Effect of Partial Replacement of Fine Aggregate with Crumb Rubber in Concrete Made with Bida Gravel

Mohammed T. A., Abbas B. A., Yusuf A. & Oritola S. F.
Department of Civil Engineering, Federal University of Technology, Minna
Corresponding author's email: engr.mohr@yahoo,com

ABSTRACT

The availability of sand at cheap rates for use as fine aggregate in concrete production is ever becoming unfeasible and this, in addition to environmental sustainability, places a huge need to search for an alternative source of fine aggregate materials. Crumb rubber made from waste automobile tires, can be used to complement sand as fine aggregate in concrete production. This study seeks to investigate the effect of partially replacing fine aggregate with crumb rubber in concrete made with Bida natural stones. Crumb rubber gotten from waste automobile tires was used to replace fine aggregate in the concrete at 0%, 5%, 10%, 15%, 20%, and 25%. The particle size distribution, workability, and compressive strength of these concrete specimens were extensively studied. Curing was done for the period of 7, 14, and 21 days. A mix ratio of 1: 1.65: 2.42 was used for cement content, fine aggregates, and Bida natural stones, respectively, at a water-to-cement ratio of 0.45. Results from the workability test performed showed that a higher percentage replacement of crumb rubber gives a corresponding decrease in the workability of the concrete. In addition, the results obtained from each concrete mix for all cases of curing ages revealed that flexural and compressive strengths decrease with an increasing percentage replacement of crumb rubber in the concrete mix. The flexural strength of the concrete mix was observed to be 6.08N/mm^2 at 5% crumb rubber replacement. While at 25% crumb rubber replacement, a flexural strength of 3.08N/mm^2 was observed. Similarly, the compressive strength of the concrete mix at 5% crumb rubber replacement was noticed to be 20.88N/mm^2 and 11.89N/mm^2 at 25% crumb rubber replacement. This implies that concrete made using crumb rubber as a partial replacement for fine aggregate can be used for structural applications such as in the construction of reinforced concrete slabs, beams, columns, and foundations where high strength is not required.

Keywords: *Bida gravel, compressive strength, concrete, crumb rubber fine aggregate, workability test, curing period, and*

1 INTRODUCTION

Concrete is a construction material consisting of cement, fine aggregate, coarse aggregate, and water with or without admixtures. Concrete is a widely used material for the construction of building and civil engineering works in Nigeria and the world at large. Based on global usage, it is placed in second position after water (Azhagarsamy, 2017). Compressive strengths, tensile strengths, and flexural strengths, which define the degree of resistance a structural element can offer to deformation, remain the most important properties of structural concrete from an engineering point of view. The relationship between concrete composition and mechanical properties has long been a matter of research interest. Concrete characteristics such as hardened mortar, coarse aggregates, and the aggregates/mortar interfacial zone determine the strength of the concrete. The same quality of mortar characterized by different types of fine and coarse aggregates, including various shapes, textures, and mineralogy, may vary the strength of the concrete. However, Alhaji (2016) reported that the concept of water-to-cement ratio (W/C) and aggregates are gaining relevance in developing high-performance concrete.

The availability of sand at a low cost for use as fine aggregate in concrete production is ever becoming unfeasible and this, in addition to environmental sustainability, provides the motive behind the search for an alternative source of fine aggregate materials. Crumb Rubber may satisfy the requirements as a substitute material for sand. Using Crumb Rubber in conjunction with Portland cement and natural aggregates has many advantages, including lower member unit weight, increased ductility, higher shock resistance capability, good shock absorption capability, and higher noise and heat insulation which may improve fire resistance performance. But because the addition of Crumb Rubber in concrete may considerably reduce the compressive strength and other properties, it is suggested that their performance should be assessed. This type of concrete should only be used for structures, such as partition walls, sidewalks, crash barriers, paving, and Architectural Concrete (beams, columns, and foundations) where high strength is not required.

The volume of normal concrete usually constitutes 70 to 80 percent of aggregate particles from natural rocks. The term aggregate is frequently used in the building industry to define rock particles or gravel which constitute the greatest part of the bulk materials used in concrete. In addition, natural sand and gravel form a fundamental part of mortar in concrete. They also find relevance in the composition of asphalts and macadams for road-making. Sand and gravels are mostly employed as drainage layers and filters and as railway ballast. Unlike aggregates from natural rocks, recycled crushed concrete, and manufactured materials (such as expanded clay, blast furnace slags, and slate pellets) are used to a very limited extent. By standard, the aggregate as a material must be durable, strong, and inert to provide satisfactory performance. More so, the sizes of the constituent particles must be appropriate for the intended application. Aggregates are described as coarse aggregate if particles are retained on a sieve with 5 mm apertures or 4 mm apertures; otherwise, they are described as fine aggregate or sand if they pass through them. (*Newman and Choo, 2003)*

The essential requirement is that the aggregate remains stable in its exposure conditions within the concrete. There are three major reasons why aggregates are mixed with cement paste to form concrete rather than using cement paste alone. The first and oldest reason is that aggregate is cheaper than cement, so its use extends the mix and reduces costs. Secondly, aggregate reduces shrinkage and creep, giving better volume stability. Thirdly, aggregate gives greater durability to concrete. Many deterioration processes principally affect the cement paste.

Currently, non-biodegradable waste materials resulting from various physical and chemical processes are a serious challenge in industrial and developing countries. As a result, extensive research on waste recycling is being done to minimize environmental damage. Consequently, Engineers, like other industrial waste recycling researchers, have achieved advances in using these waste materials. One of these non-biodegradable materials that exponentially enters the environment is used automobile tires (*Rohit et al., 2020*).

Crumb Rubber is the product from processing used tires into fine granules or particles while using mechanical or cryogenic procedures. During the mechanical or cryogenic procedure, impurities such as steel and fabric components of the tires are removed. Crumb rubber includes particles ranging in size from 4.75mm to less than 0.075mm (*Rohit et al., 2020*).

The world is rapidly advancing in technology, and so is the world of infrastructure (*Agrawal et al., 2017*). The resources required to achieve the construction of this infrastructure are also in rapid use. Fine aggregate is an essential component of concrete. According to *Azhagarsamy (2017),* pit or natural river sand is the most used fine aggregate for construction purposes. However, the global consumption of natural sand is very high due to the extensive use of concrete. To lessen the use of natural river sand, the construction industry of developing countries has been saddled with the responsibility of identifying alternative materials to reduce or eliminate the demand for natural sand.

Sand mining from pits and river-bed is a direct cause of erosion. The physical impact of sand mining includes Downstream erosion due to increased carrying capacity of a stream, downstream changes in patterns of deposition, Upstream erosion because of an increase in channel bed slope and changes in the flow velocity, Loss of adjacent land and/or structures, The undercutting and collapse of riverbanks (*Saviour and Stalin, 2012*). The act of mining sand is regulated by law in many places, but it is still often done illegally (*Kadir et al., 2017*).

A significant number of used tires are discarded each year after their useful lifetime. Several approaches have been explored to recycle used tires. In several instances, tire-derived aggregates, which are typically large aggregates, have been used as raw materials for civil engineering projects. However, a significant fraction of used tires still find their way into landfills, resulting in public health and environmental hazard. Landfill facilities require tires to be shredded to minimize the extent of floating tires; the cost of shredding is dependent on the final particle size of the rubber, with finer particles being more expensive. Several studies have explored the use of tire-derived particles as a substitute for either coarse or fine aggregates, with varying degrees of success. (*Gideon et al., 2016*) This study is therefore aimed at determining the suitability of Crumb Rubber as a partial replacement of fine aggregate in concrete, using Bida natural stones as coarse aggregates.

Crumb rubber, as defined by *Kaloush et al. (2005*), is a substance made by shredding and crushing old tires. In Cement manufacturing, high-temperature processes allow using scrap tires as an alternate fuel source. The rubber in tires is made up of hydrocarbon molecules, which, like coal and oil, have a high energy value. On an equal mass basis, tires have a 25% higher fuel value than coal (*PCA 2008*). In the United States, over 300 million used tires are produced each year (*RMA 2009*). The Environmental Protection Agency (EPA) acknowledges tire-derived fuel (TDF) as an environmentally friendly practice and encourages industries to use it. Tire-derived fuel (crumb rubber) is used in cement production to recover energy and conserve fossil fuel resources that would otherwise end up in landfills or unregulated disposal sites. The kiln's tremendous heat ensures that the tires are completely destroyed. The use of tires as fuel can actually lower certain emissions because there are no visible emissions from the tires (PCA 2008).

Rubbercrete is manufactured by substituting crumb rubber (CR) from discarded tires for part of the fine aggregate in regular concrete. (*Mohammed et al., 2018).* Many fresh and hardened qualities of rubbercrete have been improved in comparison to regular concrete, according to the literature. The fresh rubbercrete mixture has a higher percentage of air-entrained, making it more freeze and thaw-resistant (*Richardson et al., 2016*), as well as lighter unit weight and workability (*Kardos and Durham, 2015).*

According to previous studies, when the percentage of crumb rubber increases, compressive strength gradually decreases (*Najib et al., 2018*). *Najib et al. (2018)* further propounded that the reasons for the decrease in compressive and flexural strength of the rubberized concrete are as follows: extra rubber tire particles are lodged in the aged and surrounding cement material; lack of a proper bond between rubber powder and cement during the aggregation process; and low unique gravity of rubber and lack of bonding with other concrete materials.

low unique gravity of rubber and the absence of its bonding with different concrete elements

The proportion of replacement employed during the aggregation between crumb rubber and cement has an impact on the rubberized concrete strength. Rubbercrete, on the other hand, enhances other technological qualities like energy absorption. Rubbercrete improves impact energy, impact load, toughness, ductility, freeze/thaw resistance, thermal insulation, and sound insulation, and makes cement considerably eco-friendlier and lighter (reuse of rubber and minor aggregate). Because rubber has a lower specific gravity than aggregates, substituting rubber for aggregates lowers the overall specific gravity (*Valente and Sibai, 2019*).

Kunal and Ramana (2017) studied the mechanical and durability qualities of concrete using different proportions of Waste Tyre Rubber (0%, 4%, 4.5%), 5%, and 5.5%). It has been discovered that as the amount of Waste Tyre Rubber increases, the workability of concrete diminishes. With a 4 percent replacement of fine aggregate with rubber, the output of flexural and compressive strength reduces slightly.

Eshmaiel et al. (2009) tested the performance of concrete mixtures, including 5%, 7.5 %, and 10% used tires, respectively. In the investigation, rubber as aggregate and cement replacements yielded the following results: Compressive strength was reduced as the percentage of rubber replacement in concrete increased. However, the decrease in compressive strength was small (less than 5%) with no noticeable changes in other concrete properties. Concrete with chipped rubber (as a replacement for aggregates) has a lower tensile strength than concrete with powdered rubber (for cement replacement).

Gajendra et al. (2020) investigated concrete sustainability by partially replacing fine aggregate with waste tires in an experiment. A surface modification strategy was proposed in their research to introduce strong polarity groups to the rubber surface in order to create a strong chemical interaction between the rubber and the cement matrix. It was discovered that the proposed method is effective in enhancing the mechanical properties of concrete.

2 SIGNIFICANCE OF THE STUDY

The growing concern of global warming, pollution, and natural resources depletion due to rapid construction activities worldwide has challenged many researchers and engineers to seek and develop alternative materials relying on renewable resources.

Fine aggregate, which is the most common and also one of the major components of concrete is being mined at an exponential rate. Sand mining from pits and the river bed is a direct cause of erosion. The physical impact of sand mining includes

Downstream erosion due to increased carrying capacity of a stream, downstream changes in patterns of deposition, Upstream erosion as a result of an increase in channel bed slope and changes in the flow velocity, The loss of adjacent land and/or structures, The undercutting and collapse of river banks.

On the other hand, the disposal and management of waste automobile tires pose an environmental concern in several countries. This is mainly due to the non-biodegradable nature of this solid waste as a result of the presence of stabilizers, additives, and the cross-linked structure of the elastomeric polymer material. Disposal of waste tires is very difficult as it requires large spaces thereby creating environmental, aesthetics, and health-related problems for the surrounding environment. Dumped waste automobile tires in the environment, cause many environmental and health hazards such as the high risk of fire and provide shelter to harmful insects, rodents, and animals such as rats, mosquitoes, snakes, mice etc.

In this study, Crumb rubber, a product made by shredding and crushing old tires into granules of varying sizes has been used to partially replace fine aggregate in concrete and the term “Rubbercrete” is used to describe concrete manufactured by partially substituting fine aggregate with crumb rubber (CR) in regular concrete. The physical properties of the materials such as bulk density, sieve analysis etc., and concrete properties such as slump, compressive strength, flexural strength, etc. were examined. These properties were compared against values for traditional concrete to assess their comparative performances so as to achieve a better understanding of the effect of partial replacement of fine aggregates with crumb rubber in concrete made with Bida natural stone.

3 MATERIALS AND METHOD

3.1 MATERIALS

The materials used to prepare the concrete in this study are cement, fine aggregate, crumb rubber, Bida natural stone, and water.

3.1.1 ORDINARY PORTLAND CEMENT

The performance of concrete is largely dependent upon the properties of the cementitious materials, particularly chemical properties. Portland cement is indisputably the most widely used binding material in the manufacture of hydraulic-cement concrete. Cement is selected based on careful consideration of all performance requirements, not just strength. The Ordinary Portland Cement used in this study was sourced within Minna metropolis and conforms to BS EN 197- 1 (2000).

3.1.2 FINE AGGREGATE

The fine aggregates used in this study have all particles passing through a sieve size 4.75 mm and retained on a sieve size 150 μm aimed at producing good quality concrete. The fine aggregates used are in two parts as follows:

3.1.2.1 Sharp sand

The sand was sourced from Gidan Mangoro, Minna, Niger state of Nigeria. It was ensured that the sample used for this study is clean, sharp, and free from loam, clay, and organic impurities conforming to the standard requirement of BS EN 12620 (2008). The sample collected was air-dried to enhance good quality concrete in the civil engineering laboratory.

3.1.2.2 Crumb rubber

Crumb Rubber (Plate I) made from irregularly shaped torn Tires particles obtained by the industrial decomposition of used Tires was used as a partial replacement for the sand. Manufacturing of Crumb rubber from used tires is principally a three-stage process involving, shredding, granulating, and finally, fine grinding, which produces a top-notch material for several re-applications such as the production of Tartan tracks for athletics games and the production of Rubbercrete.

Plate I: Crumb rubber

3.1.3 COARSE AGGREGATES

The coarse aggregate used in this study is Bida Natural Stone (BNS) shown in Plate II and it was sourced from Bida basin. The stone is a by-product of the decomposition of parent rock, transportation, and deposition of the rock particles in the Bida Basin. These coarse aggregates have a maximum size of 19mm in diameter. The aggregates also conform to the standard requirement of BS EN 12620 (2002).

Plate II: Bida natural stone

3.1.4 PORTABLE WATER

Potable drinking water from the Civil Engineering Laboratory, Federal University of Technology Minna was used throughout this work. It was ensured that the water for the concrete was clean, free from deleterious materials, and fit for drinking as recommended by BS EN 1008 (2002).

3.2 METHODS

The physical characteristics of the aggregates were determined using sieve analysis, specific gravity, Bulk density (compacted and uncompacted), aggregate impact value, and aggregate crushing value tests.
The mechanical properties of the hardened concrete were also determined using dry density, flexural strength, and compressive strength tests respectively.

3.2.1 SPECIFIC GRAVITY TEST

Specific gravity is defined as the ratio of the density of a material to the density of distilled water at a stated temperature. Since aggregates generally contain pores, the value of the specific gravity (or relative density) varies depending on the extent to which the pores contained absorbed water at the time of testing. This test was conducted in accordance with ASTMC C33/C33 (2016).

3.2.2 SIEVE ANALYSIS TEST

The way particles of aggregates fit together in a mix, as influenced by its gradation, surface texture, and shape has an important effect on the workability and finishing characteristics of fresh concrete and consequently on the properties of hardened concrete. A sieve analysis test was carried out to determine the particle size distribution of aggregate used in the concrete mix.
BS EN 12620 (2008) for sieve analysis was used; the method employed for the determination of particle size distribution is the dry sieve analysis.

3.2.3 BULK DENSITY TEST

The Bulk density or unit weight of an aggregate sample gives valuable information regarding the shape and grading of the aggregate. Since the test measures the actual density of aggregates that fills a unit volume, the density will greatly depend on how the aggregates are closely packed together this further depends on the size, shape, and distribution of the aggregates within the unit volume. It is useful in converting quantities in mass to quantities in volume. The test will be conducted in accordance with BS EN 12620 (2008).

3.2.4 AGGREGATE IMPACT VALUE (AIV) TEST

For the toughness of concrete aggregates, the aggregate impact value test measures the resistance of the material to failure by impact. The aggregate impact value test can be achieved by subjecting a standard aggregate sample kept in a mould to fifteen blows of a metal hammer weighing 14kg and falling through a height of 38cm. The quantity of finer materials passing through the sieve 2.36mm resulting from the pounding indicates the toughness of the sample aggregate. The ratio of the weight of the fines formed, to the weight of the total sample in percentage, gives the aggregate impact value. The AIV performed in this study was done in accordance with BS EN 12620 (2008)

3.2.5 PRODUCTION OF CONCRETE FOR FLEXURAL AND COMPRESSIVE STRENGTH TESTS

A mix ratio of 1: 1.65: 2.42 was used for cement content, fine aggregate and coarse aggregates respectively at a water-cement ratio of 0.45. The percentage replacement of fine aggregate with Crumb rubber are 0%, 5%, 10%, 15%, 20% and 25%. A total of nine cubes having a dimension of 150mm x 150mm x 150mm were cast per each replacement for the Compressive strength test. Similarly, a total of nine Beams measuring 100mm x 100mm x 500mm were cast per each replacement for the flexural strength test.

3.2.6 CURING OF CUBES

Curing refers to the constant application of water to hardened concrete to ensure continuous hydration of cement so as to ensure that the design strength and durability is attained. The total immersion method of curing of beams and cubes was adopted for specific age of 7, 14 and 28 days respectively from the day of demoulding of the cast concrete (BS EN 1008 (2002).

3.2.7 COMPRESSIVE STRENGTH TEST

The compressive strength test is a test carried out on specimen of concrete cubes to determine the compressive strength of the designed concrete. The load read from the dial gauge of the compressive strength testing machine at failure, (P) of the cubes sample is divided by the cross-sectional area (A) of the cube to obtain the compressive strength as shown in Equation 1 based on guidelines contained in BS EN 197-1 (2000).

$$Compressive\ Strength = \frac{P}{A}\ (N|mm^2) \quad (1)$$

3.2.8 FLEXURAL STRENGTH TEST

Flexural strength is a measure of the tensile strength of concrete. It is a measure of the capacity of an unreinforced concrete beam sample to resist failure in bending. It is measured by loading the concrete beam having a span length of at least three times the depth on a flexural strength testing machine to determine load at failure. The flexural strength was calculated using Equation 2 in accordance with BS EN 197-1 (2000).

$$Flexural\ Strength = \frac{3FL}{2bd^2}\ (N|mm^2) \quad (2)$$

Where,
F= Load at failure
L= Effective span of beam
b=Breath of beam
d=Depth of beam

4 RESULTS AND DISCUSSION

4.1 RESULTS

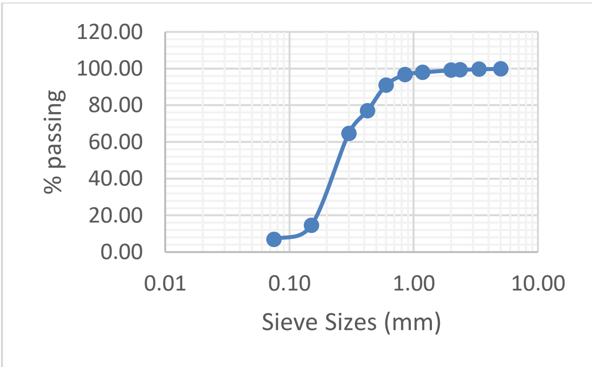

Figure 1: Sieve Analysis result for sand

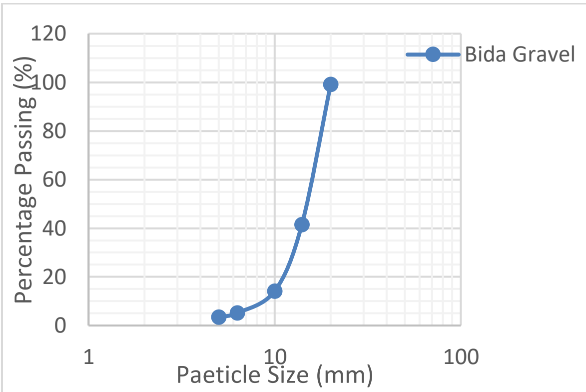

Figure 2: Sieve Analysis result for Bida natural stone

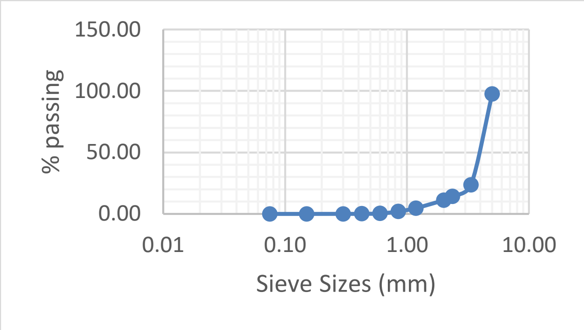

Figure 3: Sieve Analysis result for Crumb rubber

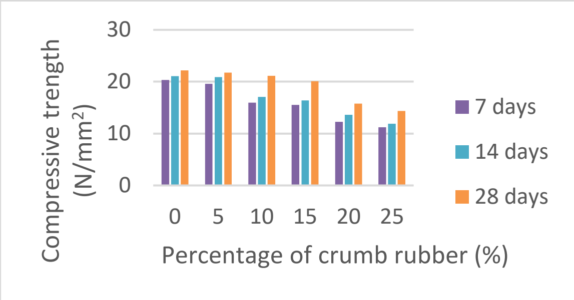

Figure 8: Compressive Strength of cubes per percentage replacement

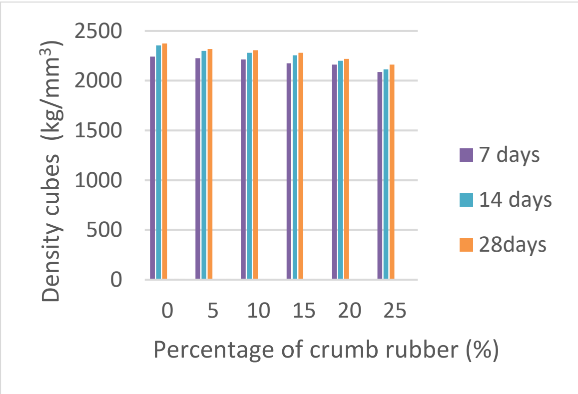

Figure 9: Density of cubes per percentage replacement

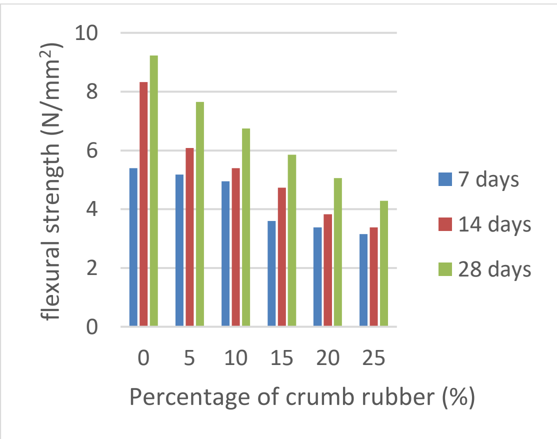

Figure 6: Flexural Strength per percentage replacement

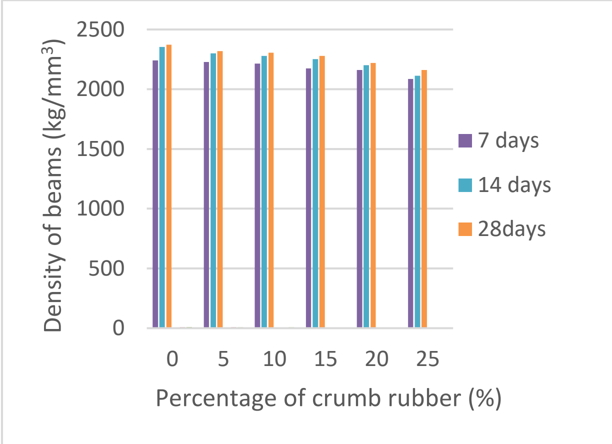

Figure 7: Density of beams per percentage replacement

Table 1: Summary of Physical properties of constituent materials

Parameters	Sand	Crumb Rubber	BNS
Specific gravity	2.61	0.99	2.7
Bulk density Compacted (kg/m^3)	1451.01	531.01	1661.81
Bulk density Uncompacted (kg/m^3)	1346.18	502.00	1485.52
AIV	-	-	19.66

5 DISCUSSION OF RESULT

5.1 AGGREGATE CHARACTERIZATION

The characterization of coarse aggregate, fine aggregate and crumb rubber performed in this study are summarized in Table 1 and Figures 1, 2 and 3. For the specific gravity tests for fine aggregate (sand), Bida natural gravel and crumb rubber, three samples, A, B and C were analyzed for each scenario and the average specific gravity for each aggregate was computed. The specific gravity of sand was computed as 2.61, that of gravel as 2.71, while the specific gravity of crumb rubber was determined as 0.99. The values obtained for fine aggregates and Bida natural stone fall within the limit for natural aggregate (1.3-3.0 and 2.6-2.7 respectively), which further implies according to Naville, 1995, that the aggregates can be used for construction work (concrete) without much need for mix proportioning adjustment. However, the specific gravity for Crumb Rubber (0.99) falls far below this lower range for natural aggregates. Thus, indicating that Crumb Rubber is a much lighter aggregate and may therefore be suitable for light weight concrete.

The calculated bulk densities of uncompacted fine aggregates, Bida natural stone and crumb rubber are, 1346.18kg/m^3, 1485.52 kg/m^3 and 502.00kg/m^3 respectively, While the calculated bulk densities for

compacted fine aggregates, Bida natural stone, and crumb rubber are, 1451.01kg/m^3, 1661.81 kg/m^3 and 531.01kg/m^3 respectively.
The Average Impact Value of coarse aggregate as illustrated in Table 1 was computed as 19.66% for Bida natural stone.

5.2 PROPERTIES OF HARDENED CONCRETE

The density of concrete cubes at various replacement levels is presented in table 1.0 and ranges from 2360.49kg/m^3 at 0% replacement, 2252.84 kg/m^3 at 10% replacement, and finally, 2116.54 Kg/m^3 at 25% replacement. It is worth noting that between 0 to 10% replacement the concrete conforms to the classification of normal-weight concrete and beyond 10% replacement up to 25% replacement, the density continues falling gradually below the standard range for normal-weight concrete. It can therefore be deduced that the density of the concrete reduces with increases in the volume of crumb rubber.
The tests result for the flexural strength of the concrete beams at curing ages of 7, 14, and 28 days are illustrated in Figure 6. The flexural strength decreases with an increasing percentage replacement of fine aggregates with crumb rubber for all curing ages considered. Similarly, the compressive strength tests result for the concrete cubes at curing ages of 7, 14, and 28 days are illustrated in Figure 8. The compressive strength of the concrete mix was observed1. to also reduce with an increasing percentage replacement of fine aggregates with crumb rubber for all curing ages. It, therefore, implies that optimum values of flexural and compressive strength can only be achieved at a very low percentage replacement of crumb rubber with fine aggregates if the mechanical properties of rubber create are2. a priority.

6 CONCLUSION

6.1 CONCLUSION

Following the observed behavioral characteristics of the fresh and hardened concrete made with Bida natural stone, while partially and incrementally replacing fine aggregates in the mix with crumb rubber, the following deductions can be made within the limits of experimental accuracy;

Bida natural stone is strong and good for concrete work.

Crumb rubber is comparatively much lighter than natural fine aggregates and may be considered for the production of lightweight concrete.

The workability of the fresh rubbercrete made with Bida natural stone decreases with the increasing content of crumb rubber in the concrete mix.

The density of rubbercrete made with Bida natural stone by partial replacement of fine aggregates with crumb rubber remain within the classification range for normal weight concrete for up to 10% replacement of fine aggregates with crumb rubber.

The flexural strength of rubbercrete made with Bida natural stone decreases with an increasing percentage replacement of fine aggregates with crumb rubber for all curing ages considered.

The compressive strength of rubbercrete made with Bida natural stone decreases with an increasing percentage replacement of fine aggregates with crumb rubber for all curing ages considered.

Standard flexural and compressive strength values for normal-weight concrete can only be sustained between 0% to 10% percentage replacement of crumb rubber with fine aggregates in concrete made with Bida natural stone.

A higher percentage replacement of crumb rubber beyond 10% in the mix suggests that rubbercrete becomes lighter and weaker in its mechanical properties

7 RECOMMENDATIONS

From the results obtained in this research work with the conclusion drawn, it is therefore recommended that;
Crumb rubber can be used to replace fine aggregates in concrete made with Bida natural stone for up to 10% replacement in normal weight and beyond 10% for lighter concrete thereby enhancing environmental sustainability in terms of reducing sand mining and utilization of waste automobile tires.
All rubbercrete made with Bida natural stone should be properly cured to achieve the required properties of design strength, durability, and long-lasting serviceability.

REFERENCES

Agrawal, V., Pankil, S., Armaan, G., & Rahul, S. (2017). The Utilization of Quarry Dust as Fine Aggregate in Concrete. *International Conference on Research and Innovations in Science, Engineering and Technology,* 170-175.
Alhaji, B. (2016). *Statistical Modelling of Mechanical Properties of Concrete Made from Natural Coarse Aggregates from Bida Environs.* Unpublished PhD Thesis Submitted to Department of Civil Engineering, Federal University of Technology, Minna.
AzAzhagarsamy, S., Sumaiya, A. M., & Thilagavathi, K. (2017). Effect of Quarry Dust on High Performance Concrete. *International Research Journal of Engineering and Technology (IRJET),* 1223-1226.
BS EN 197-1 (2000). Composition, specification and conformity criteria for common cement. London, British Standard Institution.
BS EN 12390 (2009). Testing harden concrete. Compressive strengths, flexural strengths and splitting

tensile strengths of a concrete. London W44AL UK, British Standard Institution.

BS EN 1008 (2002). Mixing water for concrete: Specification for sampling, testing and assessing the suitability of water, including water recovered from concrete industry as mixing water for concrete. London, British Standard Institution.

BS EN 12620 (2008). Specification for aggregates from natural sources for concrete. London, British Standard Institution.

ASTMC C33/C33 (2016). Standard Specification for Concrete Aggregates. *ASTMC International.* West Conshohocken.

Eshmaiel, G., Morteza, K., Ali, A., & Maghsoudi. (2009). Scrap rubber tyre replacement for aggregate and filler in concrete. Constr. *Build. Mater*, 1828-1836.

Gajendra, Rajan, R., Sakthieswaran, N., Ganesh, & Babu, O. (2020). Experimental investigation of sustainable concrete by partial replacement of fine aggregate with treated waste tyre rubber by acidic nature. *Materials Today: Proceedings.* doi:10.1016/j.matpr.2020.06.279

Gideon, M. S., Ali, A., & Pranesh, B. A. (2016). Properties of Concrete with Crumb Rubber Replacing Fine Aggregates (Sand). *Advances in Civil Engineering Materials,* 1(2), pp. 218–232. doi:10.1520/ACEM20120044

Kadir, A. A., Hassan, M. I., Sarani, N. A., Abdul, Rahim, A. S., & Ismail, N. (2012). Physical andand Mechanical Properties of Quarry Dust Waste Incorporated into Fired Clay Brick. *AIP Conference Proceedings.* 1-5.

Kaloush, K. E., Way, G. B., & Zhu, H. (2005). Properties of Crumb Rubber Concrete. *Transportation Research Record: Journal of the Transportation Research Board*, 1914(1), 8-14. doi:10.1177/0361198105191400102

Kardos, A., & Durham, S. (2015). Strength, durability, and environmental properties of concrete utilizing recycled tire particles for pavement applications. *Construction and Building Materials*, 832-845.

Kunal, B., & Ramana, P. (2017). Evaluation of mechanical and durability properties of Waste TyreRubber. *Constr. Build. Mater*, 811–817.

Mohammed, B. S., Khed, V. C., & Nuruddin, M. F. (2018). Rubbercrete mixture optimization using response surface methodology. *Journal of Cleaner Production*, 171, 1605–1621. doi:10.1016/j.jclepro.2017.10.10

Najib, N., Gergesa, Camille, A., Issab, S., & Fawazba, A. (2018). Rubber concrete: Mechanical and dynamical properties University of Balamand, Case Studies. *Construction Materials,* 9. Retrieved January 11, 2022, from https://www.sciencedirect.com/science/article/pii/S2214509518301840?via%3Dihub

Newman, J., & Choo, B. (2003). *Advanced Concrete Technology Constituent Materials.*

PCA. (2008). ire-Derived Fuels, IS325. *Portland Cement Association*, 1-4.

RMA. (2009). *Scrap Tire Markets in the United States – 9th Biennial Report.* Washington DC: Rubber Manufacturers Association.

Richardson, A., Coventry, K., Edmondson, V., & Dias, E. (2016). Crumb rubber used in concrete to provide freeze-thaw protection (optimal particle size) . *Journal of Cleaner Production*, 599-606.

Rohit, P., Alisha, S., & Ganesh, V. (2020). Partial Replacement of Fine Aggregate with Crumb Rubber in Concrete. *The International Journal of analytical and experimental modal analysis,* 10(7).

Saviour, M., & Stalin, P. (2012). Soil and Sand Mining: Consequences and Management. IOSR *Journal of Pharmacy (IOSRPHR),* 2(4), 01-06.

Valente, M., & Sibai, A. (2019). Rubber/Crete: Mechanical properties of scrap to reuse tire-derived rubber in concrete; A review. *Journal of Applied Biomaterials & Functional Materials,* 17(15). doi:10.1177/2280800019835486 Post, pp. E1, E4.