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Performance of Concrete Using Waste Glass Powder as a Partial Replacement of Cement under Saline Condition

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Abstract

The cement industry produces a huge amount of greenhouse gas every year, which affects the environment. Therefore, the exploitation of recycled waste material in construction is emphasized to reduce cost and environmental issues. Waste glass is not biodegradable, so it's stockpiling to the landfills is considered an unfriendly solution for the environment. Thus, there is a great opportunity to take advantage of utilizing waste glass powder in concrete as a partial substitution for cement. This research deals with investigating the consequence of saline water on the fresh as well as the mechanical behavior of concrete encompassing waste glass powder as a supplementary cementitious material. Concrete cylindrical specimens were prepared using glass powder with limited substitution of cement in the proportions of 0%, 10%, 15%, 20% and 25%. The specimens were kept in normal water and saline water for 28 days and 90 days, and compressive strength, as well as tensile strength tests, were carried out. There is a gradual decline in slump observed due to the inclusion of the substance of waste glass powder. It is remarked that the compressive strength, as well as the tensile strength of the saline water-cured specimens, were slightly reduced with the increase of curing days. It is also found that concrete cured in normal water has higher strength than saline water-cured concrete, and there is no significant variation in strength.

Keywords: *Compressive strength; saline water; supplementary cementitious material; tensile strength; Waste glass powder.*

1 Introduction

The production of waste is getting higher rapidly as a result of the world's rapid population growth and industrial growth, which makes recycling waste materials a major global concern (Taha and Nounu, 2009). Glass debris cannot dissolve in the atmosphere, making landfill disposal unsustainable (Islam et al., 2017). The anticipated capacity of landfilled glass globally is approximately 200 million tonnes per annum consequence of a severe hazard to the atmosphere. As glass is a non-biodegradable substance, it carries over approximately one million years to disintegrate instinctively (Clean Up Australia, 2017). Hence, recycling of waste glass is becoming a great issue to the scientific community. A large amount of CO_2 is produced by the cement production industry. This huge amount of greenhouse gas has an adverse impact on the surroundings. The recycling of every ton of glass protects in excess of one ton of native properties, and the reusing of each 6 tons of vessel glass consequences in the declination of the emission of almost one ton of CO_2 (Cattaneo, 2008). So, the utilization of recycled waste materials as supplementary cementitious material is emphasized in the construction industry for sustainable development and for reducing environmental issues and costs.

Shayan and Xu (2004) stated that glass is a good choice for reuse since it can be recycled several times without chemical changes because it is an inert material. Additionally, Wright et al. (2014) showed that glass with high silica content and particle sizes under 75 µm has potential pozzolanic capabilities. Khan et el. (2020) stated that the cement mortar and concrete encompassing glass powder considerably enhanced the mechanical and durability behavior once the magnitude of the glass powder particle is smaller than 45 µm. Finely ground waste glass exhibits pozzolanic characteristics making it impending for concrete production as cement substitution (Paul et al. 2022). In glass, amorphous silica dissolves in an alkaline environment, just like OH- ions do in cement paste. The pozzolanic reaction (CH + S + H, C-S-H) occurs when it interacts with calcium hydroxide (CH) to assemble a secondary calcium silicate hydrate (C-S-H). There is a bigger surface area accessible for the reaction, according to prior investigations, which improves the reactivity of glass particles (Shayan and Xu, 2004; Du and Tan, 2014). Grinding of glass to the particle size at the micro-meter level to increase the reactions amongst cement and glass hydrates can provide environmental as well as economic welfare once cement is substituted to some extent with crushed waste glass for the manufacture of concrete (Rashad, 2014). Paul et al. (2022) exposed that the concrete produced by using glass powder as an alternative to cement performs better than concrete produced by substituting sand or aggregate with glass powder.

The research on waste glass with concrete durability revealed improved long-term performance against chloride permeability. Due to harmful chemical components such as sulfides, sulfates, and alkalis, the alkali-silica reaction (ASR) is a concern. During the duration of the lifespan of concrete, these components raise the risk of ASR. By consuming lime, a suitable pozzolan can attenuate ASR and lower efflorescence (Matos and Sousa-Coutinho, 2012; Rashad, 2014). The durability performance of glass powder concrete is enhanced with the increase in glass powder content (Schwarz et al. 2008). Although the addition of glass powder in concrete increases the drying shrinkage, nevertheless, the results are within the allowable typical bounds (Paul et al. 2022). This research predominantly explores the mechanical performance of concrete encompassing waste glass powder as a substitute material for cement in saline water. Additionally, using the house industry's waste shard glasses to produce glass powder and use it as concrete material enhances the construction of more resilient and sustainable structures.

2 Methodology

2.1 Binder and aggregates

Ordinary Portland Cement (OPC) was utilized as a binder for the mixture. Coarse sand and stone chips were made use of as fine aggregates and coarse aggregates, correspondingly. The physical characteristics of both aggregates were determined and exhibited in Table 1.

Table 1. Physical characteristics of coarse and fine aggregates

Properties	**Test results**	
	Coarse aggregate	**Fine aggregate**
Specific Gravity (SSD)	2.75	2.51
Absorption (%)	1.8	3.3
Unit Weight (kg/m^3)	1520	1600
Fineness modulus	--	2.64

2.2 Waste glass powder

Using glass powder prepared from pieces of broken waste glass and according to their prior work, the authors created the GP concrete in this investigation. A ball mill and soil grinding machine are used to make finely ground glass powder that finally passes through the #200 sieve (depicted in Figure 1). Produced glass powder was collected in air-tight bags for further use in casting glass powdered concrete. The chemical constituents of waste glass powder and cement are ascertained through an X-ray fluorescence (XRF) test. Table 2 depicts the assessment of the elemental components of waste glass powder and OPC.

(a) Assortment of broken waste glass (b) Waste glass powder preparation

Figure 1. Production of powder from recycled waste glass

Table 2. Chemical components of waste glass powder and Ordinary Portland Cement

Materials	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	SO_3 (%)
Glass powder	67.8	1.3	0.8	12.4	2.2	1.1	14.2	0.2
OPC	22.9	5.8	3.6	62.8	1.4	1.0	0.1	1.9

2.3 Preparation and testing of cylindrical test specimens

In this investigation, cement was substituted with varying waste glass powder at different intensities of 0%, 15%, 20%, and 25% by volume. The water-cement (w/c) proportion for each specimen was 0.48. The mix proportions of concrete for each group are provided in Table 3. For each percentage, 15 cylindrical specimens were cast and then prepared to cure in saline water condition. 35g/L NaCl is used to make saline water condition. For each sample, 100 mm in diameter and 200 mm in height are maintained for the compressive and splitting tensile tests. For the curing procedure, the cylindrical samples were demolded 24 hours afterwards and cured in saline water, and concrete samples were submerged for 28 and 90 days to follow the curing method of ASTM C31. After the curing stages of 28 and 90 days, the compressive strength of the concrete was assessed in accordance with ASTM C39, and the tensile strength was determined consistent with ASTM C496.

Table 3. Mix proportions of concrete

Sample Designation	Cement (kg/m^3)	Water (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Glass Powder (kg/m^3)	w/c
0% GP	262	126	828	437	-	0.48
15% GP	223	126	828	437	39	0.48
20% GP	210	126	828	437	52	0.48
25% GP	197	126	828	437	65	0.48

3 Results and Discussion

3.1 Workability

After the making of concrete, the workability of fresh concrete was evaluated consistent with ASTM C143. The workability of concrete with the variation of cement substitution at different percentages is depicted in Figure 2. A decrease in slump was seen with an intensification of the substance of waste glass powder (illustrated in Figure 2). The waste glass powder increases the water demand due to increasing surface area and surface tension; and angularity of glass particles which causes decreasing in workability with an increase in the content of glass powder in association with a constant water-cement proportion of 0.48. The inclusion of glass powder extended the setting time and reduced the hydration heat, resulting in the reduction of the workability of the matrix (Deng et al. 2021).

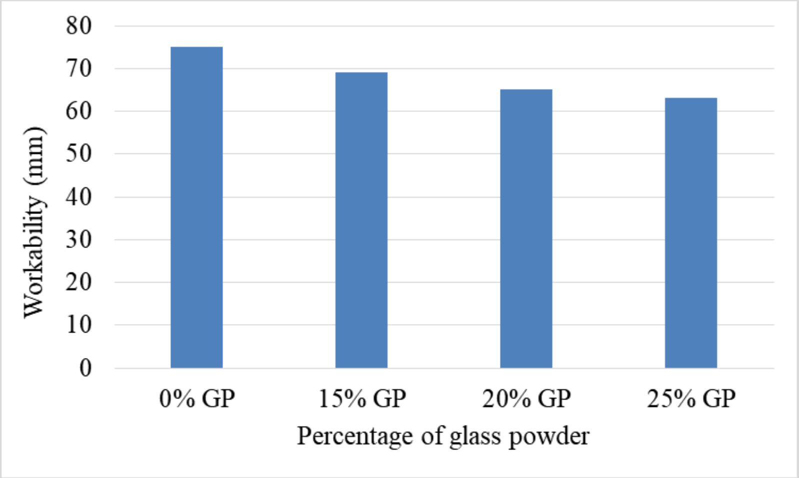

Figure 2. Variation of workability with the content of recycled waste glass powder

3.2 Compressive Strength

The influence of recycled waste glass powder as a fractional alternative to cement on the compressive strength of concrete is shown in Figure 3. Table 4 exhibits the variation of compressive strength of concrete incorporating waste glass powder cured in normal water and saline water at 28 days and 90 days. The compressive strength of concrete varies due to the various contents of waste glass powder and the ages of curing. At the curing age of 28 days, the compressive strength decreased with the adding up of glass powder substance; nevertheless, there is no substantial difference shown in 20% and 25% GP concrete. After 90 days of curing, GP concrete showed higher strength, even though it was relatively lower than conventional concrete. Using 20 percent glass powder concrete, it has approximately 85% of the compressive strength of conventional concrete. That shows an indication of pozzolanic activity. Carsana et al. (2014) reported that the pozzolanic reaction imposes the hydration product, calcium hydroxide, whose intensity is meticulous by means of the cement content. Henceforth, there is a thoroughgoing threshold for the extent of cement replacement; furthermore, no advanced pozzolanic reaction of glass powder can have effect. The author emphasized the importance of using different ratios of waste glass powder as an alternative, which was corroborated by earlier studies. The findings of this study indicated that high strength was achieved when cement was exchanged with waste glass powder in the content of 10% and 20% (Federico and Chidiac, 2009). When concrete is cured in saline water, its compressive strength is significantly low due to the NaCl effect (Emmanuel et al., 2012). Normal concrete, which was no substitute for glass powder, showed approximately 21% and 18% strength reductions, respectively, in 28 and 90 days. Moreover, the reduction in strength of glass concrete incorporating 20% glass powder was about 17% in 28 days and 15% in 90 days. This result shows a positive sign that the glass concrete is protected from the adverse effects of saline water.

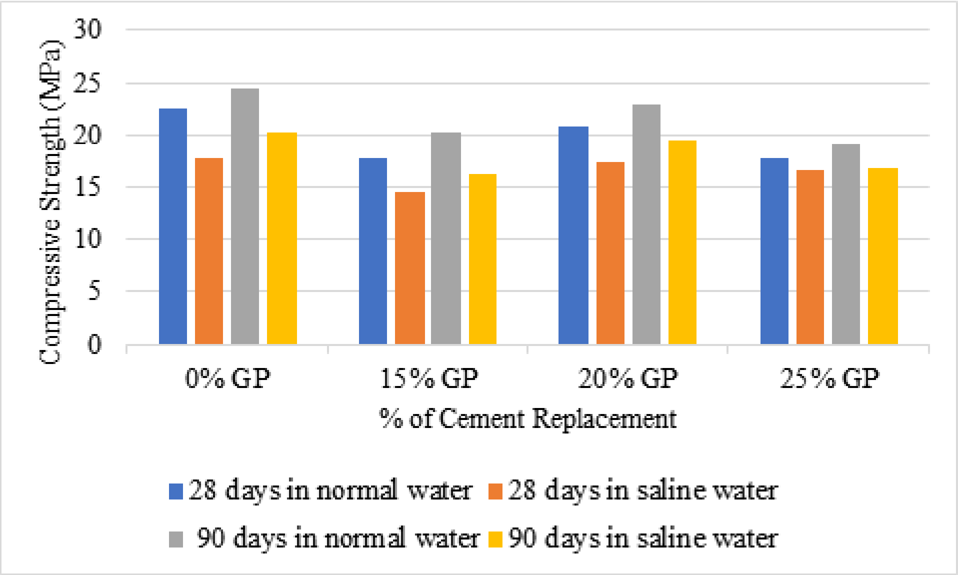

Figure 3. Comparison of compressive strength of concrete encompassing waste glass powder cured in normal water and saline water at 28 days and 90 days.

Table 4. Variation of compressive strength of concrete encompassing waste glass powder cured in normal water and saline water at 28 and 90 days.

Specimen designation	Compressive strength at 28 days (MPa)		Strength variation (%)	Compressive strength at 90 days		Strength variation (%)
	Normal water	Saline water		Normal water	Saline water	
0% GP	22.4	17.8	20.5	24.5	20.2	17.6
15% GP	17.8	14.6	17.9	20.3	16.2	20.2
20% GP	20.9	17.4	16.7	22.8	19.4	14.9
25% GP	17.9	16.7	6.7	19.2	16.7	13.0

3.3 Splitting Tensile Strength

In this research, the splitting tensile strength of glass concrete and conventional concrete specimens has also been investigated for 28 days and 90 days, as demonstrated in Figure 4. Table 5 shows the splitting tensile strength variation of concrete containing waste glass powder cured in normal water and saline water at 28 days and 90 days. At the curing period of 28 days, the tensile strength of the concrete is less than the value of the 90 day result, and the strength of the tensile value increases as the concrete gets older. The tensile strength ratio of 15% GP, 20% GP, and 25% GP to the normal concrete was near about 81%, 88%, and 79%, respectively, in the curing days of 28; at 90 days of curing, the value was correspondingly 78%, 89%, and 81%. The justification of the reasons for the compressive strength of concrete could be used to illustrate the trend of splitting tensile strength. Conversely, in conventional concrete and GP concrete, after curing in saline water, their tensile strength decreased significantly because of the NaCl effect, which is described in Section 3.2. However, there was no substantial change between the proportion of compressive strength and tensile strength of concrete. Using a concrete specimen with 20% glass powder as a fractional substitution of cement, the strength reduction in tensile strength was 5% and 14% separately in the 28 days and 90 days of saline water curing, respectively.

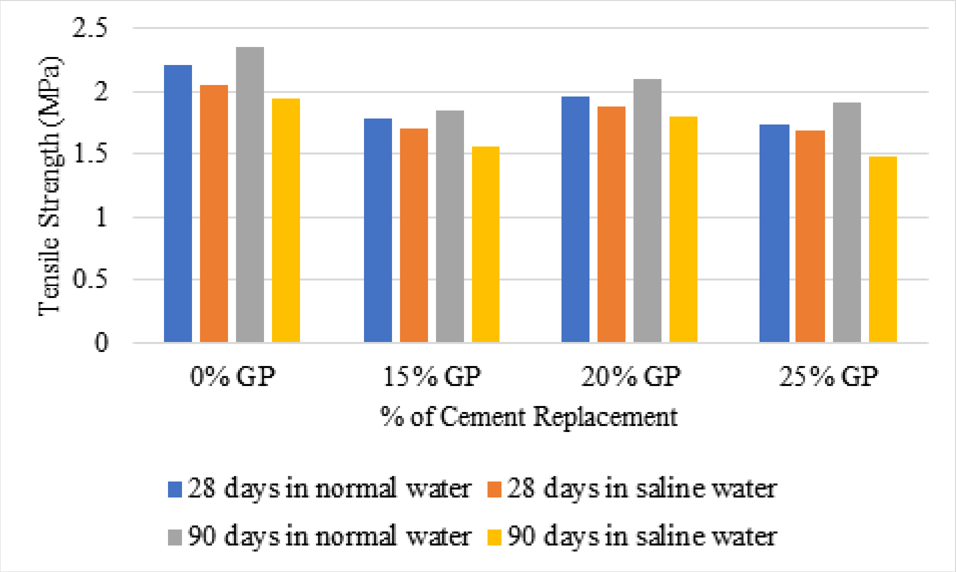

Figure 4. Comparison of tensile strength of concrete comprehending waste glass powder cured in normal water and saline water at 28 days and 90 days.

Table 5. Variation of tensile strength of concrete containing waste glass powder cured in normal water and saline water at 28 days and 90 days.

Specimen designation	**Tensile strength at 28 days (MPa)**		**Strength variation (%)**	**Tensile strength at 90 days**		**Strength variation (%)**
	Normal water	**Saline water**		**Normal water**	**Saline water**	
0% GP	2.2	2.1	4.5	2.4	2.0	16.7
15% GP	1.8	1.7	5.5	1.9	1.6	15.8
20% GP	2.0	1.9	5.0	2.1	1.8	14.3
25% GP	1.8	1.7	5.5	1.9	1.5	21.1

4 Summary and Conclusions

This research investigates the physical as well as mechanical behavior of glass powdered concrete where waste glass powder is utilized as a limited alternative for cement under saline water conditions. The following conclusion can be extracted on the basis of the experiment:

- Based on the XRF test of waste glass powder, it can be stated that glass powder possesses good pozzolanic activity.

- There is a gradual decline in slump observed due to the amalgamation of the substance of waste glass powder.
- Based on the experimental test results (splitting tensile strength and compressive strength test), waste glass powder concrete samples showed no significant reduction of strength under saline conditions in comparison with reference concrete samples (0 % glass powder integration).
- Therefore, concrete incorporating 20% and 25% partial cement substitution by waste glass powder is a prospective preference for the construction sector despite the fact that affording a solution for waste management as well as participating in a global economy.

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