TECHNICAL SCIENCES

INVESTIGATION INTO THE MECHANICAL PROPERTIES OF CONCRETE USING PEBBLES FROM BIDA ENVIRON AS COARSE AGGREGATE IN CONCRETE PRODUCTION

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Abstract

Strength performance remains the most important property of structural concrete, from engineering point of view. This paper investigates the mechanical properties of concrete made from Bida natural stones, extensive experimental work was con-ducted using 1,600 specimens for compressive strength, flexural strength, splitting tensile strength and elastic modulus (four hundred specimens for each property). Central composite design was used for the factor setting with the following range of values; W/C= 0.4, 0.5, 0.6, CA/TA= 0.55, 0.615, 0.68, TA/C= 3.0, 4.5 and 6.0. The specimens were produced and cured for 7, 14, 21 and 28days. The highest strength was achieved using low W/C, low TA/C and high level of CA/TA corre-sponding to 0.4, 3.0 and 0.68 respectively.

Keywords: Bida natural stones, mechanical properties, curing, response surface methodology.

1.0 Introduction

Attention has been seriously placed on provision of comfortable and affordable housing for human habitation right from the beginning of civilization, because shel-ter is one of the basic needs of man. Thus, problem of providing adequate housing has been a major concern, not only to individuals but to government at all levels. However, common building materials such as cement, sand, crushed granite and steel etc. have invariably become expensive and unaffordable especially by the ma-jority of the Nigerian population (Aguwa and Amadi, 2010). In addition to the is-sue of cost, extraction of crushed granite involves high energy demand, increased dust, noise and vibration, loss of forest, blasting and pollution hazard. Hence, the necessity to research for alternative naturally occurring, local and affordable con-struction materials is pertinent. Crushed stones are available in some part of Nigeria, like Abuja and its environment and are transported to Bida for production of concrete at high cost. This is because there is no quarry in Bida and its environs thereby increasing the haulage distance. Bida natural coarse aggregate are abundantly available in Bida area. This aggregate is cheaper than the crushed granite. This aggregate has been used for concrete produc-tion, but extensive research work has not been conducted on it as compared with the crushed granite. It is therefore appropriate to study the engineering properties of Bida natural coarse aggregate and the concrete produced using Bida natural coarse aggregate to provide detailed technical information that can be used in the mix proportioning, and also to design mixes for specified compressive strength of concrete and subsequent estimation of optimal quantity of aggregate material to reduce the overall concrete production cost.

This study therefore sought to proffer answers to the following question;

1. Does Bida natural stones (BNS) possess the required properties to be used in concrete Production?

2. What effect will Bida natural stones (BNS) shape have on the mechanical proper-ties of concrete?

2.0 Materials and methods

2.1 Materials

Ordinary Portland cement produced in accordance with BS EN 197-1(2000): Part 1 and classified as CEM 1 of the standard was used for this research. The cement was purchased at cement deport located at Kpakungu, Minna, Niger state. The sand was collected from Gidan Mangoro, Minna, Niger state, the sand used was clean, sharp, free from clay, loam, dirt's or organic matters (NIS 87: 2004) and also conforms to the standard requirement of BS EN 12620 (2008). Potable drinking water from Civ-il Engineering laboratory, Federal University of Technology Minna was used throughout this work, the water was clean, free from deleterious materials and fit for drinking as recommended by BS EN 1008 (2002). The coarse aggregate (natural stones in plate I.) used for this work were taken from Bida, Niger state in the mid-dle belt region of Nigeria located about 250Km North-East of Bida inland from the Federal capital city of Abuja. The deposits aggregates lie in zone 31, which fall within the latitude N 90 55′E and longitude N 50 52′ E (Salihu, 2011). The Bida natural deposits aggregates in character occur in middle Niger basin of Nigeria in several million metric tons. This aggregate is characterized with round and smooth surface, and reddish-brown in colour. The aggregate used consist of maximum size of 19mm. It also conforms to the standard requirement of BS EN 12620 (2008).

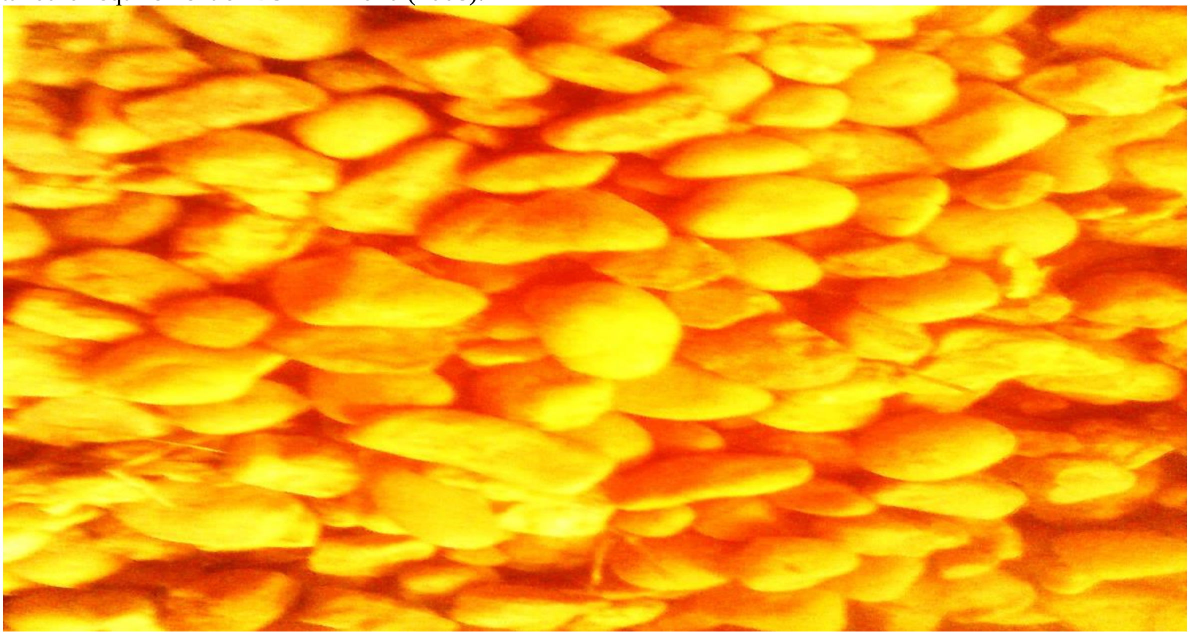

Plate I: Cluster of Bida natural stones

2.2 Methods

The concrete specimens that were tested are 150mmx150mmx150mm (cube), 100mmx100mmx500mm (prism), 300mmx150mm (cylinder) and also 300mmx150mm (cylinder) for compressive strength, flexural strength, splitting tensile strength and elastic modulus test respectively in accordance to specifications of BS 12390 (2002).

Laboratory tests that were conducted on the sample of Bida natural coarse aggre-gate and fine aggregate to determine their physical properties include the following: moisture content, specific gravity, sieve analysis, aggregate impact value, aggregate crushing value, bulk density (compacted and uncompacted), water absorption and silt test in accordance with BS EN 12620 (2008). Also, the laboratory test con-ducted on the fresh and hardened concrete are: slump test and compacting factor test (compacted and uncompacted) in accordance to BS EN 12350-1(2000), and compressive strength, splitting tensile strength, flexural strength and elastic modu-lus test in accordance to BS EN 12390 (2002) respectively.

a) Factor setting

Central Composite Design (CCD), an augmented factorial design was employed for the factor settings. In the factorial approach, the q components of a mixture are re-duced to q-1 independent variables. Factor setting involves changing one or more factor at a time to study the effect of the variable on the response, this operation is randomized by the software such that experimental result from the laboratory will yield the best mixes. In this study, four (4) concrete components of water, cement, coarse aggregate and fine aggregate were used with three (3) corresponding inde-pendent variables/factors of water-cement ratio (W/C), coarse aggregate-total ag-gregate (CA/TA) and total aggregate-cement (TA/C). The independent variable ware represented by x1, x2 and x3 respectively. The ranges of the independent varia-bles chosen are as stated below:

$$\frac{W}{C} = 0.4, 0.5, 0.6 \quad (1)$$

$$\frac{CA}{TA} = 0.55, 0.615, 0.68 \quad (2)$$

$$\frac{TA}{C} = 3.0\ 4.5, 6.0 \quad (3)$$

Absolute volume method was used for mix proportioning.

b) Production of Concrete for Compressive strength

The sample was thoroughly mixed manually until the required homogeneity was achieved; the standard iron moulds of (150×150×150) mm3 were used. The moulds were lubricated with engine oil in order to reduce friction and to enhance removal of cubes from the moulds, they were then filled with fresh concrete in three layers and each layer was tamped 25 times. The same procedure was carried out for other concrete specimen (that is prism and cylinder for flexural strength, and splitting tensile and elastic modulus respectively). Table 1 shows a breakdown of the num-ber of samples produced for the experiment.

Table 1

Breakdown of the number of samples produced for the experiment

Concrete Specimen	Curing days				
	7days	14days	21days	28days	Total sample
Compressive strength (150x150x150) mm (Cubes)	100	100	100	100	400
Flexural strength (100x100x300) mm (prism)	100	100	100	100	400
Splitting tensile strength (100x300) mm (cylinder)	100	100	100	100	400
Elastic modulus (100x300) mm (cylinder)	100	100	100	100	400
Total number of samples cast			1600		

c) Curing and crushing of the concrete

The curing method used was total immersion, the hardened concrete samples were removed after 24 hours, cured and crushed for 7, 14, 21 and 28 days respectively, the mechanical properties that were determine include compressive strength, split-ting tensile strength, flexural strength and elastic modulus.

d) Compressive Strength Test

Compressive strength test on concrete cubes (Compressive strength test on concrete cubes (four hundred specimens) were determined using an electrically operated Seidner compressive machine using standard procedure for concrete curing age of 7, 14, 21, and 28days re-spectively at Civil Engineering laboratory, Federal University of technology, Minna (destructive test) in accordance with BS EN 12390 (2002). The weight of each cube was always taken before the compressive strength test was conducted. During crushing care was taken to ensure that the cubes were properly positioned and aligned with the axis of the thrust of the compres-sive machine to ensure uniform loading on the cubes (Neville, 2002).

The compressive strength was calculated using Equation (5)

$$f_{cu} = \frac{\text{Average load}}{\text{Area}}\ (\text{N/mm}^2) \quad (5)$$

The result of compressive strength is presented in Table 2. Each result is an average of five test conducted on each mix

e) Flexural Strength Test

Flexural strength test on concrete made from Bida natural stones was carried out in accordance with BS EN 12390-5:2009 on rectangular beams measuring 100mm x 100mm x 500mm. The concrete mixes were labeled M1-M20. Four hundred (400) specimens were produced and cured for 7, 14, 21 and 28 days using one point load-ing arrangement.

While test was conducted, the development of crack and the cracking up to the fail-ure was closely observed. The flexural strength was calculated using Equation (6)

$$f_{cr} = \frac{FL}{d_1 d_2^2}\ (\text{N/mm}^2) \quad (6)$$

Were

F = The applied load

L =Supported length of the beam

d_1 = Average width of the specimen

d_2 = Average depth of the specimen

The result of flexural strength is given in Figure 3. Each result is an average of five test conducted on each mix.

f) Splitting Tensile Strength Test

Splitting tensile strength test on concrete made from Bida natural stones were car-ried out in accordance with BS EN 12390-6:2009 on cylindrical specimen measur-ing 150mm diameter and 300mm height. The concrete mixes were labeled M1-M20. Four hundred (400) specimens were produced and cured for 7, 14, 21 and 28 days. During the test, the specimens were placed with its horizontal between the plates of a testing machine. And the load was increased until failure by vertical in-direct tension in the form of splitting along the diameter took place. The rate of loading was as prescribed by BS EN 12390-6:2009. The Splitting Tensile Strength fct in N/mm2 was calculated using Equation (7)

$$f_{ct} = \frac{2F}{\pi L d}\ (\text{N/mm}^2) \quad (7)$$

Where

f_{ct} = Splitting tensile strength

F = Maximum load

L = Length of line of contact of the specimen

d = Diameter of the specimen

The result of splitting tensile strength is given in Figure 4. Each result is an average of five test conducted on each mix.

g) Elastic modulus (young's modulus)

Elastic modulus test on concrete made from Bida natural stones was carried out in accordance with BS EN 1352:1997 on cylindrical specimen measuring 150mm diameter and 300mm height. The concrete mixes were labeled M1-M20. Four hundred (400) specimens were produced and cured for 7, 14, 21 and 28 days.

The modulus of elasticity measured in this case was chord modulus of elasticity. This is the slope of a straight line originating at a point on the curve corresponding to 50μ in/ in strain and extending to the stress at 40% of the ultimate strength. The elastic modulus E in N/mm2 was calculated using Equation (8)

$$E = \frac{S_2 - S_1}{\varepsilon_2 - \varepsilon_1}\ (\text{N/mm}^2) \quad (8)$$

Where

E= Chord modulus of elasticity

S_2= Stress corresponding to 40% ultimate load

S_1= Stress corresponding to a longitudinal strain at 0.000005

™$_2$= Longitudinal strain produced by stress, S_2

™$_1$= Strain at 0.000005

The result of elastic modulus is given in Figure 5. Each result is an average of five test conducted on each mix.

3.0 Result and Discussion

3.1 Measured Responses at 7, 14, 21 and 28days Curing

The summary of experimental results of concrete crushed at 7, 14, 21 and 28days curing for compressive strength, flexural strength, splitting tensile strength and elastic modulus are respectively presented in Figures 2 - 5. The range of values obtained for compressive strength at 7, 14, 21 and 28days curing are 5.85N/mm2 - 22.90N/mm2, 6.34N/mm2 - 27.2N/mm2, 6.38N/mm2 - 29.91N/mm2, and 7.91N/mm2 - 33.42 N/mm2 respectively. Those of flexural strength at 7, 14, 21 and 28days curing are 1.0N/mm2 - 6.1N/mm2, 1.2N/mm2 - 7.45N/mm2, 1.4N/mm2 - 7.65N/mm2 and 1.6N/mm2 - 7.9N/mm2 respectively. And for splitting tensile strength for 7, 14, 21 and 28days curing are 0.36N/mm2 -2.03N/mm2, 0.51N/mm2 - 2.23N/mm2, 0.52N/mm2 - 2.53N/mm2 and 0.72N/mm2 - 2.62N/mm2 respectively. The range of value for elastic modulus for 7, 14, 21 and 28days curing are 3560N/mm2-1500N/mm2, 3630N/mm2-17782N/mm2, 5150N/mm2-2273N/mm2 and 7210N/mm2 - 25090N/mm2 re-spectively.

The strength increases as the curing age increases for all cases tested, this is primarily due to the fact that concrete hardening is caused by chemical reaction between cement and water which continues for a long period of time and consequently concrete get stronger with age (Gambhir, 2004). The tensile and flexural strength of a concrete is much lower than the compressive strength, tensile strength is usually not considered directly in design (normally assumed to be zero), though its value is still needed because cracking in concrete tends to be a tensile behaviour (Zain et al., 2002). Figures 2-5 also shows that, tensile strength, flexural strength and elastic modulus increase in the same manner with compressive strength, simi-lar trend of strength development were obtained by (Zain et al., 2002).

The highest strengths were obtained with Mix M19 with the corresponding W/C=0.4, CA/TA=0.68 and TA/C=3 for the all curing age and the properties tested. This can be at-tributed to the high amount of coarse aggregate, lower water content and high amount of cement employed for the mix. Hence, these results obtained are in lined with that of Med-dah et al. (2010) who also stipulated that the compressive strength of concrete increases with increase in coarse aggregate content. In addition, concrete should be examined as a three-phase material consisting of aggregate skeleton, hardened cement paste and transition zone. The strength property (compressive strength) of such composite material is intimately related to the property of each phase. The predominant of properties of such a phase on the compressive strength of composite material is mainly influenced by the type of concrete (normal strength concrete and high strength concrete). Considering the normal strength concrete, the weakest phases are the cement phase and the transition zone between cement paste and the aggregate.

Increasing the aggregate surface area leads to an increase in the percentage of transition zone in the concrete material and thus, increasing the volume of the weakest phase. It can be con-cluded that the granular skeleton system plays a predominant role within the concrete mix-ture regarding the development of mechanical properties. Therefore, since high amounts of coarse aggregates were used, higher mechanical properties were obtained. In addition, high amount of water/cement ratio produces concrete with less cement paste consistency (highly watery) and offers lesser adhesion to the aggregate, leading to an increase in slump value, thus resulting in a weaker strength, but as the cement content is increased, paste of stiffer consistency are produced with greater binding capability. Thus, holding the aggregate to-gether and produce concrete of lower slump value but with greater strength (Abdullahi, 2009).

The weakest strengths were obtained with mix 17 containing W/C=0.4, CA/TA=0.55 and TA/C=6. This weak strength result was expected because right from the laboratory the mix-ture provided a harsh fresh concrete, and it is a well-known fact that when low W/C ratio is employed in conjunction with low CA/TA and a high TA/C ratio, the end product will re-sult in a weaker concrete. In order words, lower coarse aggregate to total aggregate (CA/TA) means a high amount of fine aggregate leading to high value of specific surface which require much quantity of water to produce concrete of reasonable strength. Also, a high total aggregate to cement (TA/C) means the quantity of cement is low but total aggre-gate which contained high amount of sand was used (that is low CA/TA), hence leading to weak strength.

More so, all mixes for 28days compressive strength satisfied the specified recommendation for the normal strength (compressive strength) concrete whereas mixes M6, M12, M13 and M17 do not satisfy the requirement therefore such mixes should be avoided when normal strength concrete is needed. Also, for flexural strength, only mix M17 fall below the range for normal strength concrete (flexural strength), hence this mix proportion should be discouraged. However, M13 should also be discouraged because it lies slightly above the low-er limit. In case of splitting tensile strength M1, M2, M3, M5, M8, M10, M11, M14, M19, M20 fall within the required limit for the normal strength concrete (tensile strength), but the rest of the mixes fall below the range and therefore should be discouraged for production of normal strength concrete (tensile strength). For the elastic modulus, only mixes M6, M13 and M17 fall below the specified range for the normal strength concrete (elastic modulus), hence all other mixes satisfied the requirement.

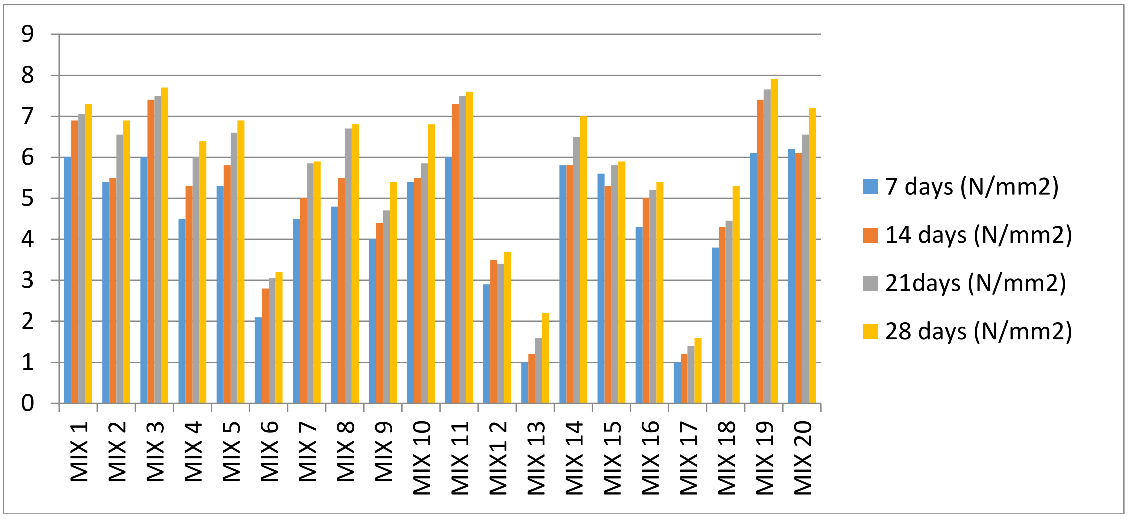

Fig 1: Summary of the Results of Compressive Strength for 7, 14, 21 and 28days Curing

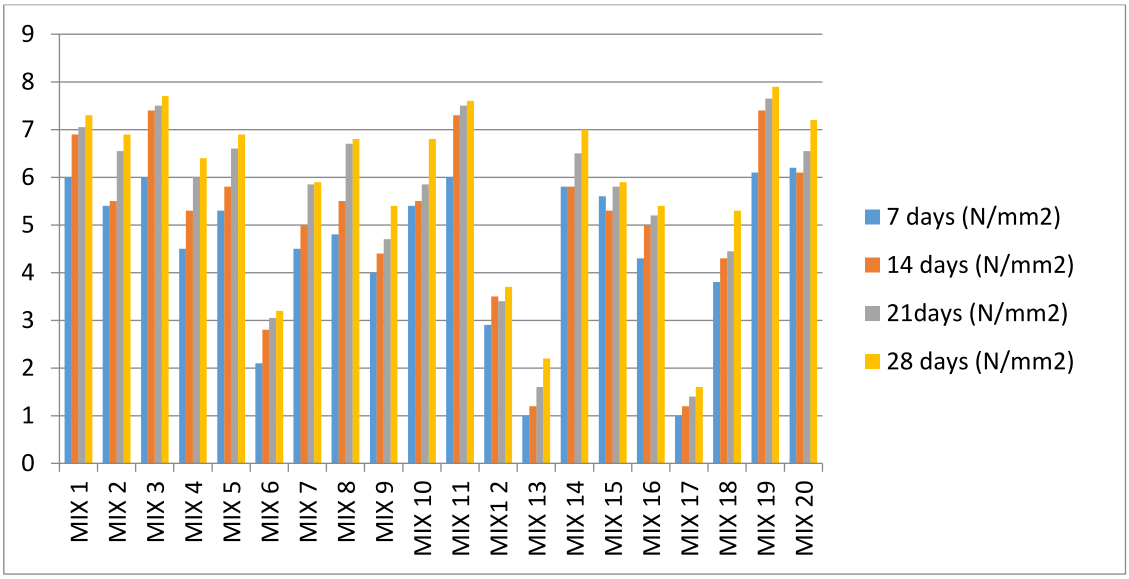

Fig 2: Summary of the Results of Flexural Strength for 7, 14, 21 and 28days Curing

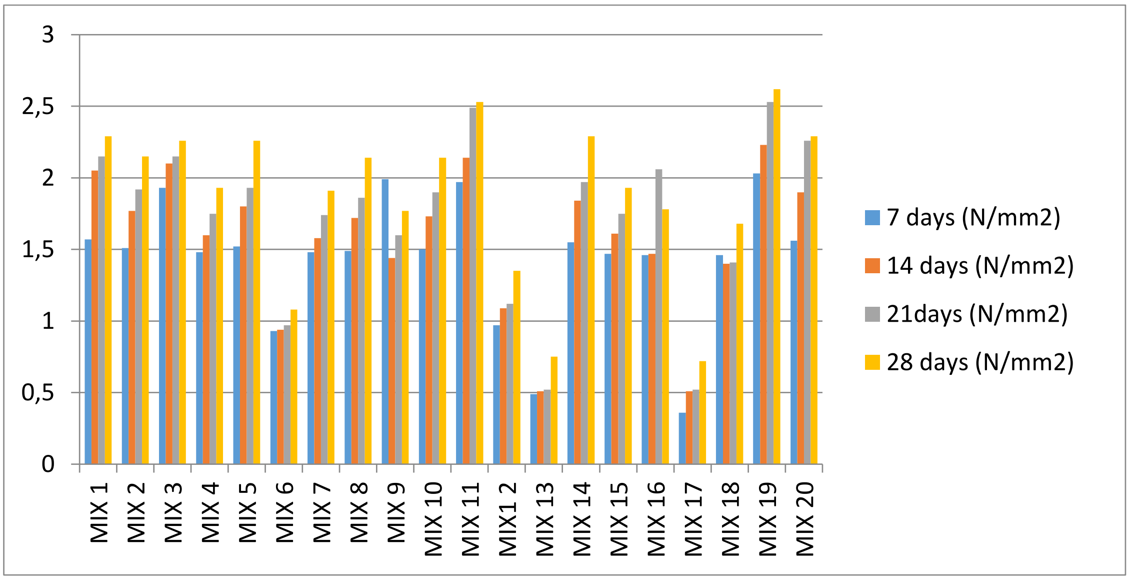

Fig 4: Summary of the Results of Splitting Tensile Strength for 7, 14, 21 and 28days Curing

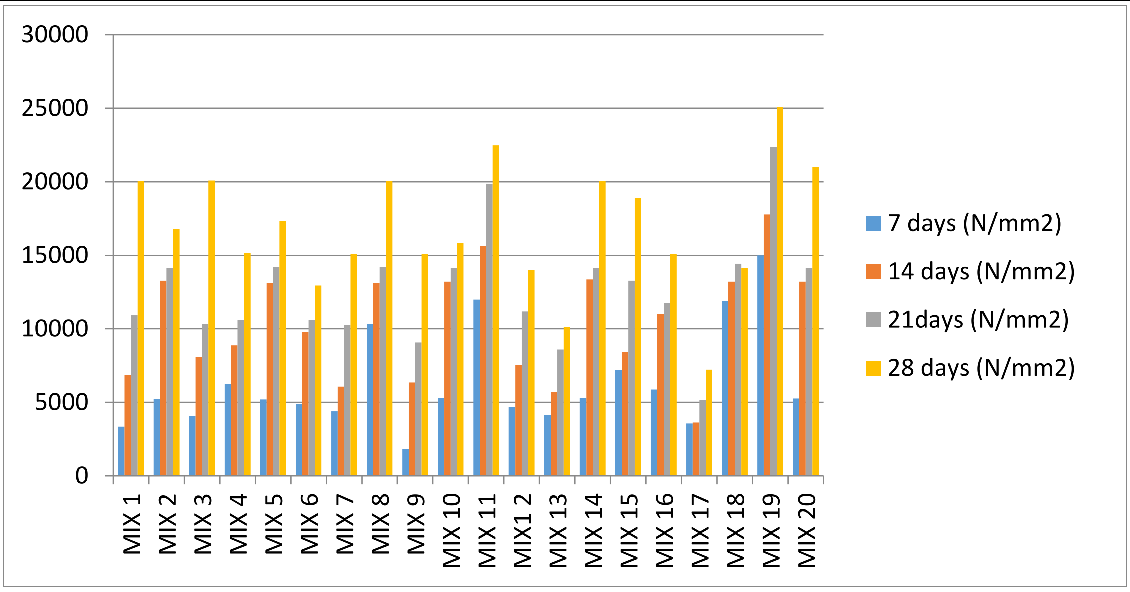

Fig 5: Summary of the Results of Elastic Modulus for 7, 14, 21 and 28days Curing

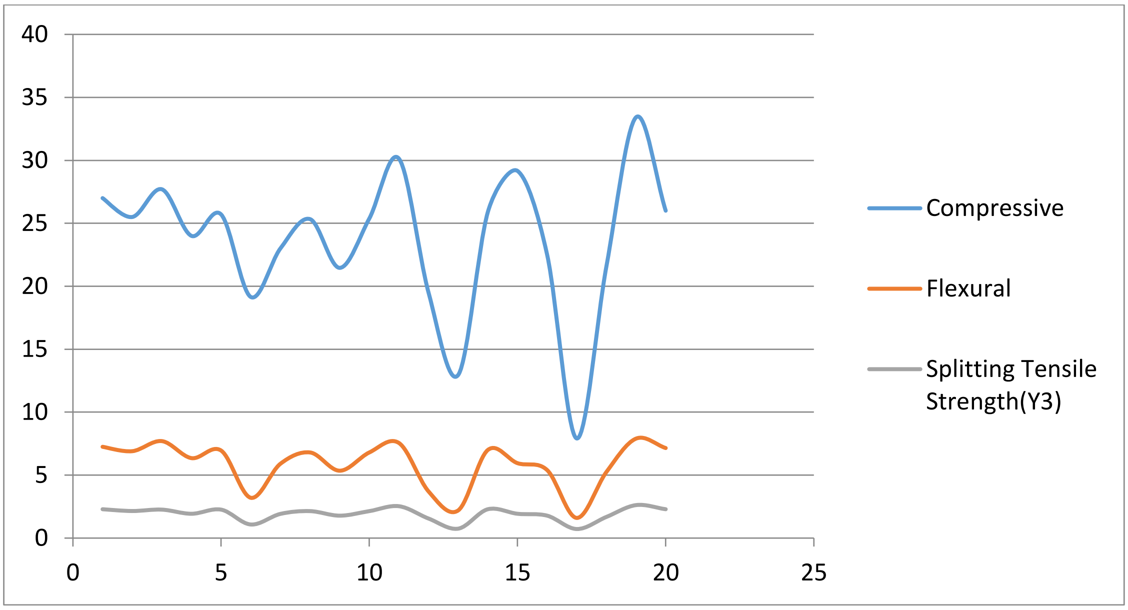

Fig. 6 Measured Responses at 28days

4.0 CONCLUSION

Based on the result of this research the following conclusions were drawn;

The strength of the concrete increases with the curing age in all cases.

The highest mechanical properties were obtained using low water/cement ratio (W/C), high coarse aggregate/total aggregate ratio (CA/TA) and low total aggregate/cement ratio (TA/C) as 0.4, 0.68 and 3.0 respectively.

4.1 Recommendations

1. Based on the result of the mechanical properties, it is recommended that the ranges of values for concrete made using washed Bida natural stones of 19mm maximum aggregate size are as follows: W/C= 0.4, 0.5, 0.6, CA/TA= 0.55, 0.615, 0.68, TA/C= 3.0 4.5, 6.0 respectively.

2. Further studies should include the development of models for compressive strength, flexural strength, splitting tensile strength, elastic modulus and slump of concrete made from BNS.

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