Use of Crushed Granite Fine as Replacement to River Sand in Concrete Production

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Received: 30 April 2009 / Accepted: 10 December 2010 / Published: 24 December 2010

Abstract

The suitability of Crushed granite fine (CGF) to replace river sand in concrete production for use in rigid pavement was investigated. Slump, compressive and indirect tensile strength tests were performed on fresh and hardened concrete.28 days Peak compressive and indirect tensile strength values of 40.70N/mm^2 and 2.30N/mm^2 respectively was obtained, with the partial replacement of river sand with 20% CGF, as against values of 35.00N/mm^2 and 1.75N/mm^2, obtained with the use of river sand as fine aggregate. Based on economic analysis and results of tests, river sand replaced with 20% CGF is recommended for use in the production of concrete for use in rigid pavement. Conservation of river sand in addition to better ways of disposing wastes from the quarry sites are some of the merits of using CGF.

Keywords

Crushed Granite Fine; Sand; Rigid pavement; Concrete

Introduction

Concrete is an artificial conglomerate stone made essentially of Portland cement, water, sand and coarse aggregates. The mixture of the materials results in a chemical reaction called hydration and a change in the mixture from plastic to a solid state.

It has found use in different fields of civil engineering, in highway engineering concrete is used in the production of slabs used as rigid pavement. The high cost of concrete used in rigid pavement construction stems from the cost of the constituent materials. Such cost can be reduced through the use of locally available alternative material, to the conventional ones normally used in concrete work, of interest to this research is an alternative to sand.

The world wide consumption of sand as fine aggregate in concrete production is very high, and several developing countries have encountered some strain in the supply of natural sand in order to meet the increasing needs of infrastructural development in recent years. A situation that is responsible for increase in the price of sand, and the cost of concrete [1].

Expensive and scarcity of river sand which is one of the constituent material used in the production of conventional concrete was reported in India [2].

To overcome the stress and demand for river sand, researchers and practitioners in the construction industries have identified some alternative namely fly ash, slag, limestone powder and siliceous stone powder [3, 4]. In India the use of quarry dust to replace river sand was reported by [2]. The use of rock dust as an alternative to natural sand was also reported by [5]. The use of up to 20% quarry waste fine as a partial replacement for natural sand in the production of concrete, in Malaysia was also reported [6]. Use of crushed granite fines or crushed rock fines as an alternative to sand in concrete production was also reported [7].

In Makurdi, the capital of Benue state of Nigeria, in West Africa, the sole source of fine aggregate for concrete production is sand obtained from the bed of River Benue. The high demand for this river sand arising from rapid infrastructural growth, in addition to export of sand from the river to major neighbouring towns of Otukpo, Annune, Aliade, Taraku, Naka and Adoka to mention but a few, has resulted in the astronomical increase in the price of River sand per cubic metre from ₦ 625 in 2003 to ₦ 1,000 in 2008. To overcome the pressure placed on Makurdi River sand, there is need for an alternative to sand, of interest to this study is crushed granite fine (CGF) which is readily available at quarry sites, located at Gboko, katsina-Ala, Otukpo and other major towns in the state.

The successful utilization of CGF as fine aggregate would turn this waste material that causes an environmental load due to disposal problem into valuable resources, reduction in the strain on the supply of natural sand, and economy in concrete production.

Most of the researchers listed above considered alternative material to sand in the production of concrete for other purposes, not for use in rigid pavement. This research is aimed at determining the suitability of CGF to replace river sand in the production of concrete for use in rigid pavement, using compressive strength and flexural strength tests as basis for assessment.

Materials and Methods

Materials

Dangote brand of ordinary Portland cement produced at the cement factory located at Obajana in Kogi state of Nigeria as obtained from the open market at Makurdi was used for the work. Washed gravel obtained from the aggregate market located at Wurukum area of Makurdi town was used. The maximum size of the gravel used as coarse aggregate was 37.50mm, with a unit weight of 1540kg/m^3 and a specific gravity of 2.65. Particle size distribution of the coarse aggregate used, CGF and Makurdi river sand is as presented in Figure 1. Naturally occurring clean sand used was obtained from River Benue and CGF was obtained from the quarry site at Ahua of Mkar, near Gboko. Aggregate Impact and Crushing values of the coarse aggregate were also carried out, in accordance with [8, 9]. Pure and clean tap water fit for drinking as found in the concrete laboratory of the University of Agriculture Makurdi was used in concrete production.

Concrete Mixture Proportions

Mixed design was carried out for concrete of grade 35 using the procedure for the design of normal concrete mixes [DOE, 1988] in [10]. The constituent materials were batched by weight. The mix produced with only Makurdi river sand as fine aggregate, served as the control mix. In other mixes the percentage of Makurdi river sand used was gradually replaced with CGF. Details of the mix proportion are presented in Table 1.

Table 1. Proportions of the constituent materials used in concrete production

Combination	Sand (kg)	CGF (kg)	River gravel (kg)	Cement (kg)	Water (kg)	Slump (mm)
100% S 0% CGF	27.89	0	65	22.90	10.53	33
90% S 10% CGF	25.10	2.79	65	22.90	10.53	35
80% S 20% CGF	22.31	5.58	65	22.90	10.53	35
70% S 30% CGF	19.52	8.36	65	22.90	10.53	35
60% S 40% CGF	16.73	11.16	65	22.90	10.53	35
50% S 50% CGF	13.94	13.95	65	22.90	10.53	35
40% S 60% CGF	11.16	16.73	65	22.90	10.76	37
30% S 70% CGF	8.37	19.52	65	22.90	10.76	37
20% S 80% CGF	5.58	22.31	65	22.90	10.99	38
10% S 90% CGF	2.79	25.10	65	22.90	10.99	38
0% S 100% CGF	0	27.89	65	22.90	11.45	38

S= Makurdi River Sand, CGF= Crushed granite Fine

Three sets of cubes were cast and tested at 7, 14, and 28 days for the different mix proportions. 132 concrete cubes of 150mmx150mmx150mm were cast and used to determine the compressive strength at each level of replacement, while 3 cylindrical specimens, each having a diameter of 150mm and length of 300mm were used to determine the indirect tensile strength. Materials were mixed at ambient temperature using a rotating pan type mixer (capacity: $0.05m^3$) the quantity of the concrete prepared for each batch was at least 10 % in excess of the required amount. Mixing of the constituent materials was undertaken for six and a half minutes. Immediately after completion of the mixing process, the fresh concrete was sampled for slump test. The slump was measured in accordance with [11]. Cylinder and cube specimens were prepared from the fresh concrete, after the slump test, in accordance with [12, 13]. The fresh concrete was placed in a cast iron cylinder mould with a diameter of 150mm and height of 300mm, and cube moulds of 150mm × 150mm × 150mm in two layers. Each concrete layer was compacted by Roding in the manner specified by [12,13], after which the moulds with their contents were vibrated on an ELE vibrating table for 5 minutes, before storage for 24 hours to allow the concrete to set before demolding and curing. The compressive strength of the concrete cubes were determined at ages of 7, 14 and 28 days respectively, in accordance with [14] while the indirect tensile strength was determined using the cylindrical specimens after curing for 28 days in accordance with [15]. The cylindrical specimens were placed in a longitudinal mode in accordance with [15], to determine the maximum load sustained by the cylindrical specimen before failure. The indirect tensile strength was calculated using equation (1) given as:

$$\sigma_{ct} = 2F/\pi ld \quad (1)$$

where σ_{ct} = the indirect tensile strength, d = diameter of cylinder in mm, l= length of cylinder in mm, F= maximum load applied to the cylinder in Newton.

In all tests for hardened concretes, triplicate specimens were used. The concrete specimens were cured by complete immersion in water, with the aid of a curing tank. The curing temperature was maintained at 30 ± 2°C. Cost implication of using the different combinations of sand and CGF to produce a cubic metre of concrete was calculated to aid in economic analysis.

Results and Discussions

Particle size distribution curves of CGF, fine and coarse aggregate used in concrete production is as shown in Figure 1. Makurdi river sand and CGF grading curves shows that both of them belong to zone c of fine aggregate based on [16]. Makurdi river sand and CGF have specific gravity and finesse modulus values of 2.60; 2.54 and 3.16; 2.79, respectively.

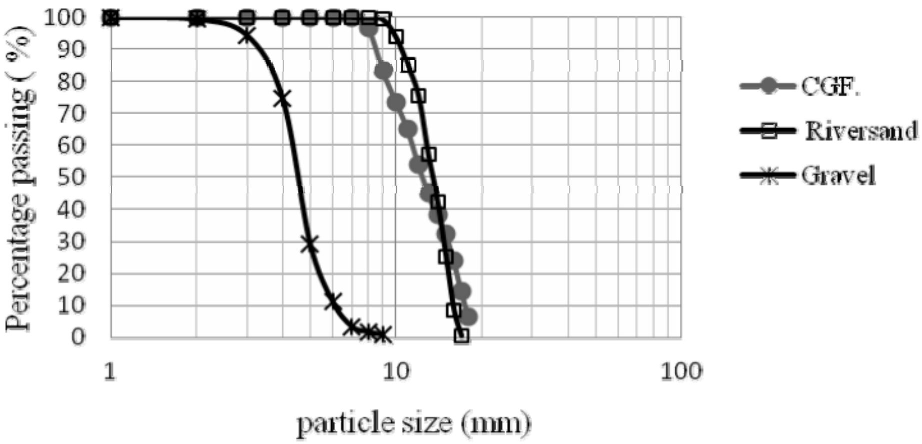

Figure 1. *Particle Size Distribution of CGF, River Sand and Gravel*

The grading curve of the gravel used as coarse aggregate shows that the maximum size of the coarse aggregate was 37.5mm. The specific gravity of the gravel was 2.65, with impact and crushing values of 15% and 33% respectively. These values are within the range of impact and crushing values of (9 – 35%) specified for crushed granite as recorded by [18], hence its suitability for use in concrete for rigid pavement. Cement content obtained from the mix design is in agreement with [19]. Slump values ranged from 33-38 mm with W/C ratio values ranging between 0.46 - 0.50, in agreement with [19]. Slump test result showed that water to cement ratio and slump value increased with the replacement of sand with CGF. This observation might not be unconnected with high quantity of water required for the lubrication of the non-rounded/ angular particle of the CGF.

Compressive Strength

Variation of compressive strength with CGF content presented in Figure 2, showed that compressive strength increase with CGF content, with the attainment of 28 days peak compressive strength value of 40.70N/mm^2, when Makurdi river sand was replaced with 20% CGF, after which a decline was observed.

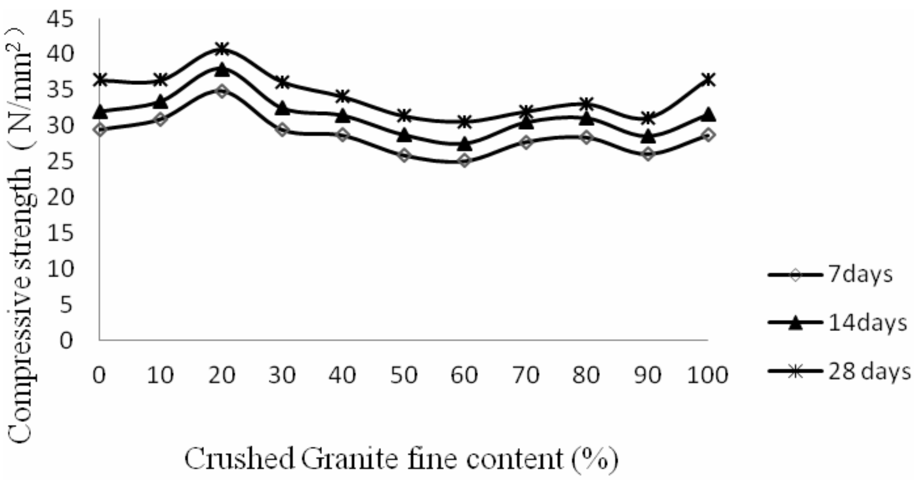

Figure 2. *Relationship between Compressive Strength and Crushed Granite Content (%)*

However, the use of 30% CGF to replace river sand yielded a 28days compressive strength value of 36.20N/mm^2 which is greater than the value of 35.02N/mm^2 obtained with the use of Makurdi river sand which served as the control. Complete replacement of river sand with CGF yielded a compressive strength value of 36.50 N/mm^2 which is the same as value obtained with the use of only river sand, an indication that river sand can be fully replaced with CGF. The partial replacement of CGF with sand gave a 28 days peak compressive strength value of 33.07N/mm^2 at 20% replacement level. Increase in compressive strength associated with partial replacement of sand with crushed granite fines can be attributed to frictional resistance's component's contribution to compressive strength arising from the rough and irregular nature of CGF particles that fills the voids between the gravel and sand particles while cement binds the components together. Strength obtained with the use of only river sand as fine aggregate and river gravel as coarse aggregate is dependent more on the bonding strength of cement that fills the voids between the coarse aggregate and the river sand particles as its frictional resistance contribution to strength is less due to smooth and rounded nature of river gravel and sand particles used as coarse and fine aggregate respectively.

Indirect Tensile Strength

Indirect tensile strength value increased with CGF content up to 20%, after which a decline in indirect tensile strength was observed. Peak indirect tensile strength value of 2.30N/mm^2 was recorded at 20 % CGF plus 80% river sand combination. The use of CGF to completely replace Makurdi river sand exhibited higher values when compared with results obtained with the use of only river sand. The factor accountable for the trend observed with compressive strength is also responsible for trend observed with indirect tensile strength. Variation of CGF with indirect tensile strength is as shown in Figure 3.

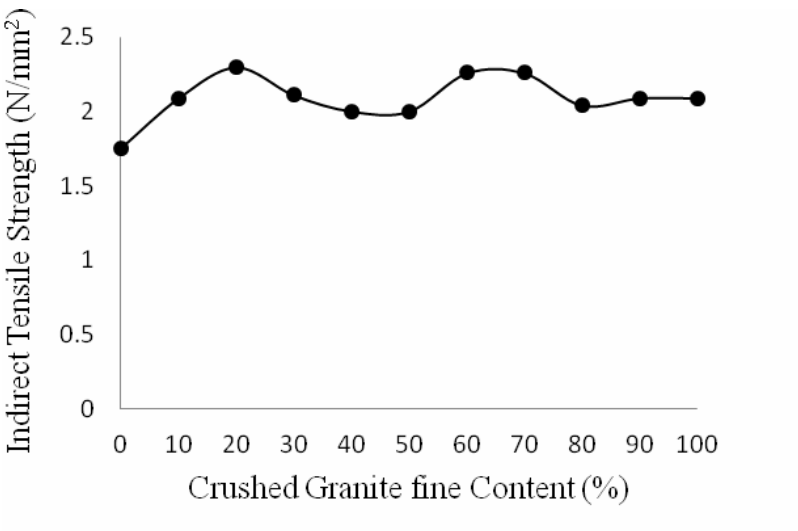

Figure 3. *Relationship between Flexural Strength and Crushed Granite Content (%)*

Cost Analysis

The quantity of the constituent material per cubic metre of concrete as determined from mix design and cost of replacing sand with CGF is as presented in Tables 2 and 3 respectively. Table 4, compares the cost of producing concrete of the same grade with different materials.

Table 2. Summary of Mix Design

Material	**Quantities (Kg) per m^3**
Cement	450
Sand	548
Gravel	1277
Water	224

Table 3. Cost of Replacing Makurdi River sand with different percentages of crushed granite fine in the production of a cubic metre of concrete

A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
100%S0% CGF	100	450	173	0	0	0	173	16,386	16,559
90%S10% CGF	90	405	156	10	45	38.25	194	16,386	16,580
80%S20% CGF	80	360	139	20	90	76.5	216	16,386	16,602
70% S30%CGF	70	315	121	30	135	115	236	16,386	16,622
60 %S40%CGF	60	270	104	40	180	153	257	16,386	16,643
50%S50%CGF	50	225	87	50	225	191	278	16,386	16,664
40%S60%CGF	40	180	69	60	270	230	299	16,386	16,685
30%S70%CGF	30	135	52	70	315	268	320	16,386	16,706
20%S80%CGF	20	90	35	80	360	306	341	16,386	16,727
10%S90%CGF	10	45	17	90	405	344	361	16,386	16,747
0%S100%CGF	0	0	0	100	450	383	383	16,386	16,769

A – Combination
B - Sand Content (%)
C - Weight of sand in (Kg) per cubic metre of concrete
D - Cost of sand in (₦) per cubic metre of concrete (at ₦ 0.385/kg)
E - Crushed Granite Fine (CGF) content %.
F - Weight of CGF in (Kg) per cubic metre of concrete
G - Cost of CGF in ₦ per cubic metre of concrete.(at ₦ 0.85/kg)
H - Total cost of sand and CGF (₦) per cubic metre of concrete
I - Cost of cement and gravel (₦)
J - Total cost of constituent material per cubic metre of concrete.(₦)

Table 4. Cost Analysis of Concrete Constituent Materials by Grade in Naira (₦)

100 %S0 % CGF	40	18,399	17,293	691.00
80%S 20 % CGF	40	18,399	16,602	1,797.00
100% S 0% CGF	35	17,453	16,559	894.00
90 %S10 % CGF	35	17,453	16,580	873.00
70% S 30% CGF	35	17,453	16,622	831.00
60%S 40% CGF	30	16,412	16,643	-231.00

A – Combination
B - Grade of concrete
C - Cost of using only sand and crushed granite as coarse aggregate /m^3 of concrete in (₦) [1]
D - Cost of using sand, CGF and gravel per m^3 of concrete in (₦) [2]
E - Difference in price. between option [1] and [2]

The cost of the fine aggregate component of concrete increased with the replacement of river sand with CGF while the compressive strength of concrete increased with CGF up to 30%, resulting in concrete of different grades. To ensure a common basis for cost comparison, cost of producing concrete of the same grade using different constituent material was compared, as presented in Table 4. The analysis shows that it is more economical to produce grade 40 concrete with a combination of 80% sand plus 20% CGF as fine aggregate, using gravel as coarse aggregate, at a cost of ₦16, 602 per cubic metre, than the cost of ₦ 17,293 per cubic metre obtained when only Makurdi river sand was used as fine aggregate and gravel as coarse aggregate, a value lower than the cost of ₦ 18,399 per cubic metre of concrete required to produce the same grade of concrete using crushed granite as coarse aggregate and river sand as fine aggregate. Based on the above economic analysis 20% crushed granite fine is recommended for use in the production of grade C40 concrete for road work.

The use of only Makurdi river sand as fine aggregate and gravel to produce grade C 35 concrete will cost ₦ 16,559 a value lower than ₦ 16,580 and ₦ 16,622 obtained with the use of Makurdi river sand partially replaced with 10% and 30% crushed granite fine respectively. The analysis also revealed that the replacement of sand with more than 30% crushed granite fine will result in the production of concrete that is uneconomical when compared with the use of crushed granite and river sand as coarse and fine aggregate respectively.

Based on compressive strength, flexural strength and economic analysis the replacement of sand with 20% CGF is recommended for use in the construction of highly trafficked rigid pavement as the 28 days compressive strength value of 40.71N/mm^2 satisfied the requirement specified by [18-21]. The replacement of sand with 30% crushed granite fine, is recommended for use in the construction of low to moderately trafficked rigid pavement. In locations where crushed granite fine is readily available and river sand tend to be more expensive the use of 80% crushed granite fine plus 20% river sand as fine aggregate is recommended for use in the construction of low to moderately trafficked rigid pavement. While the complete replacement of river sand with CGF is recommended for moderately trafficked road in agreement with [19].

Conclusions and Recommendations

The following conclusions can be drawn from the study;

1. The use of crushed granite fine to partially replace Makurdi river sand in concrete production will require a higher water to cement ratio, when compared with values

obtained with the use of only Makurdi river sand.

2. Peak compressive strength and indirect tensile strength values of 40.70N/mm^2 and 2.30N/mm^2 respectively were obtained when Makurdi river sand was replaced with 20% CGF in concrete production.
3. Peak compressive strength and indirect tensile strength values of 33.07N/mm^2 and 2.04N/mm^2 respectively were obtained when crushed granite fine was replaced with 20% river sand as fine aggregate in the production of concrete.
4. The use of only CGF to completely replace river sand is recommended where CGF is available and economic analysis is in favour of its usage.

Based on findings from the study the partial replacement of Makurdi river sand with 20% CGF is recommended for use in concrete production for use in rigid pavement. Where crushed granite is in abundance and river sand is scarce, the complete replacement river sand with CGF is recommended for use in low to moderately trafficked roads.

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