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Experimental Study on Workability of Natural Aggregate Concrete Incorporated with Crumb Rubber

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ABSTRACT: This study investigated the effect of crumb rubber on the workability of fresh concrete. Crumb rubber was used to replace fine aggregate at 0%, 5%, 10%, 15% and 25%. Physical properties (particle size gradation, specific gravity, bulk density and aggregate impact value) of the aggregates: sharp sand, Bida natural stone and crumb rubber were determined. Furthermore, the sharp sand and Bida natural stone used for this research were characterized as normal weight aggregates while the crumb rubber was characterized as a light weight aggregate. Workability of the concrete in its fresh state was extensively studied. Generally, the workability of fresh concrete reduced as the crumb rubber increased from 0% to 25%. The reduction in slump values was adduced to the absorbent nature of the crumb rubber. Hence, the research recommended a water-to-cement ratio of 0.55 – 0.60 for use in the production of concrete containing crumb rubber. It was concluded that crumb rubber can be used to produce low workability concrete for use in mass concrete foundations, lightly reinforced concrete elements and roads.

KEYWORDS: Crumb rubber; Slump; Workability; Bida natural stone

I. INTRODUCTION

Concrete is known as a strong, durable construction material and can be made to fit into different sizes and shapes (Arum and Olotuah, 2006). Concrete can be made by mixing water, cement, and admixtures in required extents (Kalyana *et al.*, 2020). Materials required to produce concrete were non-renewable materials and for over 100 years, the production of concrete leaves enormous environmental effect (Aprianti, 2017). According to Rey *et al.*, (2020), aggregate is the most extracted resources in the world and in 2018, for example approximately 5.1 billion tons of aggregates.

The volume of a normal concrete usually constitutes 70 to 80 percent of aggregate particles from natural rocks. The term aggregate is frequently used in the building industry because rock particles or gravel constitute most of the bulk materials used in general. In addition, natural sand and gravel form a fundamental part of mortars and 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 screen with 5 mm or 4 mm apertures; otherwise, they are described as fine aggregate or sand if they pass through them (Newman and Choo, 2003).

Along with the demands of globalization, the increasing demand for building materials as well as the increasing human population around the world have led to a shortage of construction materials (Nor *et al.*, 2014; Shahidan *et al.*, 2016; Shahidan *et al.*, 2016). Engineers have been challenged to convert industrial waste into useful construction materials (Ali *et al.*, 2016). This is because the development of the construction sector is crucial to economic development worldwide. The use of rubber from waste tyres to replace fine aggregate may help to alleviate disposal problems (Yogender *et al.*, 2014). Various studies have been conducted to replace the main components in concrete production with alternative materials in order to reduce cost and conserve the environment. In this research, rubber was used to replace fine aggregate in concrete. According to Thomas and Gupta (2016), by the year 2030, the number of discarded tyres would reach 1200 million tyres yearly (including the stockpiled tyres, there would be 5000 million tyres to be discarded on a regular basis).

Recently, vast study has been done by engineers and material researchers in finding the solutions to recycling the waste generated from construction activities as an alternative of resources to be used in concrete in order to ensure environmental conservation and efficient usage of natural resources. For construction of a new building, there is significant amount of construction waste generated such as concrete, timber, reinforcement bars, finishing waste from tiling. Therefore, utilization of recycled concrete aggregate and crumb rubber (CR) waste as replacement in concrete production may help in reducing the amount of concrete and crumb rubber waste at disposal site. Since cement and aggregate contain almost 70% of concrete volume, the usage of concrete waste and crumb rubber waste as recycled fine aggregate can reduce environmental impact (Modani and Mohitkar, 2014). One of the products that was derived from tyres waste is crumb rubber (Eisa *et al.*, 2020). Previous studies (Youssf *et al.*, 2014; Youssf *et al.*, 2015) showed that crumb rubber has a potential to be used in concrete mixture. Even though, the use of crumb rubber in the concrete blends helped to improve ductility, durability, and the resistance impact of the concrete but it also had adverse effects on the compressive strength, splitting tensile strength, modulus of elasticity, and flexural strength when the rubber percentage is increased. Hence, the workability of concrete with crumb rubber as partial replacement of fine aggregates was investigated in this study. Based on the result, the optimum percentage of crumb rubber as fine aggregates replacement was identified.

II. LITERATURE REVIEW

Several researchers reported that the increase of the Recycled Concrete Aggregate (RCA) content in concrete mixture up to 50% can increase the compressive strength of the concrete (Nischay *et al.*, 2015). It was also reported that the slump of recycled concrete aggregate, due to higher water absorption, angularity and rough texture of construction and demolition waste, was lower than conventional one (De Brito *et al.*, 2013). Density of concrete incorporating with crumb rubber as partial fine aggregate replacement will decrease as the percentage of crumb rubber increases (Mohammed *et al.*, 2012; Thomas *et al.*, 2016). Density for w/c ratios of 0.35, 0.45, and 0.55 reduce when the percentage of rubber ash in concrete increase (Gupta *et al.*, 2014). Concrete with crumb rubber decrease gradually on workability when crumb rubber percentages increase (Oikonomou & Mavridou, 2009).

As the percentage of CR increased, compressive strength of concrete decreases (Bashar *et al.*, 2012). This is because physical properties of CR allow entrapping of air into its surfaces and during the mixing process, water is repelled (Turatsinze and Garros, 2008). CR (4.75mm) used at a changeable percentage up to 40% with a step size of 10% as a replacement of fine aggregates also show that compressive strength decreases when percentage of CR increases (Wang *et al.*, 2013). In tensile strength test, the strength of crumb rubber concrete showed a decrease in strength in comparison to the strength of normal concrete (Siringi *et al.*, 2013). The fine crumb rubber concrete had lower tensile strength in comparison to control mix at 7 days and 28 days except for 5% of crumb rubber replacement at 7-days of age (Selvakumar and Venkatakrishnaiah, 2015). Study on the performance of concrete mix incorporating 5%, 7.5%, and 10% of discarded crumb rubber as fine aggregate showed that the water absorption increases when percentages of rubber as aggregates increases (Ganjian *et al.*, 2009).

III. MATERIALS AND METHODS

A. Materials

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

Ordinary Portland cement: Portland is widely used in the production of hydraulic-cement concrete. The ordinary Portland cement used in this study was sourced within Minna metropolis and conforms to BS EN 197- 1(2000)

Fine aggregate: Fine aggregate used in this study passes through a sieve size 4.75 mm and retained on sieve size 150 µm. Crumb rubber was used a partial replacement for sharp sand at varying percentages. Sharp sand was sourced from Gidan Mangoro, Minna, Niger state, Nigeria. The sample conforms to BS EN 12620 (2008). Crumb rubber made from torn tyre particles obtained by the decomposition of used tyres. Manufacturing of crumb rubber is a three-stage process involving, shredding, granulating and fine grinding.

Coarse aggregate: Bida natural gravel was sourced from Bida basin in Niger state. The stone is a by-product of the disintegration of parent rock, transportation and deposition of rock particles. The maximum aggregate size is 19 mm. The aggregate conforms to BS EN 12620 (2008).

Portable water: Portable water was used for this research. It was ensured that the water was clean and fit for drinking as recommended by BS EN 1008 (2002).

Figure I: Sample of Bida Natural Gravel (BNG)

Figure II: Sample of Crumb Rubber

B. Methods

The physical properties of the aggregates were determined using sieve analysis, specific gravity analysis, bulk density (compacted and uncompacted), and aggregate impact test. The slump of the fresh concrete was also determined and the effect of crumb rubber on its workability was investigated.

Specific gravity test: Specific gravity is the ratio of the density of a material to the density of distilled water at a temperature. The value of the specific gravity or relative density varies depending on the extent to which the pores contained absorb water at the time of testing. The test was conducted according to EN 12390-7 (2019)

Sieve analysis test: Gradation, surface tension and shape affects workability. Sieve analysis test was carried out to determine the particle size distribution of aggregate used in the concrete mix. The test was carried out in accordance to BS EN 12620 (2008). Dry sieve analysis method was used.

Bulk density test: Bulk density gives valuable information about the shape and grading of an aggregate. By using the distribution of aggregates within a unit volume, bulk density is useful in converting quantities in mass to quantities in volume. Compacted and uncompacted bulk density tests were carried out in accordance to BS EN 12620 (2008).

Aggregate impact value test: This test measures the resistance of the material to failure by impact. The impact value of an aggregate can be measured by subjecting a standard aggregate sample kept in a mould to fifteen blows of a metal hammer weighing 14 kg and falling through 38 cm. The quantity of finer materials passing through sieve 2.36 mm resulting from the pounding indicates toughness of the aggregate. The ratio of the weight of the fines formed to the weight of the aggregate in percentage, gives the aggregate impact value. The aggregate impact value test was carried out in accordance to BS EN 12620 (2008).

Concrete production: A mix ratio of 1: 1.65: 2.42 was used for cement content, fine aggregate and coarse aggregate respectively at a water-to-cement ratio of 0.45. the percentage replacement of fine aggregate with crumb rubber are 0%, 5%, 10%, 15%, 20% and 25%.

Slump test: The test is used to determine the resistance of fresh concrete to collapse under its own weight. It is very useful in detecting variation in the uniformity of mix of a given nominal proportion (Neville, 2000). The test was carried out in accordance to BS 1881: 102 (1983). To determine slump, fresh concrete was poured into the cone in three layers till the cone was full with each layers receiving 25 blows of the tamping rod. The excess concrete at the top was trimmed off with trowel. The slump cone was gently lifted upward and the slump cone was placed beside the slumped concrete. The difference between the highest point on the slumped concrete and the top of the slump cone was measured and recorded as the slump.

IV. RESULTS AND DISCUSSION

A. Results

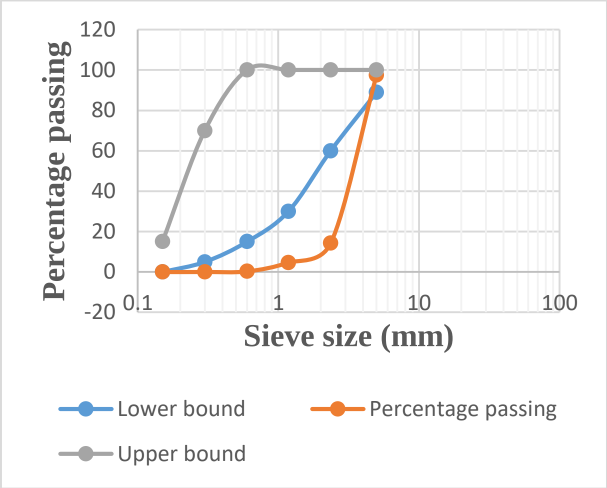

Figure III: Particle size gradation of sharp sand

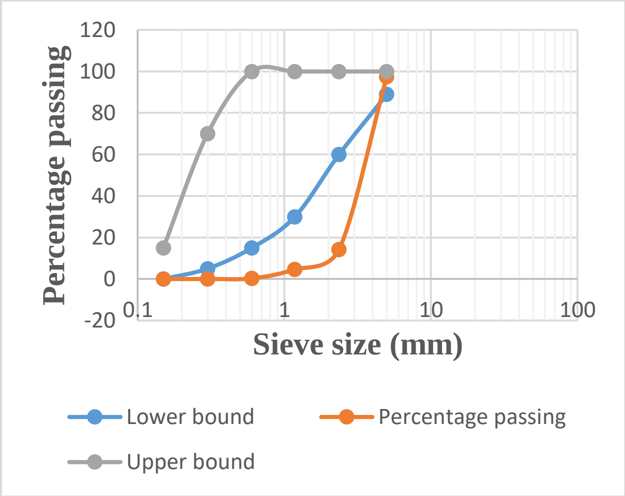

Figure IV: Particle size gradation of Crumb rubber

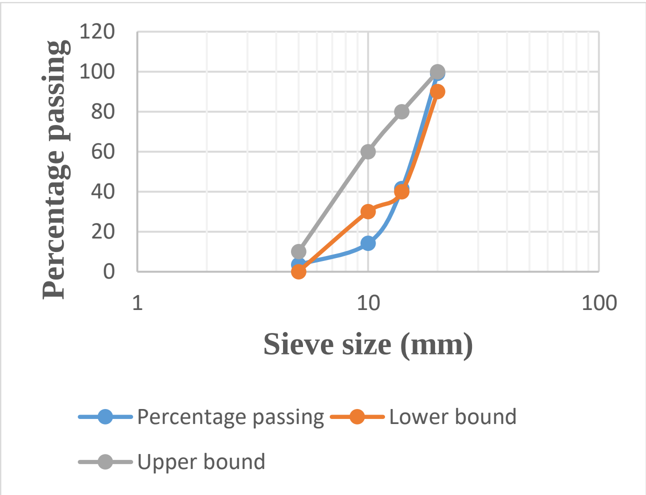

Figure V: Particle size gradation of Bida natural stone

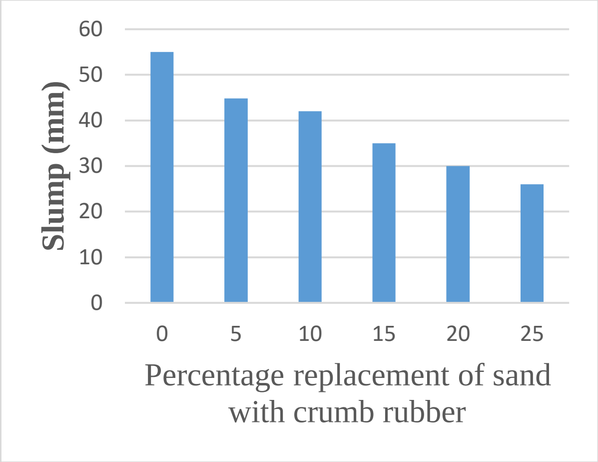

Figure VI: Slump of fresh concrete

Table I: Physical properties of aggregates

Parameters	Sand	Crumb rubber	Bida natural stone
Specific gravity	2.61	0.99	2.7
Bulk density (Compacted)	1451.01	531.01	1661.81
Bulk density (Uncompacted)	1346.18	502.00	1485.52
AIV	-	-	19.66

Table II: Slump of the fresh concrete

Percentage replacement of Sand with Crumb rubber (%)	0	5	10	15	20	25
Slump (mm)	55	44.8	42	35	30	26

B. Discussion of results

Physical properties of the aggregates: Table 1 shows a summary of physical properties of the aggregates used in their characterization. The specific gravities of the sand, gravel and crumb rubber are: 2.61, 2.71 and 0.99 respectively. The specific gravity of sand and Bida natural gravel classifies them as normal weight aggregate according to EN 12390-7 (2019). The values also fall within the specific gravity range for natural aggregates between 2.5 and 2.8 for use in concrete (Li, 2011). However, the specific gravity of crumb rubber is 0.99 which indicates that it is a light weight aggregate and is suitable for light weight concrete which is the intent of this study.

The uncompacted bulk densities of the sand, natural gravel and crumb rubber are 1346.18, 502.00, and 1485.52 kg/m^3 respectively. The compacted bulk densities of the sand, crumb rubber and natural gravel are 1451.01, 531.01, and 1661.81 kg/m^3 respectively. For the sand and natural gravel, the bulk densities fall within the acceptable limits. Bulk densities of natural aggregates used in concrete ranges between 1200 to 1750kg/m^3 (ACI, 2007). The bulk density of the crumb rubber compares closely to 432.59kg/m^3 obtained by Sulaiman *et al.*, (2020).

The aggregate impact value (AIV) of the coarse aggregate as presented in Table 1 is 19.66%. This value shall not exceed 25, 30 and 45% for concrete to be used in floors, pavements, and in other concretes respectively (Neville and Brooks, 2010).

Figures 1 and 2 show the particle size distribution curve for the sand and crumb rubber respectively. Both curves fall within the overall limit (lower and upper bounds) of well graded fine aggregates for concrete (BS 882, 2002). Figure 3 shows the particle size distribution curve of the Bida natural gravel. The curve falls slightly outside the limit for graded aggregates between 20 to 5mm (BS 882, 2002).

Slump of fresh concrete: Table 2 and Figure 4 shows the slump of the crumb rubber concrete. Highest slump value of 55mm was recorded at 0% replacement of sand with crumb rubber and the lowest slump of 26mm was recorded at 25% replacement. The slump is seen to decrease as the percentage replacement of sand with crumb rubber increases. This trend can be attributed to the absorbent nature of crumb rubber used in the production of the concrete. To cater for losses in water due to Crumb rubber content, water-to-cement ratio in concrete production containing crumb rubber can be increased between 0.55 and 0.60.

All the slump values fall within 25-75mm which classifies them as low workability concrete that can be used for mass concrete foundations without vibration, lightly reinforced concrete elements with vibration or roads vibrated by hand operated machines (Shetty, 2005).

V. CONCLUSIONS

The following are the conclusions from the research:

1. Crumb rubber is a light weight aggregate and can only be used in the production of light weight concrete.
2. Workability of fresh concrete decreases with increase in crumb rubber content in the mix. This suggests that a water-to-cement ratio higher than 0.45 should be used in the production of this type of concrete due to high absorption property of crumb rubber.
3. Crumb rubber can be used to produce low workability concrete for use in mass concrete foundations, lightly reinforced concrete elements and roads.

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