The Potential Usefulness of Recycled Aggregates and Pozzolana in Producing Green Concrete in Sudan

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***Abstract*—Concrete is one of the most widely used resources in the building industry yet it is criticized for being environmentally-unfriendly due to its destructive resource-consuming nature and severe environmental impact. The emission of huge amounts of CO_2 during the cement production process, the significant reduction in the naturally occurring amounts of aggregates and the disposal of construction and demolition waste are few examples to count. Green Concrete is thought to offer a solution leading to sustainable construction. Attempts in the use of different substituent or recycled materials gave good indications for the production of green concrete worldwide. This study tested the potential usefulness of recycled aggregates and locally available natural Pozzolana to produce green concrete in Sudan. Five scenarios were investigated (1) a standard mix (2) a mix with 100% recycled aggregates to replace the coarse aggregates, (3) 100% recycled aggregates and 10% Pozzolana, (4) 100% recycles aggregates and 20% Pozzolana , (5) 100% recycled aggregates and 30% Pozzolana. The fresh and hardened concrete mixtures were tested for workability, durability and compressive strength at the age of 7 and 28 days respectively. Variable results for the different scenarios were obtained but the optimum results were achieved with the mix that contained 100% replaced aggregates and 10% pozzolana. These results were considered promising giving reasonable indicators for the potential usefulness of recycled aggregates and the local Pozzolana in producing green concrete. It is thus recommended to repeat the mix design considering different percentages of the recycled aggregates or the Pozzolana in the mix.**

***Index Terms*—Compressive strength, Pozzolana, Recycled Aggregates, Sudan, Workability.**

I. Introduction

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" [1]. In the construction industry, sustainability has often been related to design as well as construction and could be achieved by the creation and responsible management of a healthy built environment which uses the available resources efficiently and in accordance with ecological principles. Concrete is one of the most widely used resources in the building industry. All its constituents: coarse aggregates (in the form of gravel or crushed stone), fine aggregates (sand), water, cement and admixtures are mostly naturally and locally available but in limited accessibility sometimes and hence they need to be preserved. For this reason preserving natural resources has globally become an issue of concern. According to modern developments cited in the literature, construction materials are increasingly being judged by their ecological characteristics. A number of studies pointed to the fact that "…concrete …is not an environmentally-friendly due to its destructive resource-consuming nature and severe environmental impact…" [2]. About 0.9 tons of CO2 was recorded to be produced for every ton of cement manufactured [3]. Aggregates mined from the rock mines with an equivalent rate of concrete production leads to a significant reduction in the naturally occurring amounts and lately statistical results spotted another problems associated with the disposal of construction and demolition waste which was forecasted to be 12 to 14.7 million tons per annum [3]. The environmental issues associated with this negative impact were faced with a parallel move by researchers in many countries to save depleting these resources. Green concrete is thought to be the solution leading to sustainable construction [4]. It is defined as "…concrete which uses waste material as at least one of its components, or its production process does not lead to environment destructions." [5].

Numerous techniques and/or materials treatment schemes have been proposed and tested to check the suitability for potential use or reuse of some materials to produce green concrete. Past good attempts included the use of different materials such as Geoploymers, combined with other materials to produce concrete without Portland cement. Another attempt introduced the notion of partial replacement of cement with various

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cementitious materials such as fly ash, metakaoilin, blast furnace slag, wood ash, limestone powder, Silica fume, Rice Husk ash and Slipozz [6]. Moreover, the use of recycled materials was also considered to be one of the possible solutions to conserve the natural resources and reduce the act of depleting the virgin materials. Examples for this, as cited in previous studies, included the use of post-consumer glass as partial replacement for aggregates [7], the utilization of the foundry sand (byproduct of metal casting industry) is another example [8]. The residue of left after the combustion of wood was also tried as an ash partially replacing fine aggregates or cement [9], [10].

In the construction industry an example of such sustainable solutions emerged with "[the] recycling of construction waste [which] was first done at a large scale after the Second World War …" [11] , [12]. Since then, studies were undertaken to show that recycled construction waste could have a range of uses. The use of recycled aggregates in replacing coarse aggregates is becoming widely used. According to the source, production process, physical and mechanical characteristics, "… aggregates (could be) classified into manufactured, recycled and reused by-product aggregates" [13].

Crushed aggregate is produced by crushing quarry rock, boulders, cobbles, or large-size gravel" [www.cement.org/cement concrete-basics/concrete-materials/aggregates accessed on 23/12/2016]. However, "... the shortage of natural aggregate supplies along with the increase in processing cost has encouraged the use of various reclaimed materials from old structures…" [14]. Recently, notions like recycling and sustainability have vividly emerged to account for this problem and much attention is being paid to using greater amounts of recycled or crushed returned concrete aggregates that are obtained from waste concrete.

A review of the literature on the topic of recycled concrete aggregate (RCA) showed that intensive research has been conducted lately on the use of RCA as a substitute in lieu of natural aggregates. Despite the fact that Muneera and Rupa [15] described the aggregates derived from concrete structures demolition as having "...relatively low strength, (and) secondary importance application", they stressed the fact that "...recycled aggregates can be useful for environmental protection and economical terms". In the contrary Choudhary and Kumar [16] reported that "…the use of recycled aggregates from construction and demolition waste in showing prospective application in construction as alternative to primary aggregates". Other studies showed several alterations in the properties of the concrete when recycled aggregates were used. In his work, Verian et. al [2013] illustrated that "RCA often has lower specific gravity and higher absorption values compared to those of natural aggregate which, in turn, may affect the workability of fresh concrete". They also stated that specific [gravity was] reported to range from 2.1 to 2.6, and absorption values ranged from 3.3% to 9.25% for different RCA".

It seems however that the challenge rests with the availability of "...technical specifications and quality control guidelines in the processing of RCA and in the production of concrete mixes made with RCA..." (Muneera and Rupa,[15]. Evidence from previous studies indicate that there is an increasing trend and an incentive in the potential usefulness of RCA worldwide,

In Sudan, natural aggregates used in construction are normally available in certain quarries located around the capital, Khartoum. "...Various sources of natural graded gravels" are available with different texture: rounded, elongated or angular [17]. When used in construction, these aggregates may or may not satisfy the requirements for some projects hence some modifications may be required to improve their engineering properties. Moreover, it was realized that old concrete which sits in ugly piles in different locations in Khartoum is only used as random fill or sub-base materials. The literature conducted on sustainable proposals for green concrete has not revealed any practical research on its potential production in Sudan. Since previous research results indicated a good chance for producing green concrete by any of the suggested materials or techniques, it was thought that Sudan construction industry could also benefit by utilizing some of the local natural materials or manufacturing by-products to produces environmentally-friendly concrete. This initial trial adopted the use of recycled aggregates and locally available natural Pozzolana and thus investigated their potential usefulness towards producing green concrete in Sudan.

This study portrays the results obtained from investigating the properties and characteristics of RCA, the physical properties of fresh and hardened concrete containing RCA, the mechanical behavior of concrete containing RCA, and special considerations for workability, durability, and strength.

II. EXPERIMENTAL AND MATERIAL CHARACTERIZATION

A. *Cement*

Ordinary Portland Cement (OPC) was used. Cement was tested as per (BS – 8112-1996) code, and the results were as follows:

TABLE I. PHYSICAL PROPRTIES 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.

B. Aggregates

For Natural Coarse Aggregates

TABLE II. GRADATION OF NATURAL COARSE AGGREGATES

Sieve Size (mm)	Weight retained (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

For Recycled Coarse Aggregates

TABLE III. GRADATION OF RECYCLED COARSE AGGREGATES

Sieve Size (mm)	Weight retained (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

C. Proprieties of RCA & NCA

TABLE IV. PROPRTIES OF (NCA) & (RCA)

Characteristics	NCA	RCA
Specific Gravity	2.76	2.66
Absorption	0.44	0.98

D. Fine Aggregates

TABLE V. 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	-	-

III. METHODOLOGY

A. Development of Concrete Mixes

The researchers designed and calculated the materials ratio for different Concrete Mixes (5 scenarios), according to the British Building Research Center. The target Compressive Strength value was (25N/mm2) and Slump value was within the range of (60-180) mm and the scenarios were as follows:

1. Reference concrete mix design.
2. Mix concrete by replacing (RCA) 100%.
3. Mix concrete by replacing (RCA) 100%, and replacing Pozzolana 10% of the cement weight.
4. Mix concrete by replacing (RCA) 100%, and replacing Pozzolana 20% of the cement weight.
5. Mix concrete by replacing (RCA) 100%, and replacing Pozzolana 30% of the cement weight.

TABLE VI. PERCENTAGE OF MATERIAL IN CONCRETE MIXES FOR (9 CUBES)

Concrete Mix	Cement (Kg)	Water (Kg)	Sand (Kg)	NCA (Kg)	RCA (Kg)	Pozzolana (Kg)
1	10	6	20	36	-	-
2	10	6	20	-	36	-
3	9	6	20	-	36	1
4	8	6	20	-	36	2
5	7	6	20	-	36	3

B. Casting of Cubes

All required materials for concrete mixes were prepared at laboratory, using (150*150*150)mm casting cubes as shown in Figs. (1),(2) .

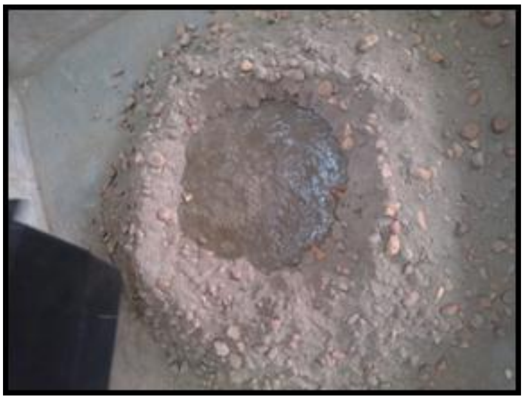

Figure 1. Method OF MIXING MATERIALS

Figure 2. Cubes USING IN CASTING CONCRETE

IV. RESULT AND DISCUSSION

A. Slump Test

The slump test Results shown from Fig. (3) confirmed all results in the specific range of slump, decreasing workability when use 100% of RCA and increasing when adding Pozzolana by (10, 20, 30) %. The result showed that the best ratio was achieved when using (100 RCA+20 Pozzolana).

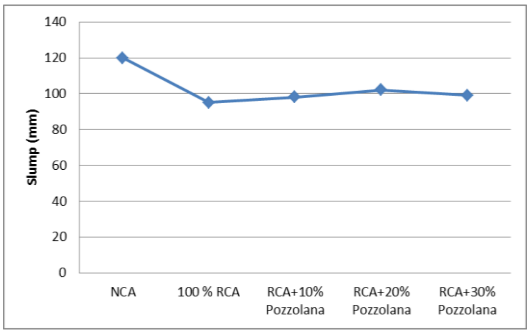

Figure. 3. Slump test result

B. *Compressive Strength Test*

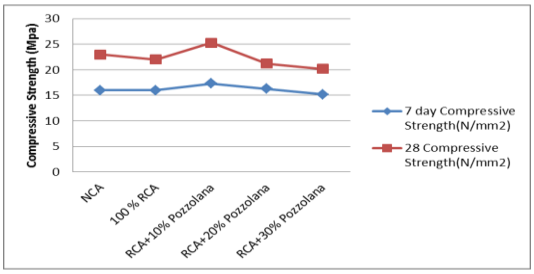

Figure 4. Compressive strength test results

The results were consistent for 7 days and 28 days compressive strength. The best results were achieved with the mix that contained 100% replaced aggregates and 10% Pozzolana.

C. *Durability Test*

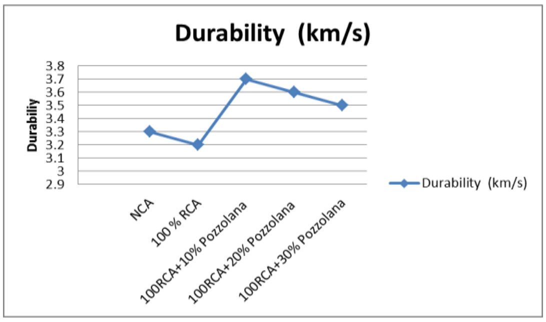

Figure. 5. Durability test result

The results for the durability test revealed a drop in the wave speed value when the natural aggregates 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

V. 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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