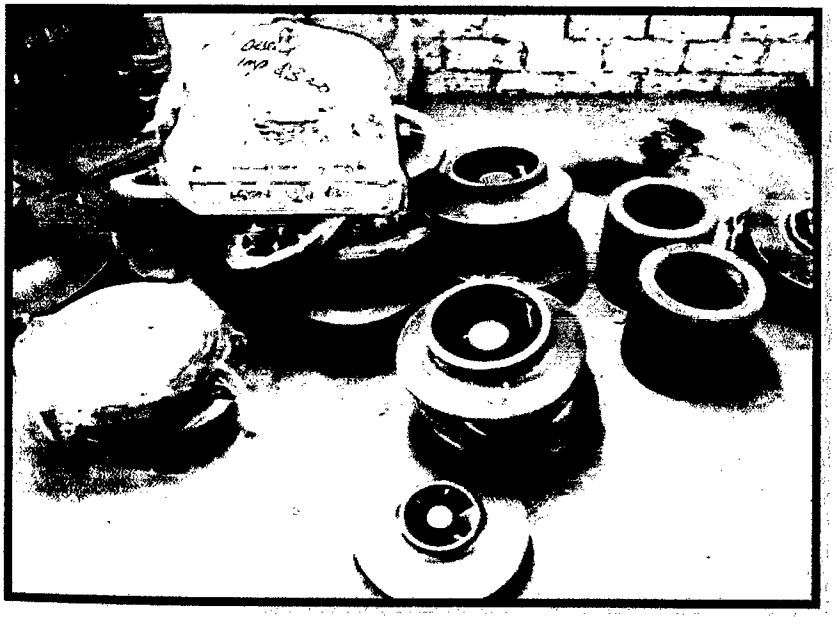

Figure 2.1: Metal product based on sand casting at Hunta Foundry Sdn. Bhd.

Foundries successfully recycle and reuse the sand many times in a foundry. When the sand cannot longer be reused in the foundry, it is removed from the foundry and is termed waste foundry sand (Rafat Siddique et al., 2008).

By referring the book of Foseco Foundryman's handbook (John R. Brown, 1994:27), most sand moulds and cores are based on silica sand since it is the most readily available and lowest cost molding materials. Other sands are used for special applications where higher refractoriness, higher thermal conductivity or lower thermal expansion is needed. Basically, in the metal casting industry there is two types of foundry commonly used which are green sand and chemically bonded sand. Common type of chemically bonded sand used in metal casting industry are resin coated sand, cold box sand, sand hot box sand (Gurpreet Singh et al., 2011). Generally, chemically bonded sand is light in colour when it compared to green sand (Rafar Siddique et al., 2010). American Foundry Society (AFC, 2011) explained that foundry sand is generally black in colour which is giving the resulting concrete a grayish cast. For green sand it consists of high quality 85-95% silica sand, 7-10% bentonite or kaolinite clay, 2-5% of water, and about 5% sea coal. Then there are chemical binders such as phenolic-urethane added (Yucel Guney et al., 2010).

By referring the book of Foundry Sand Facts for Civil Engineer (Foundry Industry Recycling Starts Today (FIRST), 2004:5) Green sand consists of 85-95% silica, 0-12% clay, 2-10% carbonaceous additives, such as sea coal, and 2-5% water. Green sand is the most commonly used molding media by foundries. The silica sand is the bulk medium that resists high temperatures while the coating of clay binds the sand together. Then, the water helps to add plasticity and the carbonaceous additives prevent the "burn-on" or fusing of sand onto the casting surface. For chemically bonded sand it consists of 93-99% silica and 1-3% of chemical binder. Common chemical binder systems used are phenolic urethanes, epoxy resins, furfyl alcohol, and sodium silicates.

Besides that the other type of foundry sand is sodium silicate-bonded sand. According to Foseco Foundryman's handbook (John R. Brown, 1994:71) sodium silicate is a water soluble glass available from suppliers in a wide range of types specified by the silica (SiO2), soda (Na2O) and water content. Manufacturer's data sheets specify the "weight ratio" of silica to soda, the water percentage and the viscosity. For foundry use, sodium silicates with ratio between 2 and 3 and water content about 56% are usually used. Sodium silicate can be hardened in a number of ways; by adding weak acid (CO2 gas or organic esters), by adding various powders (di-calcium silicate and anhydrite) or by removing water. CO2 gas and liquid ester hardeners are the most widely used of the silicate processes. Silicate binders have no smell and few health hazards, but the bond strength is not as high as that of resin binders and being an inorganic bond, it does not burn out with heat, so breakdown additives are often incorporated with the liquid silicate or added during sand mixing.

Figure 2.2: Sodium silicate-bonded sand at Hunta Foundry Sdn. Bhd., Kapar Klang

Figure 2.3: Waste foundry sand at Hunta Foundry Sdn. Bhd, Kapar Klang

For the research purpose, basic physical characteristics of foundry sand should be investigated. Generally the waste foundry sand is sub angular to rounded in shape. The foundry sand that be Foundry Sand Facts for Civil Engineer (Foundry Industry Recycling Starts Today (FIRST), 2004:9) used for many time in foundry process there is changes in apparent. Then the quality of foundry sand can be determined by its durability and soundness and chemical composition. To ensure the long-term performance of application in civil-engineering the durability and soundness information of foundry sand must be investigated. Durability of the foundry sand depends on how the sand was used in the foundry. Successive molding can cause the foundry sand to weaken due to the high temperature exposure for a long term. This can lead to the accelerated deterioration of the original sand properties. Then for the chemical properties in foundry sand is affected by the metal molded at the foundry. Its related directly with the type of binder was used and the combustible additives were applied

Table 2.1: Typical physical properties of foundry sand

Foundry Sand Facts for Civil Engineer (Foundry Industry Recycling Starts Today (FIRST), 2004:7)

Property	ASTM Standard	Foundry Sand with Clay	Foundry Sand Without Clay
Bulk density (pcf)	C29	60-70	80-90
Moisture content (%)	D2216	3-5	0.5-2%
Specific gravity	D854	2.5-2.7	2.6-2.8
Dry density (pcf)	D698 Standard Proctor	110-115	100-110
Optimum moisture content (%)	D69	8-12	8-10
Permeability coefficient (cm/s)	D2434	10^{-3}-10^{-7}	10^{-2}-10^{-6}

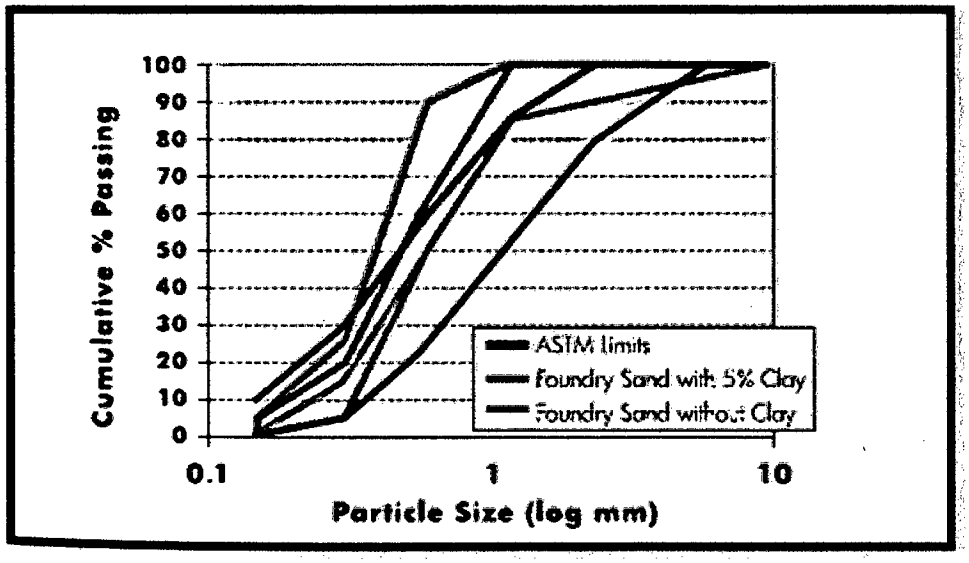

Figure 2.4: Foundry sand gradation as compared to ASTM C33

Foundry Sand Facts for Civil Engineer (Foundry Industry Recycling Starts Today (FIRST), 2004:8)

2.3 Utilization of waste foundry sand

Do to the increasing of waste foundry sand which is by-product of steel industry year by year, the awareness of this matter is also increasing. People start to think the solution for the problem of the waste. Organizations and societies are established to promote the importance to reuse the foundry waste especially foundry sand. Organization such as American Foundry Society is very committed to educate foundries, end users, government agencies and other stakeholders about the benefits of using foundry byproducts.

By referring the article of Foundry Sands Recycling (United States Environmental Protection Agency, 2007) the recycling of nonhazardous, waste foundry sand can save energy, reduce the need to mine virgin materials, and may reduce costs for both produces and end users. For example, in cold weather climates, use of waste foundry sands as construction site base materials extends the construction season because such sands won't freeze as readily as most soils. Regardless of the application, foundries and foundry sand recyclers should consult state regulators to ensure that planned uses are consistent with state beneficial use and waste management programs and that the chemical and physical properties of the sand meet applicable state environmental limits, engineering performance criteria, and other state requirements.

2.3.1 Waste foundry sand in concrete and mortar

By referring to the book of Foundry Sand Facts for Civil Engineer (Foundry Industry Recycling Starts Today (FIRST), 2004:50), generally foundry sand is too fine to permit full substitution. To meet the specification, it is necessary to remove the fines or to blend the waste foundry sand with coarser sands. Besides that the waste foundry sand can be a partial replacement of natural sand in concrete and mortar. Waste foundry

sand can be blended with them to satisfy the specification. Then, the waste foundry sand is able to comply with the specification.

Table 2.2: Fines aggregate gradation (ASTM C33)

Sieve No.	Sieve Size (mm)	Percent Passing by Weight (%)
4	4.75	95-100
8	2.36	80-10
16	1.18	50-85
30	0.6	25-60
50	0.6	10-30
100	0.15	2-10

Portland cement concrete (PCC) is one of very common construction materials that be used in the industry. According to the Portland Cement Association (PCA) (2011), more 340 million cubic yards (260 million cubic meters) of concrete are produced each year in United States (American Foundry Society, 2011). The concrete mixture that does not have enough paste to fill all the voids between the aggregates will be difficult to place and will produce rough, honeycombed surfaces and porous concrete. The main key to achieve a strong and durable concrete actually depends on the proportioning and mixing of the materials

From the book of Foundry Sand Facts for Civil Engineer (Foundry Industry Recycling Starts Today (FIRST), 2004:59), fine aggregate is one of the important materials in concrete. It consists of natural sand or crushed with particles size smaller