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Utilization of Green Waste Foundry Sand in Concrete Paver Blocks

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***Abstract*— Disposal of industrial by-products is becoming unattractive worldwide due to its associated negative economic and environmental impacts. The option of re-using Waste Foundry Sand (WFS) as fine aggregate in concrete benefits both construction and industrial sectors. The present study aimed at investigating the utilization of green WFS as fine aggregate in concrete paver blocks. It assessed the physical and chemical properties of Green WFS and the effect of Green 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 results showed that Green WFS if 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 3.50-3.78MPa and 50.2-55.2 MPa, respectively with Green 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 5% and 10% green WFS use. In conclusion, the higher strengths in the control mix are attributed to the coarser particle size of natural river sand relative to green WFS. Also, the use of green WFS as fine aggregate achieves concrete strength that is close to that from the control mix. Nonetheless, the replacement of green WFS from 5%-10% can make concrete paver blocks of the standard quality.**

Keywords— Concrete Paver Blocks, Green Waste Foundry Sand, Natural river sand, Compressive Strength, Tensile Strength, Water Absorption

I. INTRODUCTION

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(Gedik *et al.* 2008). 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(Bakis *et al.* 2006). 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 (Goodhue *et al.* 2001). 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 (ReTAP 1996). However, the fact that this sand can no longer be used for moulding does not render it completely useless, as it can find use in non-foundry applications.

Previous researchers have studied the use of waste foundry sand as partial replacement of fine aggregate and they assert that WFS performs satisfactorily in concrete (Bakis et al. 2006, Siddique et al. 2009, Lin et al. 2012 , Bhimani et al. 2013, Prajapat et al. 2013, Siddique and Dhanoa 2013, Amritkar et al. 2015) . However, other researchers maintain that waste foundry sand lowers the concrete quality when used as fine aggregate (Naik et al. 2004, Khatib et al. 2011, Salokhe and Desai ND). Table I contains the compressive strength results, from the stated studies.

Table I Compressive Strength (N/mm2) of Concrete containing different proportions of Waste Foundry Sand

Proportion of waste foundry sand (%)	(Bhimani *et al.* 2013)	(Salokhe and Desai ND)		(Siddique and Dhanoa 2013)	(Amritkar *et al.* 2015)
		Sand from ferrous metal casting	Sand from ferrous metal casting		
0%	28.5	31.7	31.7	40	37.42
5%	-	-	-	43.3	39.14
10%	29.70	21.5	30.96	44.9	40.49
15%	-	-	-	46.8	43.63
20%	30.00	27.4	24.29	45.3	43.13
30%	31.30	30.96	23.85	-	-

From Table I above, the highlighted cells indicate the highest compressive strength obtained in the sets of specimens containing different proportions of WFS as fine aggregate in concrete. In two cases, the highest compressive strength is achieved from the control mix, implying that the use of WFS lowers the concrete quality. In three cases, the highest compressive strength is observed at 20% and 30% replacement by WFS, indicating that the use of WFS improves concrete quality.

Further, the Tensile strength from the above stated studies are as shown in Table II below.

Table II Split Tensile Strength (N/Mm2) of Concrete containing different proportions of Waste Foundry Sand

Proportion of waste foundry sand (%)	Siddique and Dhanoa (2013)	Amritkar *et al.* (2015)
0%	4.23	2.67
5%	4.38	2.45
10%	4.57	2.80
15%	4.67	2.72
20%	4.5	2.57

From the results shown in Table I and Table II, the highlighted cells show the highest tensile strength in the specimens tested in the respective studies. From these results, it is evident that the use of WFS as fine aggregate improves the concrete quality in terms of tensile strength.

Therefore, the important question is whether waste foundry sand improves or lowers the quality of concrete. A highlight is given by FIRST (2004) 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 highlight, 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 green WFS as fine aggregate in high strength concrete.

The study sought to: determine the chemical composition of green waste foundry sand generated from selected foundry industries in Nairobi, determine the physical properties of the green waste foundry sand as fine aggregate and determine the optimum percentage replacement of green waste foundry sand as fine aggregate in concrete for paving blocks.

II. MATERIALS AND METHODS

A. *Materials*

1) *Cement*

Store bought Cement grade 42.5 conforming to BSEN 1338, 2003 for concrete pavers was used.

2) *Course and Fine aggregates*

Crushed course aggregates and natural sand (river sand) were used and their testing done as per BS 812, 1995

3) *Foundry sand*

Waste foundry sand was obtained from foundry industries in Nairobi. The sand was first sieved before use to eliminate any large metal particles.

4) *Water*

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

5) *Admixture*

A commercially available high range water reducing admixture was used, in quantities determined from the concrete mix design.

B. *Experimental Methods*

1) Determination 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 Green 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) Casting 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

3) Curing 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

4) Testing 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 (BSEN12390 2000):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.

C. *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 III below.

Table III Experimental design

		Proportion of Green WFS				
Property of concrete paver blocks		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 (%)						

III. RESULTS AND DISCUSSION

A. *Results*

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 IV. From the table, the particle size distribution of the natural sand is of grading Zone II while that of green WFS is of grading Zone IV.

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

Sieve Size (mm)	Aggregate % passing sieve aperture				
	Grading Zone I	Natural sand	Grading Zone II	Green WFS	Grading Zone IV
4.75	90 - 100	96.77	90 - 100	95.24	95 - 100
2.36	60 - 65	90.24	75 - 100	93.00	95 - 100
1.2	30 - 70	72.91	55 - 90	91.48	90 -100
0.6	15 - 34	36.23	35 - 59	83.04	80 - 100
0.3	5 – 20	30.14	8 - 30	67.09	15 - 50
0.15	0-10	5.90	**0 - 10**	**14.62**	**0-15**

2) Chemical composition of Waste Foundry Sand

The chemical composition of Green WFS is as shown in Table V. 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: (Bakis, et al., 2006;Siddique and Dhanoa, 2013;Siddique, et al., 2010) did not state the type of WFS whose chemical composition is shown in the highlighted cells of Table V, it is evident that the proportions of the various WFS constituents are distant from those of green WFS observed in the present study, implying that they studied a different type of WFS. Additionally, green WFS has more chemical components than natural river sand.

Table V Chemical Composition of WFS and River sand

Component	% in WFS			% in River sand
	Green WFS	Siddique (2010)	Bakis and Koyuncu (2006)	Bala and Khan, 2013)
Silica as **SiO_2**	64.472	87.91	96.83	97.31
Calcium as **CaO**	10.383	0.14	0.034	
Aluminium as **Al_2O_3**	9.961	4.7	0.59	1.69
Magnesium as **MgO**	6.333	0.3	0.024	
Iron as **Fe_2O_3**	5.165	0.94	0.21	0.21
Potassium as **K_2O**	1.511	0.25	0.06	0.25
Sulphur as **SO_3**	0.75			
Titanium as **TiO_2**	0.581	0.15		
Chlorine as **Cl**	0.268		0.01	
Phosphorous as **P_2O_5**	0.263			
Manganese as **Mn_2O_3**	0.093	0.02	0.01	
Copper as **Cu**	0.072			
Zinc as **Zn**	0.049			

3) *Tensile Strength*

The tensile strength of concrete paver blocks made using different proportions of green WFS is shown in Table VI and Fig.1. The strength was tested at the ages of 7, 14 and 28 days. The tensile strength of the paver blocks increases with age, from 7 days to 28 days in all the proportions of green WFS replacement. Also, at the age of 28 days, the tensile strength of the blocks containing green WFS is comparable to that of the blocks containing only natural sand as a fine aggregate. However, from Table VI the control mix produces the highest tensile strength of 3.79MPa at 28 days. This is nearly equal to the 28 days tensile strength of 3.78MPa achieved at 5% green WFS replacement, which is the highest among the concrete paver blocks containing green WFS. Further, the highlighted cells contain values of the block tensile strength that meets the standard 3.6 MPa recommended in BS EN 1338:2003. So the required quality in terms of tensile strength is achieved at 0%, 5%, 10% and 30% of green WFS as fine aggregate.

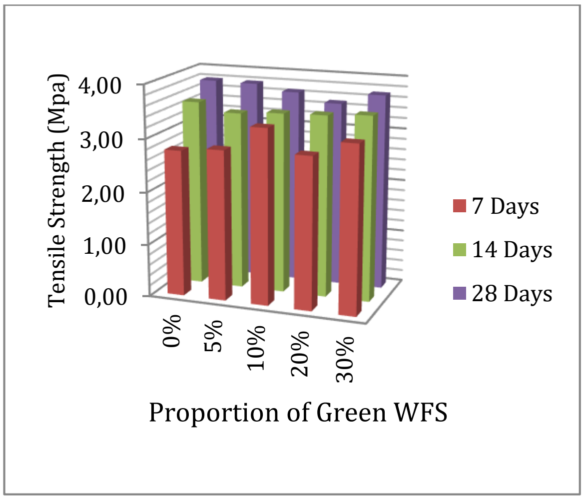

Fig. 1. Tensile strength of concrete paver blocks

Table VI Tensile strength of the concrete paver blocks

	Tensile Strength (MPa)			
Proportion of Green WFS	7 Days	14 Days	28 Days	Standard 28 Days value (in BSEN1338:2003)
0%	2.77	3.52	3.79	3.60
5%	2.85	3.36	3.78	
10%	3.32	3.42	3.66	
20%	2.88	3.44	3.50	
30%	3.16	3.49	3.71	

4) *Compressive Strength*

The compressive strength of concrete paver blocks made using different proportions of green WFS is shown in Fig. 2 and Table VII. The strength was tested at the ages of 7, 14 and 28 days. Parallel to the trend observed with tensile strength, the compressive strength of blocks increases with age, from 7 days to 28 days, at different proportions of green WFS replacement. Particularly, at 28 days, the compressive strength of concrete paver blocks from the control mix is the highest at 61MPafollowed by 55.2 MPa, achieved in the paver blocks containing 10% green WFS. From Table VII, it is evident that the quality of the paver blocks made from all the proportions 0%, 5%, 10%, 20% and 30% of green WFS as a fine aggregate meets the recommended compressive strength of 50MPa in ASTM 1988.

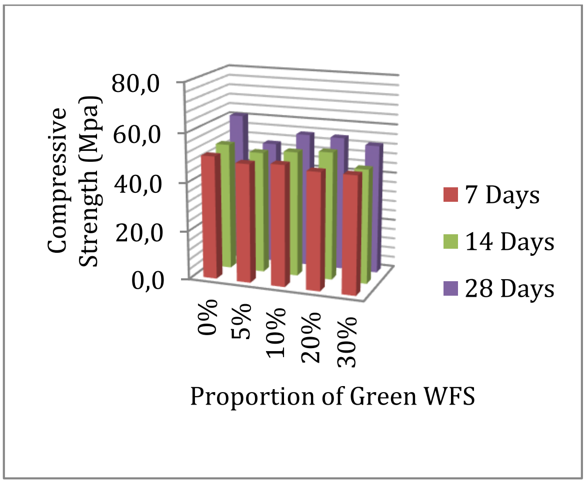

Fig. 2. Compressive strength of concrete paver blocks

Table VII Compressive strength of concrete paver blocks

	Compressive Strength (MPa)			
Proportion of **GREEN** WFS	7 Days	14 Days	28 Days	Standard 28 days value (in ASTM 1988)
0%	50.5	52.0	61.0	50.0
5%	48.6	49.8	50.2	
10%	49.5	51.2	55.2	
20%	48.0	52.3	55.0	
30%	48.0	46.7	52.9	

5) *Water Absorption of Concrete Paver Blocks*

The water absorption of concrete paver blocks made using different proportions of green WFS is shown in Fig. 3 and Table VIII. The paver blocks containing 0% green WFS have the lowest water absorption while the blocks containing 30% green WFS have the highest water absorption. Nevertheless, the difference in water absorption of the blocks ate different proportions of green WFS is not significant. This is evident from Table VIII, as the water absorption of the blocks ranges from 4.3 to 4.6% by mass. Further, as shown in the highlighted cells of Table VIII, the quality of paver blocks in all proportions of green WFS attains the standard water absorption value of ≤6% by mass recommended in BS EN 1338:2003.

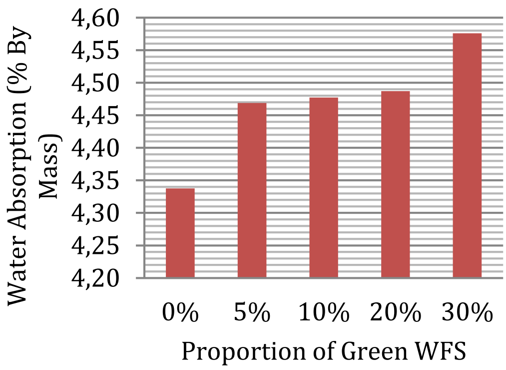

Fig. 3. Water absorption of concrete paver blocks

Table VIII Water Absorption of concrete paver blocks

	Water Absorption (% by mass)	
Proportion of Green WFS	Observed Value	Standard Value (in BS EN 1338:2003)
0%	4.34	≤6.00
5%	4.47	
10%	4.48	
20%	4.49	
30%	4.58	

6) *Optimal proportions of Green 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 3.78 MPa and 55.2 MPa, respectively, when Green WFS is used. Thus, the optimum replacement is from 5%-10% for green WFS as fine aggregate.

B. *Discussion*

1) *Impact of aggregates' physical characteristics on strength of concrete paver blocks*

As shown in Table IV, the natural sand used is coarser than Green 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 green WFS as shown in Fig.1 to Fig. 2 and Table VI to Table VII. These findings concur with those of (Rashid, et al., 2014;Siddique and Dhanoa, 2013) who establish that strength of concrete decreases with increase in fineness of aggregates. On the same note, (ASTMC33, 1997) 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.

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 V above, the following can be deduced: the proportion of silica in in natural river sand is 1.5 times the proportion of silica present in green 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 (Bhanja and Sengupta, 2005;Cakır and Sofyanlı, 2015).

However, the optimal tensile and compressive strength obtained in blocks containing Green WFS is still very close to that obtained from the control mix, as shown in Table VI and Table VII. 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 green WFS than in natural river sand by factors of 5.9, 24.3, and 6.0 respectively. Secondly, other chemical constituents including calcium, magnesium, titanium, chlorine and copper are available in Green 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, (Abalaka and Babalaga, 2011;Alzaed, 2014;Chavan and Kulkarni, 2013;Hassan, et al., 2013;Manoj Kumaar, et al., 2015;Odeyemi, et al., 2015;Ramesh, 2014;Venkateswara, et al., 2011) 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 green WFS are the reason for comparable strength of concrete paver blocks containing green WFS. This is despite the finer particle size and lower silica content in green WFS when compared to natural river sand.

IV. CONCLUSIONS

This study mainly focused on the determination of the chemical composition of green 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 Green 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 green WFS and natural river sand is different. Particularly, the proportion of silica in green WFS is lower at a factor of 0.7 times that in natural river sand while the proportions of aluminium, iron and potassium are higher in green WFS by factors of 5.9, 24.3 and 6.0 respectively. Also, green WFS contains calcium, magnesium, titanium, chlorine and copper, which are missing in natural river sand.

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

The use of green 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 green WFS at different proportions. This is attributed to the coarser particles in natural sand than in green WFS.

Despite its finer particles, and lower silica content, the use of green 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 green WFS as fine aggregate is between 5% and 10%.

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 5% to 10% of green 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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