American Journal of Construction and Building Materials
2020; 4(2): 33-38
http://www.sciencepublishinggroup.com/j/ajcbm
doi: 10.11648/j.ajcbm.20200402.11
ISSN: 2640-0022 (Print); ISSN: 2640-0057 (Online)

Sustainable Concrete Containing Recycled Aggregates and Pozzolana in Sudan

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To cite this article:
Eltahir Elshiakh, Salma Mahmoud. Sustainable Concrete Containing Recycled Aggregates and Pozzolana in Sudan. *American Journal of Construction and Building Materials*. Vol. 4, No. 2, 2020, pp. 33-38. doi: 10.11648/j.ajcbm.20200402.11

Received: July 17, 2020; **Accepted**: August 3, 2020; **Published**: August 13, 2020

Abstract: Sustainable trails in the building industry called for preserving the natural resources through the production of green 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. Experimental results from a study on the potential usefulness of recycled coarse aggregates (RCA) blended with locally available natural Pozzolana are outlined in this paper. Eight concrete mix scenarios were considered: a standard mix with 100% natural coarse aggregates (NCA), 25% RCA, 50% RCA, 75%RCA, 100% RCA and no Pozzolana, 100% RCA and 10% Pozzolana, 100% RCA and 20% Pozzolana, 100% RCA and 30% Pozzolana. Slump test was conducted and the results were all within the specific limits. It was conversely realized that the workability decreased in the cases of replacing NCA by RCA with no Pozzolana while an increase was recognized when the Pozzolana was add in the different percentages with the best results achieved with 100% RCA and 20% Pozzolana. The compressive strength results were consistent for the different curing ages with the highest strength being acquired with the mix that contained 100%RCA and 10% Pozzolana. The results of the durability test revealed better values for the wave length speed value when the NCA was replaced by the RCA. Considering these outcomes, the optimum result was achieved in the case of 100%RCA and 10%Pozzolana. Thus, the experimental results offer good indication for a potential usefulness of RCA proposing a reasonable way for preserving virgin natural materials.

Keywords: Compressive Strength, Pozzolana, Recycled Aggregates, Sudan, Workability

1. Introduction

Concrete is a heavy, rough building material made from a mixture of cement, fine and coarse aggregates, water and maybe some additives in different proportions produced to meet certain design specifications. For the many negative impacts that the concrete production poses, many researchers classified it as environmentally unfriendly. The fact that concrete production consumes natural resources such as river sand, clays and rocks which will be consumed but not returned back and involves the emission of huge amounts of CO_2 during the production of cement-as one of its major constituents- concerns arise from the associated severe negative impact on the environment. 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.

The call for cement and concrete production sustainability was stressed by [1] with estimated figures on the worldwide production of cement and the associated hazards from the manufacturing process showing how significant is the carbon footprint of the global cement and concrete industry. Being affected by economic and social transformations in societies, urbanization and patterns of population growth has changed entailing consequences of industrialization, globalization and environmental pollution. Global warming is the most important sustainability issue today in the public mind. The World Commission on Environment and Development defines sustainability as "meeting the needs of the present without compromising the ability of the future generations to meet their own needs" [2].

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" [3]. As such, it employs reduce, reuse and recycle techniques to minimize greenhouse gas emission and limit the use of natural resources such as limestone, clay, natural river sand, natural rocks that are being consumed but not returned back to the earth. 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 in continuation of the previous work presenting and testing more options for sustainable concrete using recycled aggregates. Properties and characteristics of the prepared (RCA) were determined to check their consistency with those of NCA. The physical properties of fresh and hardened RCA included concrete were investigated with and without natural pozzolana being added to the mixtures. The effect of the RCA inclusion was verified via the check of the mechanical behavior of the produced concrete as the workability, compressive strength and durability were measured.

2. Literature Review and Previous Studies

Different trials for testing the suitability of using recycled aggregate (RA), derived from construction debris and demolition waste, for partial or entire replacement of virgin aggregate when making new concrete. [4], argued that RA "… could save about 60% of limestone resources and reduce CO_2 emissions by about 15%–20%". In recent years, intensive research output on the utilization of recycled aggregate concrete (RAC) has been reported yet there are some limitations recorded on its use pertaining to its long-term durability. The consulted publications outlined the outcomes for the evaluation of physical and mechanical properties of RAC. Absorption, aggregates texture size and gradation, specific gravity, density, mortar content, percentage and type of contamination, aggregate strength and abrasion resistance are the main properties considered and their effect in the concrete was investigated. 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. Mortar adhered to RA leads to lower density, high absorption, and high abrasion loss. Moreover, sulphate and alkali contents cause expansive reactions which can be controlled if the maximum sulphate is in the range of 0.8–1.0% by mass and alkali content is below 3.5kg/m [5-8].

Numerous efforts were exerted to evaluate fresh and hardened properties of RAC. They indicated that the use of RA led to reduction in all mechanical properties, in addition to influencing the fresh stage properties and concrete durability due to high absorption and porosity [9, 10]. Consequently, more water is needed to achieve similar workability to that of NAC due to higher absorption capacity of RA which can be attributed to the presence of impurities and attached cement hydrates. [11] also confirmed the fact that as the RA content increases in the mix, the workability reduces especially at lower w/c ratio and in their study, it was found that the entrapped air content was similar when compared to normal concrete mix having a range of 2.4±0.2%. There was no significant effect recorded regarding the air content up to 25% replacements. 50 to 100% replacement of virgin aggregates with RA decreases the compressive strength by 5 to 25% despite having some studies confirming the suitability of RA to replace up to 30% virgin aggregates without any effects on concrete strength. Strength gain for RCA concrete is lower than normal aggregate concrete (NAC) for the first 7 days but adversely, fine RA has a more detrimental effect on compressive strength than coarse RA [12, 13].

Thus, RA durability can be influenced by coarse aggregate replacement ratio, concrete age, w/c ratio, and moisture content; generally, a lower w/c ratio generates a more durable concrete mix as stated by [14-17]. Argued that RAC is less durable due to the high porosity of RA. Consequently, optimizations to determine the percentage of RA that could be used without affecting the short and long-term performance were investigated and design equations based on data collected from many previous studies were proposed for that type of concrete [18, 19].

3. Experimental Work and Material Characterization

3.1. Cement

Ordinary Portland Cement (OPC) conforming to (BS–8112-1996) was used with physical properties outlined in table 1.

Table 1. *Physical Properties of Portland cement.*

Characteristics	Values Obtained	Standard Values (BS – 8112-1996)
Normal Consistency	32.5%	Not to be less than 26% and Not to be greater than 33%.
Initial Setting Time	2 hours 25 min	Not to be less than 60 minutes.
Final Setting Time	3 hours 30 min	Not to be greater than 600 minutes.
Fineness	2%	Not to be greater than 10%.
Stability Size	2 mm	Not to be greater than 10 mm.

3.2. Coarse Aggregates

Quality and availability of RA are considered as the main factors towards stable use and introduction of RAC to the construction industry. The uncrushed gravel aggregate used in this study was obtained from a recycling plant which was established and directed towards reducing construction/demolition waste in Khartoum State, Sudan (refer to figure 1).

Figure 1. *The aggregates recycling process.*

The waste was received and processed to produce several products; however, the main product was aggregate. 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

NCA and RCA Gradation

The NCA and RCA used in the study had similar gradation as depicted in Tables 2 and 3.

Table 2. *Gradation of natural coarse aggregates.*

Sieve Size (mm)	Retained Weight (kg)	Retained (%)	Cumulative retained (%)	Passing (%)	Required (%)
20	0	0	0	100	100
12.5	0.9	15	15	85	85-100
10	2.1	35	50	50	40-85
4.75	2.8	46.7	97.7	2.3	0-10

Table 3. *Gradation of recycled coarse aggregates.*

Sieve Size (mm)	Retained Weight (kg)	Retained (%)	Cumulative retained (%)	Passing (%)	Required (%)
20	0	0	0	100	100
12.5	0.75	12.5	12.5	87.5	85-100
10	2.0	33.3	45.8	54.2	40-85
4.75	3.0	50.0	95.8	4.2	0-10

Proprieties of RCA & NCA

The results from Table 4 showed that specific gravity of NCA and RCA was accepted but the absorption of RCA was higher than that of NCA.

Table 4. *Properties of (NCA) and (RCA).*

Characteristics	NCA	RCA
Specific gravity	2.76	2.66
Absorption	0.44	0.98

3.3. Fine Aggregates

Table 5. *Sieve analysis of fine aggregates.*

Sieve Size (mm)	Weight retained (kg)	Retained (%)	Cumulative retained (%)	Passing (%)
4.75	81	8.1	8.1	91.9
2.36	60	6	14.1	85.9
1.4	121.5	12.15	26.25	73.74
1.18	142	14.2	40.45	59.55
0.600	192	19.2	59.65	40.35
0.300	168	16.8	76.45	23.55
0.150	187	18.7	95.15	4.85
Pan	48.5	4.85	-	-

4. Methodology

4.1. Development of Concrete Mixes

The researchers designed and calculated the materials ratio for 8 different Concrete Mix scenarios, according to the British Building Research Center. The targeted compressive strength value was (25N/mm^2) and the slump value was within the range of (60-180) mm and the adopted concrete mix scenarios were as follows:

1. Reference mix including (NCA).
2. A mix including (RCA) replacing 25% (NCA).
3. A mix including (RCA) replacing 50% (NCA).
4. A mix including (RCA) replacing 75% (NCA).
5. A mix including (RCA) replacing 100% (NCA)
6. A mix including (RCA) replacing 100% (NCA) and Pozzolana replacing 10% of the cement weight.
7. A mix including (RCA) replacing 100% (NCA) and Pozzolana replacing 20% of the cement weight.
8. A mix including (RCA) replacing 100% (NCA) and Pozzolana replacing 30% of the cement weight.

Table 6. *Materials ratios in concrete mixes per cubic meter.*

Concrete Mix Scenario	Cement (Kg)	Water (Kg)	Sand (Kg)	NCA (Kg)	RCA (Kg)	Pozzolana (Kg)
1	325	195	641	1189	-	-
2	325	195	641	891.75	297.25	-
3	325	195	641	594.5	594.5	-
4	325	195	641	297.25	891.75	-
5	325	195	641	-	1189	-
6	292.5	195	641	-	1189	32.5
7	260	195	641	-	1189	65
8	227.5	195	641	-	1189	97.5

4.2. Mixing and Casting of Cubes

All required materials for concrete mixes were prepared at laboratory, using (150×150×150) mm casting cubes.

5. Results and Discussion

5.1. Slump Test

The slump test results shown in figure 2 depict the conformance of all results to the specifications (slump range: 60-180mm). When RCA was introduced the workability decreased 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. On the other side, an increase in the range of 3.2-7.4% was noticed with the inclusion of Pozzolana with 100% RCA concrete. In its fresh state, the optimum ratio was achieved with the full replacement of NCA with RCA and the inclusion of 20% Pozzolana.

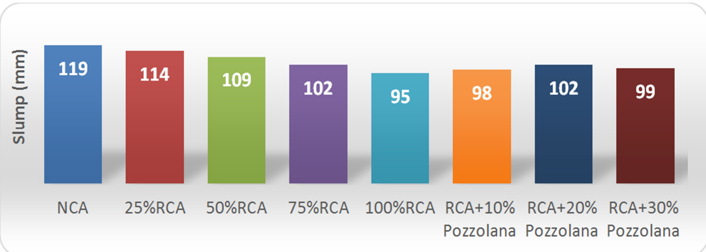

Figure 2. *Slump test results for the different mix scenarios.*

5.2. Compressive Strength Test

Compressive strength results are presented in figures 3, 4 & 5. The results were consistent for 7 days and 28 days with the strength decreasing as the RCA replacement percentage increases. However, with 100% RCA and inclusion of pozzolana, an increase in compressive strength was noticed yielding the targeted design strength at 10% pozzolana inclusion.

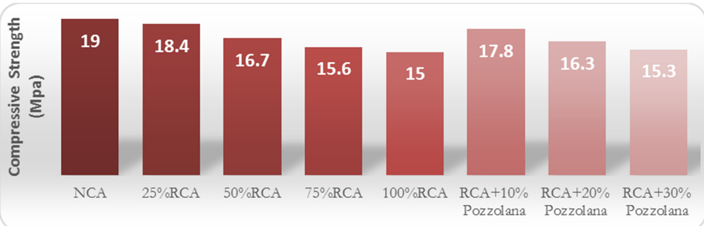

Figure 3. *7 days Compressive Strength Test Results.*

Figure 4. *28 days Compressive Strength Test Results.*

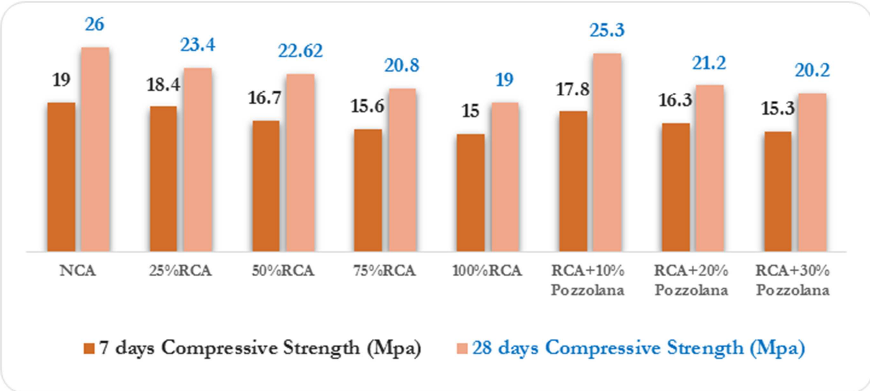

Figure 5. *7 and 28 days Compressive Strength Test Results.*

5.3. Durability Test

The results for the durability test revealed a drop in the wave speed value when the natural aggregates were used was 100% replaced by the recycled aggregates while an increased was witnessed when obvious different percentage of Pozzolana was added to mix. The optimum result was achieved when the coarse aggregates were completely replaced and 10% Pozzolana was added (refer to figure 6).

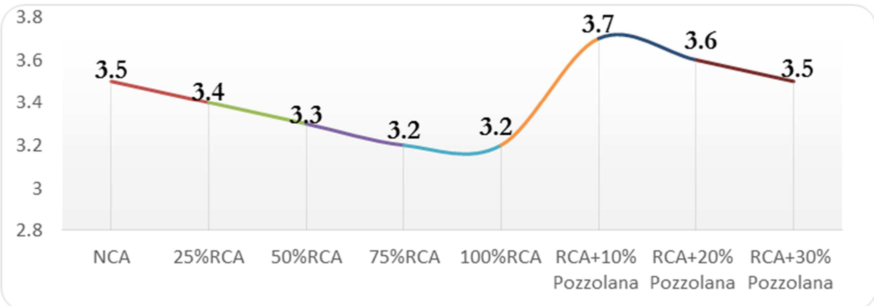

Figure 6. *Durability Test Results.*

6. Conclusion

The obtained results were considered promising giving reasonable indicators for the potential usefulness of recycled aggregates and the local Pozzolana when used in concrete mixes. More tests might be needed for further confirmation with various percentages of Pozzolana and different mix combinations. It is thus recommended to repeat the mix design considering different percentages of the recycled aggregates or the Pozzolana in the mix.

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