Workability, Compressive and Tensile Split Strength Behavior of Blue Gum Ash Glass Concrete

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Abstract- This research work investigated the plastic and hardened mechanical properties of concrete made using crushed glass as part of fine aggregates and blue gum ash dosed in the concrete. The blue gum ash cement was prepared by dosing Ordinary Portland cement (Power plus 42.5N) with blue gum ash at 0%(control), 0.5%, 0.75%, 1.0%, 1.25% and 1.5% by weight of cement and crushed glass used to partially replace river sand at 10% by weight of the fine aggregates for vibrated concrete, design mix of class 25. In order to achieve good workability, the best blue gum ash content was maintained at 1.0% and crushed glass content of 10%. For good compressive strength results of blue gum ash glass concrete, up to 10% crushed glass replacement in fine aggregates with 1.0% blue gum ash proportion in concrete attained the highest strength than the control (glass concrete only) achieving strengths of 27.8N/mm^2 and 30.1N/mm^2 at 7 days and 28 days respectively.
The mathematical relationship between the compressive strength (Fcu_{28}) at 28 days and the corresponding tensile split tensile strength (Ft_{28}) at 28 days of blue gum ash glass concrete was found to be a binomial relationship of the Equation

$$Fcu28 = 16.253Ft28^2 - 82.567Ft28 + 136.68$$

Index Terms- Blue gum ash, crushed glass, workability, compressive strength, tensile split strength

I. Introduction

Concrete has unlimited opportunities for innovative applications, design and construction techniques. Its great versatility and relative economy in filling wide range of needs has made it is very competitive building material.
Due to the increasing price, demand and consumption of cement, researchers and scientists are in search of developing alternatives to aggregates and binders, which are eco-friendly and contribute towards waste management. One of these alternatives to cement is blue gum ash (BGA). In previous studies, Rajabipour (2012) explains that concrete made through the replacement of river sand with glass aggregates demonstrated poor workability, which resulted in inefficient compaction and low strengths. Alkali Silica Reaction (ASR) was noted to be affecting most aggregate particle sizes. Ranagaraju and Afshinnia, (2015) showed that the finer the glass is crushed, the more the ability to resist ASR effect particularly when used as an aggregate replacement material, both in the case of crushed glass and natural reactive aggregates. From the manufacturer's brochure of Power plus cement (42,5N), this CEM 1 type of cement has low alkali (Na_2O equivalent<0.6%) to guard against alkali aggregate reaction in concrete and that's why it was used in the research.

Wood ash exhibits a specific gravity of 2.13 and bulk density of 810kg/m^3, (Campbell & Etiegni, 1991). These properties depend on type and source of wood, design, boiler combustion temperature and collection technique. (Tarun and Rafat, 2014) reported the following elements in wood ash: carbon (5% to 30%), calcium (5% to 30%), carbon (7% to 33%), potassium (3% to 4%), magnesium (1% to 2%), phosphorus (0.3% to 1.4%), sodium (0.2% to 0.5%)and silica (4 to 59%). Samples stored in humid and dry environments, compressive and flexural strength were measured and the microstructure examined using SEM analysis (Tarun and Rafat, 2014).
Methods for proper mixture proportioning to achieve desired strength and workability have not been established and the effects of glass, sand and blue gum ash on fresh and hardened properties of concrete are unknown. This project was aimed at bridging such knowledge gaps.

II. Materials and Methods

1.1 Materials

Wood ash from blue gum was obtained from Tegat and Toror Tea Factories in Kericho county. Blue gum ash is a waste from boiler chimney, got from burning blue gum to produce steam in electricity generation process. Waste glass was obtained from Juja town, in Kenya. The other materials; Ordinary Portland cement (Power Plus 42.5N) satisfying BS12:1991 and KS-18-1: 2000 of 28 days' strength; 42.5N/mm^2 was used. River sand obtained from Machakos county and ballast obtained from Aristocrats Concrete Limited quarry in Mlolongo which control its ballast source due to consistency quality of its products in Kenya.

1.2 Methods

Wood ash from blue gum was obtained from Tegat and Toror Tea factories in Kericho county, was dried and sieved to ensure that only particles passing 0.075mm were collected for this study so as to conform with the maximum size of cement and eliminate the constituents of fine aggregates. Waste glass was obtained from Juja town, Kenya at selected collection points. Once the waste glass was obtained, it was crushed manually and reduced to 5mm grains and below as per BS882:1992. The type of glass which was used was clear float glass of 4mm thick which is visually colorless and distortion free glass, providing high light transmission (daylight) and clarity. The crushed glass was used as partial replacement material for river sand at 10% by weight.

The ballast consisted of crushed stone mixed in a ratio of 1:2 for 10mm and 20mm single aggregate size in accordance with building research establishment BRE (1988).
The results of the specific gravity of river sand and crushed glass were found to be 2.5 and 2.4 respectively. The specific gravity of sand was found to be within the range of 2.63 and 2.70 as per BS1097-6 (2013); hence adequate. Also, the specific gravity of sand provided by Firm.net (2017) are a minimum of 2.4 and a maximum of 2.8 thus the test result was found to be credible for use in this research. The bulk density results for ballast, river sand and crushed glass were 1405kg/m^3, 1563kg/m^3 and 1414kg/m^3 respectively. According to BS 812-2 (1990), the approximate bulk density of aggregates commonly used in normal-weight concrete ranges from about 1200 to 1750 kg/m^3. The result for the bulk density of blue gum ash was found to be 798kg/m^3, while the bulk density of Ordinary Portland cement (Power plus 42.5N) has been found to range between 800 – 1000kg/m^3 so it was approximately within the range hence suitable admixture material.
The silt content results of river sand and crushed glass were found to be 2.24% and 5.58% respectively. It is recommended to wash the sand or reject if the silt content exceeds 6% (BS 812: Part 1: 1975), hence the results were satisfactory within the limit required.
Sieve analysis of river sand, crushed glass and ballast were done according BS812 (1985) and all the aggregates fell within the grading envelope indicating that they were within the acceptable limits.
For comparison between grading for river sand and crushed glass, Figure 1 below was used to show the similarities between the two materials for the research work.

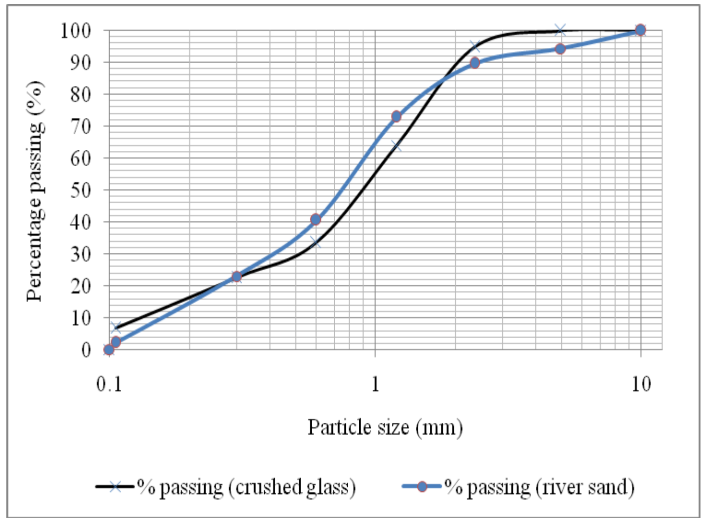

Figure 1: River sand and glass grading curves

From Figure 1 above, crushed glass and river sand grading curves were behaving in a similar manner for their individual particle size distribution. River sand was found to have more particles passing through 600µm than crushed glass. Also, the material passing sieve 150µm was more in glass at 12% compared to sand at 8%. This explained the difference in curve formation between the two materials for fine aggregates but generally the materials were suitable for use in the research. The grading curve for the coarse aggregates is as shown in Figure 2 below.

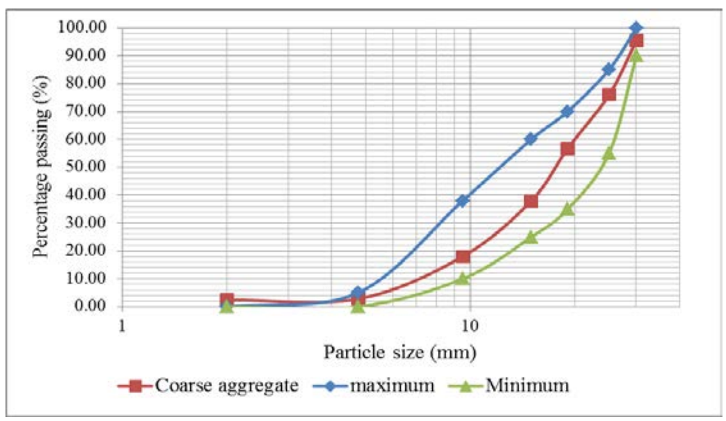

Figure 2: Coarse aggregate grading

From the aggregate curves in Figure 2 for coarse aggregates, most of the aggregates were found to lie within zone two and were within the required limits as given in BS812:103-1. (1985), hence they were recommended for use in the research work.
In determination of the workability and compressive strength effects of blue gum ash glass concrete, concrete mix of the ratio 1:1.5:3 was used where the batching was done by weight. The blue gum ash cement was prepared by dosing Ordinary Portland cement (Power plus 42.5N) with blue gum ash at 0%(control), 0.5%, 0.75%, 1.0%, 1.25% and 1.5% by weight of cement and crushed glass used to partially replace river sand at 10% by weight of the fine aggregates.

The slump test was performed according to BS EN: 12350: 2009 whereby the standard slump cone was filled with concrete in four layers, rodding 25 times per layer, then lifting the cone and measuring the extend to which the concrete collapsed. The concrete collapse (slump) was maintained between 10 – 25 mm as required for vibrated concrete. This was done for each blue gum dosage of 0% (control), 0.5%, 0.75%, 1.0%, 1.25% and 1.5% for cement in glass concrete production.
Compressive strength test was done to determine the strength of the hardened glass concrete containing blue gum ash. It was done in accordance to BS EN: 12390: 2000, whereby samples containing different dosages of blue gum ash were casted in moulds of internal dimensions of 150x150x150mm. Then the compressive strengths at 7, 14, 21, 28 and 90 days were determined by crushing the samples in a universal testing machine as shown in Figure 3(a) below. For each proportion, three cubes were casted and the average taken.

a) Cube after testing

Figure 3: Crushed cube after testing

III. Results and Discussion

In Table 1 below, 25GCBGA XX-YY means: 25 is the class of concrete 25N/mm^2, GCBGA is glass concrete containing blue gum ash, XX means percentage of glass in fine aggregate and YY means percentage dosage of blue gum ash by weight of cement. These descriptions of concrete were used throughout the study of the behavior of blue gum ash glass concrete. Table 1 below shows the resulting water cement content, slump obtained and the compaction factor.

Table 1: Water cement ratio, slump and compaction factor

Mix type	Slump (mm)	Water-cement ratio	Compaction factor
25GCBGA 10-00	35	0.555	75.73
25GCBGA 10-0.5	41	0.552	63.43
25GCBGA 10-0.75	44	0.550	79.93
25GCBGA 10-1	47	0.549	117.49
25GCBGA 10-1.25	53	0.548	98.60
25GCBGA 10-1.5	62	0.546	91.52

From Table 1 above, the slump level increased with increase in blue gum ash content but according to the consistency test, the best working value was maintained at 1% blue gum dosage. According to concrete specifications, vibrated concrete slump should be between 30mm- 60mm and most of the values were within the acceptable range as shown in Figure 4 below. For medium workability of concrete, the allowed slump is between 50-100mm hence blue gum ash proportions of between, 1.0% to 1.5% satisfied the requirements.

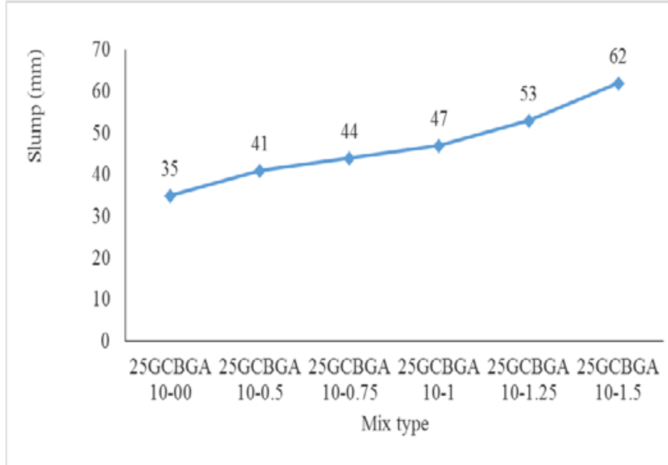

Figure 4: Slump variations

The compaction factor was seen to behave the same way as the slump, i.e. increased with increase in blue gum ash proportion up to 0.93 for 1.0% blue gum ash proportion then started decreasing. For medium workability of concrete, the allowed slump is between 50-100 mm (https://www.aboutcivil.org/concrete-slump-test.html); hence blue gum ash proportions of between, 1.0% to 1.5% satisfied the requirements. For the compaction factor, all mixes were within 0.9 ranges hence the addition of blue gum ash improved the compaction factor of class 25 concrete. The variation graphically for the compaction factor is as shown by Figure 5 below.

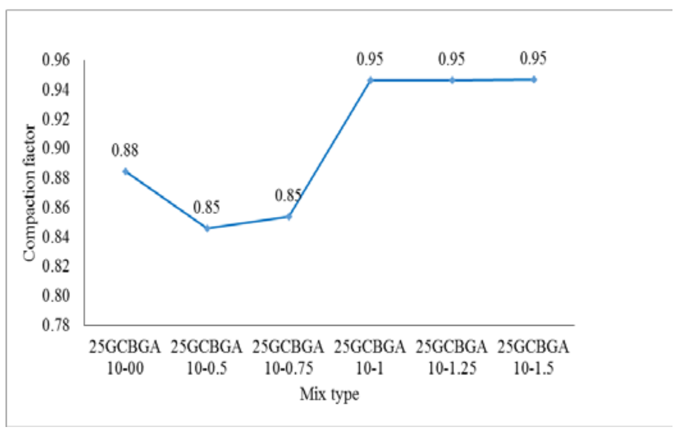

Figure 5: Compaction factor variations of blue gum ash glass concrete

According to M. T. Atoom (2002), the normal range of concrete the compaction factor lies between (0.8 – 0.92). From the results shown above, blue gum ash replacement of up to 1% dosage of cement by weight, containing crushed glass content of 10% by weight of fine aggregate satisfies the normal range of concrete compaction factor of (0.8- 0.92).

Table 2 below shows the 7, 14, 21, 28 and 90 days compressive strengths of each mix proportion and each value is the mean of triplicate results per test.

Table 2: Compressive strength of glass concrete with blue gum ash cement

Mix type	7 day strength (N/mm^2)	14 day strength (N/mm^2)	28 day strength (N/mm^2)	60 day strength (N/mm^2)	90 day strength (N/mm^2)
25GCBGA 10-0.0	25.31	28.62	31.21	35.19	38.48
25GCBGA 10-0.5	24.56	28.19	30.14	34.23	37.74
25GCBGA 10-0.75	22.48	27.56	29.19	32.05	35.42
25GCBGA 10-1.0	27.81	30.13	32.84	35.27	39.35
25GCBGA 10-1.25	26.16	28.48	32.14	34.88	38.93
25GCBGA 10-1.5	25.14	28.10	31.83	34.19	37.36

Comparatively, the strength of the glass concrete made using blue gum ash at 1.0% was found to have highest strength than the control experiment. Also, the strengths were found to decrease from 0.5% to 0.75%, increase from 0.75% to 1.0% then continuously decrease up to 1.5% blue gum ash proportion. This explains that, up to 10% crushed glass replacement in fine aggregates with 1.0% blue gum ash proportion in concrete attained the highest strength. From the different mixes containing blue gum ash, 1% dosage of cement by blue gum ash gave the highest strength and 0.75% gave the lowest strength at all ages of concrete as shown in Figure 6 below: -

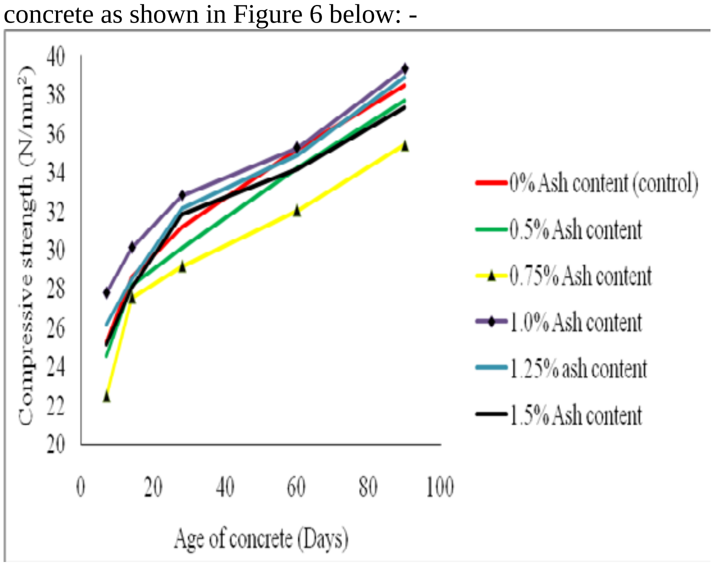

Figure 6: Compressive strength of glass concrete with blue gum ash

As the level of blue gum dosage increases, the early-age strength decreases. However, long-term strength development is improved when blue gum ash is used and at some age, the strength of the ash concrete becomes equal to that of the pozzolanic cement. The age at which strength parity with the control (pozzolanic cement) concrete is achieved is greater at higher levels of blue gum ash. The ultimate strength achieved by the concrete increases with increasing blue gum ash content, at least with dosage levels up to 1%. Generally, the differences in the early-age strength of pozzolanic cement and blue gum ash concrete are less for blue gum ash with higher levels of calcium. Notably also was the increase in strength with increase in concrete age up to 90 days. This is because concrete containing pozzolanic cement gains strength with age for the rest of its life. Table 3 below shows the results of the 7 days and 28 days tensile split strength of blue gum ash glass concrete, each value being a mean of three-cylinder test results.

Table 3: Tensile split strength of glass concrete with blue gum ash cement

Mix type	7 Day strength (N/mm^2)	28 Day strength (N/mm^2)
25GCBGA 10-0.0	2.00	2.65
25GCBGA 10-0.5	1.89	2.16
25GCBGA 10-0.75	2.03	2.66
25GCBGA 10-1.0	2.18	3.00
25GCBGA 10-1.25	1.98	2.72
25GCBGA 10-1.5	1.57	2.56

The results in Table 3 showed that the tensile split test increased with increase in the concrete curing age, and also increased with increase in blue gum ash content in the mix up to 1% by cement weight attaining strengths of 2.18 N/mm^2 and 3.0 N/mm^2 for 7 and 28 days respectively then the strengths started decreasing. Also notable is that these strengths were higher than the control (glass concrete only) as shown in Figure 7 below.

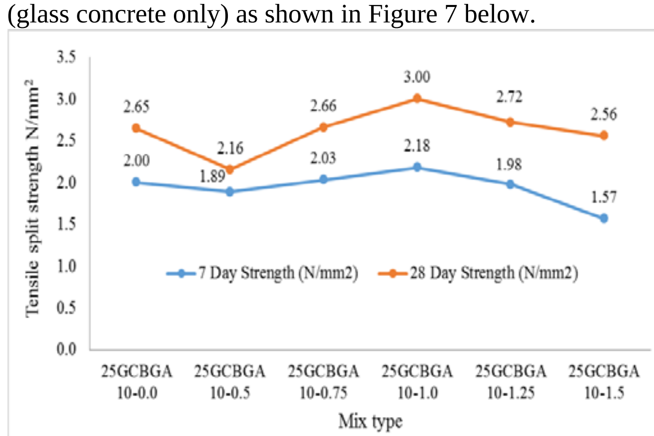

Figure 7: Tensile split strength of glass concrete with blue gum ash

Concrete is poor in tension and good in compression, hence the low tensile split strength values. Pozzolanic materials gain strength with age, hence as the curing age increases, the strength increases. The increase in blue gum ash, increased bonding between the concrete matrix, hence as the level increases, the strength increases up to the optimum level where by, increase in the blue gum ash content does not have the bonding effect, hence the decline in strength.

Table 4: Compressive strength against tensile split strength of glass concrete with blue gum ash cement

Mix type	28 Day compressive strength (N/mm^2)	28 Day tensile split strength (N/mm^2)
25GCBGA 10-0.0	35.19	2.65
25GCBGA 10-0.5	34.23	2.16
25GCBGA 10-0.75	32.05	2.66
25GCBGA 10-1.0	35.27	3.00
25GCBGA 10-1.25	34.88	2.72
25GCBGA 10-1.5	34.19	2.56

Figure 8 was used to explain the relationship based on the strengths at 28 days. The mathematical relationship between the compressive strength (Fcu_{28}) at 28 days and the corresponding split tensile strength (Ft_{28}) at 28 days is represented in quadratic Equation 1.

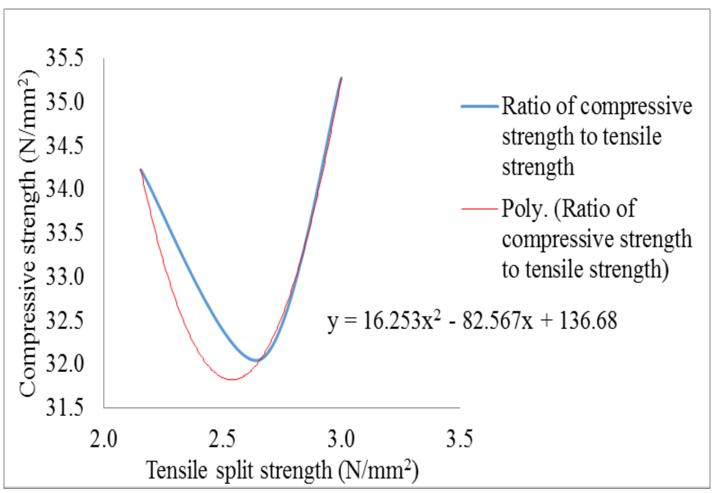

Figure 8: Compressive strength against tensile split strength of glass concrete with blue gum ash cement

$$Fcu28 = 16.253Ft28^2 - 82.567Ft28 + 136.68 \quad \text{-------------------- (1)}$$

From Figure 8, it can be seen that as the compressive strength is inversely proportional to the tensile split strength up to a certain point, whereby past that point, it relates directly proportional. This shows that the mix type containing 0.75% dosage of blue gum ash by weight of cement is the weakest point and the same can be seen from the compressive strength graph in Figure 6. This is the best design point for this type of concrete mix. The values of tensile strength of concrete are usually 10-15% of compressive strength but not more than 20%. From the equation, the estimated values were within the range of 10-15% and from the mathematical relationship; the tensile split strength can be predicted from the compressive strength.

IV. Conclusions

From the results and discussions above, it was concluded that: -

i) Blue gum ash (BGA) is hydrophilic, hence the higher the amount in concrete, the less the amount of water required for good workability to be achieved.
ii) From the results, in order to achieve good workability, the best blue gum ash content can be maintained at 1.0% and crushed glass content of 10%.
iii) For good compressive strength results of blue gum ash glass concrete, up to 10% crushed glass replacement in fine aggregates with 1.0% blue gum ash proportion in concrete attained the highest strength than the control (glass concrete only).
iv) The mathematical relationship between the compressive strength (Fcu_{28}) at 28 days and the corresponding tensile split tensile strength (Ft_{28}) at 28 days of blue gum ash glass concrete is represented by quadratic Equation $Fcu28 = 16.253Ft28^2 - 82.567Ft28 + 136.68$

V. Recommendations

From the experimental results and analysis, the following recommendations were made: -

a) In order to recycle and make our wastes useful especially in civil engineering, there is need to encourage researchers to take up research courses on these wastes to determine their engineering properties and where they can be used best. E.g. Recycled waste use in Civil Engineering.

b) Once cement is dosed with blue gum ash at 1% and fine aggregates replaced with crushed glass at 10%, good workability is achieved and early strength developments of up to 35.27N/mm^2 in 28 days. This mix can be used for lightly loaded beams like lintels and slabs in buildings.

c) There is also need to develop codes or guiding standards on the use of various wastes like blue gum ash and glass in concrete. Once developed, there will be reduced cost of construction due to use of readily available wastes and solve the problem of environmental degradation.

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