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Investigating the Durability Properties of Concrete Containing Crushed Glass and Shredded Tyre

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Abstract
Concrete is a durable construction materials which is widely used in construction and civil engineering works. Most countries around the world already device ways of recycling wastes products to replace and conserve natural resources used in producing concrete. This paper provides the performance of glass rubber concrete subjected to abrasion resistance and chemical resistance. The durability of concrete was assessed effectively by determining its abrasion resistance and chemical resistance. Cement, water, fine sand, gravel, crushed glass of 4.75mm and shredded tyre of 19mm were used as partial replacement in the composition of mix ratio of 1:2:4 with 0.50 water/cement ratio. 0% was the control and partial replacement was 5%, 10%, 15% and 20% by volume before using the aggregates to produce grade 25 concrete in (100x100x100) mm cube mould and was cured for 28 days. Physical and chemical properties, slump test, abrasion resistance and chemical resistance tests were carried out. Results show that slump decreases with increase in crushed glass and shredded tyre. 5% partial replacement has good abrasion resistance after 28 days of curing and 5% partial replacement produced high resistance to chemical resistance with 26.69 N/mm^2. Therefore, glass rubcrete shows potential for becoming an additional sustainable solution for waste recycling.

Keywords: Waste, Durability, Properties, Glassrubcrete

Introduction

Concrete is durable construction materials which is widely used in construction and civil engineering works. Most countries around the world already device ways of recycling wastes products to replace and conserve natural resources used in producing concrete. The use of scrap tyres will not only help in conserving natural resources, it will also help in replacing construction materials made from non-renewable resources (Yusuf, 2015).Concrete is one of the most widely and continuously used construction material world wide in which cement and aggregates are the most vital constituents. Further, these aggregates have been customarily treated as inert filler in concrete but in fact, aggregates not truly inert but its physical, thermal, and sometimes chemical properties influence the concrete. Due to tremendous demand of concrete as a construction material from the society, it is necessary to preserve the natural coarse aggregates by using alternative materials like recycled or waste materials. The management strategy for waste glass and waste tyres is recycling, which leads to minimising environmental impact as well as conservating of natural resources (Chandren, 2017).

In many countries around the world, the adverse environmental impacts of stockpiling waste tyres have led to investigate alternative options for disposal of waste tyres. The disposal of waste tyres has been found to be an environmental concern due to waste tyres resisting degradation. Waste tyres occupy large landfill spaces that contain nesting insects and rats. Stockpiles of tyres destined for landfill are also known to be flammable. One option to reduce this environmental concern is for the construction industry to consume a high amount of recycled tyres accumulated in stockpiles. About 3% of recycled tyres are used in civil engineering application, which is far below the range of 9% to 14% average civil engineering usage of recycled rubber in other developed regions of the world, such as the United States and Europe (Mohammadi, 2019).

Otunayo (2017), concluded that compressive strength increased up to a level of 20% replacement of fine aggregate with waste glass, at which point strength developed was 9% and 6% higher than control after 7 and 28 days respectively. This led to the conclusion that concrete containing up to 20% fine glass aggregate exhibits higher compressive strength development than normal concrete. Waste glass and waste tyre are non-degradable making them even more hazardous when they litter the environment. The need for safe disposal and the search for utility for unwanted glasses and tyres cannot be over emphasized, in order to stimulate a reduction of health risks and the conversion of waste to wealth (Garkida, 2007). The America Standard for Testing Material (ASTM) define scrap tyre as one which can no longer be used for its original purpose due to wear or damage, but has been disposed in such a manner that it cannot be used for any other purpose. Scrap tyres may have a further use as a raw material for other processes or be destined for final disposal. End-of-life tyres are called "scrap tyres" in some parts of the world. Tyres consist of a vulcanized rubber compound usually reinforced with steel and textile. Approximately 80% of the weight of car tyres is rubber compound which include carbon black which is usually used to strengthen the rubber and aid the process of wearing away by friction. Part of the carbon black may be replaced by silica in certain types of tyres; accelerator is an organic sulphur compound which increases the rate of vulcanization process and thereby enhancing the characteristics of the rubber; extender oil is a mixture of aromatic hydrocarbons. Softens the rubber and improve workability; sulphur is used to crosslink the polymer chains within the rubber and also to prevent excessive deformation at elevated temperature (Yusuf, 2015). Table I show a typical composition by weight of tyre.

Table I: Typical Composition by Weight of Tyre

Materials	Auto mobile Tyre (%)	Truck Tyre (%)
Natural rubber	14	27
Synthetic rubber	27	14
Carbon black	28	28
Steel	14 to 15	14 to 15
Fabric, filler, accelerators, antiozonants	16 to 17	16 to 17
	Average Weight (Kg)	
New Tyre	11.34	54.43
Waste Tyre	9.07	45.35

Glass is also one of the most popular materials due to progressive growth of urbanization nowadays, but increased production of glass causes also simultaneously the growth of glass wastes. Recycling of post-consumer glass for use as raw material in production of new glass is very limited, mainly due to the mixed-color nature of waste glass. In the sixties, many studies have been devoted to use crushed glass waste as an aggregate for concrete production and can be applied in road construction. The glass waste was also used for production of glass tiles and bricks, wall panels, glass fibre, agriculture fertilizer, landscaping reflective beads and tableware. The properties of glass seemed comparable to those of large aggregate in terms of constitution, strength and durability, and the larger size of the glass meant lower processing costs (Garkida, 2007). The assessment conducted in this paper hence highlights the performance of concrete containing crushed glass and shredded tyre. Section 2 show the materials and methods of the study. The acquired results is presented in Section 3 with a discussion of the results also provided in the same section. Section 4 concludes the study with some recommendations.

Materials and Method

The material that was used for this experimental research includes the following: Lime Stone Cement (OPC) Dangote brand. Fine aggregates was at saturated surface dry state having nominal maximum size of 4.75mm with average specific gravity (SSD) of 2.50 was used, it conformed to the requirements of British Standard, BS 882 (1992) specification. The coarse aggregate with average specific gravity (SSD) of 2.75 was used, having a maximum nominal size of 19mm (3/4 inch) to ensure that it conforms to British Standard, BS 882 (1992) specification. Water was obtained from the tank. The waste glass were collected from different locations, it was beneficiated by sorting, soaking, washing and drying.The waste glass was crushed using the dual-purpose waste glass processing machine (DPWGPM-STEPHEN17) passing through sieve 4.76 with specific gravity of 3.58. The waste tyres (truck tyre) were obtained and were shredded with a knife and an electric grinding machine at the Boondocks shoe accessories factory Kaduna State, it was sieved to obtain size 4.76 mm to 19 mm with specific gravity of 1.74. The mix design for concrete was based on the volume method. The mix ratio of cement, sand and gravel was 1:2:4. A number of cubes were casted and were kept for 24 hours before demoulded and immersed in fresh clean water for the required of curing at 7, 14 and 28 days respectively before testing. Table 3.1 show the quantity of materials of concrete.

Table III: Mix Proportion per Cube Specimen (100x100x100) mm of Concrete

Mix No	Mix Ratio	W/C Ratio	Rubber Aggregate		Cement (Kg/m^3)	Glass Aggregate		Fine Aggregate (Kg/m^3)		Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)
			(%)	(Kg)		(%)	(Kg)				
1	1:2:4	0.50	0	0	386	0	0		772	1544	193
2	1:2:4	0.50	5	21	386	5	40		732	1523	193
3	1:2:4	0.50	10	42	386	10	80		692	1502	193
4	1:2:4	0.50	15	63	386	15	120		652	1481	193
5	1:2:4	0.50	20	84	386	20	160		612	1460	193

The specific gravity of the fine aggregate (sand), coarse aggregate (gravel), fine glass aggregate and coarse rubber aggregate was determined using pycnometer method in accordance to American Society for Testing and Materials ASTM E975-13 (2015). The apparatus that was used are dry towel, weighing balance and pycnometer. The specific gravity of the aggregates was computed using:

$$\text{Specific Gravity (SSD)} = \frac{\mathrm{B}}{\mathrm{P+B+Ps}} ------------------ \mathbf{1}$$

B = Weight of (SSD) Sample of Air, P = Weight of Glass Jar + Distilled Water

Ps = Weight of Glass Jar + Course Aggregate + Distilled Water

X-ray Fluorescence (XRF) machine with a brand name Xenemetrix was used in carrying out the XRF analysis. The test was conducted in order to ensure that the materials conform to American Society for Testing and Materials ASTM E975-13 (2015). The processed waste glass and shredded tyre specimens were subjected to both elemental and compound test using the X-ray fluorescence spectrometry. The system is controlled by a PC running the dedicated Mini Pal analytical software.

British Standard, BS 1881: 102: (1983) specifies a method for determining the consistence of fresh concrete by the slump test, using apparatus such as slump cone, tamping rod. The cone was filled with fresh concrete in three layers and each layer was compacted with twenty-five tamps using the tamping rod. The cone was slowly raised and the fresh concrete was allowed to slump on its own weight. The slump was measured using the upturned cone and a straight flat wood was used as a guide. The value of the slump was obtained from the distance between the underside of the wood and the highest point on the surface of the slumped fresh concrete.

The density of the hardened concrete was in accordance with British Standard, BS 1881: Part 114: (1983) after 7 and 28 days of curing in water. The cube specimens were air dried with the thickness, length and breadth measured; the cubes were also weigh. The weigh was divided by the volume of the cube. Density is calculated by the relation:

$$\text{Density} = \frac{\text{W (Kg)}}{\text{V (m2)}} ---------------------------\mathbf{2}$$

Where: W = Weight of cube, V = Volume of cube

Each specimen was weighed and the values recorded as W1 before brushing its surface with a wire brush by applying constant pressure. Wire brushes attached with 3.5 Kg weight were used to stroke the surface of each specimen up to 60 times at uniform speed. The specimens re-weighed again and the value recorded as W2. The loss in weight was calculated by subtracting the final weight from the initial weight (W1 - W2). The result was expressed as loss in weight to original weight. The abrasion resistance was done after 7 and 28 days curing.

$$\%\ \text{weight loss} = \frac{\text{weight before (w)} - \text{weight after crusing}}{\text{weight before crushing}}\ \text{x}\ 100 --- --- \mathbf{3}$$

Concrete cube specimens of size (100 x 100 x 100) mm with 5%, 10% 15% and 20% partial replacement were cast and cured in 5% magnesium sulphate solution by volume. The curing was done for 7 and 28 days respectively. The cube specimens were air dry under sun light and the weight were recorded after which the specimens were subjected to compressive strength test and the results were recorded. The compressive strength tests of concrete specimen were determined according with British Standard, BS 1881: Part 116 (1983). Compressive strength is calculated by the relation:

$$\text{Compressive streght} = \frac{\text{Pmax}}{\text{A}} ----------------------- \quad 4$$

Where: P max = the maximum load that cube sustained (KN); A = the cross sectional area of the cube (mm^2).

Results and Discussion

Table IV shows the results of the specific gravity of fine aggregates, crushed glass, coarse aggregates and coarse tyre are 2.50, 3.58, 2.75 and 1.74 respectively. The results of the bulk density of fine aggregates, fine glass, coarse aggregates and coarse tyre are 1382, 1850, 1335 and 595 respectively. The normal bulk specific gravity - 2.4 to2.9, bulk density is 1520 to 1680 Kg/m^3. Light weight manufactured or natural, bulk density are less than 1120 kg/m^3, most commonly used in lightweight concrete, many must be screened to get the desired size distribution, and some must be crushed (Nemati, 2015).

Table IV: Physical Properties of Aggregates

Physical Properties	Aggregates			
	Fine Sand	Fine Glass	Granite	Coarse Tyre
Bulk Specific Gravity (SSD)	2.50	3.58	2.75	1.74
Bulk Density (kg/m^3)	1382	1850	1335	595

Table V show the chemical composition for crushed glass and shredded tyre. The result showed that the XRF machine used for the chemical analysis was able to detect the major oxides of the processed waste glass (PWG) (i.e. SiO_2, CaO, Al_2O_3 and MgO) with percentage value of 73.025%, 20.011%, 2.487% and 1.324% (summing up to 96.847%) respectively. PWG has high content of silicon and base on the periodic table of element, silicon is in metalloid group. While the major oxides composition of the shredded tyre (i.e. C, Zn, Si and O) with percentage value of 41.31%, 19.04%, 15.06% and 10.09% (summing up to 85.5%) respectively. Shahidan et al (2021), opined that ST has high carbon content compared to gravel. Carbon is in non-metal group in periodic table of element. Tyres are made from 25% rubber hydrocarbon and 35% carbon black makes the major components in rubber crumb is carbon. Therefore, with the values of the major components exceeding 50% as per requirement, crushed glass and shredded tyre therefore can be used as partial replacement of fine aggregates and coarse aggregates.

Table V: Chemical Composition of Processed Crushed Glass and Shredded Tyre

Concentration (%)				
	S/N	**Compounds (%)**	**Crushed Glass**	**Shredded Tyre**
	1	SiO_2	73.025	-
	2	O	-	10.098
	3	Fe_2O_3	0.993	-
	4	C	-	41.311
	5	S	-	5.683
	6	CaO	20.011	4.564
	7	MgO	1.324	-
	8	Al_2O_3	2.487	-
	9	Zn	-	19.041
	10	Ca	-	3.262
	11	Si	-	15.065

Figure 1 shows that the 0% (control) concrete mix was more workable than the mixes with varying partial replacement from 5% to 20%; indicating 37.5% decrease in slump. Mohammed (2016), also noted that slump has been decreased due to increase in percentage of rubber aggregates in all samples of concrete mix. The addition of crushed glass to the concrete mix was found to decrease concrete slump (Otunayo et al, 2017). Also, Sulago et al (2016) opined that the workability reduces because of the proper bonding between the glass, rubber and cement paste.

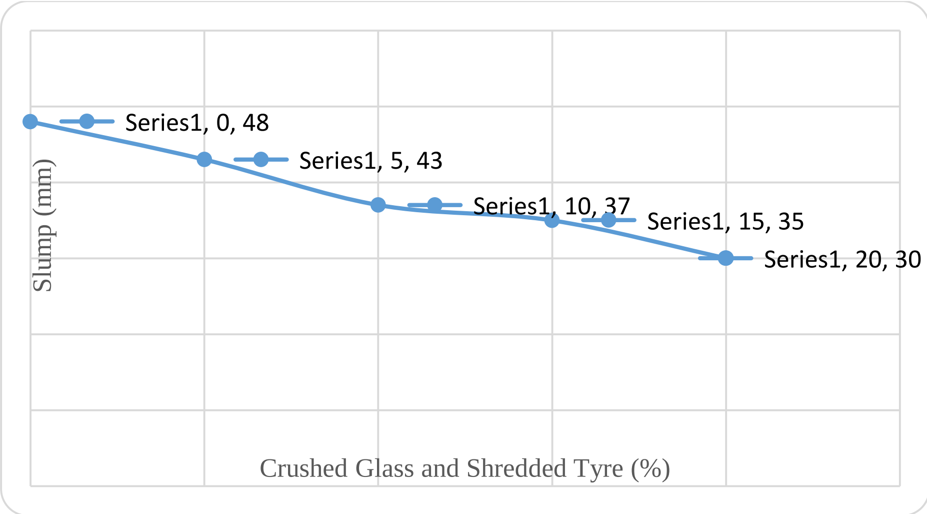

Figure 1: Slump of the Control and Glass Rubber Mix

It was discovered that in Figure 2 the inclusion of crushed glass and shredded tyre aggregates in the concrete mix decreased the unit weight of the fresh concrete mix from 2,230g/m^3 in 0% (control) to 2,080g/m^3 with glass rubber aggregate of 20%. Wakili et al (2018), opined that the replacement of natural aggregates with rubber aggregates tends to reduce the density of the concrete. This reduction is attributable to the lower unit weight of rubber aggregate compared to ordinary aggregate. But at 28 days of curing 5% partial replacement of crushed glass and shredded tyre concrete has density than 0% (control) and it could be due to the bulk density of crushed glass which is higher than the fine sand.

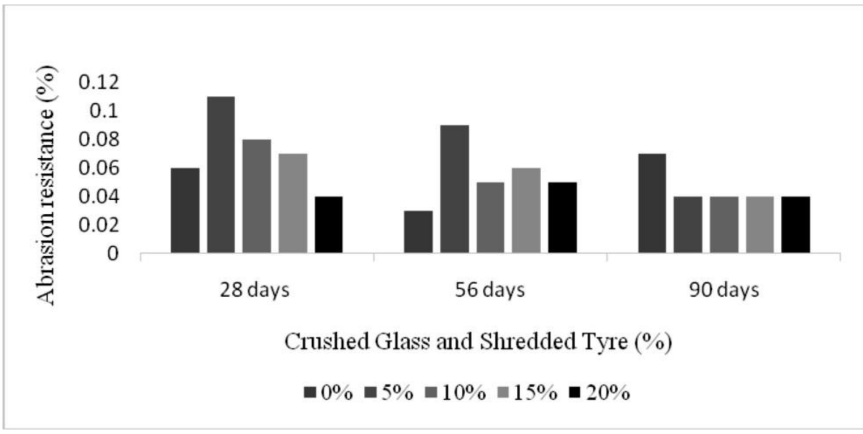

Figure 2: Abrasion Resistance Test

Figure 2 shows that at 28 days 5% partial replacement of crushed glass and shredded tyre recorded the highest strength with 26.69 N/mm^2, 0% has 26.03 N/mm^2 while 20% partial replacement of crushed glass and shredded tyre recorded the lowest strength with 18.67 N/mm^2. The specimen cured in magnesium sulphate also gave higher strength at 5% partial replacement. The compressive strength of cube cured in $MgSO_4$ is compared with that of cube cured conventionally. In this the maximum strength is also obtained at 5% replacement with glass powder (Venkatraman, 2017).

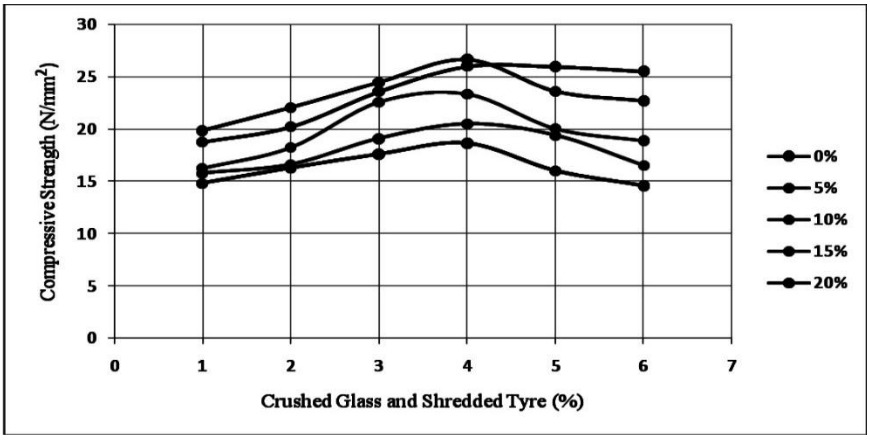

Figure 3: Compressive Strength of Glass Rubber Concrete Exposed to Magnesium Sulphate

Conclusion

This study concluded that fine aggregate (sand) and coarse aggregate (gravel) were successfully replaced partially with processed crushed glass and shredded tyre. The glass rubber concrete was potentially produced and improved physicochemical, workability and durability properties. Therefore crushed glass and shredded tyre have proved to be potential alternative sustainable materials to fine sand and gravel for building and construction application in the world.

Recommendations

i. It is recommended that glass rubber concrete should be applied in building applications where there is need for light weight structures; due to the low density of the concrete.
ii. Because of the high strength of glass rubber concrete in some mechanical properties like compressive strength, the application can be used for some structural, non-structural and low load applications such as slabs, partition and concrete blocks e.t.c.
iii. The utilization of crushed glass and shredded tyre aggregates for the production of concrete, can reduce the use of raw materials such as river sand, broken rocks.

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