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Improving durability and mechanical features of silica fume and waste glass powder in eco-friendly self-compacting concrete

Vennila Aruchamy[1], Yuvaraj Subramaniyan[2], Rajeshkumar Viswanathan[2], Arunkumar Manoharan[3]

[1]Kumaraguru College of Technology, Department of Civil Engineering. Coimbatore, India.

[2]KPR Institute of Engineering and Technology, Department of Civil Engineering. Coimbatore, India.

[3]Kongu Engineering College, Department of Civil Engineering. Perundurai, Erode, India.

e-mail: vnilaa.21@gmail.com, yuvarajsbecivil@gmail.com, rajeshcit16@gmail.com, rsmanoharun@gmail.com

ABSTRACT

The study investigates the possibility of using solid waste as an ecologically beneficial method in the manufacturing of concrete. It looks at the effects of replacing cement with glass powder at percentages ranging from 0% to 30% and a continuous 10% micro-silica replacement. The research evaluates a number of characteristics, including as resistance to freeze/thaw cycles, surface water absorption, capillary water absorption, tensile strength, bending strength, and workability. The results show that adding glass powder to concrete improves its fresh characteristics and workability. However, using glass powder in place of 30% cement results in a little loss of mechanical characteristics. In contrast to other mix designs, the concrete mixes containing 22.5% glass powder exhibit the highest increases in tensile, flexural, and compressive strengths (16.99, 23.53, and 17.65%, respectively). Concretes including 30% glass powder outperform the control design even if the strength criteria are somewhat reduced.

Keywords: Concrete strength; Glass powder; Silica Fume; Mechanical properties; Cost analysis.

1. INTRODUCTION

Due to the non-biodegradable nature of glass wastes and their environmental incompatibility, their disposal in waste sites is undesirable. In contrast to paper or organic constituents, a significant portion of glass waste lingers as residue at disposal sites even after undergoing incineration for purification. Variations in the types and quantities of raw materials used typically distinguish ordinary glasses, which commonly contain calcium lime, magnesium oxides, potassium, sodium carbonates, and amorphous silicon. The interaction between water, amorphous SiO_2, and glass containing CaO leads to the formation of low-basicity calcium-silicate-hydrate (C-S-H) crystals [1]. However, the presence of Na_2O in the glass poses a persistent challenge due to its tendency to increase the likelihood of alkali-silica reactions. It is noteworthy that sufficient quantities of reactive grains water and alkali are necessary for these types of reactions. The onset and pace of advancement of these reactions are also greatly influenced by variables such, as concrete composition, aggregate type and size, alkali permeability/solubility and water-to-cement ratio (W/C) [2]. Substituting cement with glass to impart pozzolanic properties is a logical approach, yielding a resulting material that is accessible in the form of a shapeless X-ray amorphous substance. Opting for glass as a replacement for cement is a dual benefit, benefiting both the environment and the budget. The packing density and the binder volume will be reduced by using particle size distribution without negatively affecting the rheological properties. According to KARIM *et al*. [3] pozzolanic materials should have average particle sizes and surface areas that are comparable to or less than those of Portland cement when making cementitious composites to achieve desired pozzolanic characteristics. When the particle size of glass powder is below 38 µm, its beneficial impact on concrete strength, durability, and pozzolanic behavior becomes evident. Integrating glass powder into the concrete mixture as a partial replacement for cement can mitigate the adverse effects of alkaline-silica reactions [4]. Silica fume (SF) was created during the manufacturing of ferro-silicon alloys, and exhaust gases are which release the silicon from the furnace. Addition of this SF into concrete or cement composites: 1) It can be quite pricey, 2) Reactivity is reduced as a result of the particles' high fineness and tendency to clump together,

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3) Rather than being a hydration accelerator or pozzolanic substance, it may be thought of as an inert micro-filler. Considerable amounts of portlandite are used when silica fume (SF) is employed in place of some of the cement, which leads to the development of a considerable amount of C-S-H gel [5]. For cement-based products, this gel is the main agent that imparts resistance. Elite and belite hydration form the C-S-H structure, and this structure is developed when the silica surface is specifically selected to act as a nucleation center. This process is known as the "seeding effect" phenomenon [6]. Concrete that self-consolidates (SCC) improves working conditions, productivity, and quality while it is being built. Without raising the water-to-cement (W/C) ratio, superplasticizers are essential to achieving these nice qualities and characteristics, such as permeability, flowability, and fallibility. Its chemical composition and particle-size distribution have been considered in previous studies that looked at glass waste's integration as an alternative to supplemental cementitious materials (ASCMs). According to YOUNIS *et al*. [7], adding up to 30% of powdered glass to self-consolidating concrete (SCC) improved workability and decreased density by around 1.37% at the same time. After analyzing the ultra-high-performance concretes' (UHPC) X-ray diffraction (XRD) patterns quantitatively and qualitatively. According to research investigations by GUO *et al*. [8] and PEIXOTO *et al*. [9], adding recycled glass to self-compacting concrete (SCC) that is subjected to 600°C high temperature has been shown to reduce the residual strength of the concrete. However, the water absorption and elastic modulus significantly improve at 800°C. The addition of waste glasses during the time of production of concrete materials has been described by GUO *et al*. [8] who point out that this material's remarkable resistance to abrasion and acidic chemicals contributes to its longevity. By raising the ideal SF level to 25%, it becomes easier to create concrete mixes that are more compact, with a peak compressive strength of 30%. Approximately 18% of SF is theoretically required to react with hydration products, according to the estimate given by GOLEWSKI *et al*. [10]. Using the flexible aggregates in the concrete and its negative effects have been reported by ALI *et al*. [11] to be lessened by SF, with corresponding decreases in compressive and tensile strengths of 4.7% and 1.1%. A range of 5–15% silica fume added to fiber-reinforced concrete has been linked to improved bond behavior to strength, as reported by SADRMOMTAZI *et al*. [12] This is because it has been linked to a decrease in crystallization and the formation of amorphous structures, both of which have benefits for the fiber-matrix transition zone. Further improvements in the interfacial transition zone (ITZ) structure and hydration product quality will result in improved micro-hardness and a stronger connection between the fibers and the cement paste. Around 80% of the compressive strength was increased by adding the rubber tire concrete with silica fumes based on the investigation done by TAGBA *et al*. [13].

The improvements in the mechanical properties of the concrete are ascribed to a decrease in pore volume (roughly 13%) and an increase in the strength of the Interfacial Transition Zone (ITZ). The glass and ceramic powder-modified reactive concrete and its water absorption & strength behavior were analyzed by SAIFY *et al*. [14]. A notable improvement in the mechanical properties was noted in the modified reactive powder concrete with the inclusion of 15% waste pozzolanic material, as reported in this research. TARIQ *et al*. [15] demonstrated that as the content of glass powder in concrete increased, there were enhancements observed in workability, compressive strength, and durability indicators. Furthermore, the research uncovered that the presence of waste glass powder, particularly when paired with specific superplasticizers, has a significant impact on both the flowability and the duration for which flowability is maintained [6]. The purpose of this research is to offer a viable, scientifically validated solution to tackle environmental issues related to glass waste, decrease concrete production expenditures, mitigate pollutants resulting from cement production, and enhance the characteristics of self-compacting concrete (SCC). To accomplish this objective, different proportions of glass powder (0%, 7.5%, 15%, 22.5%, and 30%) were used to replace cement, along with a fixed 10% Silica fume (SF) content. The research team then conducted a comprehensive evaluation of various aspects of fresh concrete, hardened concrete properties, and their durability. Confirmed by scanning electron microscope (SEM) analyses, the results of this investigation underscore the potential for developing self-compacting concrete (SCC) that achieves desirable technical performance benchmarks while also aligning with eco-friendly principles, thanks to the integration of Silica fume (SF) and glass powder [16]. Due to the negative environmental consequences of cement manufacturing and the significant amount of cement required to create self-compacting concrete, it is imperative to thoroughly assess the performance of concretes, including cement additives. Thorough scientific investigation is required to assess these concrete variations' performance in the areas of fresh and hardened concrete, and various durability settings. Concurrently, the use of glass powder instead of some of the cement—especially in conjunction with micro-silica—produces benefits for the environment in addition to improving the mechanical and durability qualities of fresh concrete. The goal of this research is to combine two complementary elements that are well-known for their substantial ability to increase concrete strength and durability through hydration. Also, limited attention has been given to their impact on the resistance of concrete to freezing and thawing cycles.

2. MATERIALS AND METHODS

2.1. Materials used

Glass waste materials from glass factories were ground into a 100 µm-sized powder using an electric mill. The fine and coarse aggregates with sizes of 4.75 mm and 19.5 mm were used in preparing the concrete samples. Both kinds of aggregates were readied by ASTM C33-08 [17] specifications and were maintained at a saturated surface dry (SSD) state before usage. The water utilized during the preparation and curing phases of the concrete samples complied with the requirements for drinking water outlined in ASTM C94 [18].

2.2. Mix proportions

For all five designs of the mixes made for this study, the water-cement (w/c) ratio of 0.45 with superplasticizer (0.65%), coarse and fine aggregates (1050 kg/m^3 & 680 kg/m^3) were taken into consideration. The control design is the initial mix (GP0). Fixing 10% of silica fume for the remaining concrete mix with the addition of Glass powder (7.5, 15, 22.5, and 30%) was substituted for cement in the preparation of the next four mixes, GP7.5, GP15, GP22.5, and GP30. Table 1 represents the amount of glass powder and mixes used for this current experimental investigation. Around 120 kg/m^3 of limestone powder has been added consistently to maintain the stability and homogeneity of SCC.

2.3. Testing of specimens

2.3.1. Fresh SCC properties

Concrete that self-compacts (SCC) require no mechanical compaction and is renowned for its outstanding disreputability, high fallibility, outstanding passability, and great flowability. When it comes to stability, flowability, mixing, spreading, and placement all of these processes require ideal circumstances, which determines the successful products. Slump, J-ring, V-funnel, and L-box tests are among the tests used to gauge this efficiency as they examine flowability as well as performance. The slump test is used to measure the movement and distortion of concrete caused by its weight; self-compacting concrete (SCC) usually exhibits values between 550- and 850-mm. Slump depths less than 500 mm prevent concrete from properly passing through the density of the rebar, but slump depths more than 700 mm make the concrete more prone to segregation. The purpose of the L-box test is to replicate the way that self-compacting concrete (SCC) moves through a densely packed area of rebars and describe how it behaves when it does. The test criterion for establishing SCC passability is the proportion of the observed concrete level in the apparatus's horizontal section to its vertical compartment. The L-box test ratio of 0.8 to 1 has been used to classify typical concrete. Blockage may occur due to the high viscosity of the concrete if the ratio is < 0.8. Figure 1 shows the slump cone test for concrete specimens.

2.3.2. Hardened properties of self-compacting concrete

The compressive strength of normal and glass powder added to concrete with silica fume was assessed using cubic specimens measuring 150 × 150 × 150 mm, and the final compressive strength was determined by averaging the results from three cubes. Tremendous specimens measuring 150 × 300 mm were used for the tensile strength test for each mix design, and three 150 × 150 × 450 mm beams were used to compute the flexural strength. All of the specimens were assessed at 28 days of age for the mechanical tests and the hardened portion.

Table 1: Properties of coarse aggregates used for experimental work.

TYPE OF MIX	W/C (%)	CEMENT (kg/m^3)	LIME STONE POWDER (kg/m^3)	GLASS POWDER (%)	GLASS POWDER (kg/m^3)	SILICA FUME (%)
GP0	0.45	400	120	0	0	0
GP7.5	0.45	330	120	7.5	30	10
GP15	0.45	300	120	15	60	10
GP22.5	0.45	270	120	22.5	90	10
GP30	0.45	240	120	30	120	10

Figure 1: Workability of concrete mix.

2.3.3. SCC durability

Surface water absorption testing involved examining three cubic specimens measuring 100 × 100 × 100 mm, and the average absorption rate was calculated from these samples. The samples were cured for 28 days, and then their dry weight was measured. To get a constant weight, the specimens were put in an oven. Following an hour, day, seven, and twenty-eight-day immersion in water, the specimens were removed from the tank and their saturated weights were recorded. They were then patted dry using linen cloth. Glass powder and silica fume-containing concretes were evaluated for their capillary water absorption using 3 Nos. of 100 × 100 × 100 mm cubic specimens. When the specimens acquired a stable weight during a 28-day curing period, paraffin wax was used to separate each of their four sides, and the starting weight was determined by measuring the dry weight. Water was poured from the bottom to the top side at intervals of 0.5, 1, 5, and 24 hours to determine the sorptivity coefficient (K):

$$K = \frac{Q^2}{A^2T} \tag{1}$$

Here, K is the area of the section, Q is time, A is the water absorbed level and T is the co-efficient of sorptivity. The compressive strength and loss in weight of SCC during freeze-thaw cycles, due to the addition of silica fume & glass powder has been examined using three specimens with size of 150 × 150 × 150 mm, aged for 28 days. Three concrete specimens with the size of 150 × 150 × 450 mm were used to find out the flexural strength of concrete beams and its loss in strength was examined after the free-thaw cycles. The test included 25 and 50 cycles of freeze-thaw, where the freeze temperature was between –18 and –20°C and the thaw temperature was between 18 and 20°C. Variations in weight and compressive strength were recorded during the four-hour freeze-thaw process. Using linen cloth, the surface of concrete specimens was cleaned and allowed into complete drying process after the freeze-thaw cycles. The changes in flexural and compressive strength due to freeze–thaw cycles (25 & 50) were investigated.

2.3.4. SCC – Microstructural properties

The hardened concrete and its experimental results were objectively validated by cutting sections from the center of the compressive strength test specimens and using scanning electron microscopy (SEM) photographs to look for differences in surface morphology and microstructural characteristics. The behavior of the hardened concrete was observed about microcracks, pores, ettringite, and hydration products.

3. RESULTS AND DISCUSSION

The fresh concrete test data shown in Figure 2 shows that the slump diameter for all mix designs consistently falls between 66.3 and 71.1 cm. According to the findings in Figure 2(a), improving the glass powder (0–30%) increases the slump diameter by arounnd 7.24%. The results of the J-ring test indicate that GP15 exhibits lower

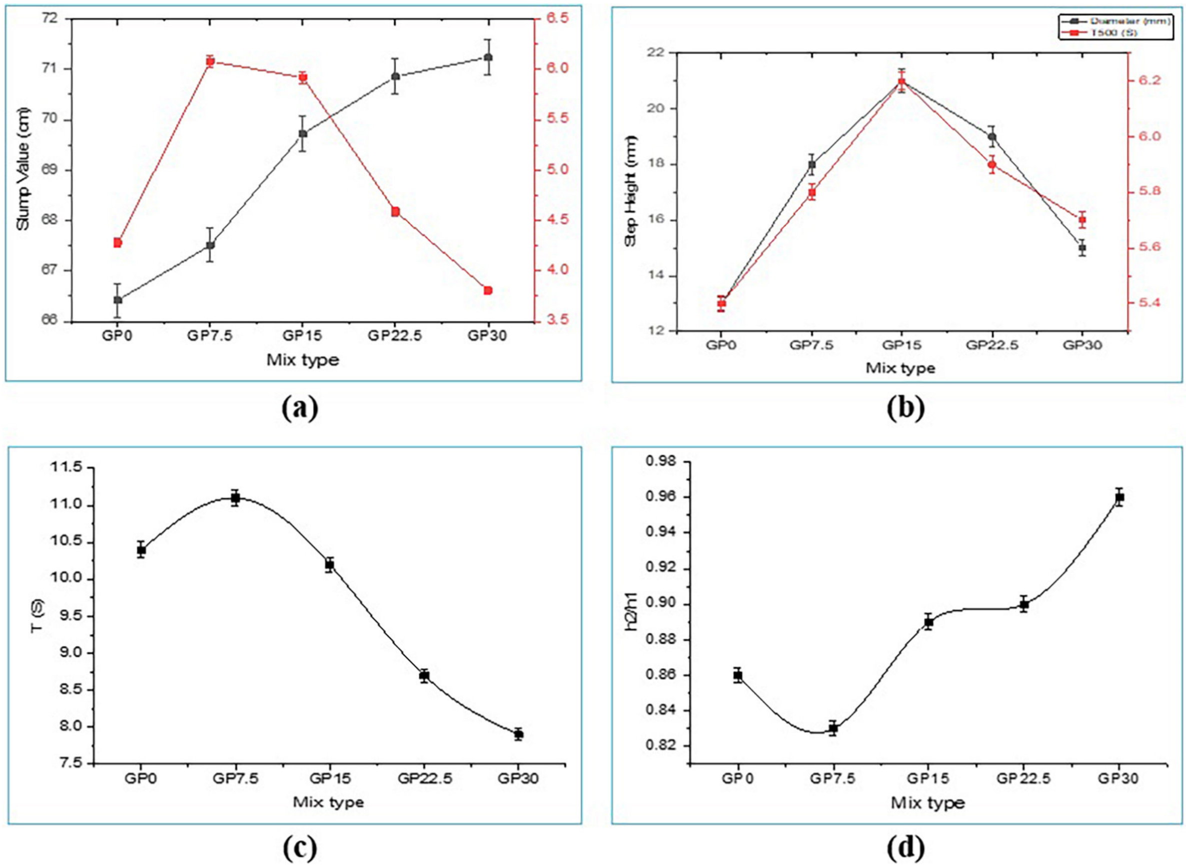

Figure 2: Tests on fresh concrete (a) Slump Value, (b) J – ring, (c) V – funnel and (d) L-box respectively.

passability compared to other mix designs, as depicted in Figure 2(b). Within the 12–20 mm interval, all mix designs exhibit variations in inner-outer ring heights. The changes in the concrete's passability through the ring rebars are comparable to the T500 variations found in the J-ring test. Concrete builds up inside the ring when glass powder content is between 0 and 15%; however, when it is increased to 30%, water absorption is reduced and W/C is raised, improving passability. Increasing the self-consolidating concrete (SCC) glass powder content leads to a reduction in T500 according to the V-funnel test results. However, GP7.5 shows a longer T500 than the control design, as seen in Figure 2(c). The EFNARC requirements are met by GP0, GP7.5, GP15, GP22.5, and GP30, as Table 1 demonstrates. The only two mix designs that are categorized as VF1 are GP22.5 and GP30, with the remaining designs adhering to VF2 requirements. Studies show that to guarantee the uniform suspension of coarse particles and avoid segregation during concrete deformation, it is crucial to maintain appropriate viscosities. This characteristic allows the grout mixture to fill the mould more effectively since it reduces the concentration of coarse aggregates and inter-particle interaction. In Figure 2(d), the h2/h1 parameters for all concrete specimens remain consistent within the 0.81 to 0.94 range, irrespective of the inclusion of glass powder. GP7.5 stands out as having less passability than GP0 among all the mixed designs. Since the replacement of cement with glass powder is based on weight, and glass is lighter than cement, this leads to an increase in the w/c ratio. Therefore, the inter-particle friction within the cement-glass pastes increases, resulting in a slight performance improvement. The highest performance of the design was achieved by 28d SCC specimens with 10% SF and 22.5% glass powder in Figure 3a. According to GP0, GP7.5, GP15, GP22.5, and GP30, these specimens have compressive strengths of 31.2, 32.8, 34.7, 36.5, and 34.5 MPa. When comparing concrete with glass powder of 30% (GP30) to GP22.5 (Highest value), a strength loss (6.4%) was seen; nonetheless, all combinations exhibit a strength improvement of 5.13–16.99% in comparison to the control design. SADIQ ISLAM *et al*. [19] state that the control mix having similar compressive strength, 5% glass-powder designs perform better than regular concretes with 20% of the cement. The mortar's performance is affected by the size of the glass particles used as a substitute for cement. CHEN *et al*. [20] described the reaction of small glass particles with lime, strengthening the mortar's compressive strength and reducing shrinkage.

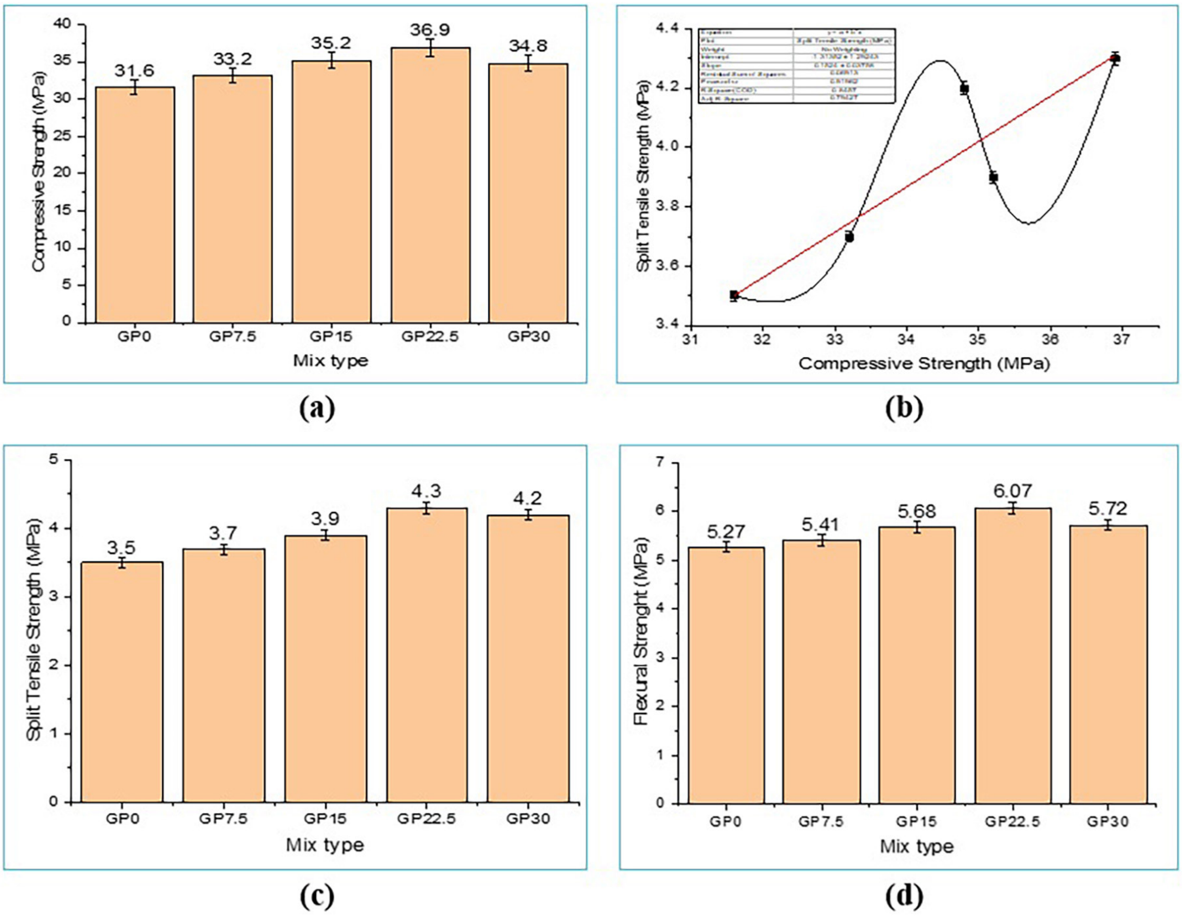

Figure 3: (a) Compressive strength, (b) Spilt tensile vs compressive strength, (c) Split tensile and (d) Flexural strength of self-compacting concrete mixes.

According to ELAQRA and RUSTOM [21] glass powder having a particle size ranging from 45–75 μm can substitute cement, improving compressive strength, lowering ASR characteristics, and generating a more compact cement-paste structure.

Glass powder's pozzolanic activity in this particular kind of concrete is what causes the rising impact [22]. The desired regression coefficient indicates a strong ascending linear association between the compressive and tensile strengths (Figure 3b). The SCC specimen's tensile strength after 28 days of curing is shown in Figure 3c. These specimens contain 0 to 30% of glass powder and 10% of silica fumes has a tensile strength range from 3.5 to 4.3 MPa. Among the various mixes, GF22.5 has the highest tensile strength (24.2%) compared to GP30 displays a minor fall in tensile strength but still exhibits a 21.26% increase over the control design. Greater tensile strengths are seen in SCCs with up to a 15% substitution of cement-glass powder; this is likely due to the enhanced production of C-S-H and other hydration products with good quality [23]. It is the interaction between calcium hydroxide and glass that gives this improvement. The glass powder and silica fume mixed concrete (GP0, GP7.5, GP15, GP22.5, and GP30) have a different type of 28-day flexural strength represented in Figure 3d. Compared to the control mix (GP0), the other concrete mix has very high compressive strength while using the Silica Fumes with 7.5, 15, 22.5 and 30% of glass powder in concrete. In comparison to GP22.5, the flexural strength will exhibit a declining trend and lose around 3.92%. According to YOU *et al*. [24] the flexural, tensile, and compressive strengths of concrete decreased when the amount of LCD glass powder increased. Reducing water absorption, a crucial component of concrete durability significantly enhances the performance of the material over the long term in demanding service circumstances. Concrete behavior during freeze-thaw cycles may be recognized and modelled with the aid of surface water absorption. The surface water absorption for each specimen including glass powder and silica fume is displayed in Figure 4 and indicates that the adsorption level is < 6.5% for all mixes at different time intervals (1h, 1d, 7d and 28d). The design with the maximum amount of glass powder (30%) for the 1h, 1d, 7d, and 28d GP0 exhibits a

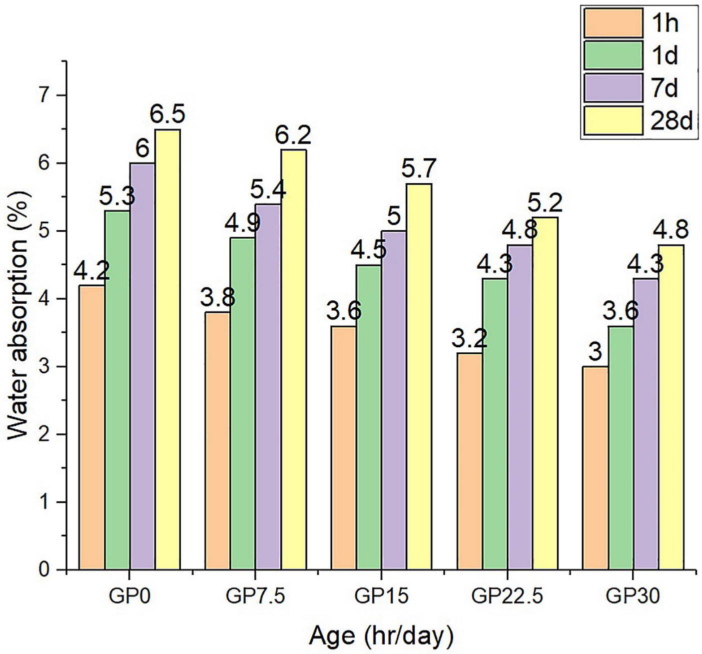

Figure 4: Water absorption of SCC in different time periods.

decrease in surface water absorption of 29.27, 32.69, 28.81, and 26.56%; the change is greatest for the 28d sample. Furthermore, it has been observed by RAHMA *et al.* [25] that less water will be absorbed by the concrete when additional glass powder is added.

The impact of water adsorption for all SCC mixes with glass powder and silica fume at 0.5, 1h, 5h, and 24 hours is displayed in Figure 5a. At all ages, the water adsorption rate is decreased without changing the silica fume content of concrete by adjusting the glass powder ratio. After 24 hours, there was a 46.77% decrease in capillary water absorption in concrete with 30% more glass powder than in the control mix. Porosity and capillary pores in the concrete's microstructure are decreased by fly ash, silica fume, and other pozzolanic additions by increasing the synthesis of C-S-H and decreasing CH. The free and thaw cycles of several SCC mixes with SF and glass powder are displayed in Figure 5b. It was found in this study that after 25 cycles, the GP0 is the only one that reduces weight by up to 0.24%. After 25 to 50 cycles, the weight increase is seen in the other mixtures. The overall weight of the absorbed water exceeds the weight of the broken concrete in GP7.5, GP15, GP22.5, and GP30 due to significant water absorption. As a result, the concrete specimen weighs more. The concrete surface is partly spalled and cannot absorb water after saturation; during this process, the spalled concrete weight decreases with the weight of water absorbed; and the concrete continues to show a slight weight gain even after 50 cycles of freeze-thaw. A weight decrease under 50 freeze-thaw cycles is also demonstrated by GP15, GP22.5, and GP30 in addition to the control architecture. Figure 5b illustrates that all mix designs have weight losses of less than 0.7%. As per theoretical explanations, the surface pop-outs were caused by free-thaw cycles and reduced the weight of concrete specimens which transpire when saturated aggregates expand at the surface and cause the surrounding cement paste to crack. According to ZHAO *et al*. [26] the loss in weight can be caused by an increase in the number of free-thaw cycles and the cycles were restricted between 75 – 225. XIE *et al*. [27] stated that there was no difference in the weights and measurements when the specimen was after 25 – 75 cycles. After 50 freeze-thaw cycles, specimens containing 20% glass powder would lose 24% of their weight, according to JURCZAK and SZMATUŁA [28] The scaling resistance would be improved by the fine particle filling effect and increased pozzolanic processes. Less than 8% of the strength is lost after 25 cycles, with GP22.5 experiencing the least loss.

Figure 6a shows that when the number of freeze-thaw cycles increases, the compressive strength of every mix design increases as well. When the glass powder volume is at its peak, the loss trend increases even if it is decreasing up to 22.5% replacement. Even if the amount of glass powder is reduced up to 22.5% replacement, the loss trend rises when it reaches its apex. The resistance drop variation between the mix designs becomes more noticeable as the number of cycles is increased from 25 to 50. By reducing inter- and surface-aggregate gaps, GP22.5 improves its performance in freeze-thaw cycles, which may be related to improving the

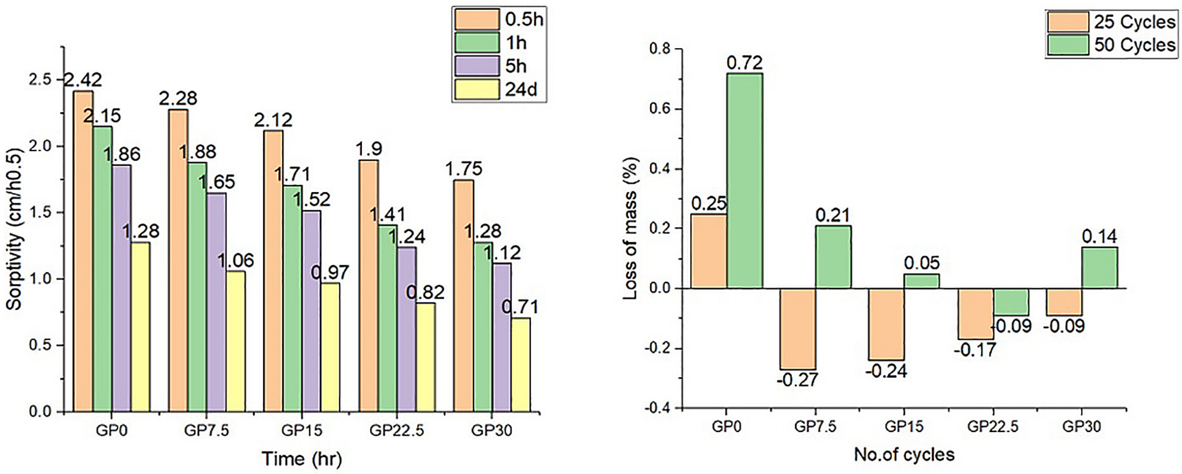

Figure 5: (a) SCC capillary water absorption and (b) Changes in weight mass after freeze and thaw cycles.

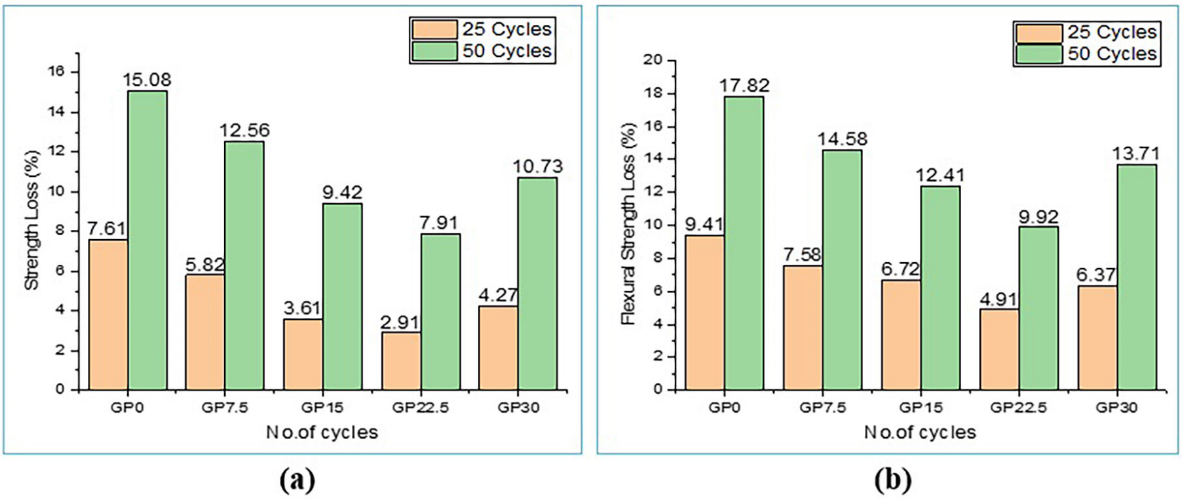

Figure 6: (a) Changes in compressive strength and (b) Changes in flexural strength after free-thaw cycles.

microstructure. The formation of hydration compounds, which result from the combination of SF, glass powder, cement, and water, makes these advancements possible. Figure 6b shows the flexural strength loss after 25–50 cycles for GP0, GP7.5, GP15, GP22.5, and GP30, which are between 4.80 and 9.32% and 9.81 and 17.61%, respectively. The findings show that when the number of cycles increases, the control design's flexural strength significantly decreases. The mix design with 10% SF and 22.5% glass powder exhibits the least amount of loss in free-thaw cycles. Even after 25 cycles, GP30's flexural strength loss is more than GP22.5's, although it is still less than that of other mix designs. However, in contrast to GP15 and GP22.5, the increase in cycles from 25 to 50 results in a greater loss of flexural strength in the mix design with the greatest glass powder concentration. The average initial fracture strengths that fall by 23.1, 15.5, and 16.9%, respectively for High-Performance Fiber Reinforcement Concrete (HPFRC) containing 0, 1.5, and 2.5% of steel fiber after 75 cycles suggested by QIN *et al*. [29]. Additionally, the flexural behavior of the materials is significantly impacted by these cycles.

In Figure 7, the SEM images of every mix design are shown. The strength loss in GP0 is mostly caused by the production of needle-shaped ettringite structures, many fractures, big unhydrated particles, and a substantial number of voids; hydration products and C-S-H structure are formed at very low levels in this mix design. Dehydrated particle size reduction and the removal of ettringite fragments from the GP7.5 microstructure are

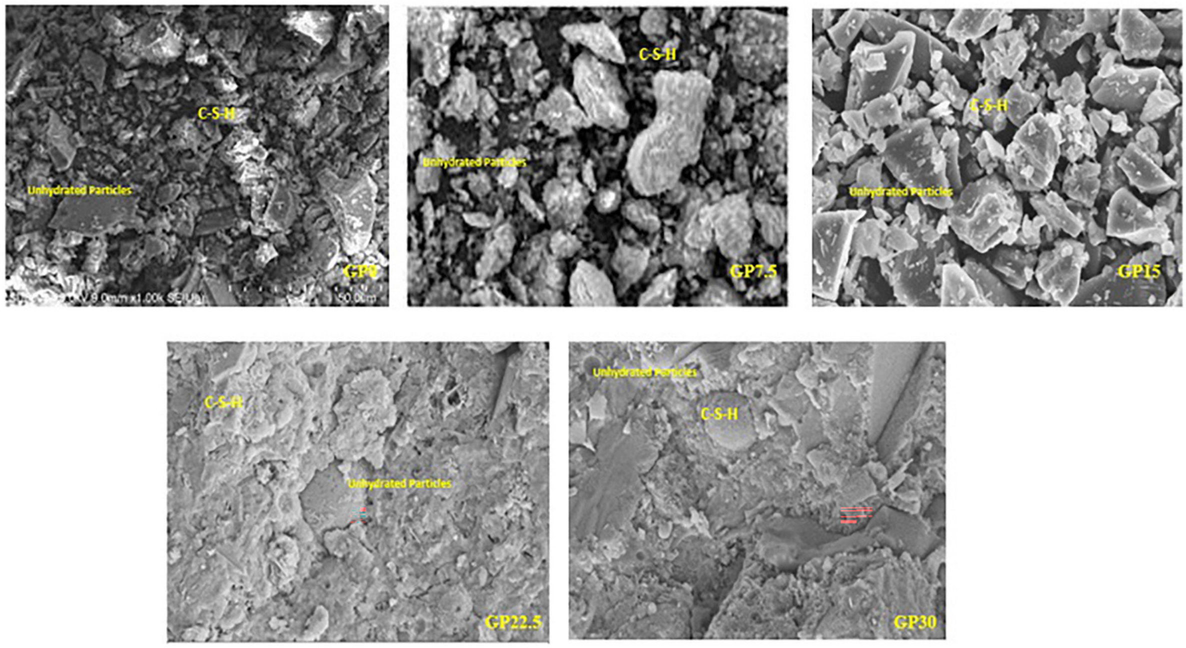

Figure 7: SEM images of concrete (SCC) mixes with different mix proportions.

not enough to prevent persistent cracks from preventing the resistance from growing substantially. GP15 has the same tendency, albeit its microstructure exhibits a more pronounced C-S-H structure, which contributes positively to the rise in resistance. Due to high thickness and volume, the homogeneous structure of C-S-H fills the voids and decreases the continuity of the fractures when the glass powder content is increased to 22.5% in produced concrete [30]. Small unhydrated particles are still seen in some areas of GP22.5, but this resistance is due to the hydration products' uniform structure. Resistance-drop features such as spaces, fractures, and needle-shaped a mineral called grains are either completely missing or periodically present at this replacement percentage [31]. The production of unhydrated particles and voids causes a modest loss in strength, even if the concretes with the biggest amount of glass powder (GP30) still have the C-S-H structure.

The findings of the EDX analysis, which are shown in Figure 8, showed the elemental compositions of the hydration products in various concrete mixes. The amounts of silicon (Si) and calcium (Ca) in GP0 were much greater than in the other concrete mixes. Additionally, spectral analysis was carried out on combinations with different compositions. Across all concrete mix types, including GP0, GP7.5, GP15, GP22.5, and GP30, the elemental distributions (in weight %) of aluminium (Al), iron (Fe), magnesium (Mg), calcium (Ca), silicon (Si), and the Ca/Si ratio were mostly found. The results showed that the elemental compositions of the plain hydrated ordinary Portland cement (OPC) and the cement pastes of the two combinations (GP7.5 and GP15) did not differ significantly. The elemental compositions of the hydration products deposited in the glass powder with silica fume, however, were statistically different from the typical mix. The silica fume-containing glass powder exhibited significantly higher calcium-to-silicon (Ca/Si) ratios in the hydration products due to the detection of very minute levels of aluminium (Al), iron (Fe), magnesium (Mg), and silicon (Si). These findings suggest that the GP22.5 and GP30 mixes had a greater quantity of calcium hydroxide (CH) crystals. Moreover, the mixture compositions had a discernible effect on the calcium-to-silicon (Ca/Si) ratio of hydration products in the tracheid lumen. In particular, it was challenging to identify components like aluminium (Al), iron (Fe), and magnesium (Mg) in the combination due to the presence of silica fume (SF) without further chemical additions. In addition to the poor mobility of the SiO4 ion, the greatest calcium-to-silicon (Ca/Si) ratio of 125.3 recorded in the research was also attributable to the presence of excess degraded polysaccharides in the extractives of silica fume (SF), which resulted in extremely low levels of silicon (Si). At the outset, the process was severely curtailed and even stopped due to the mixture's suppression of cement hydration. Less SiO_4 and other ions were thus liberated into the cement solution [32]. We studied and compared the morphological characteristics and elemental compositions of the hydration products that formed on the surface of glass powder when silica fume was added. The hydration products' microstructure and morphology that form on the surface of silica fume have a major impact on the strength of the connection between wood and cement. The combination's makeup, however, has a significant impact on the morphology of these hydration solutions. Decreased binding strength

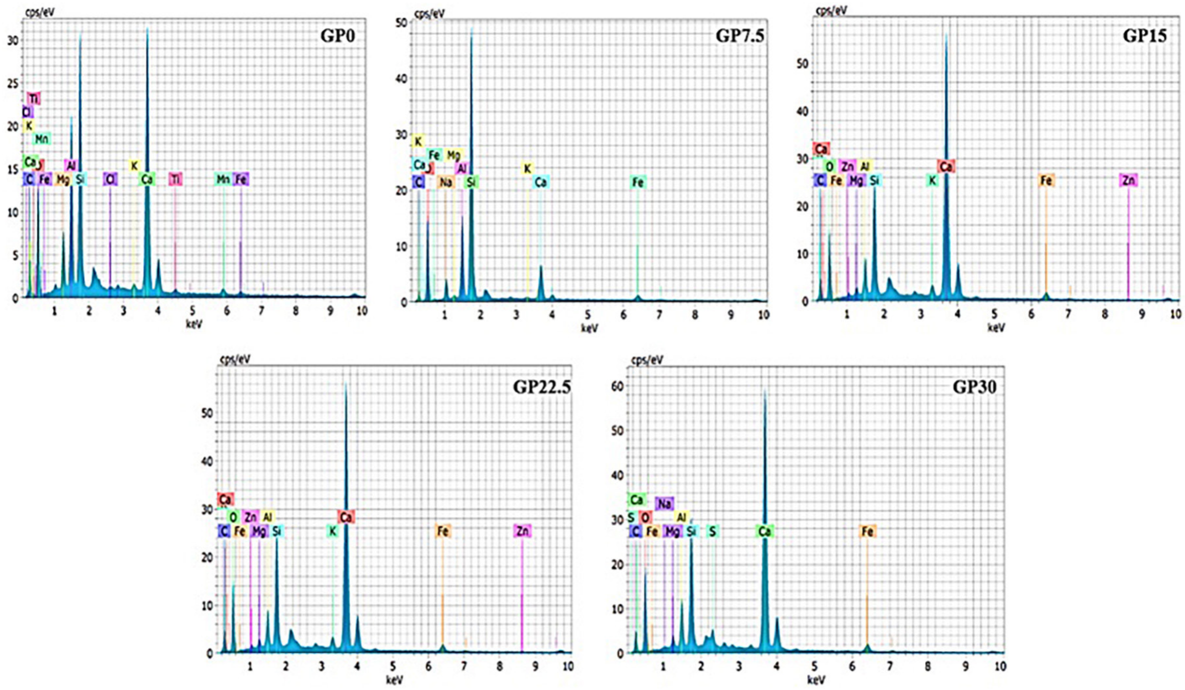

Figure 8: EDX images of concrete (SCC) mixes with different mix proportions.

Table 2: Materials and its cost details.

MATERIAL (kg)	TYPES OF MIXES					
	Cost ($/kg)	GP0	GP7.5	GP15	GP22.5	GP30
Cement	0.024	450	380	350	330	300
Limestone powder	0.051	450	380	350	330	300
Glass powder	0.006	0	30	60	90	120
Silica fume	0.0081	40	40	40	40	40
Fine Aggregate	0.0027	1050	1050	1050	1050	1050
Coarse Aggregate	0.0019	680	680	680	680	680
Water	0.0006	188	188	188	188	188
HRWR	1.42	2.6	2.6	2.6	2.6	2.6
Total ($/m^3)	–	33.19	29.38	27.46	26.82	24.22

and, as a result, decreased mechanical performance of wood in concrete can be the outcome of delayed cement hydration, which can also contribute to a worse hydration product shape.

Prices as of December 2023 are used to calculate the expenses of procurement, shipping, and quality assurance for the materials required to make GP0, GP7.5, GP15, GP22.5, and GP30. The cost/cm^3 of production for various concrete mixes without silica fume/glass powder is represented in Table 2. Based on the results, the costs of concretes with glass powder levels of 7.5, 15, 22.5, 30%, and 10% silica fume are 28.54%, 18.16, 23.35, and 12.94 cheaper than GP0, respectively. while 30% glass powder is used in place of cement while creating SCC, NAJAF and ABBASI [33] report a 23.67% reduction in costs.

4. CONCLUSIONS

The current study aims to enhance the characteristics of concrete, lower CO2, and energy consumption, and address environmental issues related to waste-glass depots and cement manufacturing. To achieve this, the self-compacting concrete was produced with 10% silica fume and a varying amount of glass powder (0 – 30%) instead of cement. A range of experiments were performed to evaluate the effects of freeze-thaw cycles, including surface and capillary water absorption, slump, compressive, flexural, and tensile strength. The following outcomes are confirmed by SEM images:

- With its smooth surfaces and little water absorption, glass powder would enhance the qualities and functionality of new concrete while simultaneously satisfying EFNARC standards for the manufacturing of SCC.
- Because additional glass powder has more C-S-H in the concrete's microstructure, is more reactive, better packs the particles, and has fewer internal voids, it decreases the amount of water absorbed by the surface and capillaries.
- Glass-powder concretes subjected to 25 and 50 freeze-thaw cycles provide a thick and uniform microstructure, appropriate pore filling, and the necessary glass particle reactivity by enhancing the synthesis of C-S-H gel. Comparing this to the control design yields extremely good compressive and tensile strengths as well as minimal weight loss.
- SEM images relate two factors that contribute to strength rise: 1) the formation of the resistance drops, which is mostly brought on by the concretes' thick C-S-H structure, which contains 22.5% glass powder; and 2) the porosity, cracks, and unhydrated particles.
- In addition to addressing a portion of the environmental issues associated with cement manufacturing and the disposal of glass waste, adding glass powder to concrete enhances its characteristics and lowers its production costs by around 23.67%. The alkali aggregate response of this concrete will be the main focus of the next study plan

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