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Reuse of Chemically Bonded Waste Foundry Sand in Structural Concrete

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Abstract: ***Disposal of industrial waste has become a great burden globally due to its associated high economic expense and environmental pollution. The possibility of re-using Waste Foundry Sand (WFS) as fine aggregate in concrete profits both construction and industrial sectors. The present study aimed at examining the reuse of chemically bonded WFS as fine aggregate in concrete paver blocks. It assessed the physical and chemical properties of chemically bonded WFS and the effect of chemically bonded WFS as partial replacement of natural sand at 0%, 5%, 10%, 20%, and 30% on compressive strength, tensile strength and water absorption of concrete pavers. The result showed that chemically bonded WFS is finer than Natural river sand and has different chemical composition. The water absorption of the blocks containing different proportions of WFS ranged from 4.3%-4.6% by mass. The 28 days tensile and compressive strength ranged from 3.15-3.73MPa and 50.5-53.7 MPa, respectively with chemically bonded WFS use but highest in the control mix at 3.79MPa and 61.0MPa respectively. Lastly, the optimal tensile and compressive strengths were observed at 10% and 20% chemically bonded WFS use. In conclusion, the higher strengths in the control mix are attributed to the coarser particle size of natural river sand relative to chemically bonded WFS. Also, the use of chemically bonded WFS as fine aggregate achieves concrete strength that is close to that from the control mix. Nonetheless, the replacement of chemically bonded WFS from 10%-20% is recommended as it can make concrete paver blocks of the standard quality.***

Keywords: Concrete Paver Blocks, Chemically bonded Waste Foundry Sand, Natural river sand, Compressive Strength, Tensile Strength, Water Absorption.

1. Introduction

1.1 Background

Waste Foundry Sand (WFS) generated from metal casting industries creates a financial and environmental burden upon disposal. This is because the industries are required to purchase land elsewhere for the discarding of their waste foundry sand. With continued disposal, the landfills become saturated and the soil much polluted. In the event that the landfills are eroded into water bodies, the organic and metal pollutants contained in the WFS pose a greater threat to the life of flora and fauna. Further, the treatment of such water for domestic use becomes more expensive.

During the casting of Ferrous metals in foundry industries, silica sands mixed with bentonite clay and water to is required to make the outside shell of the mould cavity into which molten metal is poured[1]. Since metal casting has to be done at high temperature, sands are chosen as the mould cavity material due to their desirable characteristics. These include readiness to bond with clay, and high refractory nature, ability to retain mould shape during packing and pouring, permeability for the gases liberated from the mould and solidifying metal as well as ability of the sand to be shake out[2]. Excess foundry sand is generated since varying amounts of fresh sand, water and clay must be continually added to maintain the desired characteristics. This results to a larger volume of sand than is required for the foundry process [3]. The excess sand is considered as waste because after repeated use under heat, the particles become degraded and cannot be used for the moulding process [4]. However, the fact that this sand can no longer be used for moulding does not make it completely useless, as it can find use in non-foundry applications.

1.2 Applications of Waste Foundry Sand

Previous studies indicate that the use of waste foundry sand as aggregate improves the resultant concrete quality in a number of cases.

Firstly, the test results of Siddique, Schutter and Noumowe [5] indicate a marginal increase in the strength properties of plain concrete by the inclusion of used foundry sand in proportions of 10%, 20%, and 30% by weight as partial replacement of fine natural sand.

Secondly, Bakis, Koyuncu and Demirbas [2]identify a replacement of 10% natural sand with waste foundry sand to be the most suitable for asphalt concrete mixtures. Further, they establish that waste foundry sand does not significantly affect the environment around area where the asphalt concrete is laid, hence safe for re use.

Thirdly, Lin, C. Cheng, A. Cheng and Chao [6]conclude that the performance of cement containing additives from waste foundry sand meets the standard requirements of cement made out of conventional materials, in terms of compressive strength, setting time as well as the degree of hydration.

Further, the research findings of Bhimani, Pitroda and Bhavsar [7]who investigated the water absorption of concrete cubes containing foundry sand in various proportions, indicate that the cube specimen with 50% waste foundry sand as aggregate had the lowest water absorption.

Similarly, Prajapat, Joshi and Pitroda [8] maintain that concrete containing 50% waste foundry sand as fine aggregate has the highest compressive strength and the lowest pavement thickness as well as cost of construction.

In contrast to the above findings, Naik, Rudolph, Yoon-moon, Bruce and Siddique [9]establish that the partial substitution of natural sand with used foundry sand causes a small reduction in strength of concrete. Likewise, Khatib, B. Baig, Menadi and Kenai [10] explain that the incorporation of waste foundry sand in concrete causes a systematic decrease in workability and strength as well as an increase in water absorption of concrete.

Therefore, the question remains, does waste foundry sand improve or lower the quality of concrete? An explanation is given by FIRST [11] that the quality of foundry sand depends on various aspects of foundry sand production which include the type of additives used as binders and hardeners, the amount of binder material, the type of metal cast as well as the number of times the sand is reused within the system. Consequently, the sand will differ in terms of chemical composition and physical characteristics, from foundry to foundry, which can impact its performance. They further explain that the sands produced by a single foundry are not likely to show significant variation over time and blended sands produced by a consortium of foundries often produce consistent sands.

Based on the above explanation, the present study focuses on the aspect of the a type of additive used as binder material in foundry sand, with an interest of assessing the concrete quality resulting from the use chemically bonded WFS as fine aggregate in structural concrete.

2. Materials and Methods

2.1 Materials

2.1.1 Cement

Store bought Cement grade 42.5, conforming to [12]for concrete pavers was used.

2.1.2 Course and Fine aggregates

Crushed course aggregates and natural river sand were used and their testing done as per [13].

2.1.3 Foundry sand

Waste foundry sand was obtained from foundry industries in Nairobi, namely East Africa Foundries Limited and Numerical Machining Complex. The sand was first sieved before use to eliminate any large metal particles.

2.1.4 Water

Potable tap water was used for the concrete preparation and for curing of specimens.

2.1.5 Admixture

A commercially available high range water reducing admixture was used, in quantities determined from the concrete mix design. This type of admixture helps to increase workability and flowability of the concrete mix through dispersing and deflocculating of the cement particles.

2.2 Experimental Methods

2.2.1Determination of the physical and chemical characteristics of fine Aggregates

a) Gradation and Particle Size Distribution

The gradation and particle size distribution of the fine aggregates was done through sieve analysis in accordance to the procedure stated in BS 812, 1995:Part 1.

b) Determination of the chemical composition of WFS

The chemical composition of the chemically bonded WFS was determined through X-Ray Fluorescence (XRF) analysis in the laboratory of The Ministry of Mining at the Industrial area of Nairobi, Kenya.

2.2.2Casting of Paving Blocks

The casting was done in iron moulds, with dimensions of 200x150x80mm.The procedure followed is as described in BSEN 12390, 2000:Part 1

2.2.3Curing of Specimens

In the present study, the marking and curing of the paver blocks was done according to the procedure described in BSEN 12390, 2000:Part 2

2.2.4Testing the Properties of Hardened Concrete

a) Determination of Compressive Strength of Concrete Paving Blocks

The Compressive strength test of the concrete paver blocks was done in accordance to the procedure given in [14]:Part 3(E)

b) Determination of Tensile Strength of Paving Blocks

The procedure followed in testing the concrete paver blocks is as explained in BSEN1338, 2003:Annex F.

c) Test for Water Absorption

The water absorption of the concrete paver blocks was tested according to the procedure in BSEN1338, 2003: Annex E.

2.3 Experimental Design

In order to achieve the study objectives, the following experimental design was used:

The chemical characteristics and physical properties of WFS were determined as explained in section B.1 above.

The optimal proportion of WFS as fine aggregate in concrete was determined based on the performance of the paver blocks made from different mixes as shown in Table 1 below.

Table 1: Experimental design

Property of concrete paver blocks		Proportion of chemically bonded WFS				
		0%	5%	10%	20%	30%
Compressive strength (N/mm2)	7 days					
	14 days					
	28 days					
Tensile strength (N/mm2)	7 days					
	14 days					
	28 days					
Water Absorption (%)						

3. Results and Discussion

3.1 Results

3.1.1 Gradation and Particle Size Distribution of Fine Aggregates

The gradation and particle size distribution of the fine aggregates was determined through sieve analysis, and the results are as shown in Table 2. From the table, the particle size distribution of the natural sand is of grading Zone II while that of chemically bonded WFS is of grading Zone IV.

Table 2: Grading of WFS and Natural sand into zones according to BS EN 12620:2013

Sieve Size [15]	Aggregate % passing sieve aperture				
	Grading Zone I	Natural sand	Grading Zone II	Chemically bonded WFS	Grading Zone IV
4.75	90 - 100	96.77	90 - 100	96.04	95 - 100
2.36	60 - 65	90.24	75 - 100	93.78	95 - 100
1.2	30 - 70	72.91	55 - 90	91.87	90 -100
0.6	15 - 34	36.23	35 - 59	72.28	80 - 100
0.3	5 – 20	30.14	8 - 30	47.02	15 - 50
0.15	0-10	5.90	0 - 10	6.13	0-15

3.1.2 Chemical composition of Waste Foundry Sand

The chemical composition of chemically bonded WFS is as shown in Table 3. In the Table, the highlighted cells show the chemical composition of WFS and river sand from previous studies. Despite the fact that the previous researchers: [2, 16, 17] did not state the type of WFS whose chemical composition is shown in the highlighted cells of Table 3, it is evident that the proportions of the various WFS constituents are closer to those of chemically bonded WFS observed in the present study, implying that they studied the same type of WFS. Additionally, chemically bonded WFS has more chemical components than natural river sand.

Table 3: Chemical composition of WFS and Natural river sand

Component	% in WFS			% in River sand
	Chemically bonded WFS	Siddique (2010)	Bakis and Koyuncu (2006)	Bala and Khan, 2013)
Silica as SiO_2	93.912	87.91	96.83	97.31
Calcium as CaO	0.741	0.14	0.034	
Aluminium as Al_2O_3	2.283	4.7	0.59	1.69
Magnesium as MgO	1.241	0.3	0.024	
Iron as Fe_2O_3	0.419	0.94	0.21	0.21
Potassium as K_2O	0.395	0.25	0.06	0.25
Sulphur as SO_3	0.08			
Titanium as TiO_2	0.198	0.15		
Chlorine as Cl	0.005		0.01	
Phosphorous as P_2O_5	0.113			
Manganese as Mn_2O_3	0.017	0.02	0.01	
Copper as Cu	0.004			
Zinc as Zn	0.007			

3.1.3 Tensile strength

Table 4 below shows the 7, 14 and 28 days tensile strength of the paver blocks, at different proportions of Chemically Bonded WFS replacement, in relation to the standard required in BS EN 1338:2003.

Table 4: Tensile strength of concrete

	Tensile Strength (MPa)			
% of chemically bonded WFS	7 Days	14 Days	28 Days	Standard 28 Days value (in BSEN1338:2003)
0%	2.77	3.52	3.79	3.60
5%	3.38	3.37	3.15	
10%	2.93	3.41	3.67	
20%	3.09	3.36	3.73	
30%	2.98	3.45	3.54	

From Table 4 above, the tensile strength is highest in blocks with 0% chemically bonded WFS, at 3.79 MPa. Even so, this is close to the tensile strength of 3.73MPa achieved in blocks containing 20% chemically bonded WFS, which is the highest in the blocks containing chemically bonded WFS. This observed trend differs from the previous study findings where the tensile strength of concrete specimens was highest at 15% WFS inclusion as fine aggregate and lowest in specimens of the control mix [17].

The highlighted cells in the Table 4 contain values of the block tensile strength that meets the standard 3.6 MPa recommended in BS EN 1338:2003. Thus the required quality in terms of tensile strength is achieved at 0%, 10% and 20% of Chemically Bonded WFS as fine aggregate.

3.1.4 Compressive strength

Table 5 below shows the 7, 14 and 28 days compressive strength of the paver blocks in relation to the standard required in ASTM 1988.

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Table 5: Compressive strength of concrete

	Compressive Strength (MPa)			
Proportion of chemically bonded WFS	7 Days	14 Days	28 Days	Standard 28 days value (in ASTM 1988)
0%	50.5	52.0	61.0	50.0
5%	45.3	49.6	52.7	
10%	45.2	52.4	53.7	
20%	45.9	52.4	52.4	
30%	49.9	45.4	50.5	

From Table 5 above, 28 days compressive strength of concrete paver blocks containing only natural sand as fine aggregate is the highest at 61MPa. Close to this compressive strength of the blocks made of conventional fine aggregates is 53.7 MPa, attained in the paver blocks containing 10% Chemically Bonded WFS as fine aggregate.

Also, it is plain that the quality of the paver blocks made from all the proportions 0%, 5%, 10%, 20% and 30% of chemically bonded WFS as a fine aggregate meets the recommended compressive strength of 50MPa in ASTM 1988.

3.1.5 Water Absorption

The water absorption of the concrete paver blocks is shown in Table 5 below.

Table 5: Water absorption of concrete

	Water Absorption (% by mass)	
Proportion of chemically bonded WFS	Observed Value	Standard Value (in BS EN 1338:2003)
0%	4.34	≤6.00
5%	4.52	
10%	4.57	
20%	4.58	
30%	4.62	

The difference in water absorption at the various proportions of chemically bonded WFS is insignificant because from the Table 5 above, the water absorption ranges from 4.3 to 4.6% by mass.

Further, as shown in the highlighted cells of Table 5 above, the quality of paver blocks in all proportions of chemically bonded WFS attains the standard water absorption value of ≤6% by mass recommended in BS EN 1338:2003.

The trend from the results of water absorption of concrete paver blocks observed in this study differs from that of previous study findings where the concrete from the control mix had the highest water absorption at 1.91% by mass while the concrete specimens containing 20% WFS as fine aggregate had the lowest water absorption at 1.13% by mass [18].

3.1.6Optimal proportions of chemically bonded WFS as fine aggregate

Whereas the water absorption of the paver blocks was within the range of 4.3 to 4.6% by mass the optimal values of tensile and compressive strength at 28 days are 3.73 MPa and 53.7 MPa, respectively, when chemically bonded WFS is used. Thus, the optimum replacement is from 10%-20% for chemically bonded WFS as fine aggregate.

4. Discussion

4.1 Impact of aggregates' physical characteristics on strength of concrete paver blocks

As shown in Table 2, the natural sand used is coarser than chemically bonded WFS. Consequently, the compressive and tensile strength is highest in the blocks made from the control mix that contained only natural sand as fine aggregate, compared to those containing chemically bonded WFS as shown in Table 4 to Table 5. These findings concur with those of [17, 19] who establish that strength of concrete decreases with increase in fineness of aggregates. On the same note, [20] establishes that finer aggregates provide more surface area in concrete and maximum strength in the concrete mix can only be achieved if all the surfaces of all the aggregates are covered with cement paste. This indicates that given the same quantity of cement paste, concrete containing coarser aggregates will have higher strength than concrete containing finer aggregates.

4.2 Impact of chemical composition of WFS on strength of concrete paver blocks

Having deliberated the impacts of the physical characteristics of aggregates, the effect of their chemical composition on concrete strength needs to be considered. From Table 3 above, the following can be deduced: the proportion of silica in natural river sand is 1.04 times the proportion of silica present in chemically bonded WFS. The result of having higher silica content in a concrete mix is higher strength. This is in line with the findings from the previous study by [21, 22].

However, the optimal tensile and compressive strength obtained in blocks containing chemically bonded WFS is still very close to that obtained from the control mix, as shown in Table 4 and Table 5. This suggests that the impact of the other chemical constituents in the WFS also have a considerable impact on the strength of concrete. Firstly, the proportions of aluminium, iron and potassium are higher in chemically bonded WFS than in natural river sand by factors of 1.35, 2, and 1.58 respectively. Secondly, other chemical constituents including calcium, magnesium, titanium, chlorine and copper are available in chemically bonded WFS but missing in natural river sand. Previous studies establish that the presence of higher contents of the above stated chemical constituents in concrete results to increase compressive and tensile strengths of concrete. That is, [23-30] respectively. Based on these previous study findings, the present study results reveal that the combined effect of the presence of higher proportions of calcium, aluminium, magnesium, iron, potassium, sulphur, titanium, chloride, phosphorous, manganese, copper and zinc that are higher in chemically bonded WFS are the reason for comparable strength of concrete paver blocks containing chemically bonded WFS. This is despite the finer particle size and lower silica content in chemically bonded WFS when compared to natural river sand.

5. Conclusions

This study mainly focused on the determination of the chemical composition of chemically bonded waste foundry sand generated from selected foundry industries in Nairobi, assessment of the physical properties of the waste foundry sand and determination of the optimum percentage replacement of waste foundry sand as fine aggregate in concrete for paving blocks. The performance of chemically bonded Waste Foundry Sand as fine aggregate in concrete for paver blocks was assessed in terms of compressive strength, tensile strength and water absorption. The following are the conclusions based on the experimental results obtained.

The chemical composition of chemically bonded WFS and natural river sand is different. Particularly, the proportion of silica in chemically bonded WFS is slightly lower at a factor of 0.9 times that in natural river sand while the proportions of aluminium, iron and potassium are higher in chemically bonded WFS by factors of 1.35, 2 and 1.58 respectively. Also, chemically bonded WFS contains calcium, magnesium, titanium, chlorine and copper, which are missing in natural river sand.

The physical properties of chemically bonded WFS are different from those of natural river sand. chemically bonded WFS is finer than natural river sand.

The use of chemically bonded WFS as fine aggregate in concrete can produce paver blocks of the quality required in BS 1338:2003 and ASTM 1988 standards, that is 3.6MPa tensile strength, ≤6% by mass water absorption and 50MPa compressive strength at 28 days.

The use of only natural sand as fine aggregate in concrete produces higher strength compared to the use of chemically bonded WFS at different proportions. This is attributed to the coarser particles in natural sand than in chemically bonded WFS.

Despite its finer particles, and lower silica content, the use of chemically bonded WFS as fine aggregate achieves concrete strength that is close to that from the control mix due to the higher proportion of aluminium, iron and potassium contained in the former as well as presence of calcium, magnesium, titanium, chlorine and copper, which are missing in natural river sand.

Lastly, from the results obtained, the optimum replacement of chemically bonded WFS as fine aggregate is between 10% and 20%.

From the present and previous research findings, the reuse of waste foundry sand as fine aggregate for high strength concrete such as making of concrete paver blocks is recommended. The recommended proportions are 10% to 20% of chemically bonded WFS.

The utilization of WFS in concrete can thus offer an alternative to landfilling, which is the current disposal practice by foundry industries in Kenya.

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