*Original Research Article*

# Strength Characteristics of Concrete partially replaced with Glass Powder and Palm Kernel Shells

## ABSTRACT

Portland cement is the most widely used binder globally in concrete construction but its cost continues to increase. Cement production is energy-intensive and in developing countries such as Ghana, the energy demand is hardly met by weak economies. Portland cement is therefore an imported exorbitant commodity and beyond the reach of most people in such countries. Furthermore, over-reliance on non-replenishable natural stones such as granitic rock aggregate for concrete equally affects the cost of construction. There has, therefore, been the need to find suitable alternative materials to reduce it. Hence the present study sought to investigate the properties of concrete containing glass powder as pozzolana and palm kernel shells as partial replacements of aggregates in the effort to reduce cost as well as the impact of waste generated from broken glass and palm kernel shells that are indiscriminately disposed of in the environment. The study investigated the potential use of recycled glass as pozzolana in ordinary Portland cement concrete with palm kernel shell as partially replaced aggregates with a specific look at particle size distribution of glass powder and palm kernel shell, optimum percentage of glass powder and the physical and mechanical properties of concrete with palm kernel shell as partial aggregate and varying percentages (0% to 25%) of recycled glass powder. Grade C25 concrete mix design with a batching ratio of 1:2:4 was employed as the control concrete mix (MC). 25% palm kernel shell was used as a partial replacement of coarse aggregate, while the cement was partially replaced at 0%, 5%, 10%, 15%, 20%, and 25% with recycled glass powder. The workability, density, and water absorption of the mixes were also measured. Concrete cubes and cylinders were used to investigate the compressive and split tensile strengths of the different mixes. The results indicated that the maximum compressive strength of concrete occurred at around 15% recycled glass powder replacement and beyond 15% replacement, the strength of concrete reduced. As the content of recycled glass powder increased the workability of the concrete increased and the slump of concrete with 5% - 25% recycled glass powder was higher

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than the control mix (MC). It is therefore recommended that glass powder usage as pozzolana in concrete should not exceed 15% as a partial replacement for cement.

**Keywords: Aggregate, Palm kernel shell, Recycled glass powder, Concrete.**

## 1. INTRODUCTION

Concrete is the most used man-made construction material in the world. Without concrete, most of the buildings seen around today would not have been standing. It is made up of cementitious material, fine and coarse aggregates, water, and sometimes admixtures that are combined in required ratios. The blend of all these materials when put in shuttering and allowed to cure, solidifies into a rock-like mass which is known as concrete. The strength of concrete mainly depends on the amount of cement used in the mix as well as the amount of water expressed in proportion to the cement as a water-cement ratio. Some examples of cement include ordinary Portland cement, pozzolanic cement, blast finance slag cement, and Portland limestone cement. The major strength of cement is due to the silicate content. The main chemical constituents and their proportions in ordinary Portland cement are as follows: "Lime (60%), Silica (22%), Alumina (5%), Calcisulfateate (4%), Iron Oxide (3%), Magnesia (2%), Sulphur (1%) Alkalies(1%)" (Lalitha et al., 2017) Aggregates are the other components of concrete. Aggregates take about 60-75 percent of the materials used in concrete and are more economical than cement. They provide more economy if as much of their proportion as possible is used in concrete. Their use considerably improves both the volume, stability, and durability of the resulting concrete. There are various types of aggregates that are classified as either heavyweight, normal weight or lightweight (Jackson and Dhir, 1996). Heavyweight aggregates are natural or synthetic whose densities vary between 2,080 kg/m$^3$ and 4,485 kg/m$^3$ (PEduedu,2019) whereas normal weight aggregates range between 1520 kg/m$^3$ and 1680kg/ m$^3$ (Nemati, 2015). Lightweight aggregates are either natural or synthetic that weigh less than 1100 kg/m$^3$. Aggregates are also classified as either fine or coarse. By standard classification, fine aggregates have particle sizes between 0.15mm to 4.75mm whereas coarse aggregates are particles that are retained on a sieve of 4.75mm (BS EN 933-1:1997). Aggregates are the most mined materials in the world. Some common examples of aggregates employed in general

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construction are sand, gravel, slag, crushed stone, and recycled concrete which are widely available globally.

Nevertheless, there is still the need to find alternatives to reduce the burden on the environment (infotel.ca, n.d.). A typical example of alternate aggregate may be palm kernel shells. Palm kernel shells are generally not considered as construction material in the industry (Omange, 2001). The reason may be because it is not accessible in great quantities in the world over as compared to conventional fine aggregate and coarse aggregates or since its use mechanical and physical properties have not been fully investigated.

In Ghana, there has been a drastic rise in the use of glass within the last two decades. From domestic uses to commercial and industrial uses. The most affected area is the construction industry. Glass is an undefined (non-crystalline) material that is generally, a super-cooled fluid and not a solid. Glass can be formed with super similarity in a lot of structures and sizes from minor fibers to meter-sizes pieces. Fundamentally glass is formed from sand, soda ash, limestone, and different additives. (Shi et al,2005). Glass has been utilized as an aggregate in various areas of the construction industry. (Rhat and Rao,2015; Khatrb et al,20120) Malik 2013; Malik etal 2013; The main chemical constituents and their proportions in glass are as follows: Silica "(72.5%), Alumina (22%), Lime (0.8%), Iron Oxide (0.36%), Magnesia (4.18%), Sodium Oxide (13.1%), Potassium Oxide (0.26%) and Sulphur Trioxide (0.18%)" (Lalitha et al., 2017; Shi et al 2005). Glass powder is a finely ground glass and has a specific gravity of 2.4-2.8 (Suganya et al., 2014). The disposal of glass in landfills is very expensive and the non-biodegradable nature of glass further convolutes the ecological effect of its disposal in landfills.

Then again, one of the significant ingredients used for the production of concrete is cement. Cement production is associated to be a major source of greenhouse gas emissions; one ton of cement produces roughly one ton of carbon dioxide ($CO_2$) in the atmosphere. Other poisonous gases are also produced but in moderate quantities. The most persuasive ecological worries in the utilization of Portland cement for construction are the generation of greenhouse gases during its production and the intake of nonrenewable assets as raw materials. In 2015, over 2.8 billion tons of $CO_2$ were generated globally with regard to cement production. Due to global urbanization and economic development, the use of cement is said to increase drastically thus increasing the amount of $CO_2$ and other gases during its production. There is, therefore, the need to dramatically

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reduce the emission that comes with it (Timperley, 2018). The cost of concrete products keeps increasing due to the increase in the price of cement as it is the most used binding agent in Ghana. Cement manufacturing is a high-energy-intensive venture as fuel is utilized to fire rotational kilns to produce cement clinker. Secondly, electrical energy is used in operating various units– specifically raw materials and cement grinding systems. Today, electrical energy consumption in cement production only makes up approximately 12 - 15% of the total energy consumption with energy costs costing fuel and electricity. About 118kWh is estimated as the amount of electrical energy consumed per ton of cement production (Madlool et al., 2011). There is, therefore, the need to find alternatives to further reduce its cost and augment its usage. Using supplementary cementitious materials (SCMs) to partially reduce the cement is therefore a desirable technique for decreasing the negative environmental effect of the industry.

Also, another factor affecting the cost of concrete is the over-reliance on aggregate. There is a need to curb the amount of energy used in its production by exploring other sustainable materials such as concrete aggregates. Research has shown that palm kernel shells can be utilized as aggregates in concrete (Ikumapa & Akinlab, 2018; Mannan and Ganapathy, 2002; Mannan et al., 2006; Kankam, 1999; Falade, 1992; Kankam, 2000; Jumaat et al., 2009; Acheampong et al., 2016). The shells end up as waste after the nuts are removed from them. Much research has been carried out to find alternative binding agents and materials other than ordinary Portland cement and normal coarse aggregate in the construction industry. Glass powder is one such material that has been used as pozzolana partial replacement of Portland cement (Aluko et al;2015;Chikhalikor and Tande,2012 Guralann and Seri,2013; Kumaraphpan 2013. Khatb et al; 2012). In Ghana, glass is generally used domestically and in the construction industry. It is used for decorative purposes, packaging of food and drinks, as an insulation material, structural component, as cladding, etc. As a result of its wide usage, a lot of waste is also generated causing environmental degradation due to its indiscriminate disposal. There is, therefore, the need to exploit its mechanical and physical properties as pozzolana in concrete material. This will help reduce the cost associated with the use of Portland cement and also the effect of waste generation from the glass on the environment.

## 2.0 MATERIALS AND METHODS

### 2.1 Materials

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The concrete mix was comprised of the following main original constituent materials: ordinary Portland cement which satisfies the requirement of BS 12:1996 and BS EN 197-1:2000; river sand as fine aggregate; locally crushed granite as coarse aggregate; and potable water. In addition, recycled glass powder as pozzolana and palm kernel shells as aggregates were added to the concrete. Figures 1a and b show the coarse granitic aggregates.

(a) crushed granite coarse aggregates

(b) weighing of crushed granite

**Figure 1: Coarse granitic aggregates study**

### 2.1.1 Recycled glass powder (RGP)

Glass waste available locally was collected from various construction sites and local selling points of glass (fig 2a). The glass waste collected from these points was sent to the milling machine for grinding. At the milling machine, the glass waste was crushed into smaller sizes before feeding it into the milling machine. The machine was made up of a high-speed motor with a funnel mounted on top to receive the broken glasses, all of which were mounted on four legs (fig.2b). To start with the grinding of the glass, the nozzle where the grounded powder came out from was tied with rubber bag and sack. This was done to reduce the amount of dust that came

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out when the broken glass wastes were being ground. The broken glass waste was fed into the funnel of the machine and then ground into a fine powder as shown in the figures. 2a- c.

(a) Recycled Glass wastes

(b) Machine grinding glass waste powder

(c) Recycled Glass Powder

**Figure 2: Recycled Glass Powder used for the study.**

### 2.1.2 Palm kernel shell (PKS)

The PKS used were sourced from palm kernel oil production sites where the milling was carried out. The palm kernel shells were used after all dirt and fibers were removed. The PKS samples (Figure 3) collected from the mill were flushed with hot water to remove dust and other impurities that could be harmful to concrete. They were later sundried and packed in plastic sheets to prevent contact with water. The sizes of PKS ranged from 2mm to 5mm depending on the machine used in cracking the palm nuts (Alengaram et al., 2010).

**Figure 3: Selected Palm Kernel Shells being weighed**

## 2.2 Methods

### 2. 2.2.1 Sieve Analysis

Sieve analysis was conducted on the recycled glass powder, sand, coarse granite, and PKS to determine the particle size distribution of the aggregates and silt content in accordance with BS EN 933-1:1997.

2.2.2 Specific Gravity

The specific gravity of the glass powder and cement was measured in accordance with standard procedures (BS 812-2:1995)

### 2.4 Design of test specimens

Tables 1 and 2 present the details of test specimens for six different mixes as outlined in the following:

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MC (Mix Control) = Normal concrete mix without RGP and PKS.

$M_{pks}$ = Concrete mix with only 25% PKS replacement of coarse granite aggregate.

$M_{(25,5)}$ = Concrete mix with 25% PKS replacement of coarse granite and 5% RGP replacement of cement.

$M_{(25,10)}$ = Concrete mix with 25% PKS replacement of coarse granite aggregate and 10% RGP replacement of cement.

$M_{(25,15)}$ = Concrete mix with 25% PKS replacement of coarse granite aggregate and 15% RGP replacement of cement.

$M_{(25,20)}$ = Concrete mix with 25% PKS replacement of coarse granite aggregate and 20% RGP replacement of cement.

$M_{(25,25)}$ = Concrete mix with 25% PKS replacement of coarse aggregate and 25% RGP replacement of cement.

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**Table 1: Details of compressive strength test specimens.**

| **Specimen identity** | **Concrete strength 25N/mm$^2$ with w/c 0.6** <br> **Curing period (days)** | **7 28** |
|---|---|---|
| | | No. of test specimens |

|  |  |  |  |
|---|---|---|---|
|  |  |  |  |
| MC | Normal concrete mix without RGP and PKS | 3 | 3 |
| $M_{pks}$ | Concrete mix with only 25% PKS replacement to coarse aggregate | 3 | 3 |
| M(25,5) | Concrete mix with 25% PKS replacement to coarse aggregate and 5% RGP replacement to cement. | 3 | 3 |
| M3(25,10) | Concrete mix with 25% PKS replacement to coarse aggregate and 10% RGP replacement to cement. | 3 | 3 |
| M4(25,15) | Concrete mix with 25% PKS replacement to coarse aggregate and 15% RGP replacement to cement. | 3 | 3 |
| M5(25,20) | Concrete mix with 25% PKS replacement to coarse aggregate and 20% RGP replacement to cement. | 3 | 3 |
| M6(25,25) | Concrete mix with 25% PKS replacement to coarse aggregate and 25% RGP replacement to cement. | 3 | 3 |
|  | **Total number of test specimens** | 42 |  |

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**Table 2: Details of Split Tensile strength test specimens.**

| Specimen identity | Concrete strength 25N/mm$^2$ with w/c = 0.6<br>Curing period (days) | 7 | 28 |
|---|---|---|---|
| | | No. of test specimens | |
| MC | Normal concrete mix without RGP and PKS | 3 | 3 |
| M$_{pks}$ | Concrete mix with only 25% PKS replacement to coarse aggregate | 3 | 3 |
| M (25,5) | Concrete mix with 25% PKS replacement to coarse aggregate and 5% RGP replacement to cement. | 3 | 3 |
| M3(25,10) | Concrete mix with 25% PKS replacement to coarse aggregate and 10% RGP replacement to cement. | 3 | 3 |
| M4(25,15) | Concrete mix with 25% PKS replacement to coarse aggregate and 15% RGP replacement to cement. | 3 | 3 |
| M5(25,20) | Concrete mix with 25% PKS replacement to coarse aggregate and 20% RGP replacement to cement. | 3 | 3 |
| M6(25,25) | Concrete mix with 25% PKS replacement to coarse aggregate and 25% RGP replacement to cement. | 3 | 3 |

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|  |  |  |  |
|---|---|---|---|
|  |  |  |  |
|  | **Total number of specimens** | 42 |  |

## 2.5 Preparation of Concrete Test specimens

### 2.5.1 Mix Design

Concrete mix proportions of 1:2:4 (cement; fine aggregates; coarse aggregate) by weight with a water/cement ratio of 0.6 and maximum aggregate size of 12.5mm were used to prepare the concrete. The concrete mix design was per BS 5328:1997. The cement content of 380 kg / $m^3$ was used to meet a minimum requirement of 300 kg / $m^3$ to avoid the balling effect. Sieve analysis conforming to BS 1377 part 1 1990 was carried out for both the fine and coarse aggregate. A silt test was conducted on the fine aggregates in accordance with BS 1377(Part 2):1990.

### 2.5.2 Mixing, Casting, and Curing

The fine aggregate was batched onto the watertight platform (figure 4a) and spread, cement and RGP were batched in their right quantities onto the fine aggregate (figure 4b) and mixed until the mixture was thoroughly blended and of uniform color (figure 4c). The percentages of coarse aggregate and PKS each were added (figure 4d) and mixed until the coarse and the PKS were uniformly distributed throughout the batch (figure 4e). The right amount of water was added (figure 4f) and mixed until the concrete appeared to be homogeneous and of the desired consistency (figure 4g). A slump test was conducted to determine the workability of concrete mixes in accordance with BS EN 12350-2(2009)

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(a)Fine aggregate on mixing platform

(b)Cement and recycled glass powder added to fine aggregates

(c)Mixture of cement, recycled glass powder and fine aggregates

(d)Coarse aggregate and Palm kernel shells added to the mixture of cement, recycled glass palm powder and fine aggregate

(e)Mixture of fine aggregate, cement, recycled glass powder, coarse aggregate and palm kernel shells

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(f)Water added to the mixture of fine aggregate, cement, recycled glass powder, coarse aggregate and palm kernel shells

(g)Mixed concrete

**Fig. 4: Mixing of concrete.**

Concrete cubes and cylinders were cast respectively in 150mm x 150mm x 150mm wooden molds fabricated from plywood and Polyvinyl chloride (PVC) pipes measuring 150mm in diameter and 300mm in height internally (Figures 5 and 6). The specimens were cast in accordance with BS 1881-108 (1983). A total of forty-two (42) cubes were cast to give six (6) for each percentage replacements for each mix. In addition, a total of forty-two (42) cylinders were cast to give six (6) for each percentage replacements for each mix. The molds were first cleaned and oiled, after which they were filled with concrete in three layers, and each layer was compacted 25 strokes with a 16mm diameter tamping rod. The top of the mold was leveled and smoothened with a trowel. The cubes and cylinders in the molds were labeled according to the percentages of RGP replacement of cement. The cast cubes and cylinders in the molds were placed under a shed to prevent the loss of water. The specimens were removed from the mold after twenty-four (24) hours and immediately submerged in clean and fresh water and kept until the day of testing (figure 5b).

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Curing of the test cubes and cylinders was done by full immersion in water at an ambient average laboratory temperature of 28ºC and 100 percent relative humidity to prevent micro-cracking of the test specimens.

(a)Cast specimens (b)Curing of specimens

**Figure 5: Casting and curing of concrete specimens**

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(a) Test Cubes

(b) Test Cylinders

**Figure 6: Concrete test specimens**

## 2.6 Testing of specimens

### 2.6.1 Compressive strength

The test specimens were first weighed to determine the density of each concrete mix in accordance with BS EN 12390-7:2004. The test was conducted on the 150mm concrete cubes in a compression testing machine after a curing period of 7 days and 28 days, for the $7^{th}$ and 28th-day strengths, respectively. The cubes were loaded monotonically until failure at a rate of $140 kg/cm^2$ per min in accordance with BS EN 12390-3: 2002. Figure 7 shows a concrete cube specimen under test.

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**Figure 7: Concrete cube specimens under test.**

The compressive strength of concrete was calculated using the formula in equation 1:

$f_{cu} = P/A$ Eq 1

where:

$f_{cui}$ = Compressive strength of concrete (N/mm$^2$)
P = maximum compressive load (N)
A = Cross-sectional area of the cube (mm$^2$)

### 2.6.2 Split tensile strength

The split tensile test was carried out on 150mm x 300mm concrete cylinders (figure 8) and provided an indirect way of determining the tensile strength of the concrete. The test was carried out on the cylindrical specimens after 7 days and 28 days of curing respectively for the 7th-day - 28th-day tensile strength of the concrete. The specimen was placed length-wise in a compression test machine as shown in Figure 8c, and loading was applied along its length until failure by BS EN 12390-6:2004. part 116:1983. The tensile strength of the concrete was computed using the formula:

$f_t = 2P / \pi DL$ Eq 2

where:

$f_t$ = tensile strength of concrete (N/mm$^2$)
P = maximum applied load (N)
D = diameter of cylinder (mm)
L = Length of cylinder (mm)

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(a) Test Cylinders

(b)Weighing of cylinders to be tested

(c) Load applied to cylinder until failure

**Figure 8: Concrete cylinders specimens under test.**

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# 3. 0 RESULTS AND DISCUSSION

## 3.1 Physical properties of materials

### 3.1.1 Specific gravity (RGP)

The specific gravity of recycled glass powder and cement was 2.58 and 3.15, respectively, as shown in Table 3.

**Table 3: Specific gravity of RGP and cement**

| Specific gravity | Values |
|---|---|
| RGP | 2.58 |
| Cement | 3.15 |

### 3.1.2 Particle size distribution

The results of the sieve analysis of the RGP, fine aggregate, coarse granite, and PKS are shown in Figure 9. The particle size distribution of PKS indicates that 98% passed through 14mm, 90% through 12mm, and 7% through 5mm. This distribution lies within the acceptable limit of BS 882: 1992. The maximum size of glass powder was 75µm, and it is as follows for the aggregates: sand (fine aggregate) 5mm; granitic stone (coarse aggregate) 20mm; and PKS 14mm.

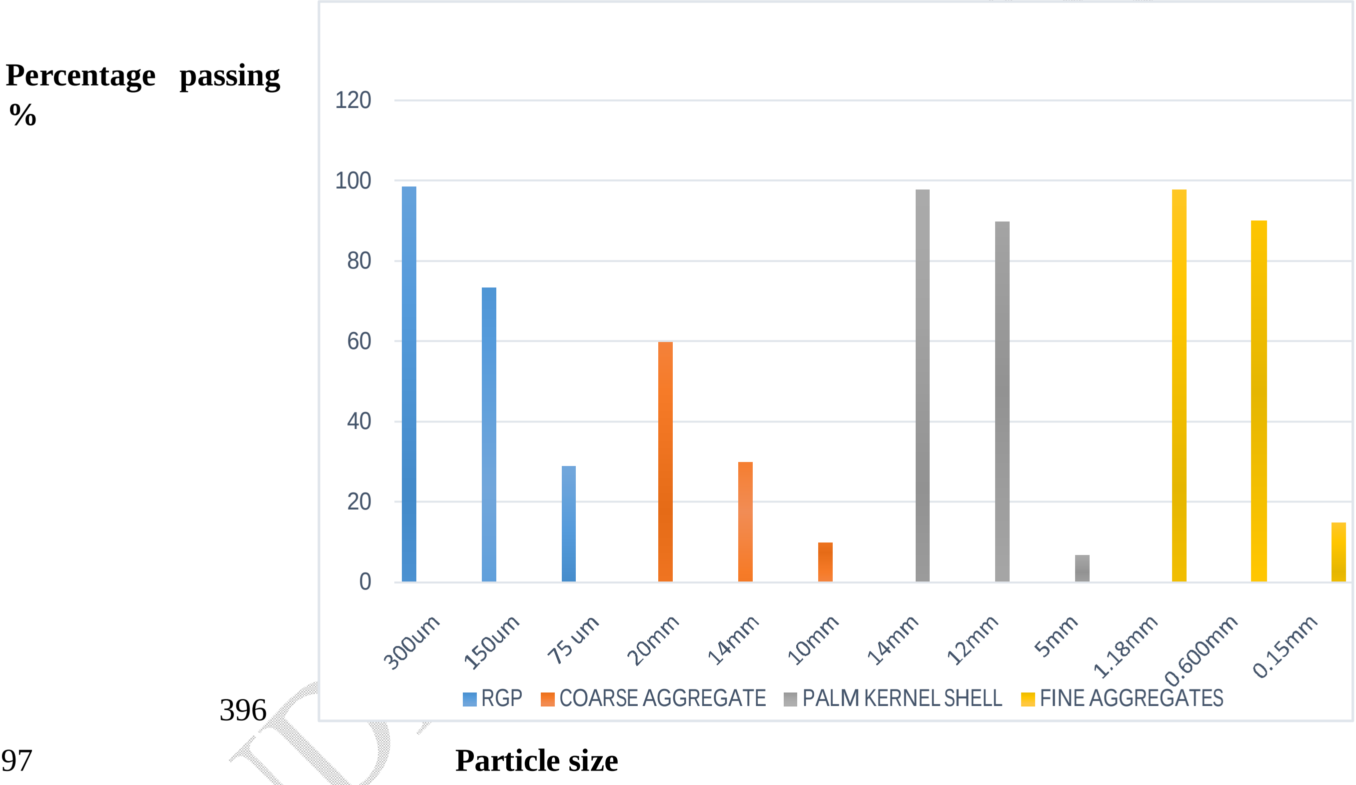

**Figure 9: Particle size distribution.**

### 3.1.3 Density of concrete

The density of the different concrete mixes was measured from 150mm cubes on the 7th and 28th days, and the values are presented in Table 4.

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**Table 4: Density of concrete mixes.**

| **The density of concrete (kg/m$^3$)** | | |
|---|---|---|
| **Specimen ID** | **7 days** | **28 days** |
| MC | 2531 | 2601 |
| Mpks | 2406 | 2378 |
| M$_{(25,5)}$ | 2382 | 2348 |
| M3$_{(25,10)}$ | 2330 | 2346 |
| M4$_{(25,15)}$ | 2345 | 2363 |
| M5$_{(25,20)}$ | 2345 | 2363 |
| M6$_{(25,25)}$ | 2356 | 2356 |

### 3.1.4 Workability

The workability of concrete with 25% PKS increased with increasing RGP replacement of cement. The optimum workability of 80mm slump value was developed in a concrete mix containing 25% PKS and 25% RGP.

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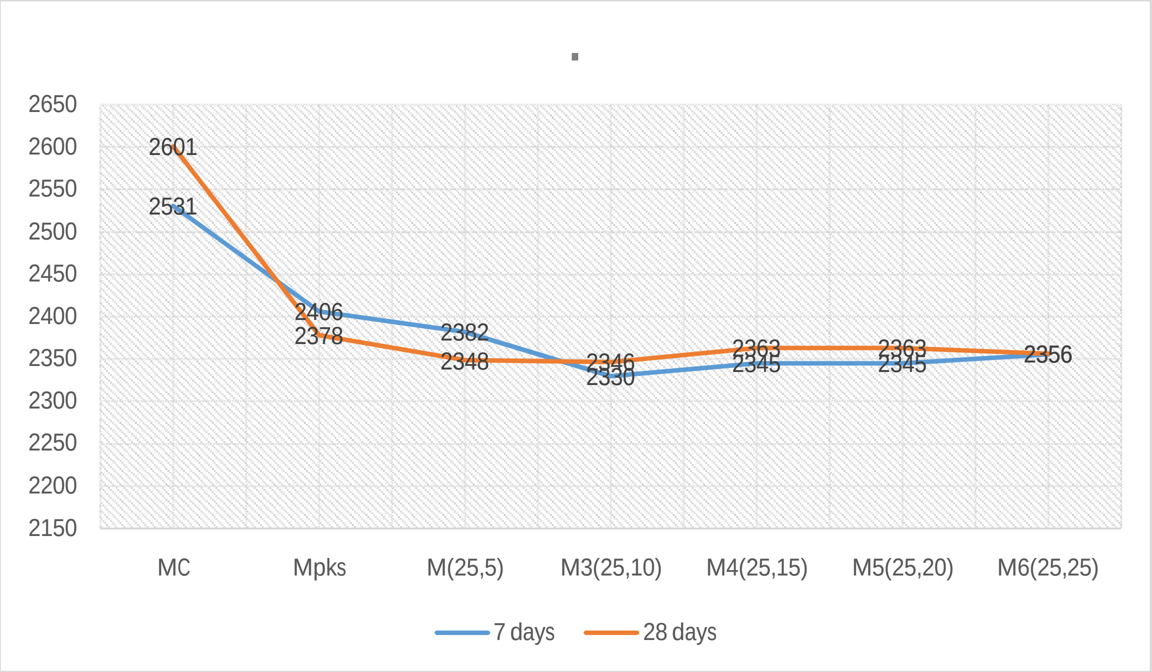
Density (kg/m$^3$).



Mix proportion

**Figure 10: Density of concrete mixes after 7and 28days.**

The density of concrete mixes including the PKS aggregates and various percentages of recycled glass powder replacements of cement on the 7th and 28th days are presented in Fig. 10, which ~~The figure~~ shows that the density of concrete made up of 25% PKS as a partial replacement of coarse aggregate was lower as compared with the control mix (MC). With the addition of RGP as a partial replacement to Portland - limestone cement in percentages of 5%, 10%, 15%, 20%, and 25%, the concrete densities further decreased up to 10% RGP placement and increased at 15% replacement then remained constant for 20% replacement and a slight increase at 25% replacement of cement with RGP. Fig.8 shows a sharp decrease in the density of concrete containing 25% PKS as a partial replacement of coarse aggregate from the control mix (MC). With the addition of RGP as a partial replacement to limestone Portland cement in percentages of 5%, 10%, 15%, 20%,

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and 25%, the concrete densities further decreased up to 10% RGP placement and increased at 15% replacement then remained constant for 20% replacement and a slight decrease at 25% replacement of cement with RGP. A similar kind of decrease in the trend of the density of concrete due to the replacement of RGP to cement is reported in previous studies by Vasudeva et al. (2013) and Małek et al. (2020) the decrease in densities compared to the control mix(MC) as a result of the replacement of cement with RGP in percentages can be attributed to the decrease in weight of concrete due to the percentage rise in glass powder and also specific gravity of the RGP i.e., 2.85 is less than that of cement i.e., 3.15 (Portland Cement Association (Pca, Sh Kosmatka and Wc Panarese, 1988).

## 3.2 Mechanical properties of concrete

### 3.3.1 Compressive strength of Concrete

The compressive strength of various concrete mixes was estimated at age of 7 days and 28 days to study the effect of partial replacement of coarse aggregate and cement with 25% PKS and RGP.

The results are given in Table 5

**Table 5: Compressive Strength of Concrete Mixes**

| 7thand 28th Compressive Strength N/mm2 | | | |
|---|---|---|---|
| | 7 Days | 28 Days | |

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| Specimen ID | Crushing load (kN) | Compressive strength (N/mm$^2$) | Crushing load (kN) | Compressive strength (N/mm$^2$) | Percentage strength achieved on 7th day |
|---|---|---|---|---|---|
| MC | 470 | 20.89 | 562.5 | 25 | 83.56 |
| Mpks | 297.5 | 13.22 | 356.67 | 15.85 | 83.41 |
| M(25,5) | 305.67 | 13.59 | 356.67 | 15.85 | 85.74 |
| M3(25,10) | 307.5 | 13.67 | 372.5 | 16.56 | 82.55 |
| M4(25,15) | 304.17 | 13.52 | 372.5 | 16.56 | 81.64 |
| M5(25,20) | 245.83 | 10.93 | 320 | 14.22 | 76.86 |
| M6(25,25) | 193.33 | 8.59 | 260.83 | 11.59 | 74.12 |

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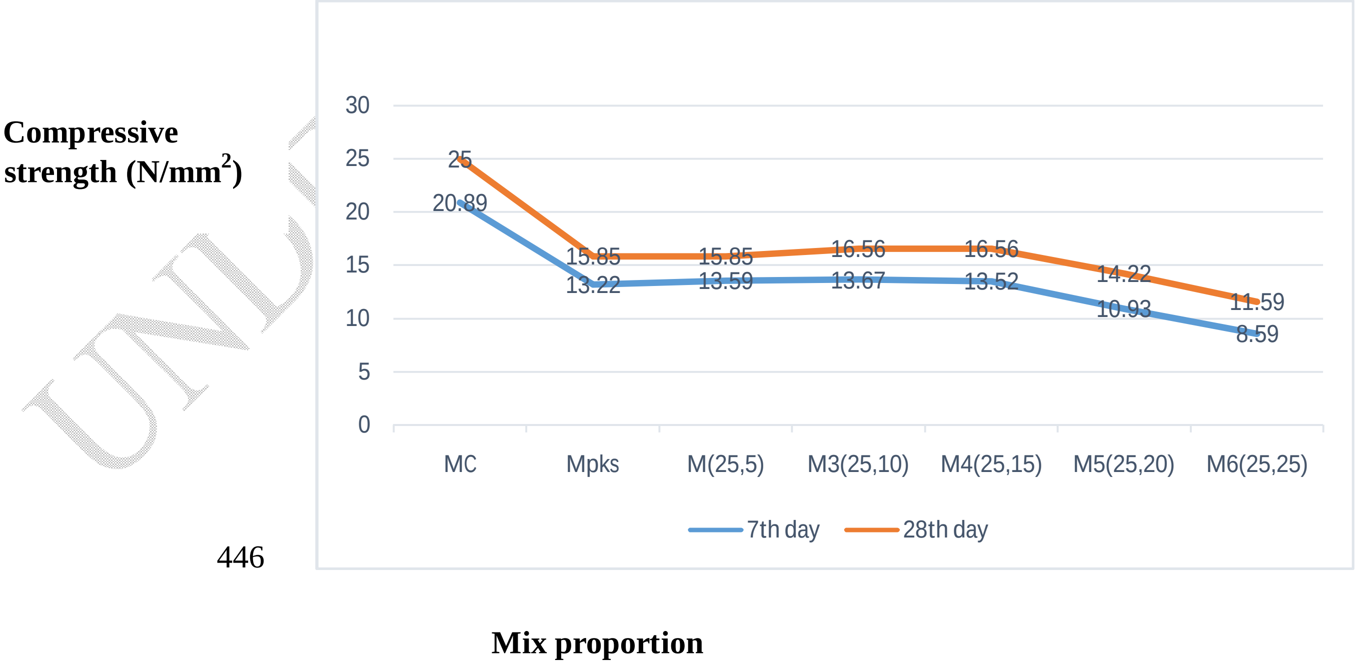

**Figure 11: Compressive strength of concrete mixes**

The compressive strengths of concrete mixes with 25% PKS replacement of coarse aggregate at various RGP replacements of cement for 7 and 28 days are shown in Figure. 11. The effects of replacement of RGP and 25% palm kernel shell on compressive strengths of concrete respectively show that the compressive strength of concrete decreases from 25N/mm$^2$ for normal mix concrete (MC) to 15.85N/mm$^2$ for concrete containing 25% PKS as a replacement of coarse granitic aggregate ($M_{pks}$). At 5% RGP replacement of cement in $M_{pks}$, the compressive strength remains 15.85N/mm$^2$. But at 10% to 15% replacement of cement with RGP saw a rise in compressive strength of concrete from (15.85 to 16.56N/mm$^2$). However further increase in RGP replacement of (20% to 25%) of cement saw the compressive strength of concrete decrease in strength for 28 days of the results. For 7 days, the compressive strength shows a decrease in strength for the concrete mix with 25% PKS replacement of coarse aggregate ($M_{pks}$) to the control mix (MC). At the introduction of 5% RGP as a partial replacement of cement in $M_{pks}$, concrete strength increases from 13.22 to 13.59N/mm$^2$. An additional increase in RGP replacement of cement saw a further rise in compressive strength to 13.67N/mm$^2$ and then started to decrease as the RGP replacement increased. Further increase in the level of replacement saw a decrease in strength as reported in previous research by Kumar and Chaudhary (2018) and Khatib et al. (2012). In general, the decrease in compressive strength of concrete containing 25% PKS ($M_{pks}$) compared to the control mix (MC), can be attributed to a low bulk density and low specific gravity of PKS compared to that of the coarse aggregate. At the

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replacement of 10% to 15% RGP content in the concrete containing 25% PKS, the compressive strength increases to 16.56N/mm$^2$. The surge in compressive strength of the concrete was a result of the pozzolanic action of the finely ground RGP since the RGP act as a pozzolanic material in the concrete. A further increase in RGP to 20% and 25% saw a reduction in the compressive strength of the concrete to 11.59N/mm$^2$. The reduction in compressive strength of the concrete with the increase in the RGP content may be due to short-term results since in such short term the pozzolanic properties would not become evident. Nassar and Soroushian (2013), Neville (2005), and Lalitha, et al. (2016) reveal that the decrease in compressive strength can be attributed to the slow pozzolanic response that happens between the reactive silica in the RGP and the calcium hydroxide produced from the cement hydration. This response produces an extra gel that raises the strength at later ages. In the use of RGP as pozzolana in concrete with 25%, PKS as a partial replacement of coarse granitic aggregate, at at15% RGP replacement of cement at most is recommended to achieve optimum results compressive strength.

### 3.3.2 Split tensile strength of concrete

The split tensile strength of various concrete mixes was estimated at age of 7 days and 28 days to study the effect of partial replacement of coarse aggregate and cement with PKS and RGP and the results are given in Table 6.

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**Table 6: Split tensile strength of Concrete Mixes**

| 7th and 28th Split Tensile Strength (N/mm$^2$) | | |
|---|---|---|
| | 7 Days | 28 Days |

| Specimen ID | Failure load (kN) | Split Tensile strength (N/mm$^2$) | Failure load (kN) | Split Tensile strength (N/mm$^2$) |
|---|---|---|---|---|
| MC | 110.83 | 1.57 | 151.67 | 2.15 |
| M$_{pks}$ | 68.33 | 0.97 | 90 | 1.27 |
| M$_{(25,5)}$ | 70 | 0.99 | 96.67 | 1.37 |
| M3$_{(25,10)}$ | 55.17 | 0.78 | 88.33 | 1.25 |
| M4$_{(25,15)}$ | 60.67 | 0.86 | 90 | 1.27 |
| M5$_{(25,20)}$ | 55 | 0.78 | 75 | 1.06 |
| M6$_{(25,25)}$ | 56.67 | 0.8 | 71.67 | 1.01 |

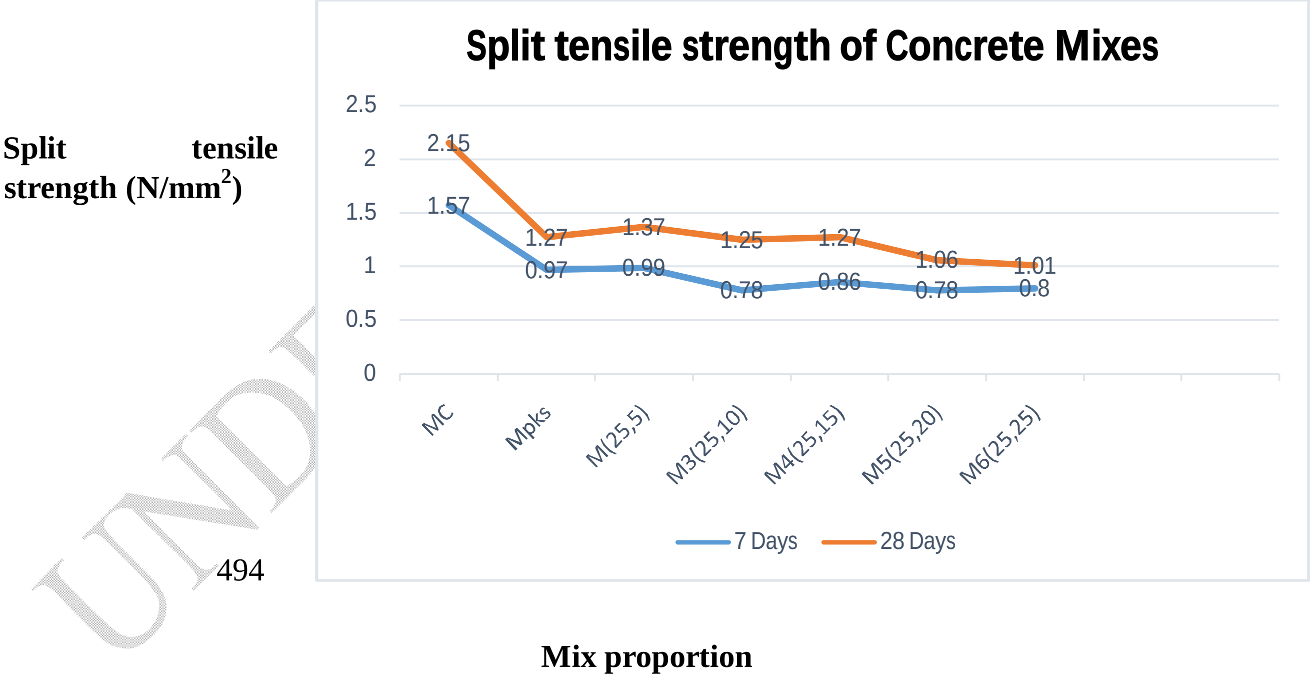

**Figure 12 Split tensile strength of concrete mixes.**

After 28days of curing, the split tensile strength of concrete with 25% PKS and 75% to coarse granitic aggregate at various RGP replacements of cement is shown in Figure 12. The effects of

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the replacement of RGP and PKS on the split tensile strengths of the concrete show that the split tensile strength of concrete decreases from 2.15N/mm$^2$ of normal mix concrete (MC) to 1.27N/mm$^2$ for concrete consisting of 25% RGP replacement of coarse aggregate ($M_{pks}$). With the introduction of 5% RGP to the mix of $M_{pks}$ the split tensile strength increases to 1.37N/mm$^2$. But at 10% replacement of cement with RGP the split tensile strength of concrete decreases to 1.25 N/mm$^2$ and later increases back to 1.27 N/mm$^2$ at 15% RGP replacement. However, further increases in RGP replacement (20% to 25%) of cement saw a reducing trend in the split tensile strength of the concrete. The split tensile strength on the 7th day of curing of the concrete mix with 25% PKS replacement of coarse aggregate ($M_{pks}$) decreased in comparison with the control mix (MC). With 5% RGP as a partial replacement of cement, the split tensile strength increased slightly from 0.97 to 0.99 N/mm$^2$. An additional increase in RGP replacement of cement produced a decrease in the split tensile strength to 0.78N/mm$^2$ and then increased to 0.86N/mm$^2$ at 15% RGP replacement. A further increase in RGP decreased the split tensile strength to 0.78N/mm$^2$. At 25% RGP replacement of cement, the split tensile strength increases to 0.8N/mm$^2$. A similar kind of decrease and increase in the trend of split tensile strength of concrete at varying levels of waste glass powder replacement of 5%, 7.5%, and 10% was reported by Shamsudeen Abdulazeez et al. (2020). Therefore, the trend of increasing and decreasing in splitting tensile strength can be attributed to the pozzolanic effect of the RGP that allows the gain of strength over a long period. To use RGP as pozzolana in concrete with 25%, PKS as a partial replacement of coarse granitic a maximum content of 5% RGP replacement of cement is recommended to develop an optimum tensile strength of the concrete.

## 4. CONCLUSION

Experimental laboratory tests were conducted to examine the suitability of recycled glass powder as a partial replacement of cement in concrete with 25% palm kernel shells as partial coarse aggregate. Particle size distribution of RGP and PKS, optimum percentages of RGP as pozzolana, workability, density, compressive strength, and split strength of concrete were investigated by replacing cement with RGP at varying percentages in concrete with 25% PKS as partial replacement of coarse aggregate. The results of the sieve analysis showed that 98.7% of the RGP passed through a sieve of 300µm, while 73.6% passed through a sieve of 150µm and 29% through a sieve of 75µm. The varied optimum percentages of RGP as pozzolana were obtained at 15% replacement of cement for compressive strength, 5% for split tensile strength

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20% for good workability, 15% for density, and 5% for water absorption of the concrete. The particle size distribution from sieve analysis conducted on PKS shows that 98% of PKS passed through a sieve of 14mm, while 90% also passed through the sieve of 12mm and 7% through a sieve of 5mm, this falls within the acceptable limit of BS 882: 1992. The workability of the concrete with 25% PKS increases with an increase in RGP content. The optimum workability of concrete was 80mm at 25% replacement of RGP to cement. The density of the concrete decreased with increasing RGP replacement of cement, although all concrete densities were within the bounds of normal weight concrete in accordance with specified standard requirements. An increase in RGP to 15% as a replacement for cement produced an increase in the compressive strength of concrete to 15 .65N/mm$^2$ at 28 days of age, while a further increase in RGP beyond 15% caused a decrease, in the compressive strength of the concrete at all ages. The split tensile strength of the concrete increased with an increase in RGP content, and a 5% RGP replacement of cement was found to be optimum for the split tensile strength of 1.37N/mm$^2$. Further increase in RGP content beyond 5% saw a decreasing trend of the split strength of the concrete.

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