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Influence of Utilizing Glass Powder with Silica Fume on Mechanical Properties and Microstructure of Concrete

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ABSTRACT
Carbon dioxide (CO_2) emissions from cement production and pollution from glass shards both contribute to critical environmental issues. To help in the elimination environmental issues, solid wastes like glass are used as a partial cement alternative. Glass powder is marked by an altitude level of silicon dioxide SiO_2 in its chemical composition, which qualifies it as a pozzolanic material. Partial cement substitution with glass powder in silica fume concrete was explored, and the results have been compared to those of both conventional concrete and silica fume concrete. The proportions of partial substitution of cement in blended (silica fume and glass powder) concrete were 10%, 20% and 30%. A variety of characteristics, including workability, dry density, compressive strength, splitting tensile strength, and microstructure, were used for evaluation the concrete mixes. Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) were used to investigate the microstructure of concrete samples. Experimental studies have manifested that replacement levels of glass powder 10, 20 and 30% enhance workability of concrete. Adding glass powder with 10% replacement level to silica fume concrete increases compressive strength by 14% compared to conventional concrete. Results of SEM micrographs and EDX analysis indicates that glass powder is promised to be an effective pozzolanic material.

Keywords: *Glass; Powder; Silica; Fume*

1. Introduction

There is a remarkable development in construction and building field because of the population increment, which is the most consuming field of raw materials and energy (Guignone et al., 2020). The development in construction and building industry is related to a boom in the concrete manufacture (Khan et al., 2020). The concrete industry depends mainly on the strategic material cement, as the concrete industry results in harmful environmental effects because carbon footprint issued by the cement industry (Tamanna et al., 2020). The cement industry results in 7% of carbon dioxide CO_2 emissions, which result in global warming (García et al., 2020; Yasouj et al., 2020). About 1.5 billion tons of Portland cement are produced each year around the world, and one ton of clinker Portland cement produces around a ton of carbon dioxide CO_2 (García et al., 2020). To reduce the environmental issues, the term concrete sustainability appeared, and its purpose is to design and produce concrete with the least amount of clinker with less CO2 emissions while maintaining the performance requirements and durability compared to traditional concrete (García et al., 2020). Durability is the capability of concrete to resist the long term aggressive surrounding factors while maintaining its original shape such as weathering factors, erosion, chemical attack, or any other factors that damage concrete (Jain et al., 2020; Tariq et al., 2020). Studies show that incorporating supplementary cement materials SCMs in concrete structures as a partial cement substitute achieves both sustainability and durability of concrete while improving its mechanical properties and behavior (Guignone et al., 2020; Pashtoon et al., 2022). Partial cement replacement materials are classified into agricultural wastes, by-product wastes and recycled wastes. Agriculture wastes having pozzolanic action that are employed as supplemental cement components include rice husk ash, sugarcane bagasse ash, wheat straw ash, and palm oil fuel ash (Uzbas et al., 20202; Amin et al., 2022). Use industrial by-product materials for instance blast furnace slag, fly ash and silica fume has a great positive impact on environment issues, and durability and sustainability of concrete (Islam et al., 2017; Raj et al., 2021; Kalakada et al., 2019). To eliminate the health hazard impact from the accumulation of industrial wastes such as paper wastes, plastic wastes and glass wastes, these wastes are recycled and used as a partial replacement for cement (Jain et al., 2020; Tayeh et al., 2019).

Silica fume has highly pozzolanic reactivity compared to fly ash and blast furnace slag, consequently, using cement in place of silica fume at a lower percentage is sufficient (Yunchao et al., 2021). Silica fume is a rich microscopic spherical particle of silicon dioxide SiO2 resulting from the melting of silicon from both metallic silicon and ferrosilicon alloys as a by-product (Uzbas et al., 2020; Padavala et al., 2022). Silica fume are very fine spherical particles with highly surface area and are 100 times smaller than cement particles [Uzbas et al., 2020; Nafees et al., 2022). The fine particles of silica fume fill the voids and gaps in the cement paste providing denser microstructure (Yunchao et al., 2021). As a consequence of this, the extremely minute girth of the silica fume granules affects the microstructure of the cement paste and fills the interfacial transition zone ITZ of matrix, which ultimately leads to an increase in concrete strength (Uzbas et al., 2020; Alaloul et al., 2021). Silica fume is classified as a highly pozzolanic substance that combines with calcium hydroxide C-H to originate extra calcium silicate hydrate C-S-H, which contributes to the early strength of concrete (Nafees et al., 2022).

Waste glass powder is a promising non-conventional cement material that has received significant attention during the past two decades because of its ability to be recycled while maintaining its chemical composition and crystalline structure (Khanet al., 2020; Tariq et al., 2020). Waste glass either as a coarse aggregate or as a partial replacement for cement, and the latter is the most utilized because of the damage generated by the alkaline interaction between cement paste and the silica in waste glass aggregates (Chen et al., 2020; Hussainet al., 2022). The main component of glass powder is silica, besides, the chemical components of glass powder almost the same chemical components of cement consequently, glass powder is promised the ideal material for partially replacement of cement (Safarizki et al., 2020). The dry mixture's surface area increases when the glass powder particles are shrunk to a size smaller than cement, which raises the rate of hydration by expanding the hydration sites (Nassar et al., 2021). The pozzolanic properties are achieved once the size of glass powder's particles is less than 300 μm, and the same pozzolanic properties are provided with particle size less than 100 μm with lower replacement ratios for cement (Abo et al., 2022; Szudeket al., 2022). Studies showed that an interaction among glass powder and cement hydration component calcium hydroxide resulted in the formation of more calcium silicate hydrate gel. The additional calcium silicate hydrate gel fills the voids, improves the porous structure, prevents connections between the micro-capillary channels and reduces the porosity of the cement paste (Te et al., 2022). By making glass powder more finely ground, pozzolanic reactivity can be boosted and reduce shrinkage brought on by the alkali-silica reaction. ASR (Kalakada et al., 2019; Najaf et al. 2022).The goal of this survey is to investigate the effects of substituting cement with glass powder in silica fume concrete for its workability, dry density, and mechanical qualities. Results of blended concrete were compared to conventional and silica fume concrete. Material characterizations were achieved by Scanning Electron Microscope SEM and concrete compositions were recognized by energy-dispersive X-ray EDX analytical technique.

2. Material and methods

2.1. Materials

In this survey, a locally consistent ordinary Portland cement with a CEM I 42.5 grade is utilized. The ordinary Portland cement is complying with E.S.S. 4756-1/2013 CEM I 42.5N and BS EN 197-1:2011 CEM I 42.5N. Fineness and specific gravity of the cement are 3472 cm2/gm and 3.15 accordance with ASTM C204 (ASTM C204, 2018) and ASTM C187 (ASTM C187, 2016), respectively. The used silica fume is a hydraulic blend of active ingredients contains fine latently reactive silicon dioxide of 0.1 μm in size (Sika Fume, 2020). Silica fume meets the requirements of ASTM C1240 (ASTM C1240-05, 2005). Fineness and specific gravity of the silica fume are 18500 cm^2/gm and 2.16 according to ASTM C204 (ASTM C204, 2018) and ASTM C187 (ASTM C187, 2016), respectively. Glass wastes were collected, crushed, and sieved to provide particles sizes of 200 μm and 400 μm. Fineness and specific gravity of the silica fume are 3260 cm^2/gm and 2.41 according to ASTM standards mentioned before. Table 1 lists the chemical compositions of waste glass powder, silica fume, and cement. Figure 1 depicts the appearance of utilized silica fume, and Figure 2 depicts the appearance of waste glass powder. In this particular study, sand and crushed dolomite are employed as the fine aggregate and coarse aggregate, respectively. Sieve analysis test were performed for sand and crushed dolomite in accordance with ASTM C136 (ASTM C136, 2019). Sieve analysis test results for sand and crushed dolomite are shown in Figure 3. Sand has a specific gravity of 2.66 and a fineness modulus of 2.07. Crushed dolomite has a nominal maximum size of 20 mm, specific gravity of 2.52 and fineness modulus of 6.06. An aqueous solution of modified polycarboxylates with density of 1.08 t/m^3 is used a superplasticizer [Sika ViscoCrete-3425, 2010]. The superplasticizer used in this paper meets the requirements of both ASTM C494 (ASTM C494, 2019) and BS EN 934 (BS EN 934, 2012). Water that was used in the casting, batching, and curing processes was drinkable. The criteria of ASTM 1602 (ASTM 1602, 2018) were applied in selection of concrete water.

Table1: Cement, silica fume, and waste glass powder chemical composition

Oxide	**Chemical Composition (%)**		
	Ordinary Portland cement	Silica fume	Waste glass powder
Silicon oxide SiO_2	21.08	98.19	71.44
Calcium oxide CaO	63.12	0.17	11.34
Aluminum oxide Al_2O_3	4.86	0.17	2.32
Iron oxide Fe_2O_3	4.43	0.38	0.66
Sulfur oxide SO_3	2.31	0.21	0.36
Magnesium oxide MgO	1.35	0.25	1.05
Sodium oxide Na_2O	0.3	0.15	11.41
Potassium oxide K_2O	0.16	0.18	0.78
Loss on ignition L.O.I.	2.35	0.32	0.64

Figure 1: Silica fume

Figure 2: Waste glass powder

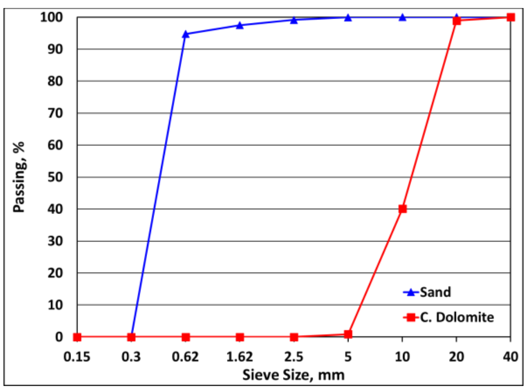


Figure 3: Sieve analysis test of sand and crushed dolomite

2.2. Mix proportions and methodology

Details and concrete mixes ratios are tabulated in Table 2. The concrete mix ratio of the conventional MC was 1:1.8:2.7 by weight of cement, sand and crushed dolomite, respectively. Water cement ratio for control mix was 0.4, where the water binder ratio for the other mixes was 0.4 also. Silica fume replacement level was constant with level 10% of cement and the quantity of superplasticizer was constant dose of 1.5% of cement. The replacement levels of waste glass powder were 10, 20 and 30% by weight of cement. Concrete mixes were prepared, cast, and cured according to ASTM C192 (ASTM C192, 2000). Silica fume and superplasticizer were added to concrete with accordance to ACI 234R (ACI 234R, 2006) and ASTM C494 (ASTM C494, 2019), respectively. Workability of the concrete mixes was assessed by applying slump test complying to ASTM C143 (ASTM C143, 2015). Density of hardened concretes was evaluated in compliance with ASTM C642 (ASTM C642, 2021) at ages of 3, 7 and 28 days. Concrete cubes with dimensions of 150×150×150 mm were tested in compression according to ECP 203 (ECP 203, 2018) and ASTM C36 (ASTM C36, 2016). Concrete cubes were examined at three different ages: three,

seven, and twenty-eight days. The splitting tensile strength of concrete cylinders 300×150 mm was determined using ASTM C496 (ASTM C496, 2017).
The purpose of the scanning electron microscopy SEM test is examining the morphology of the concrete sample. For each concrete mix, a hardened sample with a dimension of 10×10 mm was oven dried for 24 hours at 105 °C. Samples surfaced were smoothed and samples were charged electrically by posting a thin layer of platinum on it, finally the samples were placed on SEM stem. Concrete underwent Energy Dispersive X-ray (EDX) analysis to learn more about its chemical make-up and reaction products. After 28 days of drying, small samples of hardened concrete were cut from concrete cubes. The tested samples were polished and carbon-coated prior to testing.

Table 2: Details of mix proportions and concrete mix design

Mix Code	Mix Proportion (Kg/m^3)						
	Cement	Sand	Crushed dolomite	Water	Silica fume	Glass powder	Super-plasticizer
MC	400	720	1080	160	---	---	6
MSF	360	720	1080	160	40	---	6
MSFGP10	320	720	1080	160	40	40	6
MSFGP20	280	720	1080	160	40	80	6
MSFGP30	240	720	1080	160	40	120	6

3. Results

Slumps of the concrete mixes are illustrated in Figure 4. Figures 5 and 6 show densities and compressive strengths of the concrete mixes at different ages (3, 7 and 28 days), respectively. Splitting tensile strengths of the concrete mixes at age of 28 day are demonstrated in Figure 7. Figures 8, 9 and 10 show the SEM morphology, ITZ analysis and EDX analysis of the concrete mixes, respectively. Table 3 demonstrates the results of EDX analysis of concrete mixes.

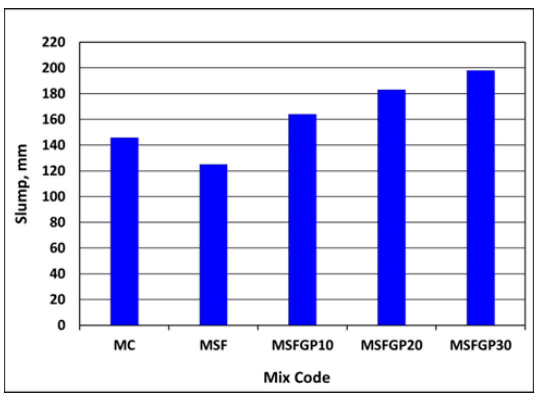


Figure 4: Slumps of concrete mixes

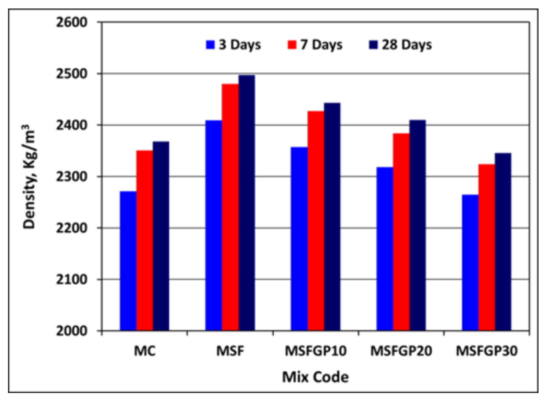


Figure 5: Densities of concrete mixes at ages of 3, 7 and 28 days

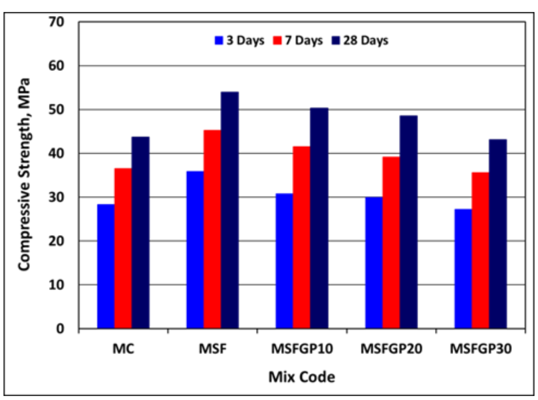


Figure 6: Compressive strengths of concrete mixes at ages of 3, 7 and 28 days

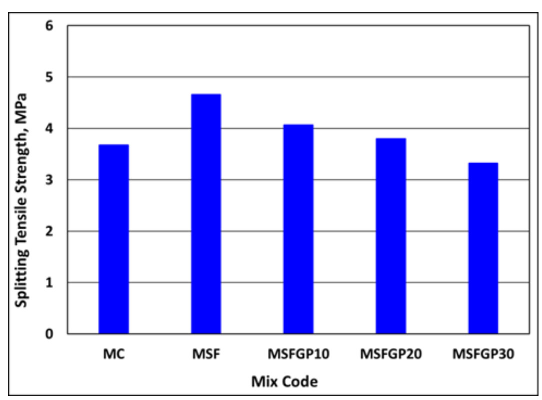
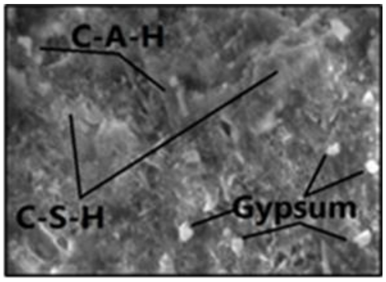
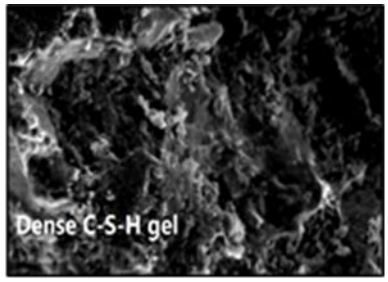


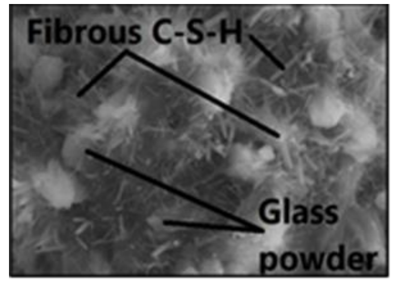
Figure 7: Splitting tensile strengths of concrete mixes at age of 28 days



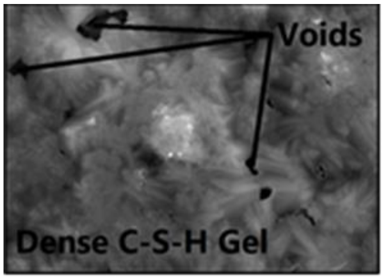
a. Control mix



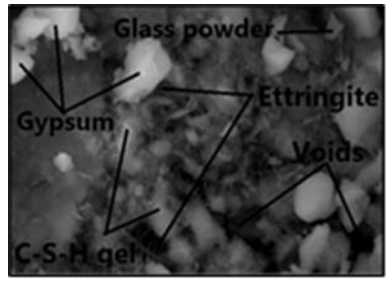
b. Mix MSF



c. Mix MSFGP10%

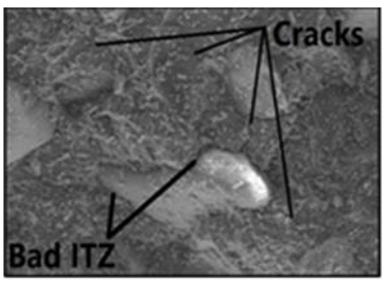


d. Mix MSFGP20%

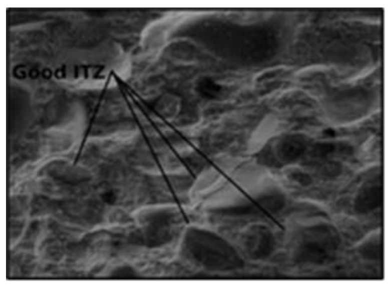


e. Mix MSFGP30%

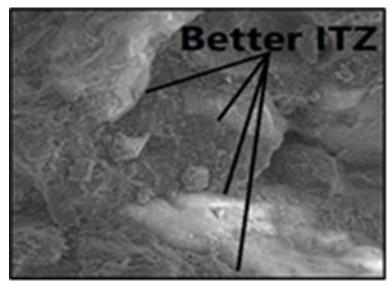
Figure 8: SEM of concrete mixes



a. Control mix

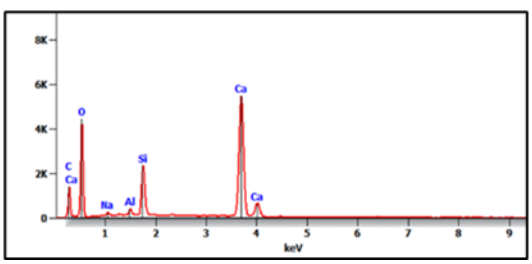


b. Mix MSF

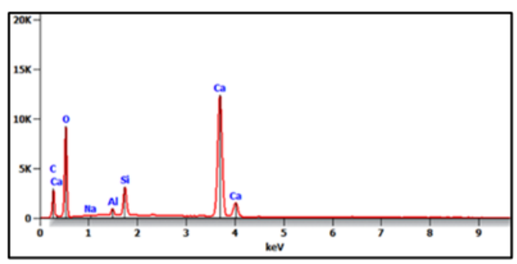


c. Blended concrete mix

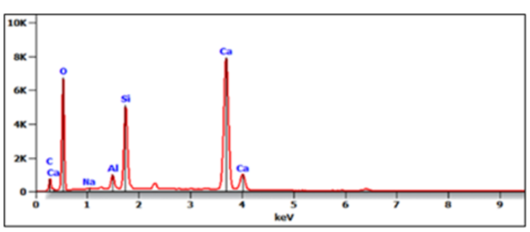
Figure 9: ITZ of concrete mixes



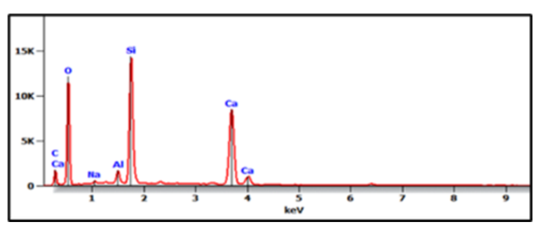
a. Control mix



b. Mix MSFGP10%



c. Mix MSFGP20%



d. Mix MSFGP30%

Figure 10: EDX analysis of concrete mixes

4. Discussion

4.1. Workability

The results clearly mark a significant increase of consistency with the glass powder content increasing, where the increments in slump were 12%, 25% and 36% for 10%, 20% and 30% of glass powder content, respectively compared to conventional concrete. Compared to silica fume concrete, theses increments were 31%, 46% and 58% for 10%, 20% and 30% of glass powder content, respectively. Workability in terms of slump test value increases because of increased glass powder content in silica fume compared to either conventional concrete or silica fume concrete. Incorporation glass powder into concrete improves the workability (Vasudevanet al., 2016; Gao et al., 2020). In comparison to cement, adding glass powder to concrete reduces the mix's water absorption, which enhances workability. On the contrary, the presence of silica fume decreases concrete workability, as the more surface area of silica fume compared to cement increases the water requirement (Elbasir et al., 2019).

4.2. Density

In comparison to conventional and silica fume concretes, Figure 5 illustrates how the insertion of glass powder as a cement substitution affects the attributes of silica fume concrete. Figure 6 shows the percentage increase in density compared to normal concrete after 3 days for silica fume concrete with 10%, 20% and 30% glass powder contents, which are 3.79%, 2.07% and -0.26%, respectively. Compared to silica fume concrete, the reduction in density as a result of increasing glass powder content of 10%, 20% and 30% were 2.16%, 3.78% and 5.98% compared to silica fume concrete. At the age of 7 days, increases in density were observed for silica fume concretes with glass powder content of 10%, 20% and 30%, and the increases were 3.23%, 1.4% and -1.15%, respectively compared to conventional concrete. In contrast, compared to silica fume concrete, replacing cement with glass powder of 10%, 20% and 30% reduce densities by 2.14%, 3.87% and 6.29%, respectively. At 28 days age, the increasing ratios in density of silica fume concrete with 10%, 20% and 30% content of glass powder were 3.17%, 1.77% and -0.93% compared to conventional concrete, but compared to silica fume concrete these increasing ratios became decrease ratios of 2.16%, 3.48% and 6.05%, respectively.

For silica fume concrete, replacing cement with glass powder slightly increases the density of concrete compared to conventional concrete but, comparing to silica fume concrete adding glass powder decreases the density of concrete. Density of the concrete increases with the increase of glass powder up to 20% glass powder replacement level. Due to the pozzolanic interaction between glass powder and calcium hydroxide, adding glass powder to concrete enhances both the interfacial transition zone and the capillary holes in the concrete microstructure (Nassar et al., 2011; Nassar et al., 2012). Within the same framework, the adding of silica fume to concrete boosts the interfacial transition zone, filles the porous, densifies the microstructure and increases the density because of its high pozzolanic activity (Sasanipour et al., 2019; Lü et al., 2019).

4.3. Compressive Strength

Obviously, the uppermost increase in the compressive strength is remarked for silica fume concrete with 26.48%, 23.86% and 23.55% increment compared to conventional concrete, respectively at ages of 3, 7 and 28 days. Replacement levels 10%, 20% and 30% of glass powder for silica fume concrete showed increases in compressive strength of 8.58%, 5.75% and -3.88%, 13.62%, 7.19% and -2.6%, and 15.24%, 11.12% and -1.21%, respectively at 3-, 7- and 28-days ages compared to conventional concrete. The decreases in compressive strength because of blended concrete with replacement levels of 10%, 20% and 30% were 14.15%, 16.39% and 24.01%, 8.26%, 13.45% and 21.36%, and 6.72%, 10.06% and 20.04% at ages of 3, 7 and 28 days, respectively compared to silica fume concrete.

Silica fume concrete shows improved compressive strength than conventional and blended concrete at different ages. Everything stated above makes it abundantly evident that that incorporation of glass powder into silica fume concrete increases compressive strength up to substitution level of 20% at ages of 3, 7 and 28 days compared to conventional concrete. Interaction between silica fume as a pozzolanic material and calcium hydroxide (C–H) as a hydration product of cement giving rise to the production of calcium silicate hydrate (C–S–H) which improves compressive strength of concrete (Rashidi et al., 2021; Raju et al., 2021). In concrete, glass powder can be used in place of silica fume as the pozzolanic material answerable for the conversion of calcium hydroxide (C-H) to calcium silicate hydrate (C–S–H). Up to 20% substitution of glass powder increases the compressive strength of concrete, and this amount is regarded as the ideal level. (Kushartomoa et al., 2015; Luo et al., 2014).

4.4. Splitting Tensile Strength

As observed in Figure 7 concrete mix MSF achieves higher splitting tensile strength, however silica fume concrete provided an increase in splitting tensile strength by 26.58% compared to conventional concrete. Adding 10% and 20% glass powder to silica fume concrete increases splitting tensile strength by about 10.54% and 3.26% compared to conventional concrete, and by -12.67% and -18.42% compared to silica fume concrete, respectively. On the other hand, adding 30% glass powder to silica fume concrete reduces splitting tensile strength by 9.78% compared to conventional concrete and by 28.72% compared to silica fume concrete. From the aforementioned, it was discovered that adding silica fume and glass powder to concrete increases its compressive strength, which in turn increases its splitting tensile strength.

4.5. SEM and EDX Tests

Clinker of cement consists of alite C3S (Tricalcium silicate Ca_3SiO_5), belite C2S (Dicalcium silicate Ca_2SiO_4), aluminate C3A (Tricalciumaluminate $Ca_2Al_2O_6$) and ferrite C4AF (Tetracalcium aluminoferrite Ca_4AlFeO_5) (Nuhu et al., 2020). Once mixing water is added to dry components of concrete, the basic abrasion and hydration products are produced (Liu et al., 2020). After the completion of cement hydration process, new phases are formed such as portlandite, calcium silicate hydrates, gypsum, ettringite and calcium aluminate hydrate (Nguyen et al., 2015; Choudhary et al., 2015). Both alite and belite combine with water producing portlandite C-H (Calcium hydroxide $Ca(OH)_2$) and calcium silicate hydrate C-S-H ($3CaO.SiO_2.3H_2O$). Portlandite and calcium silicate hydrate look like plate, and fibrous and gelatinous, respectively (Liu et al., 2020; Kirgiz, 2014). Gypsum ($CaSO_4.2H_2O$) which causes the softening and weakness of concrete is formed as a consequence of the reaction between portlandite and sulphate ions (Sahmaran et al., 2009; Al-Dulaijan et al., 2003; Al-Dulaijan et al., 2003). Reaction between the formed gypsum and aluminate results in the formation of ettringite ($3CaO.Al_2O_3.3CaSO_4.32H_2O$) which causes the cracks, expansion and deterioration of concrete and is like needle (Al-Dulaijan et al., 2003; Łukowski et al., 2020). The second hydration reaction forming calcium aluminate hydrate C-A-H ($Ca_3AL_2(OH)_{12}$) (Christensen et al., 2004).
Silica fume is very strong pozzolanic material in which silica fume fills voids of microstructure and reacts with C-H producing C-S-H gel [Uzbas et al., 2020; Bhalla et al. 2018] as illustrated in Figure 8.b. Figure 8.b shows highly dense microstructure with C-S-H gel as a result, silica fume achieves the highest compressive strength. Figures 8.c and 8.d show SEM images of silica fume concrete with 10% and 20% glass powder, respectively. Silica fume concretes with 10% and 20% of glass powder contain C-S-H but silica fume powder with 20% glass powder contains voids more than 10% glass powder. Silica fume concrete with 10% glass powder gains compressive strength higher than 20% of glass powder. Figure 8.a shows SEM image of conventional concrete which contains gypsum and C-A-H more than the previous mentioned concrete mixes, consequently conventional concrete shows compressive strength less than them. Silica fume with 30% glass powder shows more gypsum, ettringite and voids compared to the other concrete mixes as observed in Figure 8.e, consequently silica fume concrete with 30% glass powder shows the lowest compressive strength.
The interfacial transition zone ITZ is the area among the cement paste and the aggregate, which is characterized as the weakest link in mechanical load resistance and its resistance depends on the interaction between the aggregate and the cement paste (Golewski, 2018). As observed in Figure 9.b silica fume concrete shows good interfacial transition zone ITZ because silica fume particles reacts with calcium hydroxide C-H producing an array of calcium silicate hydrate C-S-H fills, strengthens and reduces the thickness of the area between cement paste and aggregate efficiently (Neˇzerkaa et al., 2019; Bhalla et al., 2018). Adding glass powder to silica fume concrete provides better ITZ compared to conventional concrete as shown in Figures 9.c and 9.a. Fine particles of glass powder dense and compact both microstructure and ITZ of the concrete attributable to the pozzolanic action of the glass powder. Adding glass powder to silica fume concrete enhances mechanical properties up to replacement level of 20% and strengthens the ITZ between cement paste and aggregate.
Table 3 represents the outcomes of an energy-dispersive X-ray EDX investigation. EDX analysis of the surface components yielded the results shown in Figure 10. Figures 10.a and 10.b indicate that mix MSFGP10% is rich in Si compared to conventional concrete, and Table 3 indicates that Si/Ca ratios for MSFGP10% and MC are 0.19 and 0.11, respectively. SEM and EDX analyses test results stated that calcium silicate hydrate C-S-H increased as the Si/Ca ratio increased (Te et al. 2022). As expected, and as shown in Figures 8.a and 8.c. silica fume with 10% replacement level of glass powder achieved microstructure dense with C-S-H because of glass powder pozzolanic action compared to conventional concrete. In the same pattern, Si/Ca ratios of mixes MSFGP20% is 0.29, consequently the presence of C-S-H is more than conventional concrete as illustrated in Figures 8.a and 8.d. For concrete mix MSFGP30%, the presence of gypsum, ettringite and voids are presented due to the high Si/Ca ratio as revealed in Figure 8.e.

Table 3: EDX analysis of concrete mixes

Element		Concrete Mix							
		MC		MSFGP10%		MSFGP20%		MSFGP30%	
		Weight, %	Atom, %	Weight, %	Atom, %	Weight, %	Atom, %	Weight, %	Atom, %
Silicon	Si	4.18	3.12	6.98	5.16	10.48	8.05	18.75	13.71
Calcium	Ca	38.48	20.08	35.74	18.5	35.77	19.24	24.86	12.74
Oxygen	O	50.82	66.42	49.77	64.55	49.19	66.29	49.26	63.24
Aluminum	Al	0.97	0.75	0.76	0.59	1.55	1.24	1.57	1.20
Sodium	Na	0.01	0.01	0.56	0.50	0.24	0.23	0.49	0.44
Carbon	C	5.54	9.63	6.20	10.70	2.76	4.95	5.07	8.68

Conclusion

In this work, blended (glass powder and silica fume) concrete was tested in workability, dry density, compressive strength and splitting tensile strength compared to conventional concrete and silica fume concrete. Scanning electron microscopy SEM and energy dispersive X-ray EDX techniques were used to investigate concrete mixes. Based on the experimental works results, the following conclusions were extracted:

1. Blended (glass powder and silica fume) concrete with replacement levels of glass powder with 10%, 20% and 30% of cement increases slump of concrete by 12%, 25% and 36% compared to conventional concrete, and 31%, 46% and 58% compared to silica fume concrete.
2. Blended concrete with replacement level of glass powder up to 20% increases dry density at ages of 3, 7 and 28 days compared to conventional concrete and silica fume concrete. The increase in the dry density of the blende concrete decreases as both the amount of time that has passed since the concrete was mixed and the percentage of glass powder that was used as a substitution increases.
3. When compared to conventional concrete at ages 3, 7, and 28 days, blended concrete exhibits an increase in compressive strength at the replacement level of glass powder up to 20%. When compared to concrete made using silica fume, the compressive strength of blended concrete is lower.
4. With an increase in both concrete age and replacement level, the glass powder-induced increase in compressive strength of blended concrete was reduced.
5. The incorporation of up to 20% glass powder into silica fume concrete increases splitting tensile strength relative to ordinary concrete but decreases splitting tensile strength compared to silica fume concrete up to a 30% replacement level.
6. Analyses using SEM and EDX showed that the glass powder pozzolanic reaction considerably consumed calcium hydroxide with a replacement level of up to 20%. This resulted in a densified microstructure and improved mechanical properties of the concrete.
7. SEM and EDX analyses indicated that the glass powder pozzolanic effect is less than that of silica fume.
8. SEM analysis indicated that blended concrete with 30% replacement level of glass powder generates abrasion and harmful hydration products compared to 10% and 20%.

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Non

Disclosure

We pledge that we are not involved in the interests of the financial, commercial legal, or professional relationship with other organization, or with the people we worked with them, that could influence research.

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