Mechanical Properties of Concrete using Bida Natural Aggregate as Coarse Aggregates

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Abstract

Significant volume of concrete is occupied by aggregates. Most of these are obtained from rock fragment which depletes natural resources and thereby distorting the ecosystem. The use of alternative aggregate has the potential of reducing this menace. This paper investigates the slump and strength properties of concrete made by varying Bida Natural Aggregate to total aggregate ratio (BNA/TA). Nine different mixes were prepared for three Water to Cement (W/C) ratios and three BNA/TA ratios while Total Aggregate to Cement ratio (TA/C) was kept constant. Properties of the aggregates were determined and found to be satisfactory for concrete production. Three 150x150x150 mm concrete cubes, three 100x100x500 mm concrete prisms and three 100x200 mm concrete cylinders were produced for W/C of 0.4, 0.5 and 0.6 and BNA/TA of 0.55, 0.6 and 0.65. The compressive strength, flexural strength and splitting tensile strength of the specimens were determined at 28 days curing duration. Test results indicates that the higher the BNA /TA content, the lower the slump of concrete. A combination of BNA/TA of 0.55, W/C of 0.4 and TA/C ratio of 3 gave maximum compressive, flexural and splitting tensile strength of 44.30 N/mm^2, 7.60 N/mm^2 and 3.42 N/mm^2 respectively. It was concluded that BNA can be used in place of crushed granite in concrete production.

Keywords:
Bida Natural Aggregate; Compressive Strength; Flexural Strength; Splitting Tensile Strength; Water-Cement Ratio.

1. Introduction

Nigeria is one of the developing countries and it is expected that enormous resources will be consumed for the erection of buildings, industries, dams, bridges, roads and other structures to cater for the ever-increasing population. The principal material for the construction of these infrastructures is Portland cement-based concrete. Concrete is composed of cement paste and aggregates. The cement paste is made of Portland cement and water while the aggregates is coarse (natural gravel or crushed rock) and fine aggregates (natural river sand). Aggregates occupy 60 - 70 % of the total volume of concrete. Coarse aggregates which occupies close to 55% of the concrete volume has been reported to have a direct relationship to the strength, durability, workability, volume stability and elastic modulus of concrete (Fowler and Quiroga, 2003; Shetty, 2005; Mehta and Monteiro, 2001; Neville, 2011; Abdullahi 2012). The major coarse aggregate used in the production of concrete in Nigeria is crushed granite. Although other natural aggregates such as river gravel and naturally occurring stone deposits have been utilised in the production of concrete in different regions of the world and particularly in Nigeria (Apebo *et al*, 2013; Aginam, *et al.,* 2013; Ezeokonkwo *et al,* 2015; Bamibgoye, *et al,* 2016; Ode and Eluozo 2016; Sulyman *et al,* 2017; Tijani *et al,* 2018; Fakuyi *et al,* 2019).

The ever-increasing population calls for the need to source for alternative coarse aggregates suitable for use in concrete as quarry locations are not always close to construction sites. Since coarse aggregate accounts for the largest proportion of concrete and the least expensive, a research of locally available gravel with satisfactory engineering properties is important. Previous research reported that poor choice of aggregate, reactive, unsound and unsuitable aggregates are part of the causes of building failure (Gollu *et al.*, 2016; Akinleye and Tijani, 2017; Ajagbe and Tijani, 2016). De Larrard (1999) and Dewar (1999) opined that aggregate source has an effect on concrete strength. Concrete strength is however a function of the aggregate size, grading, type, content and source (Hassan, 2014: Aginam *et al.,* 2013; Jimoh and Awe, 2007; Abdullahi, 2012). Apebo *et al,* (2013) studied the compressive strength of concrete using coarse aggregate from river Benue while Ezeokonkwo *et al,* (2015) used natural coarse aggregates obtained from Anambra, South-East Nigeria to prepare concrete measuring the compressive strength. Coarse aggregates sourced from South-East, South-South and South-West Nigeria have also been used in the production of concrete (Aginam, *et al.*, 2013; Sulyman *et al,* 2017; Fakuyi *et al.* 2019; Ode and Eluozo 2016 and Bamibgoye, *et al.* (2016). The outcome of this researches confirmed that river gravel as well as naturally occurring stone deposit can be used in place of conventional crushed granite in concrete production. Bida Natural Gravel (BNA) used as coarse aggregate in this research was used to produce self-compacting concrete by Ilyasu, (2014) and Shehu *et al,* (2016). Workability, compressive and flexural strengths measured at various curing ages were found to be similar to self-compacting concrete made of crushed granite. Similarly, Salihu (2011) and Alhaji (2016) used BNA in producing concrete of the normal strength range with satisfactory results. This research is focused on assessing the strength properties of concrete containing different coarse aggregate to total aggregate ratio using BNA.

3. Materials and Methods

3.1 Materials

Fine aggregate: Natural river sand having minimum particle size of 300 μm with physical properties (SG = 2.5, FM = 2.7, Cc = 3 and Cu = 1.23) obtained from river Chanchaga was used as fine aggregate.

Coarse Aggregate: Natural gravel obtained from Bida, Niger State, Nigeria was used as coarse aggregate. The aggregate occurs as a deposit in several million metric tons in the Bida Basin. The aggregate was sieved and those containing maximum size of 14mm were collected, washed and dried. It was found to possess physical properties (SG = 2.65, WA = 1.58%, Cc = 1.24 and Cu = 1.63).

Cement: Ordinary Portland Cement designated as grade 42.5R obtained from local retailer was used as binder.

Water: Potable water from Civil Engineering Laboratory, Federal University of Technology, Minna was used for mixing and curing.

3.2 Mix Design and Experimental Programme

Three parameters were used to generate nine (9) mix combinations as shown in Table 1. The parameters used were water to cement ratio (0.4, 0.5 and 0.6), coarse aggregate to total aggregate ratio (0.55, 0.6, 0.65) and total aggregate to cement ratio was kept constant at 3 for all mixes. This is in accordance to previous works by Alhaji, (2016), Bilal (2006) and Abbasi (1985). Absolute volume method was used to calculate the quantities of each constituent required in a cubic meter of concrete. The concrete was prepared and the slump was determined for each of the 9 mixes according to BS 1881: Part 102 (1983). Concrete cubes of size 15 x150 x150 mm, concrete prisms of size 100 x 100 x 500 mm and concrete cylinders of size 100 x 200 mm were cast and cured for 28 days and their compressive, flexural and splitting tensile strength were determined in accordance to BS EN 12390 (2009) part 3, 5 and 6 respectively.

Using absolute volume method, it is believed that the total volume of concrete sums up to one.

$$Vw + Vc + Vfa + Vca + Vv = 1 \tag{1}$$

$$\frac{Ww}{1000Gw}+\frac{Wc}{1000Gc}+\frac{Wfa}{1000Gfa}+\frac{Wca}{1000Gca}+Vv=1; \tag{2}$$

using 2% air void,

where,Vw = volume of water, Vc = volume of cement, Vfa = volume of fine aggregate, Vca = volume of coarse aggregate, Vv = volume of air void, Ww = weight of water, Wc = weight of cement, Wfa = weight fine aggregate, Wca = weight coarse aggregate, Gw = specific gravity of water, Gc = specific gravity of cement, Gfa = specific gravity of fine aggregate, Gca = specific gravity of coarse aggregate

Given that;

$$Ww=\left(\frac{Ww}{Wc}\right)Wc \tag{3}$$

$$W_{FA}=\left(1-\frac{W_{CA}}{W_{TA}}\right)\left(\frac{W_{TA}}{W_{C}}\right)W_{C} \tag{4}$$

$$W_{CA}=\left(\frac{W_{TA}}{Wc}\right)\left(\frac{W_{CA}}{W_{TA}}\right)Wc \tag{5}$$

Table 1: Mix Composition for 1m^3 of concrete

S/N	BNA /TA	TA/C	W/C	Water (kg/m^3)	Cement (kg/m^3)	Fine River Sand (kg/m^3)	Bida Natural Gravel (kg/m^3)
1	0.55	3	0.5	247.95	495.90	669.32	818.14
2	0.6	3	0.5	248.19	496.14	595.51	893.15
3	0.65	3	0.5	248.19	496.62	521.47	968.40
4	0.55	3	0.6	283.16	472.02	637.00	778.58
5	0.6	3	0.6	283.41	472.26	566.81	850.22
6	0.65	3	0.6	283.65	472.74	496.38	921.61
7	0.55	3	0.4	208.88	522.19	705.02	861.55
8	0.6	3	0.4	209.12	522.67	627.11	940.91
9	0.65	3	0.4	209.36	523.15	549.20	1020.02

4. Results and Discussion

4.1 Slump (slump is measured to the nearest 5mm)

The slump of all mixes is presented in Figure 1. The mixes prepared with a W/C ratio of 0.4 recorded slump between 22 - 40 mm described as low slump according to BS EN 206 - 1 (2000). These mixes were partially stiff but workable to some extent. This is because the amount of water required to adequately lubricate aggregate surface to achieve high slump is in d low range for all levels of BNA /TA. Mixes K4, K5 and K6 recorded slump of 195, 190 and 192 mm respectively while mix K7, K8 and K9 had slump of 270, 230 and 225 mm respectively. These mixes were made with W/C ratio of 0.5 and 0.6 high enough to produce mixes with high slump range (>160mm) according to BS EN 206 - 1 (2000). All these mixes were made with very low TA/C ratio (3). Indicating that the water was in excess of that required to lubricate and produce adequate cohesion of the cement, sand and BNA.

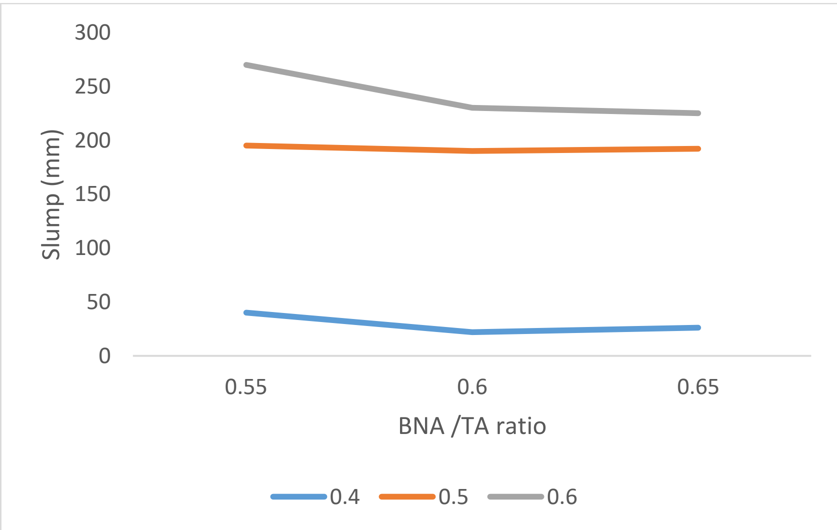

Figure 1: Slump of all mixes

4.2 Compressive Strength

The compressive strength of all mixes at 28 days of curing is presented in figure 2. W/C ratio of 0.4, BNA /TA ratio of 0.55 and TA/C ratio of 3 gave the highest compressive strength. Other BNA /TA ratios and W/C ratios gave acceptable compressive strength values applicable for different concrete grade requirements. The lowest compressive strength was recorded by the mix prepared with BNA /TA ratio of 0.65, W/C ratio of 0.6 and TA/C ratio of 3. These results are in agreement that strength of concrete is inversely proportional to the W/C ratio and directly proportional to the cement content and aggregate content (Bilal, 2006; Abdullahi, 2012; Neville 2011; Abdullahi *el al*, 2017).

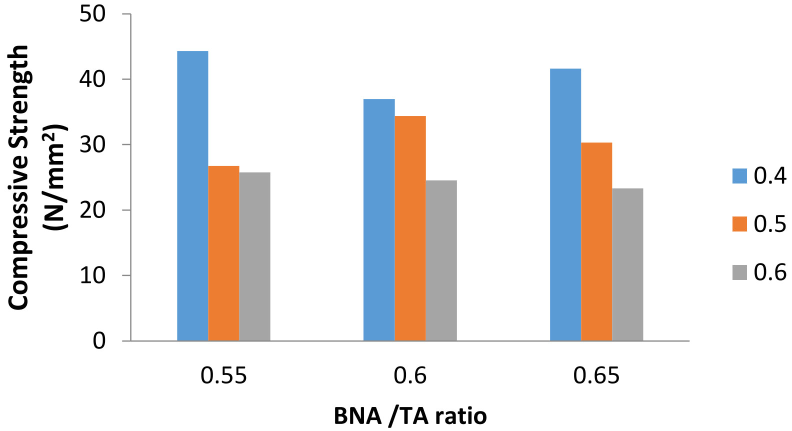

Figure 2: Compressive Strength results for all mixes

4.3 Flexural Strength

Figure 3 shows the flexural strength obtained for each mix designation. The values obtained were between 3.73 N/mm^2 to 7.6 N/mm^2. The highest flexural strength was recorded at low W/C ratio, high cement and high proportion of BNA while low flexural strength was obtained at high W/C ratio and high sand content corresponding to low CA/TA ratio and low cement content. These results follow similar trends with the compressive strength results.

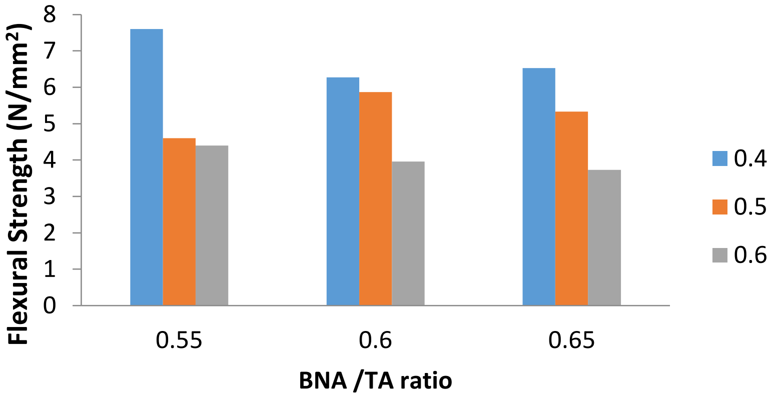

Figure 3: Flexural Strength results for all mixes

4.4 Splitting tensile Strength

The splitting tensile strength recorded by all mixes was between 1.57 - 3.42 N/mm^2 as depicted in figure 4. Acceptable splitting tensile strength value is scarce in literature. Researchers have based their judgement on the result of the compressive strength. Splitting tensile strength obtained at 28 days by Joseph and Maurice, 2012; Juki, 2013; Kanawade *et al.*, 2014; SagarTanwani, 2016; Sallal *et al.*, 2018; and Ali *et al.*, 2018 were between 1.85 and 4.96 N/mm^2 using different coarse aggregate type, content and distinct constituents. The results obtained are however within this range.

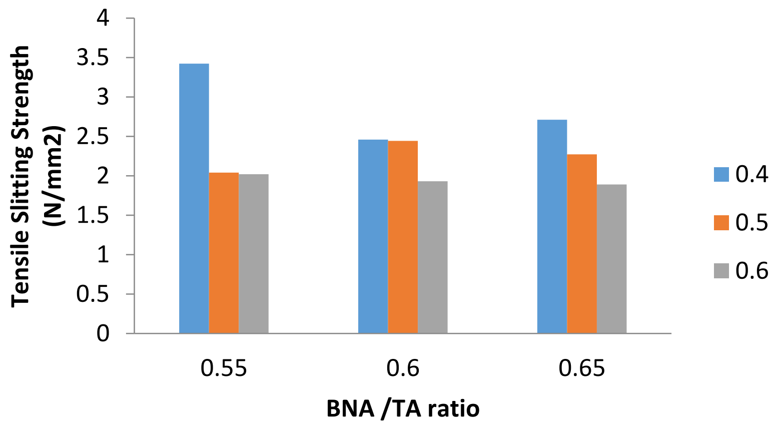

Figure 4: Splitting tensile Strength results for all mixes

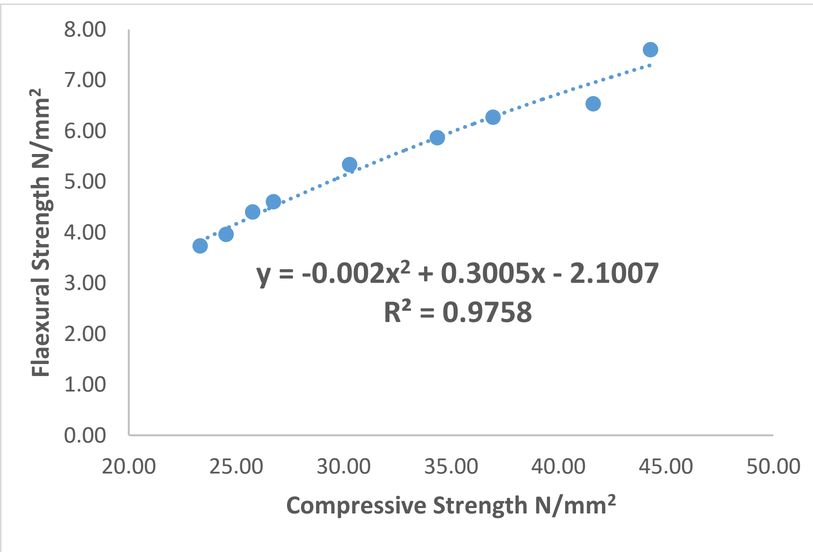

Figure 5: Relationship between compressive and flexural strength.

4.5 Relationship between compressive and flexural strength

Relationship between the compressive and flexural strength was developed in excel 2010 package. A second order polynomial equation was obtained for estimating flexural strength from compressive strength result of concrete made using BNA as depicted in figure 5. The flexural strength obtained using this equation is adequate. This is evident from the fact that about 98% variance in the flexural strength is accounted for by the equation.

4.6 Relationship between compressive and splitting tensile strength

Similarly, relationship between the compressive and splitting tensile strength was developed in excel 2010 package. A third order polynomial equation was obtained for estimating splitting tensile strength from compressive strength result of concrete made using BNA as depicted in figure 6. The model statistic showed that 97% of the variability in the splitting tensile strength result is explained by the equation. The splitting tensile strength obtained using this equation is therefore acceptable.

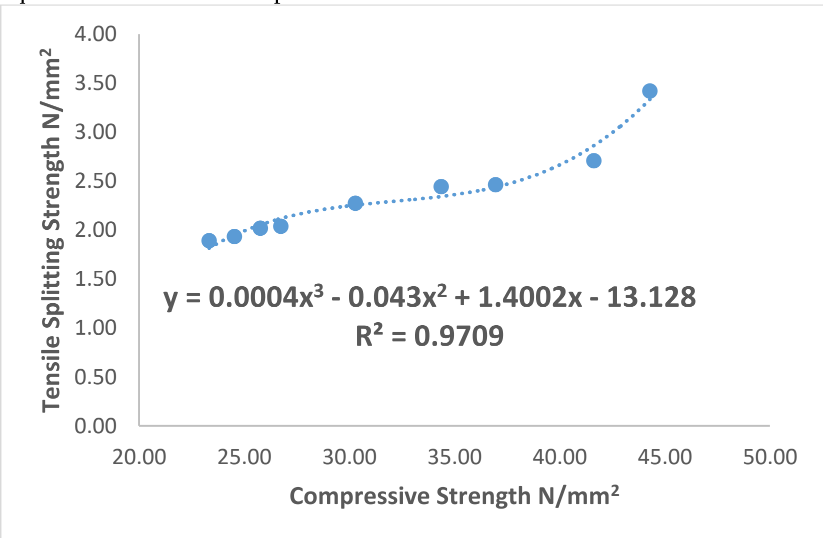

Figure 6: Relationship between compressive and splitting tensile strength.

5. Conclusion

From the outcome of this work, the following conclusions are made.

1. A combination of BNA/TA of 0.55, W/C of 0.4 and TA/C ratio of 3 gave maximum compressive, flexural and tensile splitting strength of 44.30 N/mm^2, 7.60 N/mm^2 and 3.42 N/mm^2 respectively while a combination of

BNA/TA of 0.65, W/C of 0.6 and TA/C ratio of 3 gave 23.33 N/mm^2, 3.73 N/mm^2 and 1.89 N/mm^2 the lowest recorded strength properties.

2. Second and third order polynomial equation were generated for estimating flexural and tensile splitting strength from compressive strength results respectively.
3. Bida Natural Aggregate can be used as a viable alternative in the production of concrete in the normal strength range.

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