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The Use of Waste Glass Cullet (WGC) and Waste Tyre Crumb (WTC) As Fine Aggregate in Concrete Production for Rigid Pavement

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Abstract : - This paper reports the findings of using Waste Glass Cullet (WGC) and Waste Tyre Crumbs (WTC) as partial replacement of fine sand in concrete for rigid pavement construction. The performance of WGC and WTC in concrete were investigated by the following laboratory tests: slump, compressive strength (at 7, 28, 56 and 90 days curing), and flexural strength (at 7 and 28 days curing). The parameters varied in this study were the Waste Glass Cullet at 10% and 20% replacements of fine sand and Waste Tyre Crumbs at 5%, 10%, 20% and 30% replacement. The concrete design mix ratio adopted was 1:0.8:2.4 with water-cement ratio of 0.35. The test results obtained revealed that concrete containing Waste Glass Cullet (WGC) and Waste Tyre Crumbs (WTC) significantly improved in compressive strength at both 28days and 90days curing, with optimum results achieved at fine aggregate proportioning of 10% WGC, 5% WTC and 85% river sand also at 10% WGC, 10% WTC and 80% Sand. The former proportioning improved in strength by 18.69% and 44.53% (at 28days and 90days curing respectively) while the latter improved in strength by 8.71% and 45.45% (at 28days and 90days curing respectively).

Keywords: - Alkali-Silica Reaction, Compressive Strength, Flexural Strength, Waste Glass Cullet, Waste Tyre Crumb

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I. INTRODUCTION

Engineering and construction activities consume, on average, 40% of the total global resource expenditure or 3 billion tons of raw materials [1]. With this in mind, sustainability is becoming increasingly important topic in the field of engineering and construction. Hence it has become very important to examine the design and construction process in the hopes of discovering more sustainable options.

Concrete is one of the most commonly used material in building and rigid pavement construction because of its versatility, durability and compressive strength. Concrete is made from a mixture of four main raw materials including fine and coarse aggregates, cement and water. It is evident, by examining the general design of concrete mixtures, that portions of the raw material used in concrete design can be replaced with recycled materials.

Glass is a transparent material produced by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperature followed by cooling, where solidification occurs without crystallization.

Glass makes up a large component of household and industrial waste due to its weight and density. The glass component in municipal waste is usually made up of bottles, broken glassware, light bulbs and other items. A recent study carried by the Bayero University Kano Consultancy Unit [2] estimated that 8.7% of the total waste generated in Nigeria are made of glass. The amount of waste glass has gradually increased over the years due to an ever-growing use of glass products with most of the waste glasses being dumped into landfill sites. The land filling of waste glasses is undesirable because they are also non-biodegradable, which makes them environmentally less friendly. Therefore, using waste glass in the concrete construction sector is advantageous, as the production cost of concrete will go down and its environmental effects will be reduced.

Waste glass shares very similar characteristics with the sand traditionally used in concrete works but the applications are limited due to the damaging expansion and cracks in the concrete caused by Alkali-Silicon Reaction (ASR) between high-alkali pore water in cement paste and reactive silica in the waste glasses [3]. The chemical reaction between the alkali in Portland cement and the silica in glass forms silica gel that not only causes crack upon expansion, but also weakens the concrete and shortens its life [4].

Polypropylene fibers are used to minimize cracks in concrete structures, therefore, tyre crumbs may have similar characteristics and can be used to minimize the expansion and cracks caused by ASR.

Waste tyres are the tires removed from automobiles and trucks. The use of vehicles is on the increase, thus, the amount of waste tyre rubber is increasing. This creates a major problem for the earth and their livings. For this issue, the easiest and cheapest way of decomposing of the rubber is by burning it. This creates smoke pollution and other toxic emission. It also creates global warming. Currently, 75-80% of scrap tyres are buried in landfills. Only 25% or fewer are utilized as fuel substitute or as raw material for the manufacture of a number of miscellaneous rubber goods. Burying scrap tyres in landfills is not only wasteful, but also costly. In order to reuse waste tire rubber effectively, one of the possible solutions is to incorporate it into cement-based material. Partial replacement of mineral aggregates in concrete with waste tire rubber could control environmental pollution and save sandstone resources [5], [6]. Fattuhi and Clark [7] also suggested that scrap tyres could possibly be used where vibrations damping is needed, such as in foundation pad for machinery, and in railway stations, for trench filling and pipe bedding, pile heads and paving slabs and where resistance to impact or blast is required such as in railway buffers, jersey barriers and bunkers.

There is therefore huge potential for using waste glass and waste tyre crumbs in the concrete construction sector. When these wastes are reused in making concrete products, the strength of concrete can be improved, effect of Alkali Silica Reaction in concrete can be eliminated as a result of the waste tyre crumb, the production cost of concrete will go down and the problem of disposal of these non-biodegradable wastes which causes environmental hazards will significantly reduce.

II. MATERIALS AND METHODS

A. Materials

Ordinary Portland cement

The Dangote 3X Portland cement was used as a binder. This was sourced locally.

Waste Glass Cullet (WGC)

Waste glass were obtained and ground into cullet passing the 4.75mm sieve.

Plate 1: Waste Glass Cullet (WGC)

Plate 2: Waste Tyre Crumb (WTC)

Waste Tyre Crumb (WTC)

Tyre crumb with the particle size passing the 0.425mm sieve was used for this study. They were procured from Tensquare Engineering Limited, Lagos, Nigeria at no cost.

Fine Aggregate (River Sand)

The sand used passed the 4.75mm sieve and was determined to be within the specified requirement for fine aggregates in accordance with ASTM C136.

Coarse Aggregate (Granite)

For this study, 20 mm maximum nominal size granite aggregate was used.

B. Methods

The laboratory tests conducted are presented in Table 1.

TABLE 1: Laboratory Tests Conducted

Mix ID	Material/ Combination	Laboratory Test
	Cement, Sand, WGC, WTC and Coarse Aggregate	• Sieve Analysis (Sand, and WGC only).

		• Specific Gravity
M1	0% WGC + 0% WTC + 100% Sand (Control Sample)	• Workability (Slump test) • Compressive Strength, cube tests (7days, 28days, 56 days and 90days) • Flexural Strength, cylindrical beam tests (7days and 28days)
M2	10% WGC + 0% WTC + 90% Sand	
M3	20% WGC + 0% WTC + 80% Sand	
M4	10% WGC + 5% WTC + 85% Sand	
M5	10% WGC + 10% WTC + 80% Sand	
M6	10% WGC + 20% WTC + 70% Sand	
M7	10% WGC + 30% WTC + 60% Sand	
M8	20% WGC + 5% WTC + 75% Sand	
M9	20% WGC + 10% WTC + 70% Sand	
M10	20% WGC + 20% WTC + 60% Sand	
M11	20% WGC + 30% WTC + 50% Sand	

Mix Proportion

In this research, 132 cubes and 66 beams were cast. Concrete was prepared by replacing fine sand with WGC and WTC. A Grade 40 concrete using mix ratio of 1:0.8:2.4 by weight was adopted with water/cement ratio of 0.35. The mix proportions are summarized in Table 2.

TABLE 2: Mix Proportions of M40 Grade with W/C of 0.35

Mix ID	**Water (Kg/m^3)**	**Cement (Kg/m^3)**	**Sand (Kg/m^3)**	**WGC (Kg/m^3)**	**WTC (Kg/m^3)**	**Coarse Aggregate (Kg/m^3)**
M1	188.17	537.63	430.10	0	0	1290.31
M2	188.17	537.63	387.00	43.10	0	1290.31
M3	188.17	537.63	343.90	86.20	0	1290.31
M4	188.17	537.63	365.45	43.10	21.55	1290.31
M5	188.17	537.63	343.90	43.10	43.10	1290.31
M6	188.17	537.63	300.80	43.10	86.20	1290.31
M7	188.17	537.63	257.97	43.10	129.03	1290.31
M8	188.17	537.63	322.35	86.20	21.55	1290.31
M9	188.17	537.63	300.80	86.20	43.10	1290.31
M10	188.17	537.63	257.70	86.20	86.20	1290.31
M11	188.17	537.63	214.87	86.20	129.03	1290.31

III. RESULTS AND DISCUSSION

Sieve Analysis

The results of the sieve analysis carried out on sand and WGC are presented in Fig 3.

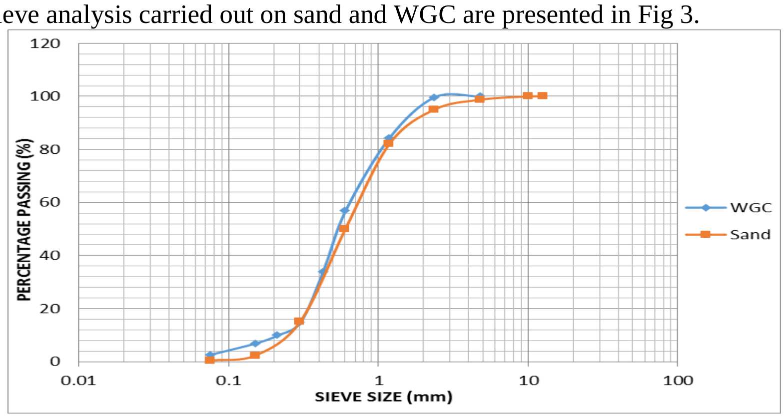

Fig. 1: Particle-Size Distribution Curve of WGC and Sand

The Coefficient of Uniformity C_u, the Coefficient of Curvature C_c and Fineness Modulus of the sand used are 3.00, 0.85 and 2.56 respectively which indicate that the sand is Uniformly Graded and fine [8].
The Coefficient of Uniformity C_u, the Coefficient of Curvature C_c and Fineness Modulus of WGC used are 2.60, 0.98 and 3.03 respectively which indicates that the WGC is Uniformly Graded and coarse [8].

Effect of WGC and WTC on Workability (Slump Test)

From Fig. 4, it is observed that workability decreases with addition of Waste Glass Cullet (WGC) and Waste Tyre Crumb (WTC). The reduction in slump can be attributed to the irregular shape of the WGC particles and their large surface area which traps more air within the concrete as well as the reduction in the density of concrete due to the increase of the air content by the incremental presence of WTC or to actual changes in the yield value and plastic viscosity of the mixture, causing workability to reduce as WGC and WTC are incrementally added.

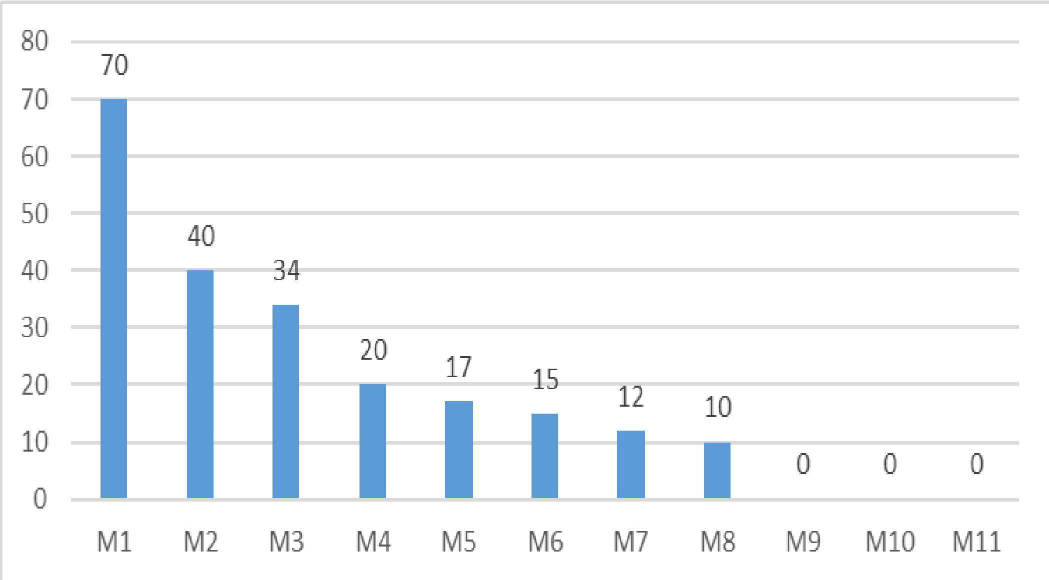

Fig. 2: Variation of Slump of Concrete for The Different Sample Mixes

Effect of WGC and WTC on Compressive Strength

The recommended compressive strength for rigid pavement is 35-40N/mm^2 at 28 days [9]. From the results as presented in Fig. 5, the recommended compressive strength was satisfied by all the mixes (M1 to M11) but with maximum strength observed at mix 4 (M4: 10% WGC + 5% WTC + 85% Sand) which is 18.69% increment compared to control sample M1. This increment can be attributed to the pozzolanic effect of WGC. Also, WGC has a denser gradation than sand, which suggests more of the air voids would be filled by the WGC resulting in a stronger compressive strength. The compressive strength increased at the 56th day curing for all mixes but decreased after 90 days for mixes 2 and 3 which contained 10% and 20% WGC respectively. The decrease in compressive strength after 90 days for mixes 2 and 3 are due to the detrimental effect of Alkali Silicon Reaction (ASR). This proves that compressive strength slowly degrades overtime after 90 days for mixes containing WGC only. It is also observed that the inclusion of WTC eliminated the detrimental effect of Alkali Silicon Reaction (ASR) and ensured continuous increase in strength even after 90 days with maximum strength attained at mix 5 (M5: 10% WGC + 10% WTC + 80% Sand) which is 45.45% increment compared to control sample M1 at 90 days.

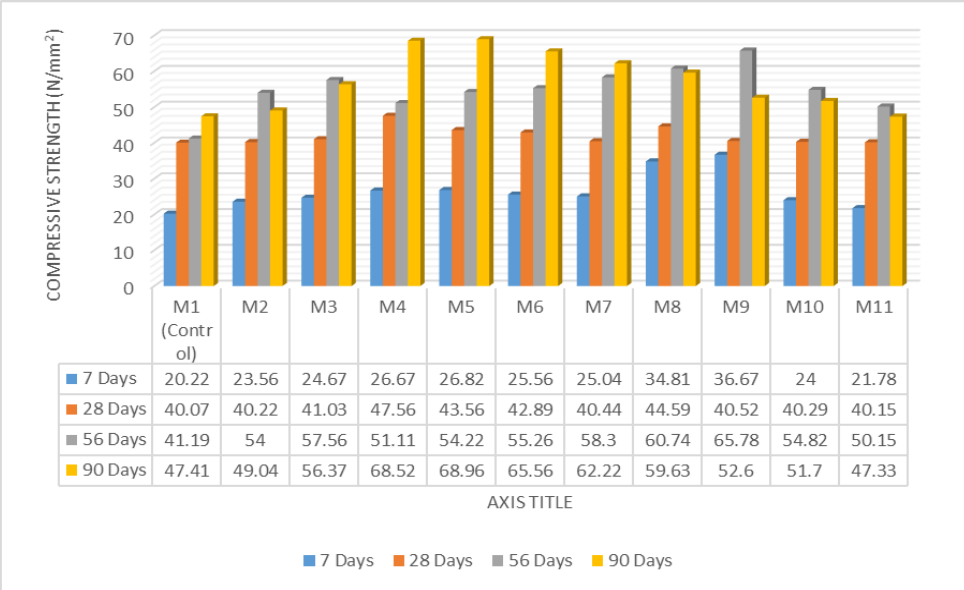

Fig. 3: Bar Chart Showing Compressive Strength of Samples at Different Curing Days

Effect of WGC and WTC on Flexural Strength

The recommended flexural strength for rigid pavement is 3.5-4.0N/mm^2 at 28 days [9]. The results obtained, as presented in Fig. 6, show that the recommended flexural strength was satisfied by all the mixes (M1-M11) but with maximum strength observed and maintained at the control mix. The reduction in flexural strength for mixes 2 to 11 (M2-M11) as compared to concrete mix M1 may be due to lesser bonding ability of the WGC and WTC compared to natural sand in the concrete mixtures.

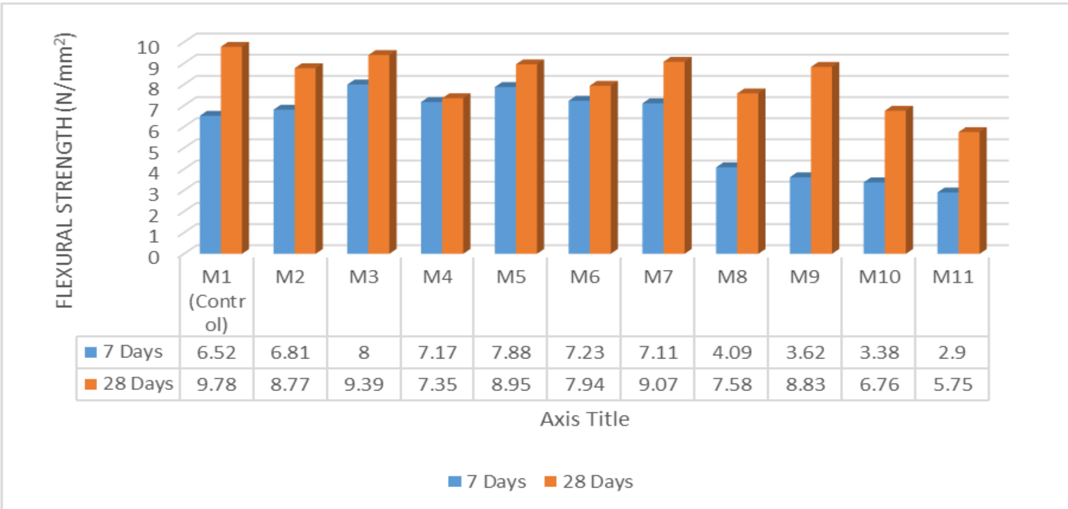

Fig. 4: Bar Chart Showing Flexural Strength of Samples at Different Curing Days

Analysis of Variables (ANOVA)

One-way ANOVA analysis was used to express the differences between the recommended compressive strength and flexural strength and those obtained from the laboratory tests carried for the different samples. This analysis as shown in Tables 3-5 will confirm if the Waste Tyre Crumbs (WTC) and Waste Glass Cullet (WGC) are structurally adequate for rigid pavement construction.

TABLE 3: Compressive and Flexural Strength for The Different Samples

MIX ID	**COMPRESSIVE STRENGTH**		**FLEXURAL STRENGTH**	
	RECOMMENDED STRENGTH AT 28 DAYS (N/mm^2)	OBTAINED STRENGTH FOR THE MIXES (N/mm^2)	RECOMMENDED STRENGTH AT 28 DAYS (N/mm^2)	OBTAINED STRENGTH FOR THE MIXES (N/mm^2)

M1	40	40.07	4.0	9.78
M2	40	40.22	4.0	8.77
M3	40	41.03	4.0	9.39
M4	40	47.56	4.0	7.35
M5	40	43.56	4.0	8.95
M6	40	42.89	4.0	7.94
M7	40	40.44	4.0	9.07
M8	40	44.59	4.0	7.58
M9	40	40.52	4.0	8.83
M10	40	40.29	4.0	6.76
M11	40	40.15	4.0	5.75

TABLE 4: Summary Output of ANOVA for Compressive Strength

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	9	360	40	0		
Column 2	9	381.1	42.34444	6.429628		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	24.73389	1	24.73389	7.693723	0.013555	4.493998
Within Groups	51.43702	16	3.214814			
Total	76.17091	17				

TABLE 5: Summary Output of ANOVA for Flexural Strength

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	10	40	4	0		
Column 2	10	80.39	8.039	1.383188		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	81.56761	1	81.56761	117.9415	2.47E-09	4.413873
Within Groups	12.44869	18	0.691594			
Total	94.0163	19				

From the results obtained, it is observed that F is greater than F*crit* in all cases. This shows that the mean of the population is not equal and that there is significant difference between the recommended compressive and flexural strengths and that obtained from the different mixes. It is then safe to conclude that Waste Tyre Crumbs (WTC) and Waste Glass Cullet (WGC) are structurally adequate for rigid pavement construction.

Comparative Cost Analysis

Having determined from the statistical analysis, that Waste Tyre Crumbs (WTC) and Waste Glass Cullet (WGC) are structurally adequate for rigid pavement construction, the next stage is to determine whether there is cost advantage in its usage. In order to carry out the cost analysis, mix M7 is used, which contains 10% WGC and 30% WTC and possessed compressive strength of 40.44N/mm^2 and 62.22 N/mm^2 at 28days and 90 days respectively as against 40.07 N/mm^2 and 47.41 N/mm^2 at 28days and 90 days respectively for control mix. The production cost of the concrete used in this work is calculated from the cost of each of the constituents for the concrete, and presented in Tables 6 to 8.

TABLE 6: Production Cost for The Control Specimen Per m^3

S/N	**Materials**	**Quantity (kg)**	**Unit Cost (N)**	**Total Cost (N)**
1	Cement	537.63	2800/50kg	30,800
2	Sand	430.10	40,000/5000kg	3,440.80
3	Granite	1290.31	140,000/30,000kg	6021.45
4.	Labour			7,500
Total (Production Cost)				**47,762.25**

TABLE 7: Production Cost for Mix M7 Per m^3

S/N	Materials	Quantity (kg)	Unit Cost (N)	Total Cost (N)
1.	Cement	537.63	2800/50kg	30,800
2.	Sand	258.06	40,000/5000kg	2064.48
3.	Granite	1290.31	140,000/30,000kg	6021.45
4.	Waste Glass Cullet	43.01	20/kg	860.20
5.	Waste Tyre Crumb	129.03	1200/1000kg	154.84
6.	Labour			7,500
Total (Production Cost)				**47,400.97**

TABLE 8: Summary of Cost Analysis Per m^3

Specimen	Production Cost (N)
M1 (Control Sample)	**47,762.25**
M7 (10% WGC + 30% WTC + 60% Sand)	**47,400.97**
Cost Reduction	**361.28**
% Cost Reduction	**0.77%**

From the Table 8, it can be seen that there are economic benefits to be derived from the use of WGC and WTC in concrete construction in addition to its environmental benefits. The cost reduction of 0.77% per m^3, when translated to highway construction of lengthy kilometers and its maintenance, will have significant savings monetarily.

IV. CONCLUSIONS

From the results obtained, the following conclusions have been drawn:

- From the slump test, Waste Glass Cullet (WGC) and Waste Tyre Crumb (WTC) reduces workability with increment in their contents.
- The partial replacement of sand with WGC and WTC increased the compressive strength of the concrete when compared to the control concrete sample.
- At 28days, mix M4 which contained 10% WGC and 5% WTC gave the highest strength but at 90days, mix M5 which contained 10% WGC and 10% WTC gave the highest strength.
- The compressive strength of concrete containing WGC only reduced as it approached 90days which confirms the deteriorating effect of Alkali-Silica Reaction (ASR) on concrete containing WGC only.
- The inclusion of WTC reduced the effect of ASR on the concrete and ensured continuous increase in strength. However, WTC was ineffective in reducing the effect of ASR at WGC content greater than 10%.
- Concrete containing WGC and WTC had satisfactory flexural strength, although they were observed to be lower than that of the control concrete sample.
- The ANOVA analysis confirmed that WGC and WTC are structurally adequate for rigid pavement construction with optimum result derived at fine aggregate proportioning of 10% WGC, 10% WTC and 80% Sand.
- The inclusion of WGC and WTC proved to be economically advantageous over conventional concrete.
- The results showed that WGC and WTC are viable options in partially replacing Sand with environmental benefits, as it provides an alternate and effective solution to the disposal of glass and tyre wastes and as well conserve our natural resources.

RECOMMENDATIONS

In view of the results presented, the following are recommended:

- Field testing to evaluate the pavement performance of rigid pavement containing Waste Glass Cullet (WGC) and Waste Tyre Crumb (WTC) when subjected to traffic loading.
- Highway and Transportation agencies should seek to conserve our natural resources by utilizing non-biodegradable wastes such as waste glass and tyre crumbs.

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