International Conference on Civil Infrastructure and Construction (CIC 2020)
February 2-5, 2020 Doha, Qatar

Eco-friendly Concrete Using Local Materials From Sudan

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ABSTRACT

This study is aimed at investigating the potentiality for utilizing some locally available eco-friendly materials to replace some concrete constituents as a possible opportunity to introduce sustainable construction in Sudan. Six suggested scenarios were explored to visualize the possible outcomes : (1) 100% recycled aggregates (RA) and natural pozzolana in replacement of coarse aggregates (2) steel slag replacing fine aggregate or cement (3) treated sawdust replacing fine aggregates (4) sawdust ash in partial replacement of cement (5) meta-kaolin (MK) in partial substitution for ordinary Portland cement (OPC) (6) quarry dust (QD) in partial replacement of sand or cement. Laboratory experiments were conducted and concrete workability and compressive strength were determined. The results confirmed the suitability of RA for full replacement of natural coarse aggregates. Steel slag was more appropriate in replacing sand than cement when added in small percentages not exceeding 15%. Sawdust needed treatment to eliminate the unfavorable properties before using it as a substitute for sand but when the ash was used to replace cement, it was not possible to achieve the required strength at early ages and better results were achieved in 28 days. With a chemical composition comparable to cement, MK showed impressive results when used in partial replacement of OPC. The addition of QD in replacement of 15% of sand offered a reasonable workability but the compressive strength was only approaching the targeted value. According to these results, it could be inferred that the tested options offer reasonable evidence to confirm their potentiality for producing green concrete in Sudan.

Keywords: Green concrete; Meta-kaolin; Sudan; Sustainability

1 INTRODUCTION

Concrete is a heavy, rough building material made from a mixture of cement, fine and coarse aggregates, water and maybe some additives. For the negative impacts resulting from its production, concrete has been classified as environmentally unfriendly. Its production consumes natural resources such as river sand, clays and rocks which are normally not returned back and involves the emission of huge amounts of CO_2 during the production of cement-as one of its major constituents. Accordingly, sustainable trails in the building industry called for preserving these natural resources through the production of eco-friendly concrete. This is concrete where waste materials are used as at least one of its components or its production does not lead to environmental destruction through the reduction, reuse or recycling techniques.

2 SUSTAINABILE ALTERNATIVE BUILDING MATERIALS

The call for cement and concrete production sustainability was stressed in several previous studies. Green concrete is thought to be one of the solutions leading to sustainable construction because it "... uses waste material as at least one of its components, or its production process does not lead to environment destructions" (Akbarnezhad et al., 2013; De Brito & Saikia, 2013). They evaluated the physical and mechanical properties of different material options when used in substitution for some of the main components of concrete. Durga and Andira (2016) tested the use of construction debris and demolition waste, for partial or entire replacement of virgin aggregate when making new concrete and argued that it "… could save about 60% of limestone resources and reduce CO_2 emissions by about 15%–20%". It has been reported though that there are some limitations recorded on its use pertaining to its long-term durability. It was found that variation in the RA properties, different environmental conditions in addition to the crushing process, contamination and impurities, affect the new concrete properties (El Shiekh et al., 2012; Mahmoud & El Shiekh, 2018; Juenger et al., 2012; McNeil & Kang, 2013; Mehta, 2010; Pachipala, 2017).

The use of alternative materials to replace aggregates was another option to avoid depleting the natural aggregates. Silica sand, a by-product of the glass industry, is an alternative incorporated to partially replace natural sand in concrete mixtures (Pimraksa et al., 2018; Silva et al., 2015). The results showed up to 32% increase in compressive strength and 13% improvement on tensile strength upon replacement of natural sand by 60% and 40% respectively (Ulloa et al., 2013).

The behavior of concrete with supplementary cementitious materials (SCM) has been investigated in many studies. "Natural supplementary materials such as volcanic rock and limestone are used for their economic benefit and early-strength and durability improvements" (Vishnumanohar, 2014). Among the commonly used SCM are coal fly ash, silica fumes, metakaolin and blast furnace slag (Xiao et al., 2014). Calcined clays, municipal solid waste incinerator residues and limestone fillers are few examples cited in the literature where their use as alternative supplementary materials was outlined.

3 TRIALS TO PRODUCE ECO-FRIENDLY CONCRETE IN SUDAN

Initially, the chemical and physical properties of the different materials used in these trials were determined, different mix designs considering several options were developed then the concrete was prepared and casted in cubes. The fresh concrete mixtures were tested for workability and the hardened concrete was tested for compressive strength after 7, 14 and 28 and in some instances for 90 in all trials.

3.1 100% recycled aggregates (RA) and natural pozzolana in replacement of coarse aggregates

This study built on a preliminary study conducted by the authors on the reuse of building demolition wastes and their potential usefulness in producing new concrete. More investigation scenarios were included. The physical properties of fresh and hardened RCA included concrete were investigated with and without natural pozzolana being added to the mixtures. OPC conforming to (BS–8112-1996) was used with 32.5% normal consistency, 2 hours and 25 minutes initial setting time, 3 hours and 30 minutes final setting time, 2% fineness and 2mm stability size. Specific gravity and absorption were determined as shown in table 1.

Table 1: Aggregates Characteristics

Characteristics	Natural Coarse Aggregates (NCA)	Recycled Coarse Aggregates (RCA)
Specific Gravity	2.76	2.66
Absorption	0.44	0.98

The recycling process involved crushing, separation of metals by a magnet, manual removal of other impurities (plastic, wood, etc.), and classification of aggregates to different grades based on particle size as illustrated in Figures 1a, 1b, 1c respectively.

Figure 1a: Aggregates crashing

Figure 1b: Metals separation

Figure 1c.: Aggregates classification

Proportions for 8 different mix trials were considered and the materials proportions are presented in table 2. The targeted compressive strength value was (25MPa).

Table 2: Mix Trials materials proportions

Trial	Cement (Kg)	Water (Kg)	Fine Aggregate (Kg)	NCA (Kg)	RCA (Kg)	Pozzolana (Kg)
1	325	195	641	1189	-	-
2	325	195	641	891.8	297.3	-
3	325	195	641	594.5	594.5	-
4	325	195	641	297.3	891.8	-
5	325	195	641	-	1189	-
6	292.5	195	641	-	1189	32.5
7	260	195	641	-	1189	65
8	227.5	195	641	-	-	97.5

Slump test values ranged between 60-180mm. However, workability was noticed to decrease in the range of 4.2-14.3% with increasing replacement ratios of RCA up to a maximum of 20.2% with 100% RCA in comparison to NCA. Contrary wise, an increase in the range of 3.2-7.4% was reported with the inclusion of pozzolana with 100% RCA concrete. In its fresh state, the optimum ratio was achieved with the full replacement with RCA and 20% pozzolana. Compressive strength results depicted in figure 2 showed a strength decrease as the RCA replacement percentage increases. The target strength was achieved with 10% pozzolana and 100% RCA.

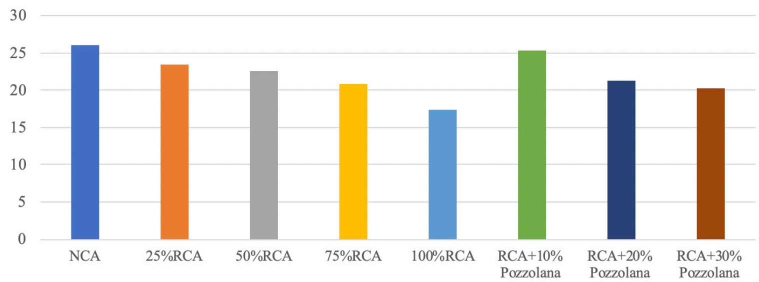

Figure 2: 28-Days compressive strength results for the different mix trials

The results for the durability test presented in Figure 3, revealed a drop in the wave speed value (Km/sec) when the NCA were completely replaced by RCA while an increase was witnessed with the different percentages of Pozzolana added to mix.

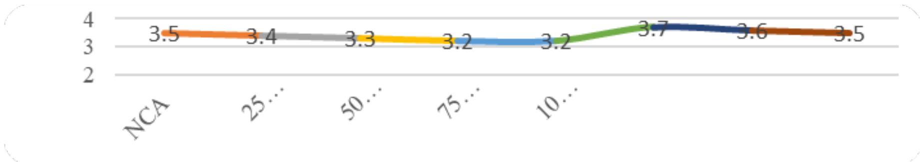

Figure 3: Durability Test Results (Wave speed Km/sec)

3.2 Steel slag replacing fine aggregate or cement

Blast furnace slag (BFS), a by-product from the production of steel at Giad Factory south of the city of Khartoum – Sudan was used. Both chemical analysis and XRD test were conducted on a BFS sample and the results showed similar oxides in comparison to OPC but with different proportions (SiO_2, 33%; Al_2O_3; 7%; Fe_2O_2; 11%). It was incorporated in partial substitution for sand then cement in concrete mixtures.

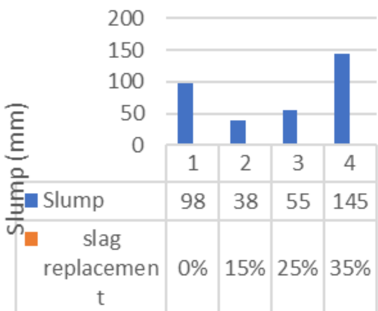

Figure 4a: Workability Results for mixtures containing Steel Slag in Replacement for Sand

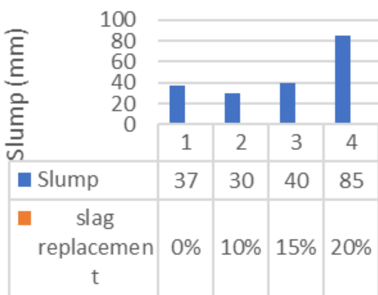

Figure 4b: Workability Results for mixtures containing Steel Slag in Replacement for Cement

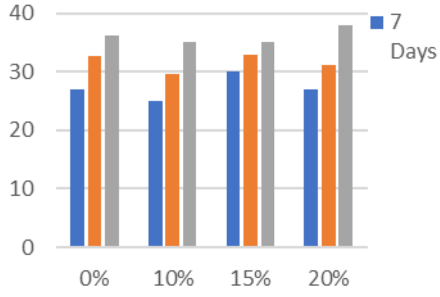

Figure 5a: Compressive Strength Results for Concrete with the Inclusion of Steel Slag in Replacement for Sand

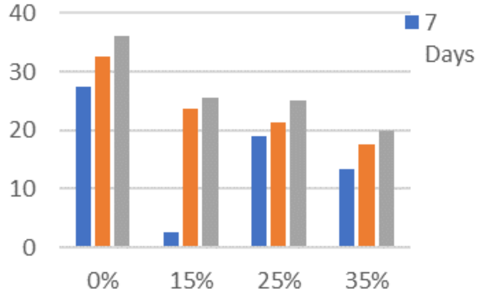

Figure 5b: Compressive Strength Results for Concrete with the Inclusion of Steel Slag in Replacement for Cement

A standard mix and 3 others where the slag replaced (10%, 15%, and 20%) of the sand weight and (15%, 25%, and 35%) of the cement weight. The slump and compressive strength results are shown in figures 4a, 4b, and 5a, 5b. The results for slag replacement for sand confirmed that both the workability and the compressive strength have increased. Alternatively, in the case of replacing the slag with varying percentages of the cement weight, the results showed an increase in workability parallel with the increase in the slag amount while the compressive strength has dropped.

3.3 Treated sawdust replacing fine aggregates

Samples of the abundantly available sawdust (SD) from the local furniture market on Khartoum State, Sudan were collected, treated then used in concrete mixtures. Seven cases, shown in table 3, were analyzed. Compressive strength at the different curing ages was as illustrated in table 3.

Table 3: Compressive strength results for treated Sawdust included in replacement of fine Aggregates Concrete mixtures

Scenario	Streangth (MPa)		
	7 Days	14 Days	28 Days
Untreated Sawdust	34.5	37.03	38.96
Unsoaked Sawdust with 10% repalcement	8.77	9.31	9.8
Unsoaked Sawdust with 20% repalcement	2.08	3.9	6.3
soaked Sawdust with 10% repalcement	16	15.9	18.07
soaked Sawdust with 20% repalcement	11.5	13.8	17.8
Sawdust treated with calcium hydroxide + 10% MC	15.13	11.3	18.1
Sawdust treated with calcium hydroxide + 20% MC	3.24	5.5	12.3

The unfavorable properties of SD made if hardly possible to approach the targeted strength. With unsoaked SD, 10% replacement offered better results and when the dust was soaked nearly equal results were obtained for 10 and 20% replacement which are also equal to the strength value 10% replacement when the SD was treated with the calcium hydroxide and coated with varnish.

3.4 Sawdust ash in partial replacement of cement

The ash was prepared as depicted in figures 6a, 6b, 6c and 6d and the mix trials were prepared with the proportions shown in table 4

Figure 6a: Raw Sawdust

Figure 6b: Sawdust burning

Figure 6c: Sawdust ash sieving

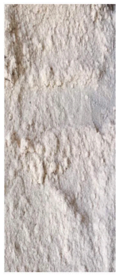

Figure 6d: Hardened sawdust concrete mix

Table 4: Compressive strength results for Sawdust ash included in replacement of cement in Concrete mixtures

Mix Trial (% replaced)	Compressive strength (MPa)		Slump (mm)
	7 days	28 days	
0%	24.1	37.67	37
10%	18.14	22.04	35
20%	15.87	24.9	34

Better results are achieved when the ash was used in replacement for cement. Slump values are within the designed for limit (30-60mm) and the compressive strength is just as the targeted value with 20% replacement ratio.

3.5 Meta-kaolin (MK) in partial substitution for ordinary Portland cement (OPC)

A two stages process was followed. The first stage was concerned with the kaolinite clay (KC) collected from different locations in Sudan. The chemical composition was determined using X-Ray florescence where the major oxides were identified then compared to the major constituents of OPC. KC was transformed to Meta-Kaolin (MK) through a calcination process then tested according to the ASTM-C618 to determine its pozzolanicity. The evaluation of the pozzolanic activity of the MK was conducted via chemical and mechanical tests. The former comprised measurement of the amount of the three major oxides (SO_2+Al_2O_3+Fe_2O_3), Loss on ignition percent and the later was concerned with assessing the strength properties of MK included concrete. The results shown in table 5, confirmed the pozzolanicity of the MK.

Table 5: The evaluation of the pozzolanicity activity of the Meta-Kaolin from Sudan

Elements	Meta-kaolin from different locations in Sudan				Pozzolanicity
	Site 1	Site 2	Site 3	Site 4	Limits according to ASTM C618 (%)
SiO_2+Fe_2O_3+Al_2O_3	93.05	88.42	97.30	97.60	≥70%
LOI	4.08	5.65	0.68	1.3	≤6%

MK was then added to concrete mixtures in (0, 5, 10, 15, 20, 30) % replacement for cement. Workability of the fresh concrete samples was tested through the slump test where all results were conforming to the required limit (60-180mm) then a set of 56 (150×150×150)mm cubes were casted and cured for 7,14,28,90 days. The results depicted in figure 7 show an increase in the strength with the MK inclusion with an optimum limit of 20% yielding 35.8MPa in 28 days. It was also evident that very promising results could be achieved at long ages as shown in 20 and 30% MK which yielded 40.1 and 42.3MPa respectively exceeding by that the targeted strength and indication the pozzolanic reactivity of the MK at longer ages.

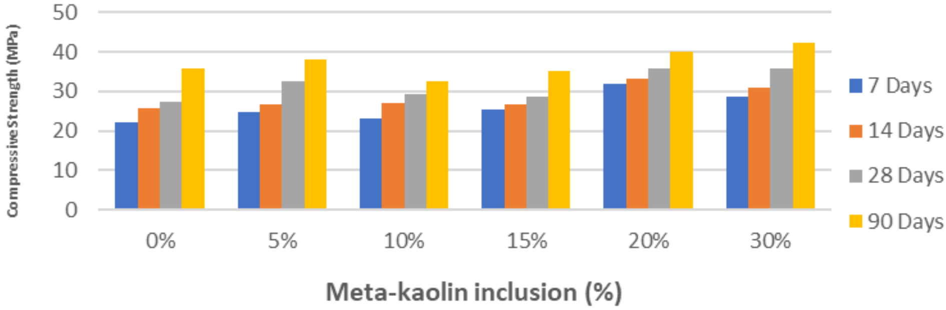

Figure 7: Compressive strength of meta-kaolin included concrete mixtures

3.6 Quarry dust (QD) in partial replacement of sand

Quarry dust is a sediment or residue from the process of extracting and treating rocks. For this study, the dust was obtained from two locations; (Toureah) Mountain, south of Omdurman, and Algabaleen. When collected its physical appearance is as depicted in figures 8a and 8b.

Figure 8a: Quarry Dust Collection

Figure 8b: Collected Dust

In replacement for sand, concrete mixtures containing (15%, 25%, 35%) of the QD and in replacing cement (15%, 25%, 50%) were designed and prepared then cured in water. Workability of fresh concrete was measured for all mixtures and the compressive strength of hardened concrete was defined for 7 and 28 days. The results showed that the target strength was nearly achieved in the two cases. The replacement of sand by 15% QD yielded the best results among the mixing ratios while further increase in the dust reduced the compressive strength. In replacing cement, the optimum results were achieved with 25% replacement for cement, refer to figures 9a and 9b).

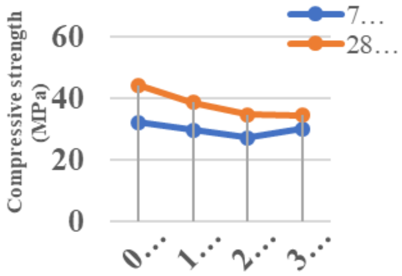

Figure 9a: Quarry Dust inclusion (%) from Omdurman-Sudan

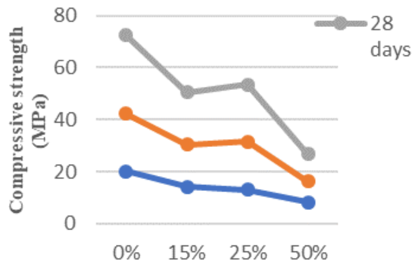

Figure 9b: Quarry Dust inclusion (%) from Algabaleen-Sudan

4 CONCLUSION

The results confirmed the suitability of RA for full replacement of natural coarse aggregates. Steel slag was more appropriate in replacing sand than cement when added in small percentages not exceeding 15%. Sawdust needed treatment to eliminate the unfavorable properties before using it as a substitute for sand but when the ash was used to replace cement, it was not possible to achieve the required strength at early ages and better results were achieved in 28 days. With a chemical composition comparable to cement, MK showed impressive results when used in partial replacement of OPC. The addition of QD in replacement of 15% of sand offered a reasonable workability but the compressive strength was only approaching the targeted value. According to these results, it could be inferred that the tested options offer reasonable evidence to confirm their potentiality for producing green concrete in Sudan.

REFERENCES

Akbarnezhad, A., Ong, K. C. G., Tam, C. T. & Zhang, M. H. (2013). Effects of the parent concrete properties and crushing procedure on the properties of coarse recycled concrete aggregates. *Journal of Materials in Civil Engineering*, Vol. 25, No. 12, pp. 1795-1802.

De Brito, J. & Saikia, N., (2013). *Recycled aggregate in concrete: Use of industrial, construction and demolition waste*. London, the UK: Springer.

Durga, B. & Andira, M. (2016). Experimental study on various effects of partial replacement of fine aggregate with silica in cement concrete and cement mortar. *International Journal of Engineering Trends and Technology (IJETT)*, Vol. 33, no. 5.

El Shiekh, A. A., Mahmoud, S. Y. & Attaalmanan, M. (2012). Study of the effect of steel slag on some of the properties of concrete. *Sudan Engineering Society Journal*, Vol. 57, No.1, pp1-8.

Juenger, M., John, L. P., Elsen, J., Winnie, M. & Doug, H. R. (2012). Supplementary cementitious materials for concrete: Characterization needs, *Materials research society symposium proceedings*. Vol. 1488.

Mahmoud, S. & Elshiekh, E. (2018). The potential usefulness of recycled aggregates and pozzolana in producing green concrete in Sudan. *International Journal of Structural and Civil Engineering Research*. Vol. 7, No.2.

McNeil, K. & Kang, T. H. K. (2013). Recycled concrete aggregates: A review. *International Journal of Concrete Structures and Materials*, Vol. 7, No.1, pp. 61-69.

Mehta, P. K. (2010). Sustainable cements and concrete for the climate change era – a review, *Proceedings of the 2nd International Conference on Sustainable Construction Materials and Technologies*. Ancona, Italy, pp. 28-30.

Pachipala, S. (2017). A study on mechanical properties of concrete using silica sand as partial replacement of cement. *International Journal of Civil Engineering* (SSRC-IJCE), Vol. 4, No. 5, pp. 34-39.

Pimraksa, K. P., Chindaprasirt, J. S. & Ling, T. C. (2018) Alternative cementitious materials and their composites. *Advances in Material Science and Engineering*, Vol. 2018, article 50746.

Silva, R. V., de Brito, J. & Dhir, R. K. (2015). Prediction of the shrinkage behavior of recycled aggregate concrete: A review. *Construction and Building Materials*, Vol. 77, pp. 327-339.

Ulloa, V. A., García-Taengua, E., Pelufo, M. J., Domingo, A. & Serna, P. (2013). New views on effect of recycled aggregates on concrete compressive strength. *ACI Materials Journal*, Vol. 110, No. 6, pp. 1-10.

Vishnumanohar, A. (2014). Performance of normal concrete with eco sand (finely graded silica) as fine aggregate. *International Journal of Engineering Science Invention*, Vol 3, No. 5, pp. 27-35.

Xiao, J., Li, L., Tam, V. W. & Li, H. (2014). The state of the art regarding the long-term properties of recycled aggregate concrete. *Structural Concrete*, Vol. 15, No. 1, pp. 3-12.

Cite this article as: Mahmoud S. Y. M., Alshiekh E. T. A. M., “Eco-friendly Concrete Using Local Materials From Sudan”, *International Conference on Civil Infrastructure and Construction (CIC 2020)*, Doha, Qatar, 2-5 February 2020, DOI: https://doi.org/10.29117/cic.2020.0118