

Characterization of Five Different South African Waste Foundry Sands to Determine their Suitability for Use in Concrete

Patrick I. Iloh, Prof. George Fanourakis, Aurobindo Ogra

Abstract— South Africa, like many other countries is witnessing the fast growth of the construction industry. Concrete is one of the key materials used for the development of infrastructures. Sand as one of the natural resources and major concrete components is depleting universally. At the same time, the solid waste generated from industries is gaining momentum and increasing drastically. Researchers have indicated that Waste Foundry Sand (WFS) has the potential properties for use as fine aggregate in concrete. The full/partial replacement of sand in concrete with WFS not only makes concrete manufacturing economical, but also helps in reducing disposal problems and promote sustainable construction. In this study, the physical and chemical properties of five WFS's from Gauteng, South Africa were analysed (two green and three chemically bonded moulding sands). The samples were investigated with a view to determine their conformity with applicable engineering standards when used as fine aggregate. The physical and chemical properties evaluated were particle gradation, specific gravity, moisture content, clay contents, bulk density, XRF and pH. The physical and chemical results of the five WFS's analysed indicate acceptable variations in chemically bonded moulding sand. The green sands proved unacceptable for use as fine aggregate for concrete use due to their: clay contents, poor grading which cannot be blended with other sand, and due to the presence of fine and silt particles which can cause bleeding and segregation.

Keywords— Chemical properties, Gradation, Physical properties, Waste Foundry Sand (WFS).

I. INTRODUCTION

In this 21st Century, concrete has become the largest utilized synthetic construction material product on earth. Globally, concrete production in the year 2010 was estimated to be 16 billion tons [1]. Based on an approximate world population of 7 billion, this translates into more than two tons of concrete produced per person per year, which brings into spotlight the scale of concrete usage. Concrete is a mixture of

cement (10 % - 11 %), Aggregate (70 % - 85 %), Water (13 % - 20 %) [2]. Natural sand (river sand) is one of the main ingredients used as a fine aggregate in concrete production. Because of these immense amounts of natural sand needed, the industry has left a large negatively impacting environmental track, which is a sturdy challenge to overcome.

A growing demand for construction material has led to the over-exploitation by legal and illegal mining and this has led to damaging costs e.g. an increase in riverbed depths and lowering of the water table [3]. In South Africa, a large amount of natural sand has been extracted. The sand utilization in 2015 was 1900 Mt and trends suggest an 8 % annual increase in sand usage. To abate the use of natural sand in concrete, the South Africa Waste Management Act 2008 [4] provides an incentive that encourages the use of waste materials as an alternative material. Substituting the natural sand with WFS, where practicable, allows for present levels of sand demand to be met, whilst conserving the prime aggregates and accordingly reducing deposits on landfills. According to previous studies, WFS grain size distribution is uniform, with 85% - 95% of the material between the 0.6 mm to 0.150 mm size range, and approximately 5% to 20% of WFS can be finer than 0.075 mm [5]. According to Dayton et.al. (2010), spent foundry sand prevailing size portion ranges from 0.05 to 2 mm, which extends from 76.6% to 100%, with a median of 90.3% on the research done on 39 spent foundry sands. The specific gravity of WFS differs between 2.39 and 2.79. WFS has a low water absorption limit and is non-plastic [6]. Other researchers have suggested that the workability and suitability of WFS in flowable fill depends upon its physical properties such as particle gradation, fine contents, density, and absorption and specific gravity [7]. Whereas others have reported that variation in the bulk density (1052–1554 kg/m³), specific gravity (2.38–2.72) and absorption (0.38–4.15%) largely depends on the sand mineralogy, particle gradation, grain shapes and fine contents [8]. WFS been rich in silica content, few researchers have reported that its chemical composition relies on the type of binder, type of metal and combustible utilised [9]-[10]. It is coated with a thin film of burnt carbon, residual binder (bentonite, sea coal, and resins/chemicals) and dust. Its pH has been reported as varying between 4 and 8, depending on the type of binder and type of metal cast [11]. Previous research reported that due to the presence of phenols in foundry sand, some waste sand could be corrosive to metal. This raised concerns that infiltration of

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precipitation over build up stocks could assemble leachable segments, resulting in the discharge of phenol into ground water supplies or surface water supplies [12].

For this reason, the WFS physical properties and chemical composition must be well understood. An International survey [13] found that particle size and grading, strength, water requirement, absorption and specific gravity are amongst the most significant material characteristics for concrete quality. Hence, the effect of the inclusion of WFS on the above properties of concrete warrants investigation.

In this research study, the suitability of two commonly used South African WFS's namely the greensand (clay bonded) and the chemically bonded moulding sand for use in concrete was ascertained.

II. TESTING PROGRAM

A. Materials

Five WFSs were collected from five different independent metal casting foundries with different casting processes from Gauteng Province, South Africa. Two greensands were collected from Auto Industrial (Isando Foundry) and Guestro Casting and Machining, representing samples (WFS 01 and WFS 03), and three chemically bonded moulding sands from Forbes Bros. Foundry, Johannesburg Foundry rebranded as Sinvac Casting, and Thomas Foundry representing samples (WFS 02, WFS 04, and WFS 05) respectively. Each sample of 10kg disposable WFS to landfill site was collected from the respective foundries. All the samples were decanted into clean buckets and were transported for subsequence investigation to the laboratory. The methods used to determine the physical and chemical properties of the material are discussed below.

B. Methods

Physical Properties:

Sieve analysis (Grading): This is the process of dividing an aggregates sample into certain segments, each comprising of particles of similar size [14]. Sieving can be done in different ways; SANS 201 [15] describes the method for dry sieving of aggregates, which was used as the method for determining the particle size distribution curve (PSD) of the five WFS in this study. Gradation, especially grading of the WFS, is an important factor in concrete production as it influences the concrete properties in fresh state.

Hydrometer analysis: The TMH1-Method A6 [16] test method was used to determine the distribution of the five WFS particle size smaller than 0.075 mm, by means of the sedimentation process, based on Stokes's law.

Relative density (SG): Specific gravity of solid soil is the proportion of the mass of a unit volume of a solids soil to the mass of the same volume of gas free distilled water at 20°C. Determination of relative density was conducted in accordance with SANS 3001-AG23:2014 [17] for solids soil that pass through 4.75 mm sieve by pycnometer method.

Moisture content: Determination of the moisture content by oven drying of the five WFSs used in this study conform to SANS 3001-GR20 [18]. The moisture form of WFS is

significant as it affects the overall water content of the mix, in turn, affecting strength and workability.

Uncompacted bulk density: A standard method, which conforms to SANS 5845:2006 [19], was used to determine the uncompacted bulk densities of the five WFS samples. Reasonably, the density of aggregate affects the concrete aggregate proportioning.

Fineness Modulus (FM): FM is a dimensionless limit, which defines the average particle size [20] and give a suggestion of the fineness or coarseness of the aggregate [21]. The Fineness Modulus of the five WFS samples used in this study was determined by sieving the material on the specified sieves and calculated by adding the cumulative percentage passing the 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm and 0.15 mm, and divided by 100. This method was carried out in accordance with SANS 201 [15].

Chemical properties :

XRF: The five WFS samples were analysed using a Rigaku ZSX Primus II X-ray spectrometer. An approximate 10g sample of each non-grounded dry sample was pressed to form a pellet after mixing with wax. It was then placed into the sample holder of the XRF spectrometer for quantitative analysis of the chemical composition.

pH: The acidity or basicity of the five WFS was measured using as aqueous solution. Solutions with a pH fewer than 7 are said to be acidic and solutions with a pH more than 7 are basic or alkaline. The pH was determined in accordance with (SANS 11:1990) [22].

III. RESULTS AND DISCUSSION

A. Physical Properties of WFS

Grading: The grain size distribution of WFS is relatively uniform, with a mainstream of the sizes falling within a narrow range between the 0.600 mm and 0.150mm sieves. The majority of the WFS materials reported are found to be medium to fine sand. WFS have been found to be too fine to satisfy the specifications for general fine aggregate [23]. This includes the effective size, coefficient of curvature, and coefficient of uniformity of WFS samples. According to Unified Soil Classification System ASTM D2487-06 [24], coefficient of curvature, C_c , ranges from 1.5 to 2.5; coefficient of uniformity, C_u , ranges from 0.9 to 1.5. The gradation results are consistence with previous research [25]–[26]. Figure 1 summarizes the test results of five WFS samples gradation curves. The sieve analysis data of five WFS sample are presented in Table 1, along with the SANS 1083: 2017 [27] standard grading requirements for fine aggregate used in concrete mixes. Each value was achieved from a sample test. WFS samples from the chemically bonded moulding sand (WFS 02), and greensand (WFS 01), had respective grain sizes of 12 and 21% passing through the 0.150mm sieve, satisfying the grading limit criteria. Similarly, 42% and 53% of WFS 03 and WFS 05 were poorly graded and, as a result, cannot be blended with other fine aggregate for concrete, as they did not meet the grading limit of 0.150 mm. The WFS 04, which had 4 % passing the 0.150 mm sieve, complies with Alexander and Mindess, 2005 suggestion of a lower limit of 3% passing the

0.150mm [28]. These plots variations show that WFS's are less graded and finer than fine aggregate for concrete, with the majority of the sizes falling within SANS 1083:2017 [27] range of 0.150 mm sieves with grading limit of 5 % and 25 %.

From the grading curve presented in Table 2, the uniformity coefficient and the coefficients of gradation of D_{10} , D_{30} , and D_{60} diameters corresponding to 10%, 30% and 60% finer in the particle-distribution of WFS 01-WFS 05 for C_u is 5.25, 2.00, 7.87, 2.33, and 2.25, while for C_c is 2.03, 0.89, 1.61, 1.20, and 0.84.

Fines content results are shown in Table 3, i.e., particles proportions of five WFS finer than $75\mu\text{m}$ by dry sieving. The results ranged between 16.77g (13%), 3.51g (2.8%), 31.77g (25%), 2.2g (1.76%), and 5.52g (4%), respectively and were on average 9.3%, consistent with previous report results [28]. The clay bonded WFS samples, WFS 01 and WFS 03 contained comparatively more fines (on average 19%) than chemically bonded WFS samples (on average 2.9%). For the clay bonded WFS, it is contingent that clay bonded WFS occupied the most of fine contents. Apart from the clay contents, fines are also comprised of very fine sand particles and silt which are dispersed by the wash water, the residue chemical additives and binders from the casting process.

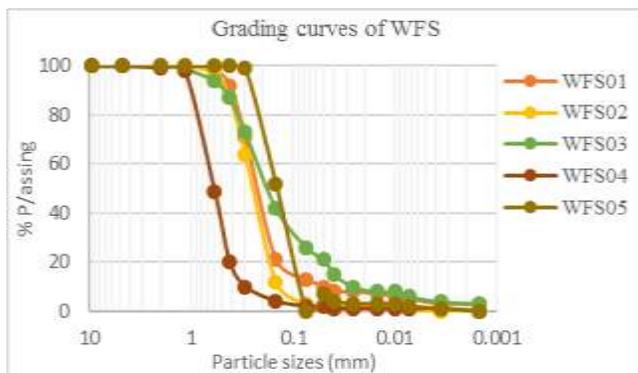


Fig. 1 Gradation curves of sieve and hydrometer analysis of WFS

TABLE 1: PARTICLE SIZE DISTRIBUTION (SIEVE ANALYSIS AND HYDROMETER ANALYSIS) RESULTS

Total Mass	* Sample: 125 grams					
Sieve Size (mm)	WFS01	WFS02	WFS03	WFS04	WFS05	Grading Limit ¹
4.750	100	100	100	100	100	90 -100
2.000	100	100	100	99	100	-
1.180	100	100	99	98	100	-
0.600	98	97	94	49	100	-
0.425	92	87	87	20	100	-
0.300	71	64	73	10	99	-
0.150	21	12	42	4	52	5 - 25
0.075	13	3	26	2	11	
0.050	10	2	21	2	7	
0.040	8	2	15	1	4	
0.026	8	2	10	1	3	
0.015	7	2	8	1	3	
0.010	6	2	8	1	3	
0.0074	5	1	6	1	2	
0.0036	4	0	4	1	1	
0.0015	3	0	3	0	0	

* WFS01-05 (% passing); 1SANS 1083: 2017

TABLE 2: WFS EFFECTIVE SIZE, UNIFORMITY COEFFICIENT, AND COEFFICIENT GRADATION SUMMARY RESULTS

Samples	WFS 01	WFS 02	WFS 03	WFS 04	WFS 05
D_{10}	0.055	0.15	0.028	0.3	0.08
D_{30}	0.18	0.20	0.10	0.5	0.11
D_{60}	0.29	0.30	0.22	0.7	0.18
C_c	2.03	0.89	1.61	1.20	0.84
C_u	5.27	2.00	7.87	2.33	2.25

Relative density (SG). The specific gravity of WFS rests on the internal porosity of the constituent particles as well as chemical composition of the sand. Sands with high metal contents will have higher specific gravities. The specific gravities reported in the previous works on four green sand samples ranged from 1.985 to 2.45 [10, 29]. The specific gravity of a chemically bonded WFS was found to be 2.60 [29]. The variation in the specific gravity as shown in Table 3 from the five WFS samples (WFS 01-WFS 05) ranged between (2.3-2.8). This dissimilarity may be attributed to the variation in particle gradation, sand mineralogy, fine content, grain shape, and sand binder. The sea coal dust, which is known to be porous with carbon content, might have resulted in lower specific gravity for the green WFS.

Moisture contents of the WFS test results represent the "Equilibrium Moisture" state of individual sample; that is, the sample will neither absorb water nor give up water to the paste. In previous research, WFS's have been reported to be virtually dry. Though, variation from one foundry to another, and the method in which the WFS's are stockpiled may result in the moisture contents inconsistency. The moisture content for greensand samples has been reported to be in the range of 0.08% to 4.59%, and chemically bonded samples was reported to be in the range of 0.11% to 3.48% [10]. The moisture content of the five WFS analysed ranged from 0.2 % to 8.3%, as presented in Table 3. The chemically bonded sample, WFS 02, exhibited a very high water content of 8.3%, while sample WFS 03 had a moisture content of 1.9%. Samples WFS 01, WFS 04 and WFS 05 had moisture contents less than 1 %. The varied initial water content set in the foundry sands and binder type may be related to these differences. Green sand (clay-bonded) system require approximately 10% of water to activate (bentonite binding), however 2%-3% water is required as a catalyst or solvent for organic binders' activation [30]. Neglecting moisture content can incorrectly affect the calculation of volume of water in mix design.

Uncompacted bulk density. The results of the five sands, which are included in Table 3, ranged from 1165 kg/m^3 to 1473 kg/m^3 . This capacity possibly will be ascribed to the variation in particle gradation, sand mineralogy, fine content, and grain shape. According to SANS 5845:2006 [19] The uncompacted bulk density should exceed 1120 (for lightweight concrete). Hence, all the sands complied with this criterium.

Fineness Modulus (FM) of the five samples are shown in Table 3. According to SANS 1083: 2017 [26], the limiting FM for fine aggregate for concrete use range from 1.2 to 3.5. Samples WFS 01, WFS 02 and WFS 04 complied with standard FM's of 1.2, 1.4, and 3.2, respectively. Samples WFS 03 and WFS 05 had FM's of 1.0 and 0.5, respectively.

TABLE 3: PHYSICAL PROPERTIES OF WFS SAMPLE

Samples	Most. Content (%) (A)	Bulk Density (B)	SG (C)	FM (D)	Clay Content (2, 0 %) (E)	pH	WFS finer than 75µm
WFS 01	0.4	1247	2.5	1.2	3.0	8.88	13
WFS 02	8.3	1387	2.6	1.4	0,0	9.34	3
WFS 03	1.9	1165	2.3	1.0	3,0	8.87	26
WFS 04	0.5	1221	2.6	3.2	0,0	9.89	2
WFS 05	0.2	1437	2.8	0.5	0,0	9.52	4

(A) SANS 3001-GR20; (B) SANS 5845:2006 Kg/m³; (C) SANS 3001-AG23:2014; (D) SANS 1083:2017(1,2 – 3,5); (E) SANS 1083:2017; (F) SANS 11:1990 Alkaline; (G) SANS 1083:2017

B. Chemical Properties of WFS

X-ray fluorescence (XRF): From the results, which are shown in Table 4, the predominant element existing in all samples is silica oxide with highest percentage present. When comparing the elemental composition of clay bonded WFS samples (WFS 01 and WFS 03) to chemically bonded samples (WFS 02, WFS 04 and WFS 05), it was observed that the latter comprised fewer Al₂O₃, and had no trace of MgO; this can be ascribed to partial loss of binder and high casting temperature. The main components were found to be silica (SiO₂), alumina (Al₂O₃), and ferric oxide (Fe₂O₃).

The composition was found to be very suitable for the manufacturing of Portland cements.

pH: These results are very important in the evaluation of sand compatibility with applied resins. The clay bonded (WFS01 and WFS03) and chemically bonded (WFS02, WFS04, and WFS05) showed a result variation, as indicated in Table 3. The chemically bonded WFS's exhibited a comparatively high pH values of 9.89, 9.52, and 9.34, compared to the clay-bonded sands, which exhibited comparatively low pH values of 8.88 and 8.78, respectively. The slightly lower pH values of clay bonded (WFS01 and WFS03) might be because of acidic cations (binder) presence and type of metal been cast. The pH results disclose that both types of WFS's used in this study possess a specified pH level of strong alkalinity and pose no threat to the environment.

TABLE 4: CHEMICAL COMPOSITIONS (MASS %) OF ALL THE WFS SAMPLES AS DETERMINED BY XRF

Compositions	Value (%)				
	WFS01	WFS02	WFS03	WFS04	WFS05
SiO ₂	82.68	88.82	73.00	89.32	68.93
Al ₂ O ₃	8.10	3.22	11.90	2.01	6.23
Fe ₂ O ₃	3.54	2.82	6.33	3.26	8.31
CaO	-	-	1.92	-	-
MgO	1.48	-	2.16	-	-
SO ₃	-	-	1.26	-	-
Na ₂ O	-	1.03	1.36	2.87	-
K ₂ O	1.15	2.53	-	-	3.18
TiO ₂	-	-	-	-	-
Mn ₂ O ₃	-	-	-	-	-
SrO	-	-	-	-	-
Cr ₂ O ₃	-	-	-	-	3.30
LOI	4.8	3.39	15.58	4.35	3.88

IV. CONCLUSION

The physical and chemical results of the five WFS's analysed indicated acceptable variations in chemically bonded moulding sand but proved unacceptable in the case of the green sand. The unacceptable aspect for green sand was because of their clay contents, poor grading (cannot be blended with other sands), contain a very fine and silt particle, which can cause bleeding, and segregation. There is a correlation between the properties between chemically bonded samples and research done by previous researchers on the gradation, moisture content, fineness modulus, and specific gravity. The chemical characteristics of the chemically bonded sands also correlate with the results from previous researchers on XRF and pH.

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