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Assessing the Suitability of South African Waste Foundry Sand as an Additive in Clay Masonry Products

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***Abstract*—**The foundry industry generates large quantities of solid waste in the form of waste foundry sand. The ever-increasing quantities of this type of industrial waste put pressure on land-filling space and its proper management has become a global concern. The South African foundry industry is not different when it comes to this solid waste generation. Utilizing the foundry waste sand in other applications has become an attractive avenue to deal with this waste stream. In the present paper, an evaluation was done on the suitability of foundry waste sand as an additive in clay masonry products. Purchased clay was added to the foundry waste sand sample in a 50/50 ratio. The mixture was named FC sample. The FC sample was mixed with water in a pan mixer until the mixture was consistent and suitable for extrusion. The FC sample was extruded and cut into briquettes. Water absorption, shrinkage and modulus of rupture tests were conducted on the resultant briquettes. Foundry waste sand and FC samples were respectively characterized mineralogically using X-Ray Diffraction, and the major and trace elements were determined using Inductively Coupled Plasma Optical Emission Spectroscopy. Adding purchased clay to the foundry waste sand positively influenced the workability of the test sample. Another positive characteristic was the low linear shrinkage, which indicated that products manufactured from the FC sample would not be susceptible to cracking. The water absorption values were acceptable and the unfired and fired strength values of the briquette's samples were acceptable. In conclusion, tests showed that foundry waste sand can be used as an additive in masonry clay bricks, provided it is blended with good quality clay.

***Keywords*—**Foundry waste sand, masonry clay bricks, modulus of rupture, shrinkage.

I. Introduction

THIS paper outlines the initiative taken to recycle foundry waste sand. Foundry industries recycle and reuse silica sand during casting process [1]. Recycling and reusing processes are performed successfully several times, however, there is a point when it is impossible to process the reused sand further, and at this stage the sand is classified as foundry waste sand [2]. In most instances foundry waste sand is disposed of in landfill sites. This poses a risk in South Africa, since there is shortage of landfill sites to dispose waste.

Various researchers took initiatives to recycle waste foundry sand by reusing it in different civil engineering functions, such as highway applications, leaching aspects of usage of foundry, controlled low strength materials, concrete and concrete related products like bricks, blocks and paving stones, asphalt concrete [2]. This paper exhibits initiatives taken to recycle waste foundry sand. The following factors are investigated:

- Assess the viability of using waste foundry sand as an additive when forming clay bricks
- Characterize the chemical properties of original waste foundry sand and the mixture formed
- Determine the physical properties of the final product

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II. Literature

The stockpile waste creates problems to the environment, hence there must be plans to recycle and reuse generated waste. The disposal of foundry waste sand causes direct contamination of soil, due to metals [3].

The focus of this paper is to determine the suitability of using foundry waste sand as an additive in clay brick products. The brick industry is considered to be popular in terms of beneficiating waste materials because bulk amounts of raw material are required during manufacturing of the final product [4]. The manufacture of clay bricks with the amalgamation of waste materials results into a successful factor for the brick industry since this contributes to a more sustainable construction material [5]. The advantages are on one hand, a reduction of the clay extraction and, on the other, minimization of waste in landfills.

Various laboratory tests are performed to characterize the quality of brick products manufactured and the raw material used. Reference [3] studied the structure, composition and morphology of the foundry waste sand and clay samples through the scanning electron microscope and mineralogical composition through the X-ray diffraction. Laboratory tests conducted on the test sample bricks were porosity, water absorption, specific gravity, bulk density and compressive strength. Positive results were obtained since the bricks manufactured conformed to IS 1077 guidelines. The bricks manufactured were consequently characterized as class III. These bricks can be used in single storied load bearing buildings, and also in the construction of inner walls in multi-stored buildings. Negative results were also obtained because after firing the formed samples, the bulk density reduced, whereas the water absorption increased.

Reference [6] conducted a study on recycling waste foundry sand as a substitution for fine aggregate during the manufacturing of concrete bricks. The manufactured bricks were characterised through density, compressive strength, water absorption, drying shrinkage and moisture movement.

The integration of waste foundry sand in a concrete mixture enhanced the strength of the final product and best results of the amalgamation were received between 20 and 30%.

Foundry waste sand can be blended with different waste materials. The study [7] demonstrates that foundry waste sand and Waelz slag can be used to replace clay in the manufacturing of red clay bricks.

III. Methodology

A. Chemical and Mineralogy Analysis

It is vital to determine the chemical and mineralogical compositions of raw materials used to form bricks because the quantities of minerals greatly influence the behaviour of the products during the stages of forming, drying and firing [8]. The chemical and mineralogical composition of the purchased clay and FC sample were respectively determined using the following methods:

Chemical analysis was conducted through Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-EOS). ICP-EOS is a multi-element analytical technique used to analyse major, minors and minor trace elemental concentration levels in a sample. Metal oxides in the sample were determined using this technique.

To obtain the bulk mineralogical composition, the sample was pulverised and subjected to XRD analysis. Cu Kα radiation, a 2θ scan range of 5-80º, a step size of 0.02º 2θ, and a counting time of 3 s per step was employed. Only crystalline phases in amounts sufficient to diffract (usually 3-4 mass %) under the conditions employed, are detectable [9], [10].

B. Extrusion

The raw materials required for the tests were foundry waste sand and clay which was purchased at a local shop. The purchased clay sample was in a useable state whereas the foundry waste sand sample had to be prepared before the experiment. The moisture in the foundry waste sand sample was removed by drying the sample in a Labcon electrical drying cabinet at 110 °C for 24 hours. The dried foundry waste sand sample was crushed with a jaw crusher and sieved through a 3 mm sieve to reduce the size of the sample. The mixture was formed by blending the fine foundry waste sand with purchased clay separately in a 50/50 ratio. The mixture was named FC sample. The FC sample was homogeneously blended with water in a pan mixer. The FC sample was extruded into a column with a cross section measuring 47 mm by 25 mm with a Germatec vacuum extruder. After extrusion, briquettes measuring 150 mm were cut from the extruded column. The extruded samples were air dried for seven days before firing. The formed briquettes were respectively fired at 950 °C, 1000 °C, and 1050 °C using an electrically powered laboratory furnace.

C. Quality Tests

The quality of the final products (FC briquettes) was confirmed through shrinkage, water absorption and modulus of rupture (MoR) tests.

Fired shrinkages were determined across indentations made 100 mm apart by a digital Vernier calliper on the test briquettes. The dried specimens were measured at the indentations to determine its longitudinal shrinkage to the nearest millimetre. The measured lengths were subtracted from the indentations measured 100 mm to obtain the shrinkage in millimetres where

$$Totallinearshrinkage(\%) = 100 - firedlength(mm) \quad (1)$$

The linear shrinkage result was calculated from the average of ten briquettes after each firing (950 °C, 1000 °C, and 1050 °C) to ensure reliability of the results.

D. Water Absorption

Water absorption tests were conducted on the briquettes to determine the amount of water absorbed by the briquette samples after soaking in cold water for 24 hours. The water absorption result was calculated from the average of ten briquettes after each firing (950 °C, 1000 °C, and 1050 °C) to ensure reliability of the results.

The following masses were required to calculate water absorption percentage:

- M1 (dry mass): mass of the sample after drying
- M2 (24 hrs soak mass): soak set of bricks inside the water bath containing cold water

Water absorption is expressed as increase in weight percent. The equation for calculating water absorption is as:

$$24hrWaterabsorption(\%) = \frac{M2-M1}{M1} X100 \quad (2)$$

E. MoR

The MoR values of each specimen were calculated and reported to the nearest 0.01 MPa as follows [11], [12]:

$$\text{MoR}(MPa) = \frac{3FL}{2bd^2} \quad (3)$$

where: F = maximum load indicated by the testing machine, (kN), L = distance between the supports, (mm), b = net width, (face to face minus voids), of the specimen at the plane of failure, (mm) and, d = depth, (bed surface to bed surface), of the specimen at the plane of failure, (mm).

III. Results

A. Chemical Analysis

The foundry waste sand sample has a high content of silica (73.4%), and this meant that the samples did not have adequate plasticity; therefore the sample could not be extruded. High content of silica is not acceptable since it contributes to low strength and breakability after firing the brick sample [13]. Silica content of FC sample is better as compared to the foundry waste sand sample, because it decreased from 73.4% to 63.1% as a result of the clay addition. The FC sample could be extruded, after addition of purchased clay. The foundry waste sand sample had a high loss on ignition (LOI) value (20.34%). LOI of the FC sample improved since it is 13.3%. The calcium oxide content of FC

sample decreased as compared to the foundry waste sand sample. This is a good phenomenon since the lime popping defect did not occur after firing the sample. Lime popping is caused by high contents of calcium [9]. The aluminium content of the FC sample increased from 12.5% to 4.52. This is a good advancement since dominant amount of aluminium in a clay sample increases the plasticity and refractoriness [14]. Oxides such as MgO, TiO_2, Cr_2O_3, MnO, Na, and K are in trace amount in foundry waste sand and FC samples. The chemical analysis results of the samples that were tested are listed in Appendix, Table I.

B. X-Ray Diffraction (XRD)

The foundry waste sand and FC samples were characterized mineralogically by XRD to identify the present minerals and relative proportions. The foundry waste sand sample has major amounts of quartz and plagioclase, intermediate potassium feldspar and trace amounts of portlandite and kaolinite. The FC sample has predominant amounts of quartz, minor kaolinite and trace amounts of potassium feldspar, plagioclase and portlandite.

C. Appearance and Texture

FC sample has a medium iron oxide content (3.05%), which resulted in the sample being red after firing. The iron oxide less than 7% provides red colour after firing the brick, enhances absorptivity, strength and hardness. The manufactured briquette samples do not have defects such as bloating after firing despite the fact the LOI is 13.3%. The samples were extruded effortlessly without sticking on the centre of the extruding column and resulting into tearing along the edges of the column. Fig. 1 illustrates the unfired briquette which is grey in colour and not labelled, briquette fired and labelled 950 °C, briquette fired and labelled 1000 °C, briquette fired and labelled 1050 °C.

Fig. 1 FC test briquettes

D. Water Absorption Results of FC

The water absorption values of FC samples are within the specifications ranging from 17.96% after 950 °C firing, 16.50% after 1000 °C firing and 13.29% after 1050 °C firing. According to [14], [15] acceptable water absorption values of bricks should be between 5% and 20%. Laboratory results of each sample tested are recorded and illustrated in Appendix Tables II-IV.

E. Shrinkage Results of FC Sample

The average shrinkage values of FC sample respectively fired at 950 °C, 1000 °C and 1050 °C are within the required limit ranging from 4.47%, 5.42% to 6.28%. This is a good phenomenon because samples did not crack after firing. According to [16] the shrinkage values of the brick must be below 8% to assure that the formed product is a good quality. Laboratory shrinkage results of each sample tested are recorded and illustrated in Appendix, Tables V-VII.

F. Strength

The average MoR results of FC samples fired at 1050 ºC is 5.59 Mpa, and this is high compared to 2.92 MPa of the samples fired at 950 ºC and 3.72 MPa of the samples fired at 1000 ºC. It is therefore recommended that samples should be fired at 1050 ºC and/or higher temperature. Laboratory MoR results of each sample tested is recorded and illustrated in Appendix, Tables VIII-X.

IV. Conclusion

A preliminary evaluation was conducted to determine if it is possible to manufacture clay bricks with foundry waste sand. Positive results were obtained after mixing purchased clay with foundry waste sand sample because the formed briquette samples had vivid colours, acceptable water absorption and shrinkage values, high unfired and fired strength. These proved that it would be possible to use foundry waste sand as an additive in clay brick manufacture. Alternative uses of waste foundry sand would reduce the dumping cost currently incurred by the South African foundry industry and recycling this waste will extend the use of mineral resources.

Appendix

TABLE I
Chemical Analysis Results

Elements	Foundry waste sand (%)	FC (%)
MgO	0.81	0.63
Al_2O_3	4.52	12.66
SiO_2	73.4	63.1
CaO	0.43	0.09
TiO_2	0.31	0.61
Cr_2O_3	0.07	0.09
MnO	0.06	0.06
FeO	2.51	3.68
Na	0.41	0.21
K	0.86	0.57
L.O.I	16.62	13.3

TABLE II
WATER ABSORPTION VALUES OF SAMPLES FIRED AT 950 °C

Dry mass	Wet mass	Water absorption (%)
279.20	328.40	17.62
279.20	328.70	17.73
278.92	328.50	17.78
279.90	329.20	17.61
278.50	328.90	18.10
277.42	328.52	18.42
277.20	328.24	18.41
277.52	329.40	18.69
279.40	328.54	17.59
279.20	328.52	17.66
	Average	17.96
	Minimum	17.59
	Maximum	18.69

TABLE III
WATER ABSORPTION VALUES OF SAMPLES FIRED AT 1000 °C

Dry mass	Wet mass	Water absorption (%)
266.00	310.30	16.65
266.90	310.60	16.37
266.20	310.40	16.60
269.20	312.70	16.16
267.00	310.40	16.25
267.90	311.60	16.31
266.20	310.40	16.60
269.20	312.70	16.16
266.20	310.40	16.60
269.20	315.70	17.27
	Average	16.50
	Minimum	16.16
	Maximum	17.27

TABLE IV
WATER ABSORPTION VALUES OF SAMPLES FIRED AT 1050 °C

Dry mass	Wet mass	Water absorption (%)
268.00	304.30	13.54
276.90	310.60	12.17
266.20	304.40	14.35
269.20	302.70	12.44
267.00	302.40	13.26
266.23	302.60	13.66
266.20	303.40	13.97
279.20	312.70	12.00
266.20	303.40	13.97
269.20	305.70	13.56
	Average	13.29
	Minimum	12.00
	Maximum	14.35

TABLE V
SHRINKAGE VALUES OF SAMPLES AFTER 950 °C FIRING

Length of samples before firing	Length of samples after 950 °C firing	Total linear shrinkage (%)
100	95.8	4.20
100	95.8	4.20
100	96.4	3.60
100	95.9	4.10
100	94.0	6.01
100	95.7	4.30
100	93.2	4.62
100	94.9	4.37
100	95.5	4.50
100	95.2	4.80
	Average	4.47
	Minimum	3.60
	Maximum	6.01

TABLE VI
SHRINKAGE VALUES OF SAMPLES AFTER 1000 °C FIRING

Length of samples before firing	Length of samples after 1000 °C firing	Total linear shrinkage (%)
100	95.03	4.97
100	94.83	5.17
100	94.60	5.40
100	94.40	5.60
100	94.62	5.38
100	94.30	5.70
100	94.20	5.80
100	94.20	5.80
100	94.80	5.20
100	94.80	5.20
	Average	5.42
	Minimum	4.97
	Maximum	5.80

TABLE VII
SHRINKAGE VALUES OF SAMPLES AFTER 1050 °C FIRING

Length of samples before firing	Length of samples after 1050 °C firing	Total linear shrinkage (%)
100	94.0	6.00
100	93.6	6.40
100	93.6	6.36
100	93.6	6.44
100	94.0	6.01
100	94.0	5.98
100	93.6	6.44
100	93.6	6.39
100	93.8	6.23
100	93.4	6.56
	Average	6.28
	Minimum	5.98
	Maximum	6.56

TABLE VIII
MOR VALUES OF SAMPLES AFTER 950 °C FIRING

Height	Width	Load	Span	MPa
26.40	48.58	520.00	100.00	2.30
25.77	47.75	500.00	100.00	2.37
27.07	47.73	610.00	100.00	2.62
27.07	47.73	772.00	100.00	3.31
27.07	47.73	870.00	100.00	3.73
27.08	46.27	789.00	100.00	3.49
27.09	47.71	627.00	100.00	2.69
27.10	47.71	628.00	100.00	2.69
25.77	47.75	500.00	100.00	2.37
27.07	47.73	610.00	100.00	2.62
			Average	2.72
			Minimum	2.30
			Maximum	3.49

TABLE IX
MOR VALUES OF SAMPLES AFTER 1000 °C FIRING

Height	Width	Load	Span	MPa
25.88	47.63	820	100	3.86
26.34	47.49	950	100	4.32
26.03	47.58	780	100	3.63
27.08	47.79	750	100	3.21
25.88	47.63	940	100	4.42
26.34	47.49	810	100	3.69
26.03	47.58	780	100	3.63
27.08	47.79	750	100	3.21
26.54	47.23	780	100	3.52
27.08	47.79	978	100	4.19
			Average	3.72
			Minimum	3.21
			Maximum	4.42

TABLE X
MOR VALUES OF SAMPLES AFTER 1050 °C FIRING

Height	Width	Load	Span	MPa
25.88	47.63	920	100	4.33
26.34	47.49	1456	100	6.63
26.03	47.58	1235	100	5.75
26.08	47.79	1390	100	6.41
25.88	47.63	920	100	4.33
26.34	47.49	1256	100	5.72
26.03	47.58	1320	100	6.14
26.08	47.79	1345	100	6.21
27.08	47.79	1120	100	4.79
26.54	47.23	1356	100	6.11
			Average	5.59
			Minimum	4.33
			Maximum	6.63

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