Effect of Cullet Pozzolanic Properties on the Compressive Strength of Cementitious Bricks

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The hardened reactivity and adhesive force of cementitious properties in brick derivation indurates compaction strength and resistant performance during loading. This characteristic is evidenced in the pozzolanic reactivity of cullet-cement adhesion, which influences the brick's performance under compressive loading and resistance at break. The study investigates the behaviour of the cullet in cementitious compositions during compressive force and resistance limit to the load at break. Three supplementary cementitious materials (cullet, river sand, and granite dust) were used to mould 30 specimens of cementitious bricks and water cured for 28 days. These SCMs were mechanically pulverised into the finest particle size density (Kg/m^3) for densification characteristic of the bricks and elemental properties were determined through Particle Induce X-ray Emission. The materials were comparatively sole and intermixed with equal cement replacement of 6-10% (SP_{1-5}) for examination of compaction technique and compressive strength. The study unveiled the pozzolanic reactivity of the cullet, and at a high level of compaction, the resistant capacity of cullet is suitable for brick derivation in civil structures. The adhesive strength of bricks made with cullet and its intermixture have a higher linear resistance with the increase in cement as a stabiliser, but bricks that are made with river sand have a lower linear resistance during compressive loading. The compressive strength of cullet-compacted bricks (CL-CM) for the five $specimens_{1-5}$ were 1.25, 1.31, 1.37, 1.45, and 1.59MPa respectively. In comparison, river sand (RS-CM) has a strength density of 1.16, 1.23, 1.31, 1.39, 1.47MPa, and granite dust (GD-CM) has a strength density of 1.24, 1.29, 1.37, 1.42, 1.52MPa. An intermixture of cullet induces cement strength at deterioration of river sand specimens (CL-RS-CM) which proved its partial cement replacement in structural solidity of concrete and reduction in carbonic emission of cement.

Keywords: Cementitious Materials, Cullet, Compressive Strength, Elemental Properties, Waste Pollution

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INTRODUCTION

Most of the non-biodegradable pollutants are undesirable products of chemical science and advancements in human technology; accumulated in the environment as a result of economic wastage from non-utilisation. The cumulative effect of these wastes poses a threat to ecological niche and environmental safety, particularly due to the indiscriminate strewing of these materials all over the earth's surface. These non-putrescible pollutions usually occur through the emission of industrial-waste materials or by post-consumer usage of heat-transmutable products derived from a combination of different chemical properties. These polluted waste matters are threatening the global ecosystem and degrading the totality of the earth's surface. The indiscriminate disposal of these materials on the earth's surface is becoming a global concern (Khoo, 2019; Wang *et al.*, 2019), and the disposal of these polluted waste matters into landfills and incineration ultimately leads to the depletion of the environment.

Wilson (2015) warns against the increase in non-biodegradable pollution in the environment that if the current situation continues, these waste matters will outnumber fish in the sea and cause damage upon marine life. The category of these chemically transformed wastes are plastic, glass, porcelain ware, nylon, and rubber which have become a threat to the organisms within the environment. The dissolution of these waste materials are difficult due to their chemical combination and vitrification. Improper disposal of these waste matters has become a significant menace to the environment and their multiplicative increase on the earth's surface heightens danger for the global ecosystem. Most of these solid wastes are not industrially utilised but are disposed of in landfills due to their heat resistance in incinerators. But as Kalilu (2013) recommends, some of these waste materials could be lessened in the environment through recycling or industrially harnessed for highly-developed products. Some of these waste matters are suitable for refractory resistant products on account of the chemical properties and heat responsive process at the first vitrification, but become a threat to ecological niches due to physical or scientific solutions of their needs in creating new products. Although the recycling of complex non-biodegradable products of glass related components poses many challenges of right usage, it consequently, gave alternative usages after research-intensive concentration of feasibility, particularly, in liquid or pulverised form. Glass waste is one of the indiscriminately discarded poly-crystalline solid materials, made with brittle chemical oxides. Glass is a fragile structure and can easily crack or fracture. Cullet is a technical term for waste or scrap glasses. Glass is made from silica and forming compounds of SiO_2 + Al_2O_3 + X where X = (CaO, Na_2O, MgO, TiO_2, PbO, FeO, ZnO, ZrO_2) (Ajadi, 2019; Kalilu & Ajadi, 2023).

The heat transmutation of these poly-chemical oxides metamorphosed into a brittle transparent solid structure and a non-biodegradable matter that occupies space after the product's life cycle and in a number of cases post-consumer usage. Consequently, unutilized in Nigerian context (Kalilu & Ajadi, 2023), particularly for economic benefit in the recycling industries. Glass is of various chemical components, and the oxide compositions influence the quality, colour, structural solidity, and melting temperature (Ajadi, 2019). The classifications of glass based on oxide compositions are soda ash lime glass, borosilicate glass, sodium crystal glass, and electric/smart glass (Kalilu & Ajadi, 2023; Scholez, 1991; Glass Technology Services, 2004; Vieitez *et al.*, 2011; European Integrated Pollution Prevention and Control Bureau, 2012; Rutkowski, 2014; International Commission on Glass, 2015). However, the hardened reactivity of pulverised cullet under water implies its suitability in the manufacture of all kinds of mortars in cementitious compositions. Recycling of cullet is eco-friendly and has a lot of energy-saving potential for cementitious bricks (Paul *et al.*, 2022).

The role of cementitious bricks in walling units can never be overstressed (Afolayan *et al*., 2017) and they are widely used in masonry in 20th-century civil construction (Mohammed & Anwar. 2017; Anosike & Oyebade, 2012). The composition of cementitious bricks is composite materials of aggregate, cement, supplementary and measured water for hardened reactivity of the coalesced particles into solid forms (Rasheed & Akinleye, 2016; Akinpelu & Adekanmbi, 2017). In Nigeria, these solid forms are designed for load-bearing units of the wall house (225mm thick) and non-load bearing (150mm thick) for partitioning units. Durability, density, water absorption, cost, and materials' availability often determine the choice of brick designs (Raheem *et al.*, 2012; Wasiu & Makoji, 2017), and compacting techniques, cured periods, amount of constituents and coalescence of supplementary materials enhance compressive strength (Usman & Gidado, 2013; Sholanke *et al.*, 2015). These characteristics are evidenced in the pozzolanic reactivity of cullet-cement adhesion. Hardened reactivity of cullet increases confining pressure of concrete, reduces swelling properties of soils in cementitious mixes (Tang *et al.*, 2002; Blatz *et al*., 2002), is cost-effective for the consumer, and is environmentally friendly for the improvement of ecological niches.

The partial replacement of cement with supplementary cementitious materials (SCMs) has been a concern for many researchers in concrete technology, especially regarding the usage of wastes or by-products. United Nations Environment Programme Sustainable Building and Climate Initiative also asserts that the utilisation of Low-CO_2 cement-based supplements in cementitious mixes as partial cement replacement and the reduction of cement usage in civil structures are alternative ways to minimise global carbonic emission from cement (Scrivener *et al*., 2018). Besides ecological benefits, partial cement substitution offers advantage in civil construction through structural solidity, enhancement of workability, reduction of the shrinkage and segregation risks (Matos & Sousa-Coutinho, 2024), and provide an eco-efficient viable solution for Low-CO_2 cement-based material (Scrivener *et al*., 2018). Diverse waste materials have been explored by different scholars in search of alternative ways to substitute the percentage of cement as a stabiliser in cementitious compositions.

In evidence of these waste explorations, Edike *et al*. (2022) assess the performance of laterite, sharp sand, and stone dust compacted in waste PET plastics without cement as eco-brick under uniaxial compressive loading for walling units of civil structures. Partial substitution of sharp sand for waste foundry sand (WFS) for properties of concrete compressive strength and durability (Blardwaj & Kumar, 2017; Bilal *et al.*, 2019; Salman *et al.*, 2022). Premium mechanical traits of clays, limestone filler, fly ash, ground granular blast furnace slag, meta-kaolin, and silica fume on ultra-high-performance of mortar in cementitious technology (Zhang *et al.*, 2023; Alsalami & Abbas, 2024; Schmidt *et al*., 2018; Lothenbach *et al*., 2011). Khmiri *et al.* (2012) experiment on pozzolanic material of waste glass obtained from crushed containers as partial cement replacement in mortar and concrete structures. Research on concrete technology has proved that the particle size density (PSD) of cullet optimises its pozzolanic reactivity and the finer the particle, the higher the responsiveness to the concrete.

The properties of scrap bottle glass as supplementary cementitious material influence the brick's performance under compressive loading (Matos & Sousa-Coutinho, 2024), and cullet adhesiveness optimises structural solidity (Wiebe *et al.,* 1998; Prakasha & Chandrasekaran, 2005). Generally, cullet enhances the workability of mortar (Nassar & Soroushian, 2012; Matos *et al.*, 2016; Paul *et al.*, 2022), and induces cement reactions leading to enhancement in performance (Mirzahosseini & Riding, 2015; Kamali & Ghahremaninezhad, 2016). Pulverised cullet at different fineness levels and mixtures as a cement replacement for the strength development of mortar was examined by

(Idir *et al*., 2011) and the finer the cullet powder, the stronger the cement mortar (Liu *et al*., 2015; Aliabdo *et al.*, 2016; Khan *et al.*, 2020). Also, the particle size density (PSD) of the cullet improves its pozzolanic reactivity (Du & Tan, 2017). The conversion of cullet to grains as a supplementary material in cementitious mixes is structurally interesting with its enhancement on mortar performance against water capillary absorption, chloride immersion, and alkali-silica reaction (Matos & Sousa-Coutinho, 2024).

However, the paucity of literature on the statistical relation of cullet-resistant performance to other grains of rocks in cementitious compositions is still evidenced. The surveyed research gives relevant information for the current study. The study, therefore, is an investigation of cullet pozzolanic reactivity on compressive strength of cementitious bricks in a comparative degree of examination to the resistant capacity of conventional grains of rocks (river sand and granite dust) at equal cement replacement of 6-10% mixes. The rationale for these cement replacement ratios was based on the fact that cement higher than 10% in brick derivation is uneconomical and friable when less than 5% (Anifowose, 2000; Walker, 1995). The specific objectives of the study are: to comparatively determine the suitable proportion and behaviour of cullet in cementitious bricks during compressive force and resistant capacity to the load at break, to examine the influence of heat transmutation on the vitrified polycrystalline chemical of cullet through oxide analysis and most importantly, to clarify the pozzolanic properties in cementitious mixes, and to offer alternative ways of utilising cullet in enhancing concrete strength and lessening its menace in the environment.

MATERIALS AND METHODS

Cullet (CL) of alcoholic drink bottles and windowpane types from waste dumps and building construction sites were used for this study (Plate 1). River sand (RS) and granite dust (GD) were equally collected from a river pit and stone pit respectively in Ogbomoso, Nigeria, and Portland cement manufactured by Dangote Company was purchased as a stabiliser for this experiment. The three supplementary cementitious materials (cullet, river sand, and granite dust) were carefully washed to get rid of unwanted materials (Plate 2) and thoroughly desiccated for accurate results of elemental properties during oxide analysis. These raw samples were individually crushed with a hammer mill machine into a coarse powder (Plates 3-5) before being pulverised with a pulveriser machine (Rocklabs, CRC 3E) (Plate 6) for a finer particle size density (PSD).

Plate 1
Collection of Cullet

Plate 2
Washing of Cullet

Plate 3
Milled Cullet

Plate 4
Milled River sand

Plate 5
Milled Granite

Plate 6
Pulverising Processes

Thus, the three samples were also separately pulverised in a minute-regulated operation of the pulveriser machine for the finest and equal particle size results. The particle size distribution of each material and their specific densities were ascertained through the Laser Method (kg/m^3) as shown in Table 1 below.

The table highlights the pulverized density of each particle. Cullet, as a material for partial cement replacement and strength enhancement in cementitious compositions, is better when the particle is finer. The finer the cullet powder, the higher the pozzolanic reactivity (Aliabdo *et al*., 2016; Khan *et al*., 2020; Du & Tan, 2017). The nanoparticle size of SCMs improves the strength development of mortar in cementitious composition (Grissom, 2024). However, the chemical properties of the pulverised materials were analysed at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria. The materials were examined in a tandem accelerator machine (1.7MV Tandem Pelletron Model: 5SDH), using Particle induced X-ray Emission. The machine operates in Ion beam components of an Ion source, particle accelerator, quadrupole magnet, switching magnet, and scattering chambers, and the sample spectra are monitored through a Pelletron digital system. Afterward, the materials were measured with cement and homogenised on dry weights based in Jar Mill machine (G90, GE: 1880913) on batch specifications of soles and intermixtures of the samples. All the batches were equal in cement variation to the SCMs measurements (Plate 7) both in soles and intermixtures to form 30 mortar specimens shown in Table 2. The mixtures were coded and numerically inscribed for identification of the specimens' specifications (SP_{1-5}).

Table 1. Particle size density of Cement, Cullet, Granite dust, and River Sand

Materials	Cement	Cullet	Granite dust	River sand
Density (Kg/m^3)	3110	2280	2280	2280

Brick of 5 x 10 x 4cm^3 was produced through a manual hydraulic press from each specimen (Plates 8-13) to examine the mechanical strength of each composition at 28 water-cured days and the reaction of these mortar to 6, 7, 8, 9, 10 % cement replacement of the three supplementary cementitious materials (Table 2) during compressive loading.

The rationale for these multiple cement replacements on each batch specification is to validate the influence of compaction technique on the brick products' compressive strength. Pulverised cullet, as a supplementary cementitious material, does not yet have established measurements in cement replacement (Matos & Sousa-Coutinho, 2024; Mohammad, 2021; Bignozzi *et al*., 2015). Therefore, the cement proportions of this study were based on the fact that cement becomes uneconomical when greater than 10% (Anifowose, 2000) and too friable for easy handling when less than 5% (Walker, 1995).

To whatever degree, water absorption properties contribute to the resistant capacity of specimens during compressive loading. Water retention capacity was carried out on pulverised samples to determine the retention capacity of water volume and water absorption properties to determine amounts of liquid porosity in solid specimens. For the water retention capacity of pulverised samples, 5 grams of the samples were measured on filter paper for saturation in (20ml) distilled water using a measuring cylinder. The saturated solutions were subjected to filtrations to determine the retention capacities of the samples. The solutions were homogeneously mixed and filtered into conical flasks for outflow and retention examinations. Filtrates were collected for six (6) hours and the rate of final outflowed water volume (ml) was determined as shown in equation (1):

Initial Water Volume = *IWV*

Outflowed Water Volume = *OWV*

Retained Water Volume = *RWV*

Retention Capacity Percentage = *RCP*

That is: $$\frac{(IWV - OWV) \times 100}{IWV} \quad (1)$$

Water absorption properties on solid specimens were measured through liquid porosity by surface capillaries and pore formations of the bricks. The initial weight of thoroughly desiccated specimens was measured (kg) after the 28th water-cured day. The kilograms of each of the specimens were determined immediately after their removal from thorough immersion in separate water containers for 24 hours. The water absorption rate of each specimen was ascertained as shown in statistical equation (2):

Initial Weight Specimen = *(IWS)* at thorough desiccation

Drenched Weight Specimen = *(DWS)* after 24 hours in water

Absorption Capacity Volume = *(ACV)*

Absorption Capacity in Percentage = *(ACP)*

That is: $$\frac{(DWS - IWS) \times 100}{IWS} \quad (2)$$

The mechanical strength of the specimens was assessed with the digitally powered universal testing machine (Model Instron 3369K1781) and the equipment can measure 50 kilo Newton KN (11250Ib) of any material. The given parameters for the average measurement of all specimens are: anvil height 14.95000mm, thickness 149.04000mm, and width 45.05000mm and were determined in metric units of length equal to one thousand of a meter. The parametric measurement is to examine weight against the compressive strength (MPa) which was determined as shown in equation (3):

Compressive strength (MPa) =

$$\frac{\text{force (N) or Load (N)}}{\text{Area } (mm^2)} \quad (3)$$

Mega Pascal (MPa) = N/mm^2

Table 2: Batch Specifications of the Specimens ($SP_{1\text{-}5}$) in 6-10% Cement Replacement

Cullet Cement CL-CM		River sand Cement RS-CM		Granite dust Cement GD-CM		Cullet/River sand Cement CL-RS-CM		Cullet/Granite dust Cement CL-GD- CM		Cullet/River sand Granite dust/Cement CL-RS-GD- CM	
SP_1	94-06	**SP_1**	94-06	**SP_1**	94-06	**SP_1**	47 / 47 / 06	**SP_1**	47 / 47 / 06	**SP_1**	31.4 / 31.3 / 31.3 / 06
SP_2	93-07	**SP_2**	93-07	**SP_2**	93-07	**SP_2**	46.5 / 46.5 / 07	**SP_2**	46.5 / 46.5 / 07	**SP_2**	31 / 31 / 31 / 07
SP_3	92-08	**SP_3**	92-08	**SP_3**	92-08	**SP_3**	46 / 46 / 08	**SP_3**	46 / 46 / 08	**SP_3**	30.7 / 30.7 / 30.6 / 08
SP_4	91-09	**SP_4**	91-09	**SP_4**	91-09	**SP_4**	45.5 / 45.5 / 09	**SP_4**	45.5 / 45.5 / 09	**SP_4**	30.4 / 30.3 / 30.3 / 09
SP_5	90-10	**SP_5**	90-10	**SP_5**	90-10	**SP_5**	45 / 45 / 10	**SP_5**	45 / 45 / 10	**SP_5**	30 / 30 / 30 / 10

Plate 7
Cullet's Measuring

Plate 8
CL-CM

Plate 9
RS-CM

Plate 10
GD-CM

Plate 11
CL-RS-CM

Plate 12
CL-GD- CM

Plate 13
CL-RS-GD- CM

RESULTS AND DISCUSSION

Properties of Cullet, River sand, Granite dust, and Cement

Table 3 presents the result from Particle Induced X-ray Emission which shows the percentage of chemical oxides in cullet, river sand, granite dust, and cement. As can be deduced from the table, cullet like other supplementary cementitious materials has a higher percentage of silica oxide in quart crystalline form. The percentage of elements in the glass does not differ widely, except for variation in aluminum and calcium, and often comprises an approximation of 65-75% silicon, 10-15% sodium, 5-16% calcium, and 5% potassium (Ajadi, 2019). The percentage of calcium (CaO) enhances the pozzolanic reactivity of the cullet in cementitious compositions and stimulates the strength of cement.

Table 3: Oxide properties of Cullet, River sand, Granite dust, and cement (% by mass)

Oxides	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	Fe_2O_3	ZrO_2	ZnO	Cl	PbO	SrO	Total
Cullet	12.79	3.10	0.57	70.14	0.22	0.39	-	11.72	0.41	0.30	0.02	-	-	0.25	0.09	100
River sand	6.74	0.86	4.42	72.46	0.13	-	3.48	3.99	0.11	3.80	0.07	0.40	-	2.21	1.33	100
Granite dust	4.90	0.88	11.82	70.18	0.18	0.12	6.10	2.20	0.30	3.03	-	-	-	0.05	0.24	100
Cement	0.45	1.91	4.83	21.33	-	2.85	0.73	63.04	-	3.52	-	-	0.94	0.40	-	100

Water Retention Capacity

Table 4 identifies saturated solution (5 grams of pulverised samples and distilled water), outflowed water volume (ml), retained water (ml), and percentage (%) of retained water. The volume of filtrate differences were the determinant for retention capacity which were observed through the retained water on each sample in the filter paper. These were calculated by arithmetic minus of the initial volume of water (ml) from the volume of filtrate (ml) (i.e., *IWV-VOF=RCV*). The retained water volume (*RWV %*) in percentages was equally determined by multiplying retained water volume (*RWV*) with hundred (100) divided by initial water volume (*IWV*). From the table, pulverised river sand (RS) exhibited higher percentage of retention capacity and granite dust equally demonstrated a good water-holding capacity. The finest fraction of all materials aid the filtrate differences between the outflowed water and retained water of the samples. Based on these results, the water retention capacities of the three samples were approximately 5.0 which may influence the rate of water absorption and compressive strength of the solid specimens.

Table 4: Water Retention Capacity of Pulverised Samples

S/N	Samples	Saturated Samples/ Water (5g+20ml)	Outflowed Water Volume (ml)	Retained Water Volume (ml)	Retained Water Percentage
1	**Cullet**	20	15.2	4.8	24%
2	**River-sand**	20	14.6	5.4	27%
3	**Granite dust**	20	15.1	4.9	24.5%

Water Absorption Properties

Water absorption by capillary actions and pore formations was assessed on the solid specimens$_{1-5}$ of batch specifications CL-CM, RS-CM, GD-CM, CL-RS-CM, CL-GD-CM, and CL-RS-GD-CM. The equal substitution of soils and cullet (CL-RS-CM and CL-GD-CM) are higher resistance of water absorption and the cullet shows a partial cement replacement in the performance characteristic of surface tension for the specimens in these two compositions. Figure 1 summaries the percentages of water absorption rates and resistant properties of the compositions to the movement of water in batch specifications with partial cement replacement of 6-10%.

From the results, SP_1(RS-CM), SP_2(GD-CM), SP_2(RS-CM), SP_2(GD-CM), SP_1(CL-RS-GD-CM) and SP_1(CL-CM) have the highest water absorption properties of 6.35, 5.97, 5.88, 5.56 and 5.17 respectively. It was significantly evidenced in all batch compositions that water absorption properties decreased as the amount of cement replacement increased and reduced the spaces for liquid caused by intermolecular force. Hardened responsiveness of cullet partially provides surface tension at the dried phase which results in the depression of liquids in capillaries (CL-RS-CM and CL-GD-CM), and reduction of hygroscopic properties of the soils. This aligns with the statement of Scrivener *et al.* (2018). Coalescence of cullet in cementitious mix enhance mortar performance against water capillary absorption, chloride immersion and alkali-silica reaction. The pulverised cullet in the mixes reduced the capillary water absorption of the specimens, and the pozzolanic reaction decreased the porosity of all specifications in the cullet mixes. The result affirms Chopperla *et al.* (2023) which is evidenced in the degree of hydration, physical weight, and optimization of their structural solidity. Therefore, an increased amount of water absorption indicated multiple connectives of small internal pore formations and a weakened interfacial transition zone. Higher resistance of water movement by surface tension provided by the cullet proves hardened force for the specimens which leads to an improvement in strength and scratchy resistance. Thus, the coalescence of cullet and granite dust (CL-GD-CM) decreased the water absorption rate and increased in resistant capacity at compressive loading.

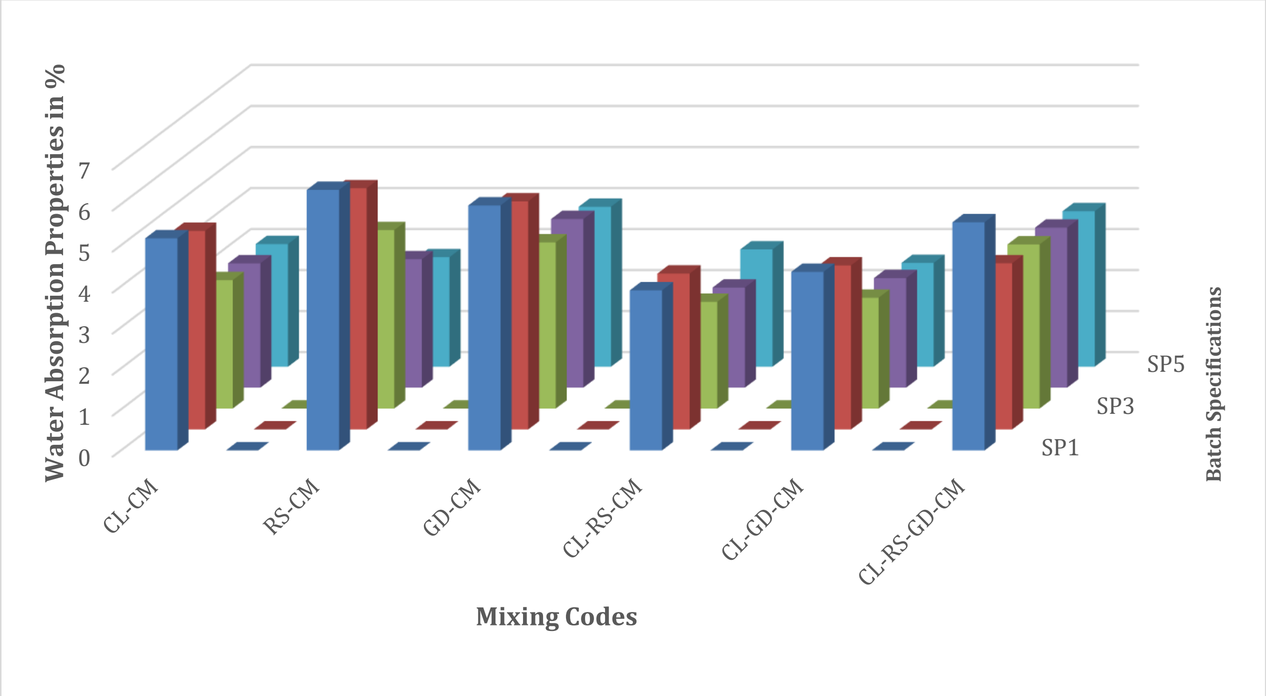

Figure 1: Water Absorption Properties of Bricks in Batch Specifications

Compressive Strength

Figure 2 presents the results of the compressive strength of the specimens both in mixing compositions and batch specifications with cement replacement of 6-10% after 28 days of water curing. Comparatively, the mixes of cullet (CL-CM) exhibited higher strength compared to the compositions of river sand (RS-CM) and granite dust (GD-CM). The compressive strength of each mix increases in batch specifications with the addition of the cement replacement to the SCMs. The reaction showcases the adhesive reactivity of cement in quantities and qualities.

As can be perceived in the results, the pozzolanic reactivity of the cullet influenced the strength of batches with cullet specifications (CL-CM, CL-RS-CM, CL-GD-CM, and CL-RS-GD-CM). Wiebe *et al*., (1998) describe the pozzolanic reactivity of the cullet as the adhesive agent that optimises structural solidity. Granite dust (GD-CM) also demonstrated a good compressive strength result in the batches. Higher water absorption rates manifested in the lower compressive strength results of river sand (RS-CM). In the intermixture results, the equal substitution of cullet and granite dust (CL-GD-CM) exhibited a good coalescence with high compressive strength. The resistant performance of intermixture under compressive loading gives a higher compressive strength results to their singly mixed with cement. Equal replacement of cullet and river sand (CL-RS-CM) enhanced the performance of river sand as the cullet present in the mix heightened the interfacial zone between cementitious pastes. The results corroborate Mirzahosseini and Riding, (2015) and Kamali and Ghahremaninezhad, (2016) submissions that, the finest pulverised cullet is a material that stimulates cement reaction at the deterioration in performance and enhances the reaction of SCMs in concrete. Generally, the pozzolanic reactivity of cullet in the strength test has shown that its partial cement replacement offers the cementitious mix a structural solidity, enhances cement workability, decreases the concrete porosity, and reduces carbonic emission of cement CO_2 (Blatz *et al*., 2002; Scrivener *et al*., 2018).

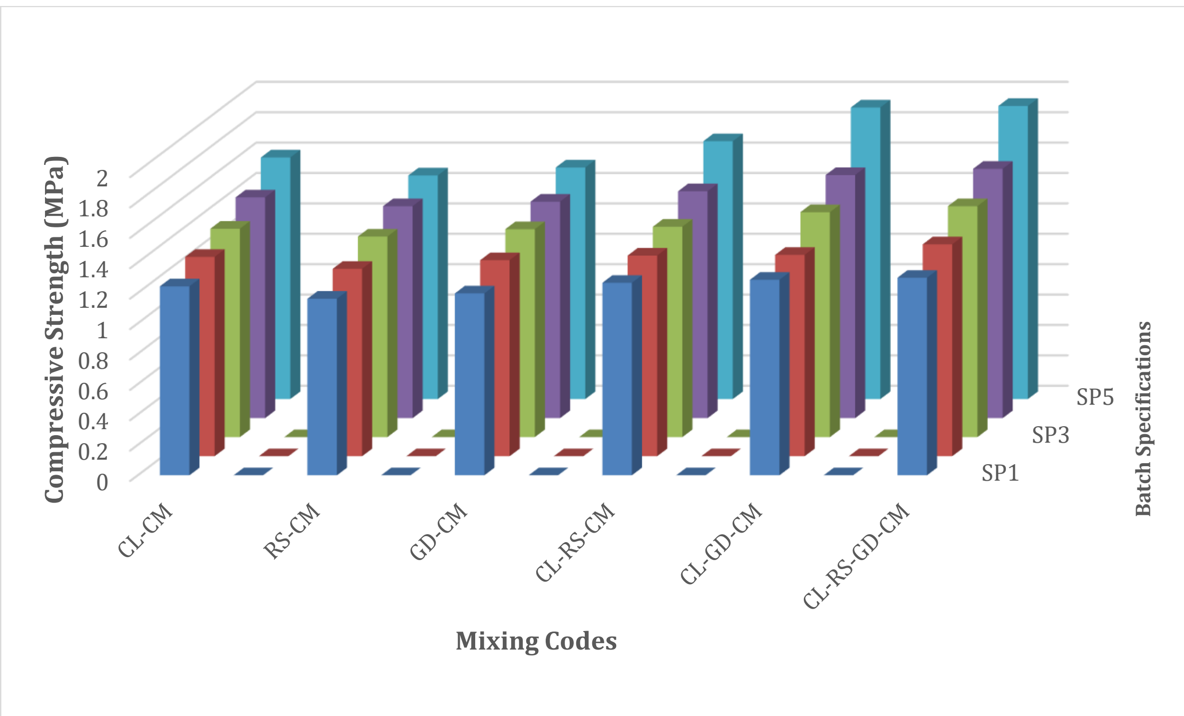

Figure 2: Compressive Strength of Brick Specimens

CONCLUSION

The pozzolanic reactivity of the cullet as a potential material for cementitious strength was investigated. Comparatively, the particle size density (PSD), oxide properties, and water retention capacity of all selected samples were analysed at pulverised phase while water absorption properties and compressive strength of the specimens were evaluated at the solid phase. The main conclusions can be summarized as follows:

1. The major oxides in the pulverised cullet of this study are S_1O_2 (70.14%), Na_2O (12.79%), CaO (11.72%), and MgO (3.10%).
2. Cullet exhibited the lowest water retention capacity in the three supplementary cementitious materials and this characteristic enhances hydration, setting

times, dry density, and densification of solid specimens.
3. The cullet pozzolanic reaction reduced hygroscopic properties of the soil samples and decreased the capillary water absorption and liquid porosity of the specimens.
4. Pozzolanic reactivity of the cullet stimulates the strength of cement at deterioration. The reaction is evidenced in the cullet enhancement of river sand specimens (CL-RS-CM) which proved its partial cement replacement in cementitious mixes with structural solidity and reduction in carbonic emission of cement CO_2.

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