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Experimental Investigation on the Effect of Cement in Abrasion Resistance and Microstructure of Glassrubcrete

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Abstract

Rubber concrete is a new construction materials which is widely used in material science and civil engineering works. Most countries around the world already device ways of recycling wastes products to partially replace and conserve natural resources used in producing concrete. This paper give the performance of glass rubber concrete subjected to chemical resistance. Cement, water, fine sand, gravel, crushed glass of 4.75 mm and shredded tyre of 19 mm 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. Grade 25 concrete in (100x100x100) mm cube was produced and cured for 28 days. Physical, chemical properties, compacting factor test, density, abrasion resistance and SEM-EDS were carried out. Results show that compacting factor (CF) decreases gradually and 5% partial replacement produced high resistance to abrasion. Therefore, rubber glass concrete shows potential in becoming an additional sustainable solution for waste management.

Keyword: Waste, Durability, Properties, Glass, concrete, microstructure.

Introduction

Raw materials required for manufacturing of Portland cement are calcareous materials such as limestone, chalk, argillaceous (materials such as clay). Cement factories are built around the location of the raw materials. The procedures for manufacturing cement consists of grinding the raw materials, mixing the raw materials in certain proportions base on composition and burning the raw materials in a kiln at a temperature that ranges from 1300^{0}C to 1500^{0}C allowing the raw materials to fuse together to form nodular shaped clinker. The clinker is cooled and ground to fine powder with the addition of gypsum. The two processes for producing Portland cement are wet and dry; depending upon whether the mixing and grinding of the raw materials are done in wet or dry conditions. The raw materials used for the manufacturing of Portland cement consist of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. C (calcium) represent CaO, S (silica) represent SiO_2, A (alumina) for Al_2O_3, F (iron) for Fe_2O_3 and H (hydrogen) for H_2O. When Portland cement is mixed with water its chemical compound constituents undergo a series of chemical reactions that cause it to harden. This chemical reaction with water is called "hydration" [1].

The chemistry of concrete is essentially the chemistry of the reaction between cement and water, because cement alone cannot bind fine and coarse aggregate. It requires adhesive property when mixed with water. The cement compound dissolve to produce a supersaturated solution from which different hydrated products get precipitated. Cement plays a major role within a concrete mixture and affects most important aspects of the mix, such as: workability, compressive strength, drying shrinkage and durability [1].

Table 1 shows the Bogues compounds with formula and names.

The main chemical reactions associated with the formation C_2S, C_3A, C_4AF and C_3S hydration are outlined in Equations 1, 2, 3 and 4.

$2C + S \xrightarrow{\Delta} C_2S$ (Belite) ---Equation 1

$A + 3C \xrightarrow{\Delta} C_3A$ (Celite) --Equation 2

$A + F + 4C \xrightarrow{\Delta} C_4AF$ (Felite) --Equation 3

C_4AF (Felite)

$C_2S + C\ \ 4C \xrightarrow{\Delta} C_3S$ (Alite) ---Equation 4

Table 1: Bogue's Compounds (ASTM C150)

Name of Compound	Formula	Abbreviation Formula	Name
Tricalcium silicate	$3CaO.SiO_2$	C_3S	Alite
Dicalcium silicate	$2CaO.SiO_2$	C_2S	Belite
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	Celite
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	Felite

Glass has proven its importance in our lives through manufactured products such as sheet glass, bottles, glassware and vacuum tubing. However, it is not biodegradable and therefore creates a problem for solid waste disposal. The disposal into landfills also does not provide any environment-friendly solution. Hence, the use of waste glass in construction materials can be a worthy solution to the environmental problem caused by this solid waste [2].

Most of the aggregates used are naturally occurring aggregates, such as crush rock, gravel and sand which are usually chemically interactive or inert when bonded together with cement. On the other hand, modern technological society is generating substantially high amounts of solid wastes both in municipal and industrial sectors; posing an engineering challenge for their effective and efficient disposal. Hence, giving rise to partial or full replacement of fine aggregates by other compatible materials like sintered fly ash, crushed rock dust, quarry dust, glass powder, recycled concrete dust, and others are being researched from past two decades, in view of conserving the ecological balance [3]. Concrete is durable construction materials which is widely used in construction works. Most countries around the world already devise ways of recycling wastes products to replace and conserve natural resources used in producing concrete. Waste tyres will not only help in conserving natural resources, it will also help in replacing construction materials made from non-renewable resources [4].

Mohmmed (2016), [5] emphasized the prospects for growth in using recycled crumb rubber, particularly in road construction applications. In order to reduce unnecessary landfills and preserve the environment, recycled tyres can feasibly be used as an alternative raw material in the construction industry. For example, in the pavement industry, trialling the use of crumb rubber has been initiated with asphalt mixes. However, some difficulties have been found that limit its application, such as the high viscosity of the rubberised bitumen and the higher temperature for production of rubberised asphalt. The first rubberised concrete was introduced and explored for potential engineering applications in the early 1990s. Although combining recycled rubber and concrete aggregates for making conventional concrete was an innovative idea, it was found that the resulting rubberised concrete had lower strength, and this was not preferable especially for structural applications.

Rubcrete can be advantageous for special applications; the mechanical properties such as the production of sound barriers, terraces and platform. The association of waste tyre concrete can be used in applications where there is a need for weak penetration of chloride ions in structures and where the corrosion of the reinforcements must be avoided. In spite of the bad compressive strength, the concretes of waste tyre present obvious interest in all the applications where compressive strength is less of interest than the post rupture behavior [6]. Adaway (2015) [7] opined that the construction industry presents an attractive market for the use of waste glass. One of the principal components of construction is concrete, due to its high compressive strength, durability and ease of construction. However, concrete production is highly resource and energy intensive, with the industry responsible for approximately 5% - 8% of worldwide greenhouse gas emissions. As such, opportunities to reduce the environmental impacts of the concrete industry are required. With natural aggregates within Nigeria being present in limited quantities, producing crushed aggregate for use in the construction industry is costly. The addition of shredded tyre to the concrete mix has been found to decrease concrete slump, yet workability was still deemed sufficient adequate without the need for admixtures for replacement levels up to 20%.

In higher mix proportions, the addition of waste glass was found to negatively affect the properties of fresh concrete, resulting in severe segregation and bleeding of the mix. Fresh and dry densities of concrete have been shown to be directly influenced by the addition of glass aggregate. An increase in the percentage of natural aggregate replaced with waste glass leads to a reduction in the unit weight of concrete and can be seen as one of the key benefits of incorporating glass aggregate into concrete. It was discovered that concrete containing 20% fine glass aggregate exceeded the compressive strength compared with the control concrete [7]. The use of waste materials in concrete can be an important step towards sustainability of the construction industry by ensuring a scenario having less environmental impact. Further we know pozzolanic materials like glass are materials of current use in concrete [8]. Jitender et al. [9] reported that waste glass when grounded to very fine powdered form prevents alkali silica reaction. Partial replacement of coarse aggregates of concrete with shredded tyre aggregate can improve the qualities such as low unit weight, high resistance to abrasion, durability, absorbing, shocks and vibrations, high ductility e.t.c [10].

Otunyo et al. [11] concluded that abrasion test conducted on glassrubcrete, at 28 days, 5% partial replacement of glass and shredded tyre has the highest resistance. This led to the conclusion that concrete containing up to 5% fine glass aggregate exhibits higher abrasion resistance development than the control (5%) concrete. In concrete, ST has shown an increase in abrasion resistance of concrete when used as partial replacement for coarse aggregates while comparing with the control concrete. This paper, therefore focused on the effect of cement bond of glass and shredded tyre aggregate for glass rubber concrete production; because waste glass and waste tyre are readily available in Nigeria. The results and findings of this research have contributed to the properties and application of concrete in research.

Materials and Methods

The methodology encompasses materials such as lime stone blended cement (Dangote) brand, water, fine aggregate (sand), coarse aggregate (gravel), fine glass aggregate (cullet), coarse rubber aggregate (shredded tyre), The apparatus used in carrying out the experiment in the laboratory includes head pan, hand scoop, AVERY balance scale, shovel, measuring cylinders, hand trowel, tapping rod, mixing board, standard sieve, concrete mixer, shovel, wheel barrow, tapping rod, stopwatch, vibrator machine, measuring scale, cube mould (100mm x 100mm x 100mm), slump mould, dual-purpose waste glass processing machine (DPWGPM-STEPHEN17), knife, STYE-2000 compressive strength testing machine, an electric grinding machine, jaw crusher and SEM (Hitachi SU3500, Japan) machine.

This paper determines the physicochemical properties of aggregates, evaluate the workability; compacting factor test, to know the density, to assess the durability properties such as abrasion resistance and the scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS).

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:

$$\text{Specific Gravity} = \frac{\text{B}}{\text{P} + \text{B} + \text{Ps}} - - - - - - - - \quad \mathbf{1}$$

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

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

The compacting factor test was carried out in accordance with BS 1881-103:1983, using the conventional (gravimetric) procedure or by using the alternative (volumetric) procedure. The fresh concrete was filled into the upper hopper and the hopper clamp was opened, the fresh concrete falls into the lower hopper and the clamp was also opened and the fresh concrete falls into the cylinder; where the fresh concrete is stuck off to level with the top of the cylinder. The cylinder + concrete were weighed, to give the partially compacted weight of the fresh concrete (A). The cylinder was filled with fully compacted fresh concrete; it was filled in four layers and tamped, the cylinder + concrete were weighed to give the fully compacted weight of concrete (B). The compacting factor was computed using equation 2:

$$\text{Compacting factor} = \frac{\text{weight of partially compacted fresh concert}}{\text{weight of fully compacted fresh concrete}} - - - \ - - - \mathbf{2}$$

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 28 days.

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

However, SEM provides morphology (images) of the microanalysis and EDS provides element composition of the materials. The images of the materials were observed by using SEM-EDS instrument. This analytical technique is integrated SEM and EDS.

Results and Discussion

Physical Properties of Aggregates

Table I 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 [12].

Table 1: Physical Properties of Aggregates

Physical Properties	Fine Sand	Fine Glass	Granite	Coarse Tyre
Bulk Specific Gravity	2.41	2.94	2.71	1.72
Elongation (%)	-	-	40	26.53
Flakiness (%)	-	-	25	11.15
Shape of Aggregate	Rounded	Finely Angular	Angular	Elongated

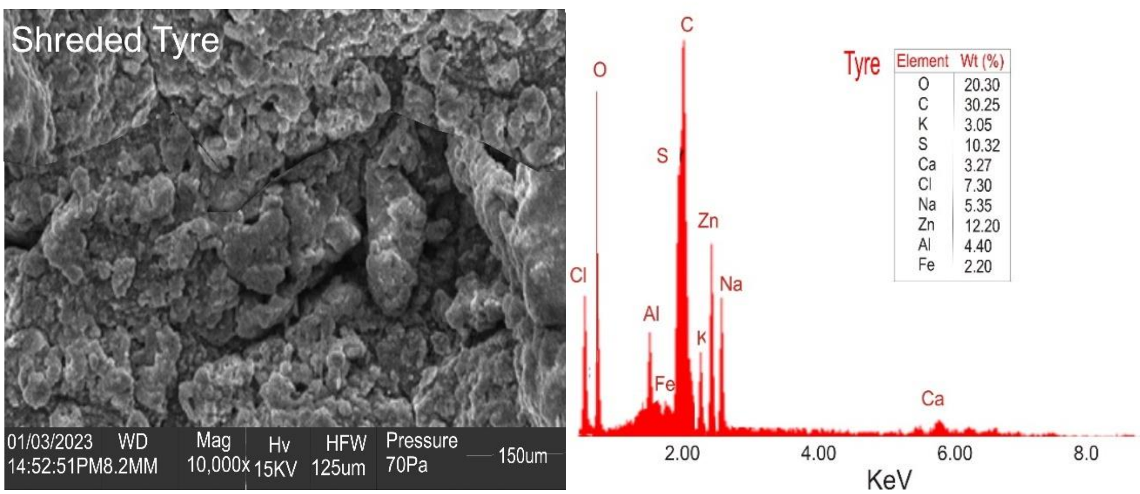


Figure 1: Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) of Shredded Tyre.

Figure 1 shows the morphology of the shredded tyre at 10,000x magnification. The image shows that the shredded tyre has curve edges; to prove the effect of surface treatment using NaOH. The EDS of the shredded tyre show that carbon (C) has 30.25 wt (%) of calcium (Ca) and 3.20 wt (%) and oxygen (O) has 20.30 wt (%). It can be seen that the shredded tyre has high carbon content.

Table I shows 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 [13], 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 I: 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
	6	CaO	20.011	4.564
	7	MgO	1.324	-
	8	Al_2O_3	2.487	-
	9	Zn	-	19.041
	11	Si	-	15.065

Compacting factor test

Figure 2 show that the compacting factor (CF) decreases gradually. The control (0%) mix had 0.91 (medium) workability, 5% mix had 0.89 (medium) workability, 10% mix had 0.89 (medium) workability, 15% mix had 0.89 (medium) workability and 20% mix had 0.87 (medium) workability; indicating 4.4% reduction. The implication is that the workability is medium. The results show that, the compacting factor decreased as the rubber content was increased. Compacting factor of 0.95 (high workability) for control concrete mix; while 10% and 25% with rubber aggregate in the concrete mixes had 0.91 and 0.88 respectively [14].

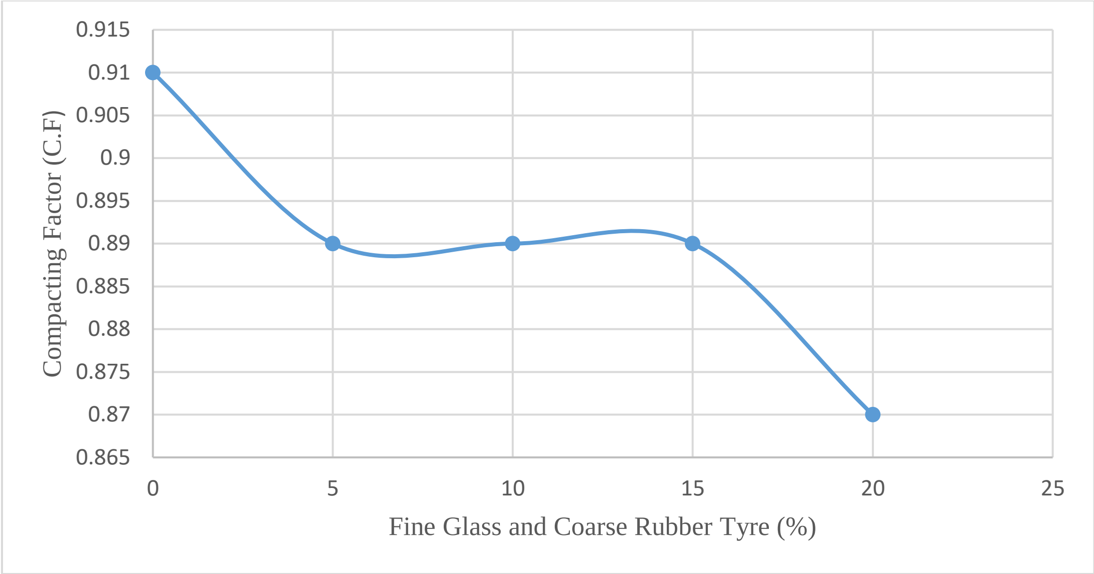


Figure 2: Compacting factor of the Glass Rubber Concrete

Density

It was discovered that in Figure 3 the inclusion of crushed glass and shredded tyre aggregates in the concrete mix decreased the unit weight of the fresh concrete mix from 2,230 g/m^3 in 0% (control) to 2,080g/m^3 with glass rubber aggregate of 20%. Wakili et al [15], pined 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.

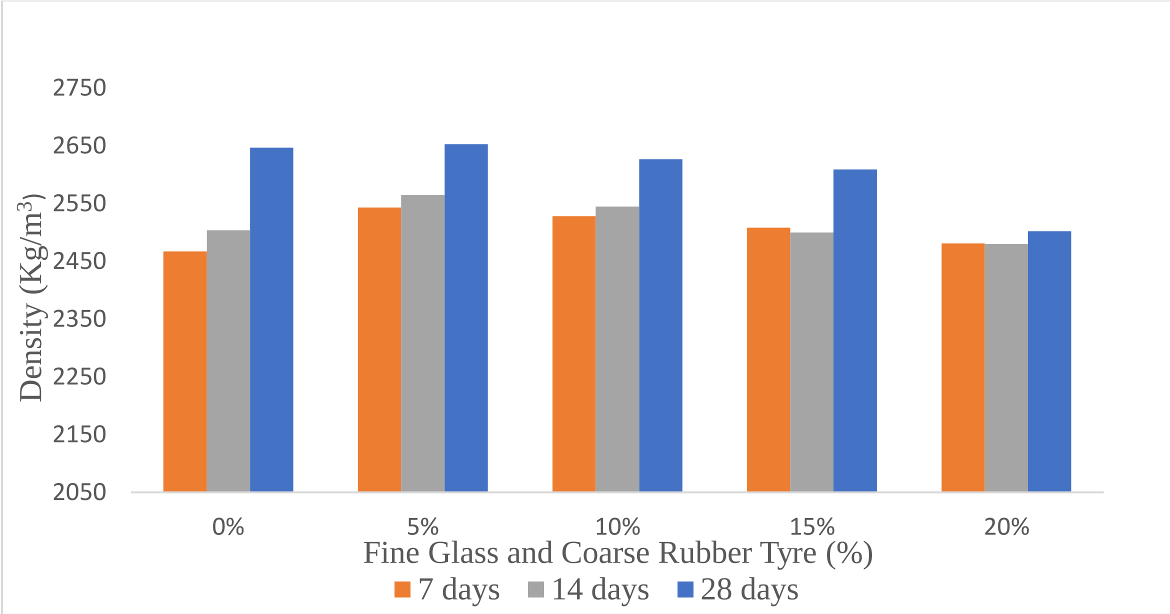


Figure 3: Average Densities Concrete Cubes

Abrasion resistance

Figure 4 show abrasion test conducted on GRC, at 28 days 5% partial replacement has the highest resistance. At 56 days, 5% partial replacement of PWG and ST recorded high resistance to abrasion. It was noted that the abrasion resistance which depends upon exposed phases of 5% partial replacement at 28 and 56 days respectively; proved higher resistance to abrasion test. Extra abrasion resistance was noted by 0% (control) at 90 days; it means that the rubber resistance to abrasion is reduced by the days of curing in water. Rubberized concrete show better resistance than the control mixes up to 20% at same W/C ratio. Addition of rubber is significant in abrasion resistance except 7.5% inclusion of rubber in concrete. Rubber particles at the surfaces act as resistance during testing and resulted in comparatively less abrasion. Bonding between rubber aggregate and cement is not influenced by abrasion but compressive strength test. Addition of rubber in concrete has positive effect on abrasion resistance [16].

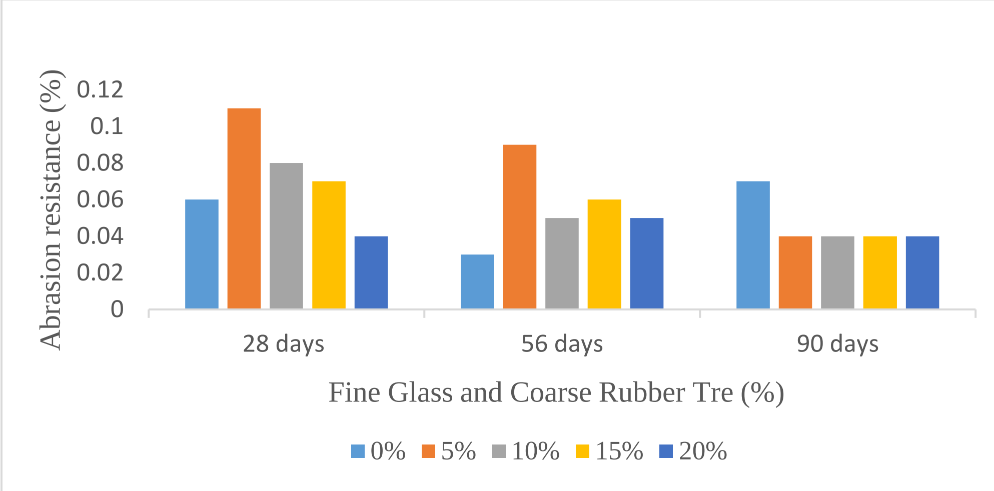
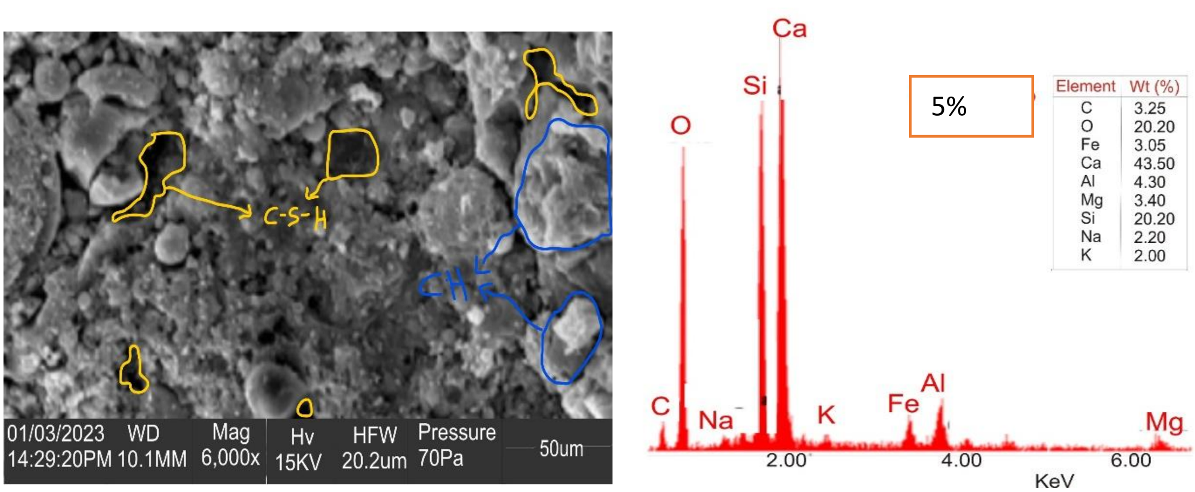


Figure 4: Abrasion Resistance Test

Scanning electron microscope (SEM) with Energy-Dispersive Spectroscopy (EDS)

Figure 5 shows the SEM images 5% specimen. The images show that calcium silicate hydrate C-S-H and crystal of portlandite (CH) are visible in the microstructure. This confirms the higher abrasion resistance recorded by 5% specimen. Roz-Ud-Din et al [17] discovered that the introduction of shredded tyre as partial replacement for coarse aggregate is observed to produce a relatively dense and uniform microstructure when compared with that of control concrete. These effects can be attributed to the pozzolanic reactions of processed waste glass yielding secondary calcium silicate hydrate (C-S-H). The EDS 5% specimen shows that 0 % specimen has 43.50 wt (%) of Ca (calcium) and 20.20% wt (%) of Si (silica). There was an increase in calcium at 5% partial replacement. It shows that the tyre effect was significant.



Element	Wt (%)
C	3.25
O	20.20
Fe	3.05
Ca	43.50
Al	4.30
Mg	3.40
Si	20.20
Na	2.20
K	2.00

Figure 5: SEM with EDS of 5% concrete subjected to abrasion resistance

Conclusion

This study concluded that cement has good bonding effect in the concrete, 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 abrasion resistance with evidence to the SEM-EDS result. Therefore, the inclusion of crushed glass increased the pozzolanic reaction of cement and the shredded tyre have proved to be potential alternative sustainable materials by resisting abrasion.

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