

EXPERIMENTAL STUDY ON CEMENT BASED MATERIALS INCORPORATING GLASS POWDER AND GUAR GUM UNDER EXTREME ENVIRONMENTAL CONDITIONS

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ABSTRACT:

Mortar and concrete are the mostly used construction material composed of a mixture of cement, water, aggregates (such as sand, gravel, or crushed stone), and often additional additives or admixtures. It is widely used in the construction industry for various applications due to its strength, durability, and versatility. Key characteristics of concrete include strength, durability, versatility, fire resistance, cost-effectiveness, weather resistance, insulation, and decorative options. Concrete plays a vital role in the construction industry, providing the foundation for most buildings, infrastructure, and many other structures worldwide. Its composition and properties can be tailored to meet specific project requirements, making it an indispensable material in modern construction. Various fibers can be used to enhance the mechanical and bonding properties of concrete. Additionally, waste fibers after recycling can reduce the environmental burden. Keeping in this view, glass powder sodium silicate glass (SSG) is used as a replacement of cement with different percentages 0%, 5%, 10%, and 15% in combination of guar gum (GG) 1% for all mixes to prepare Glass Powder–Guar Gum Concrete (GPGGC). An experimental study is conducted to investigate the mechanical and durability properties of concrete by performing compression test, flexural test, alkali silica reactivity test, sulfate resistivity test and drying shrinkage test. For this, forty-eight concrete cylinders are prepared for compression test, twelve concrete prisms for flexural test and twenty-four mortar bars of four mixes are prepared for durability testing. Workability is checked of fresh concrete during the pouring of concrete cylinders. Poured cylinders' samples are left for 7, 14, 21 and 28 days of curing. Various tests are performed on hardened concrete and mortar samples to evaluate the mechanical and durability properties. Results concluded that workability of four mixes lies between 62-94mm and the compressive strength of concrete has been improved using glass powder (SSG). Optimum results have been achieved at 15% as compared to other mixes 5% and 10% of concrete samples. Fibrous material is used as a binding agent and fibrous concrete is suitable for humid environments where high strength and voidless concrete are required. Quantity of cement can be reduced by using different fibers as a replacement of cement. Research recommended that recycled glass powder can be used in concrete as construction material and 15% replacement is suitable for optimum results.

1. INTRODUCTION

Concrete is a composite building construction material which is used in construction industry. Consumption of concrete is now increasing day by day (Jiang, X. et al., 2022). It is the 2nd largest building material which is mostly used in construction industry. Many environmental issues producing by the use of concrete which are never be neglected and needed to be taken under consideration (Ashiq, S. Z., 2022). A lot more natural resources are used for the production of concrete as fine and coarse aggregates (Nsengiyumva et al., 2022).

Approximately one-ton quantity of carbon dioxide is discharged

into the atmosphere by production of one ton of cement. It is 7% of the world's total annually production of CO₂ (Kusnezoff, M., 2022), (Lee, H., 2018), (Orouji, M., 2021), Now it's our duty to save all natural resources for upcoming generation and release the burden from the environment for ecological balance (Souza, E. R. et al., 2022), (Buitrago R. et al., 2021). In Pakistan it is time to find out the residue to save the environment and fulfil the construction needed without disturbing the natural resources (Hendi, A., 2019), (Ibrahim, S., 2020).

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This can be only achieving by using waste material in our surrounding like waste glass powder, fly ash, coconut fiber, plastic etc. (Sadiqul G.M., 2017), (Wang, Y., 2019). The use of waste materials in concrete will reduce the economic factor in major construction projects (Crueira, P. J. et al., 2021), (Mota, G. P et al., 2022). Concrete is a mixture of cement, fine and coarse aggregate having properties like compressive strength, tensile strength, workability, durability. When the cement mix with water it takes chemical reaction due to which heat generated and hardened (Mahmood, A. H., 2022) (Manikandan, P., 2019). The initial setting time of cement starts within a few minutes. It takes some weeks to gain full strength and continue to gain strength over many years (Dzionic, A. et al., 2021), Objectives of this research is to evaluate the effect of waste glass powder (SSG) in combination with xanthan gum on workability, compressive strength, ASR, Sulphate Attack and drying Shrinkage of concrete specimens (Patel, D., 2019), (Szudek, W., 2019)

Recycled glass powder in cement will increase the strength properties due to the reaction of alkali with the cement (Almeshal, I., 2022). It helps the manufacturing process of bricks and it can be preserved as a raw material (Chu, S. H. et al., 2020), (Onaizi, A. M. et al., 2020). Waste materials can be used after recycling. Waste materials like fly ash, coconut fiber, steel fiber and glass powder are used in different forms of construction materials after recycling (Derinpinar, A. N., 2020). When cement is replaced with glass powder it gives better workability and also in higher strength for concrete (Mejdi, M. et al., 2019), (Zhan, P. M. et al., 2020).

To achieve the sustainable environment, a necessary action is needed to clean environment and introduce some alternative as a replacement of cement (Zhang, T. et al., 2021). The usage of waste glass in concrete will increase the alkali content in the cement. Recycling ratio of this mix is close to 100%, and it is also used in concrete to improve the durability properties of concrete (Szudek, W. et al., 2019), (Ayat, A. et al., 2020). Recently, glass and its powder have been used as a building material in different structural applications like beams. Also, the major benefit is to reduce the environmental problems which lead to sustainable construction. Hence, glass powder is abundantly used as a replacement of supplementary cementitious materials (Mohammed, T. K. et al., 2021), (Kalakada, Z. et al., 2022).

The main utilization of this study lies in optimizing the rheological performance of sustainable cement pastes by carefully selecting and controlling the physical properties of supplementary cementitious materials (SCMs). It enables engineers to predict and manage shear-thickening behavior, improving workability and stability in advanced concrete applications like 3D printing, self-compacting, and pumpable mixes, Kemer et al. (2021). The main utilization of this study is to establish calcined bentonite as a sustainable supplementary cementitious material (SCM) that can partially replace cement (8–14%) in mortar. It helps reduce CO₂ emissions while maintaining mechanical strength and microstructural integrity, making it ideal for eco-friendly construction. (Mesboua, N., et al 2021). The main utilization of this study is providing a simple, cost-effective method to estimate high yield stress in cement pastes using an enhanced slump test model. The results showed strong agreement with rheometer data, proving the model's accuracy and making it practical for on-site quality control and rheology prediction in high-performance concrete. (Kemer H. 2021).

2. MATERIALS AND METHODS

Concrete is a mixture of cement, fine aggregates and coarse aggregates. When water is added in it then chemical reaction has

been started as a result heat is produced. This heat directly effects the strength of concrete:

- Ordinary Portland cement (OPC) is used for this study to prepare a Glass Powder–Guar Gum Concrete (GPGGC).
- Chenab sand and Sargodha crush are used and collected from a single vendor for the preparation of Glass Powder–Guar Gum Concrete (GPGGC).
- Guar gum is a natural polysaccharide extracted from the endosperm of guar beans (*Cyamopsis tetragonoloba*), widely used across various industries for its thickening, stabilizing, and emulsifying properties.
- Raw glass is collected from a single source and grind it to a fine powder form. Consumption of glass powder in concrete as a replacement of cement may lead towards sustains ability and cost-effective resource. Raw glass in powdered form and guar gum are shown in Figure1.



Figure 1. Sample of Cementitious material: (a) Glass Powder (SSG), (b) Guar Gum

Both guar gum and glass powder are ultra-fine materials and used as a replacement of cement in this study. Chemical composition of glass powder and cement are given in Table 2.

| Composition | Cement (%) | Glass Powder (%) |
|--------------------------------|------------|------------------|
| SiO ₂ | 21.3 | 70.0 |
| Al ₂ O ₃ | 4.8 | 2.1 |
| CaO | 61.9 | 7.10 |
| Na ₂ O | 0.16 | 7.8 |
| K ₂ O | 0.82 | 0.81 |
| Fe ₂ O ₃ | 3.3 | 2.43 |
| MgO | 1.6 | 1.1 |
| SO ₃ | 2.4 | 0.1 |
| TiO ₂ | -- | 0.13 |
| Other | 1.8 | 1.0 |

Table 2. Chemical composition of cementitious material

2.1 Mixing Detail

Mix ratio 1:2:4 is same for all mixes with water cement ratio is 0.45. In this research study, raw glass powder has been used as a partial replacement of cement at different percentages 0%,5%,10%, and 15% in combination with guar gum which is 1% constant for all mixes. Mixing of concrete is done with mixer as shown in Figure 3.



Figure 3. Concrete mixing with cementitious material

2.2 Mix Proportion

Mixing detail of four mixes with different ratios is shown in Table 4.

| Mix Type | C (%age) | GP (%age) | GG (%age) | FA (%age) | CA (%age) | W/C |
|----------|----------|-----------|-----------|-----------|-----------|------|
| M1 | 99 | 0 | 1 | 100 | 100 | 0.45 |
| M2 | 94 | 5 | 1 | 100 | 100 | 0.45 |
| M3 | 89 | 10 | 1 | 100 | 100 | 0.45 |
| M4 | 84 | 15 | 1 | 100 | 100 | 0.45 |

Table 4. Mix Proportions

Where: c is cement, F.A. fine aggregates (lawrancepur sand), C/A. coarse aggregates, Glass Powder (GP), Guar Gum (GG).

2.3 Casting and curing

Firstly, measure the workability of concrete then cast the samples of four mixes as per the different percentages. Test the samples (cylinders, prisms & mortar bars) at different curing ages 7, 14, 21, and 28 days.

2.4 Sample Preparation of Glass Concrete

Forty-eight concrete cylinders 6"x12" (150mmx300mm), thirty six mortar bars (40mmx40mmx160mm) of four mixes (M1, M2, M3 and M4) are prepared by adding glass powder with different percentages of 0%, 5%, 10%, and 15% and 1% guar gum as cement replacement as shown in table 4 and hardened concrete cylinders and mortar bars as shown in Figure 5 and Figure 6 respectively.



Figure 5. Casting of concrete cylinders and mortar bars



Figure 6. Curing of concrete cylinders and mortar bars

3. MECHANICAL PROPERTIES OF GLASS CONCRETE

3.1 Workability

Workability of four mixes M1, M2, M3 and M4 are measured on fresh concrete by performing Slump Test according to ASTM C 143. Measuring of slump is shown in Figure 7.



Figure 7. Measurement of slump

3.2 Compression Test

Compression test is performed on hardened concrete samples. In this research, four groups of concrete mixes are prepared in laboratory. The replacement level of cement to glass powder is 0%, 5%, 10%, and 15% which is shown in Figure 8.

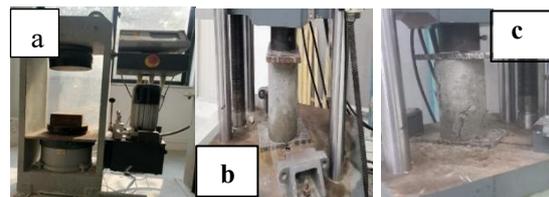


Figure 8. Experimental setup (a) Compression Testing Machine (b) sample before testing & (c) sample after testing

3.3 Flexural Test

Crack resistance is measured by performing flexural test which is carried out on prisms to evaluate the strength of concrete according to ASTM C78. Prisms are casted at different replacement level and evaluate the strength at 28 days which is shown in Figure 9.



Figure 9. Experimental setup: (a) Sample (mortar bar) before testing & (b) after testing

4. DURABILITY PROPERTIES OF GLASS CONCRETE

4.1 Alkali Silica Reactivity Test

Alkali silica reactivity (ASR) test is a chemical reaction between certain alkalis in concrete and reactive forms of silica in some aggregates. This reaction can result in the formation of a gel-like substance within the concrete causing it to expand and potentially lead to cracking and other forms of damage. The alkali-silica reactivity test is performed to assess the potential for this reaction to occur in concrete structures. This test helps ensure the long-term durability and structural integrity of concrete constructions, especially in areas where reactive aggregate materials are prevalent.

4.2 Sulfate Resistivity Test

Sulfate resistivity (SR) test is a method used to assess the resistance of concrete to sulfate attack. Sulfate attack is a chemical reaction that can occur in concrete when it is exposed to sulfates, typically found in soil or groundwater. This reaction can lead to the formation of expansive products, causing concrete to deteriorate and potentially result in cracking and loss of structural integrity. The results help in determining the concrete's resistance to sulfate attack and guide engineers and construction professionals in selecting suitable materials and protective measures to prevent potential damage. Sulfate resistance can be determined by ASTM C452.

4.3 Drying Shrinkage Test

The drying shrinkage test is a procedure used to assess the extent to which a concrete mixture will shrink as it dries. When concrete dries, water evaporates from the mixture, causing it to undergo a reduction in volume. Excessive drying shrinkage can lead to cracking and structural issues in concrete constructions, impacting their long-term durability and performance. Drying shrinkage test is performed to measure the change in size of the sample.

5. RESULTS AND DISCUSSIONS

Following results have been summarized from the experimental data of fresh and hardened specimens. Glass powder fills voids between cement particles, improving particle packing and early hydration contact. Also, Guar gum improves the water retention, ensures adequate internal curing and moisture availability.

5.1 Workability of concrete

Glass powder increased the workability of concrete. There is a systematic increase from 62mm (for control mix) to 94 mm (at 15% replacement).

Figure 10 shows the result of slump at different percentage levels. This graph shows that workability of fresh concrete increases by adding the glass powder in addition to guar gum. This increase may be the use of glass powder (SSG) in addition to the combined effect of increasing glass powder (0% to 15%) and the constant addition of 1% guar gum. Glass powder improves flow by filling voids and reducing internal friction, while guar gum stabilizes the mix and retains moisture—together enhancing workability significantly.

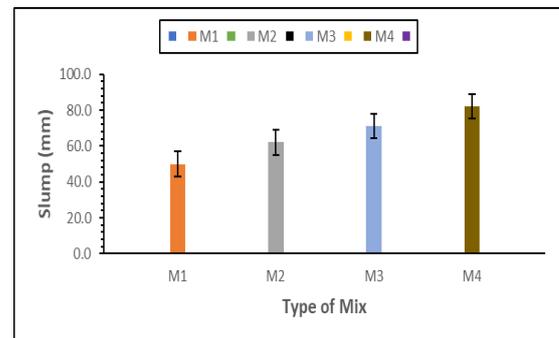


Figure 10. Slump at Different Percentage of Glass powder and Guar Gum

5.2 Compression Test Results

After evaluating the workability, concrete moulds are poured into well-oiled concrete cylinders and left for 24 hours. The hardened concrete remolded off the cylinder and cured for 7, 14, 21 and 28 days inside a curing tank by complete immersion in water.

Figure 11 shows the graphical representation of compressive strength of concrete cylinders on 7, 14, 21 and 28 days. Strength increases by the increase in glass powder content. Each mix includes 1% guar gum and varying glass powder content:

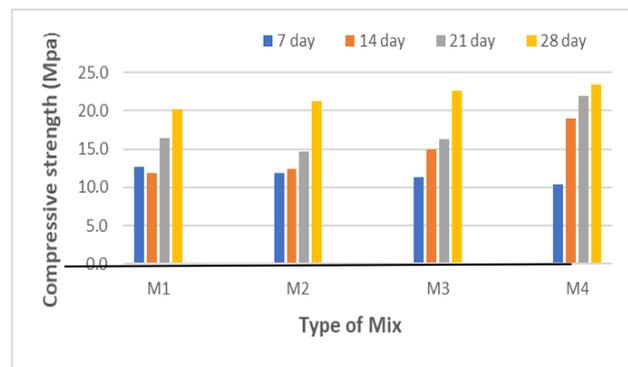


Figure 11. Compressive Strength of concrete at 7, 14, 21 & 28 curing days

Strength of concrete increases and makes concrete durable as compared to conventional concrete but the strength of 28 days nearly equal to conventional concrete. Also bonding behaviour are improved by adding guar gum and reduced voids as a result enhanced permeability. Glass powder fills voids between cement particles, improving particle packing and early hydration contact but Guar gum's water retention: Ensures adequate internal curing and moisture availability. Optimal strength is achieved with 10% glass powder (M3) and 1% guar gum.

Strength is mostly due to cement hydration at early ages. Glass powder's pozzolanic reaction hasn't fully developed yet, so early gains are moderate. Pozzolanic reactions of glass powder become more significant. Additional C-S-H strengthens the concrete matrix, especially in M3 and later Age (14–28 Days). Glass powder enhances compressive strength due to pozzolanic activity and filler effects, especially noticeable after 14 days. Exceeding 10% (as in M4) leads to diminishing returns, where reduced cement content weakens overall strength despite pozzolanic contributions.

Guar gum plays a supporting role in improving both hydration and curing, complementing glass powder's contribution. The combination of 10% glass powder + 1% guar gum delivers the best compressive strength due to a synergy of pozzolanic reactivity, internal curing, and optimized microstructure.

5.3 Flexural Test Results

Results of flexural test have been summarized as by the increases of sodium silicate glass (SSG), increases the flexural strength at 28 days as shown in Figure 12. The maximum value of strength increases at the replacement level of 15% i.e. 16%. SSG powder increased the flexural properties of concrete.

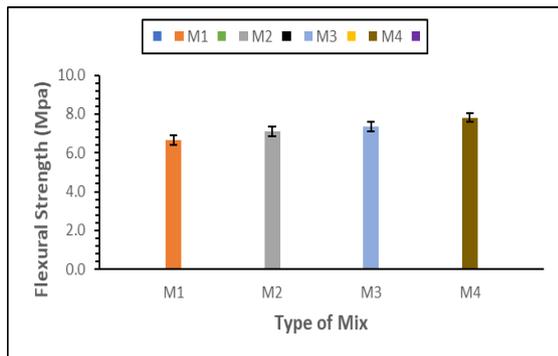


Figure 12. Flexural Strength of concrete at 28 Days

At 5%, glass powder begins contributing to pozzolanic activity, forming additional calcium silicate hydrate (C-S-H) which enhances matrix strength. Guar gum improves dispersion and reduces microcracks. At 10%, glass powder reacts more actively, densifying the matrix. Guar gum enhances fiber-matrix adhesion and reduces porosity. While at 15%, highest flexural strength observed due to maximum beneficial reaction of glass powder. Guar gum stabilizes the mix and improves load transfer across the matrix. Beyond this, excess glass powder may cause dilution of cementitious content.

5.4 Permeability & Durability

To evaluate the durability and permeability properties, alkali silica reactivity test, sulfate resistivity test and drying shrinkage test are performed. Graphical representation of results are shown in Figure 13. By adding more content of glass powder, concrete is more resistant against water penetration.

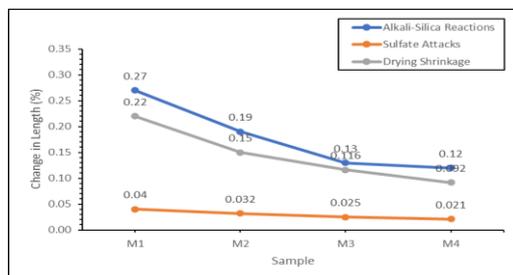


Figure 13. Percentage change in length due to expansions Caused by Alkali silica reaction, Sulfate Attacks and Shrinkage by Drying

5.5 Sustainability Aspects of Glass Fiber

Production of waste Glass is produced in a massive quantity and is considered as a non-biodegradable material. It's a big burden on environment and makes a cause of pollution. Also, it is a big challenge to decompose in a proper way. Now, it's a need to use in a productive way after recycling. By the utilization of waste glass in powdered form after recycling as a construction material, improve the strength and aesthetic properties. Glass powder is a cost-effective material and can be reduced the cost of construction.

5.6 Factors to Be Considered while Using Glass Fibers

It has been observed in various studies that utilization of fibers in concrete may enhance the strength as well as bonding and binding properties. Almost all fibers are significantly work in composite materials. A greater fiber content is not always beneficial. Although fiber reinforcement is known to increase material mechanical characteristics, it generally only does so to a certain amount, beyond which the qualities begin to deteriorate.

Therefore, a composite material's ideal fiber composition is critical for achieving the greatest outcomes. Physical parameters such as fiber length, fiber count, and fiber distribution should be considered. In concrete, as the number of fibers grow, the workability of the mixture declines, necessitating the use of additives. Water repellence, alkaline treatment, and surface enhancement are all examples of treatments that may be utilized to improve the qualities of fibers.

Other matrices have been employed to generate high-performance composites using fibers. The mechanical behaviour of the composite is influenced by the physicochemical interaction between the components of the composite, the degree of adhesion, and the bonding between the fibers and the matrix. A robust contact between the fibers and the matrix is usually responsible for the best composite characteristics. Coupling agents and other additives have been utilized to strengthen the adhesion between the composites, resulting in stronger linkages. They aid in the bonding and uniting of the fibers with the matrix resulting in a composite with superior characteristics.

5.7 Application of Glass Fibers

GFRC is becoming an increasingly popular and commonly utilized material. Both in structural materials, and items associated with the construction process. In addition, modest architectural features are being manufactured with GF to create more appealing, durable, and safer public places. Glass fiber-reinforced polypropylene composites are becoming more popular in the automobile sector due to their good mechanical qualities, ease of fabrication, lightweight, and low cost. These composites have been used to make products, including bus bumpers and automobile seats.

Glass fibers offer promise as well, although their resistance to alkali conditions is poor. Khan and Ali examined the use of glass and nylon fibers in concrete bridge decks to reduce early age micro cracking. When compared to the control sample, the inclusion of the fibers resulted in a decrease in compressive strength and before cracking energy absorption, but an increase

in toughness and flexural and splitting tensile stress. Overall, the addition of nylon and glass fibers to concrete bridge decks was shown to be effective in preventing early age micro cracking. Prefabricated façade panels for residential and cultural buildings, airports, stadiums, museums, and galleries are produced from GFRC.

They are stronger than standard reinforced-concrete facades, and also have better resistance to temperature fluctuations, solar radiation, pollution, and corrosion, as well as hydrophobic properties. Glass fiber-reinforced concrete is lighter in weight and higher in tensile strength compared to concrete. This prompted a recent research effort to investigate its feasibility as a structural material.

The study was conducted in collaboration with concrete precast enterprises, for which the enhanced properties are particularly desirable since the precast pieces decreased weight is critical for shipping and installation.

Reinforcement methods, such as carbon or glass strands and stainless-steel bars, were also investigated in order to achieve a GRC with high endurance, resulting in corrosion-free solutions. One of the most troubling issues in the early stages of GRC development was the durability of the glass fibers, which grew brittle over time owing to the alkalinity of the cement mortar.

5.8 Applications of Guar Gum in Concrete and Mortar

- **Water Retention Agent**
Role: Guar gum significantly improves the water retention capacity of mortar.
Benefit: Helps maintain workability for longer periods and reduces the risk of plastic shrinkage cracking.
- **Rheology Modifier / Thickening Agent**
Role: It modifies the viscosity of concrete or mortar mixes.
Benefit: Improves pumpability and cohesion, making it suitable for applications like sprayed concrete (shotcrete) and self-compacting concrete (SCC).
- **Set Retardant (Mild Effect)**
Guar gum can slow the hydration rate slightly, especially in high dosages.
This may benefit hot-weather concreting where early setting is an issue.
- **Improves Cohesion / Anti-Segregation**
By increasing the viscosity of the mix, guar gum minimizes segregation and bleeding, especially in mortar or lightweight concrete mixes.
- **Improved Adhesion**
The film-forming and sticky nature of guar gum enhances bonding to substrates, which is beneficial in repair mortars, plasters, and tile adhesives.
- **Eco-Friendly Additive**
Being biodegradable and non-toxic, guar gum is suitable for green construction practices.

Mechanism of Action:

- Guar gum swells in water to form a gel-like structure.
- This gel increases the viscosity and reduces the free water in the mix, which controls the water loss rate and helps in hydration optimization.

Significant progress has been achieved since then, and the issue is now essentially eliminated with new forms of alkali-resistant glass fibers and mortar additives that inhibit the processes behind GRC embrittlement.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Following conclusions have been drawn from experimental results:

- By the addition of glass powder, workability increases of normal concrete. And 82mm slump is observed at 15% which is 66%. Required workability has been achieved from 62mm to 94mm which is suitable for the normal use of concrete.
- All mechanical properties are within the acceptable limits. Compressive strength of concrete increases by the addition of raw glass powder. Maximum strength is achieved by 15% replacement of waste glass powder in concrete which will increase the compressive strength by 14.3% in 28 days and min. strength is increased around 10%. Moreover, Flexural strength of glass concrete increases slightly (14% at 15% SSG)
- Utilization of SSG powder reduces the permeability and improves the durability properties. SSG powder may contain organic minerals that stabilize the strength property and have no adverse effect on the strength of concrete. Also, all concrete mixtures has achieved the desired strength (25MPa).
- ASR values decrease from 0.27% (M1) to 0.12% (M4). Glass powder is a pozzolanic material rich in amorphous silica. At low replacement levels, it may contribute to ASR. However, with higher percentages (10%–15%), it starts to consume excess alkalis and forms secondary C-S-H, which binds the alkalis and reduces their availability to react with reactive silica in aggregates. Guar gum may help by reducing permeability, thereby limiting moisture ingress essential for ASR.
- In sulfate attack, slight reduction from 0.04% (M1) to 0.021% (M4). Glass powder refines pore structure through its pozzolanic activity, thus making concrete denser and less permeable to sulfate ions. The additional C-S-H gel formed reduces the amount of free lime ($\text{Ca}(\text{OH})_2$), which otherwise reacts with sulfate to form expansive ettringite. Drying shrinkage decreases from 0.22% (M1) to 0.12% (M4). The incorporation of glass powder leads to a denser microstructure and reduced water demand. Guar gum, being a natural polymer, helps retain internal moisture, thus reducing shrinkage stresses. Pozzolanic reaction of glass powder also reduces capillary pores, limiting shrinkage-related deformations.

By the use of (SSG) raw glass powder and guar gum can save the natural resources, cost, energy and environmental pollution.

6.2 Recommendations

Further research and testing are recommended of glass concrete by the addition of different fibers and some microstructural properties by performing SEM and EDX. It is also recommended that by the increase of glass powder, strength improved at certain level after that it weakens the concrete but can be used where glass concrete used externally as aesthetic requirement.

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Summary

Optimum strength of glass concrete M1, M2, M3 and M4 are not significantly changed but the addition of guar gum improves the bonding effect and reduction in voids; Moreover, glass concrete is durable and more water resistant. Also, it exhibits better insulation and sulfate resistance properties. Addition of glass powder in concrete will give the better outcomes without any strength loss. Glass powder is recommended to be used in the construction industry at 15% replacement for mixing of normal and also improve the aesthetic properties of concrete.

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