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Effect of glass powder as partial fine aggregate replacement on properties of basalt fibre reinforced concrete

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ABSTRACT

High strength concrete is finding application in many structures in the past few years. In order to achieve concrete possessing high strength, various materials have been added to it that has superior durable properties. In order to increase the flexural strength in concrete, fibres are added to make it high strength. The use of several fibres in the making of such concrete and their advantages has been discussed in this work. The fibre obtained from basalt rocks known as basalt fibre is used in concrete in recent years and have attracted a lot of attention. In this paper, glass powder is used as a replacement for fine aggregate while basalt fibre is added to improve the mechanical properties of concrete. In order to attain the desired strength in concrete, the quantity of glass powder replacing the fine aggregate as well as the dosage of basalt fibres to be added are investigated. Test conducted in laboratory show that a 10% replacement of glass powder increased the strength and possessed good durability properties compared to conventional concrete. Compressive strength of 84.5 MPa, flexural strength of 11 MPa and split tensile strength of 3.2 MPa was achieved. The durability properties in terms of sorptivity and chloride penetrability were also found to be good compared to the conventional mix.

1. Introduction

The challenge in Construction Industry is getting superior material properties to be used in construction, based on the relevant application. Tall buildings and bridges have been designed using concrete which offers an advantage in reducing the size of structural members. This can be achieved by proportioning high strength concrete. The advantage of this concrete is to provide higher strength and durability properties with reduced sectional area thereby resulting in reduction of self-weight of the structure. [1]. High strength concrete involves use of fibres in the matrix which gives various advantages like controlling the propagation of cracks and increasing the flexural capacity of the structural members [2]. Concrete with strength greater than 60 MPa have been extensively used in airport pavements, bridges and in special structures like cooling towers. Many types of fibres like glass fibre, basalt fibre, kevlar fibre, carbon fibre, steel fibre and polypropylene fibres in concrete have been studied by various researchers. [3]. Extensive research works have been carried out using basalt fibres in combination with polymer composites and the strength parameters have been reported [4,5]. The strength characteristics of chopped basalt fibres have been explained well with the microstructure studies [6]. Basalt fibre composite has been advantageously used in marine constructions due to their superior impact resistance and durability properties [7,8].

Apart from material characterisation the bonding characteristics of the fibre in the matrix has been studied by researchers [9]. With all these studies and review of overall performance of concrete containing basalt fibres, it has been evident that this material can be used in high strength concrete [10]. There are many waste and recycled materials that have been investigated to be used as replacement to sand and they have also been performing well. Now that the demand for fine aggregate is increasing there is a need to find alternate sources of fine aggregate. Glass is a waste material which is abundantly discarded after use though a considerable quantity is recycled. Disposing of glass may cause environmental hazards as it does not decompose. Hence in the recent years use of glass powder in concrete is found to be advantageous in making it a sustainable construction material [11,12]. Glass powder has not only ben used as fine aggregate replacement, but

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also as cement replacement as some researchers have reported that it has some pozzolanic reaction [13,14]. Depending on its fineness and composition of the raw material it exhibits different degrees of pozzolanic reactivity [15,16,17]. Based on durability parameters, studies show that the rapid chloride penetration of concrete containing glass is less compared to conventional concrete [18,19,20]. It is also evident from researchers that finer glass powder used up to 40% replacement to cement has been very effective in mitigating alkali silica reaction in concrete [21,22,23]. In this study, the strength characteristics of an economical high strength concrete with incorporating basalt fibres are investigated, since basalt fibres are relatively cheaper. The focus on the experimental investigation in this study is to determine the improvement in the properties of a high strength with glass powder and basalt fibres and to study the durability parameters which will enable the researchers and construction industry to use these materials in their construction.

2. Materials and methodology

Proportioning of the concrete mix for this study was done using a fly ash based Portland Pozzolano Cement conforming to IS 1489 (part 1) 1991. ACI method of mix design was followed for calculating the mix proportion. The fine aggregate used had a bulk density of 1625 kg/m^3. The coarse aggregate was selected in two size fractions such that 40% of the aggregates were 12 mm to 20 mm in size and the remaining 60% had size fraction between 4.5 and 6 mm. This combination was adopted to enable an effective particle packing of the aggregates so that the space between the aggregates would be reduced. The bulk density of the aggregates used was 1707 kg/m^3. The water/cement ratio was limited to 0.3. Superplasticiser was used as 1% by weight of cement to enhance the workability of concrete. The properties of glass powder that was used as replacement to sand is given in Table 1. Basalt fibres used in this experimental work had the properties as specified in Table 2. Also the images of these materials used in this work are given in Fig. 1 and Fig. 2. Particle size of sand and glass powder is determined by sieve analysis and the results are as explained by the graph in Fig. 3.

The results of weight passing through each size fraction show that glass powder is finer than sand. The different mixes that were used in the work are designated as follows:

Mc-Control mix –M70 concrete

M1-Mix with 5% basalt fibres and 5% glass powder

M2-Mix with 5% basalt fibres and 10% Glass powder

The individual materials were loaded in the mixer machine and mixed in dry condition for 5 to 6 min until the dry materials were blended homogeneously. After that the required quantity of water was introduced into the mix and then superplasticiser mixed with some mixing water was also added to the mix. After complete mixing of the concrete the mixer was unloaded. Fresh concrete was subjected to slump cone test to find out the workability. Then the fresh concrete was filled in moulds like cubes, cylinders and

Table 1
Composition of cement and glass powder.

Composition	OPC	Glass powder
SiO_2	22.3	70.8
Al_2O_3	5.2	3.7
Fe_2O_3	3.4	0.4
CaO	64.2	12.4
MgO	2.2	0.9
SO_3	1.8	–
Na_2O	0.5	11.6
K_2O	0.4	0.2

Table 2
Properties of Basalt fibres.

Properties	Basalt Fibre
Filament diameter (μm)	10–20
Mass Density (g/m^3)	2.5–2.8
Tensile strength (MPa)	4000–4700
Modulus of Elasticity (GPa)	80–100
Ultimate elongation (%)	2–3.5
Thermal resistance (°C)	−200 to 650

Fig. 1. Basalt Fibres.

Fig. 2. Glass powder.

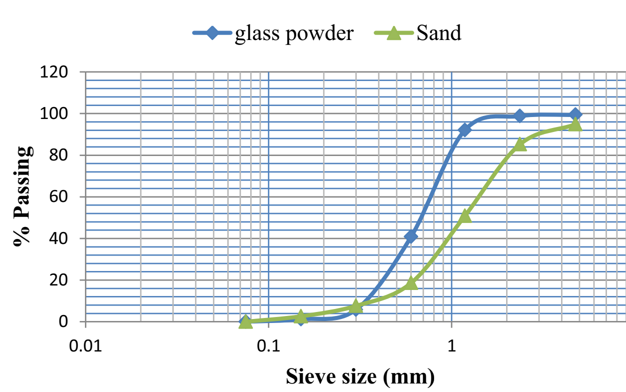

Fig. 3. Particle size distribution of Sand and glass powder.

prism as per IS code dimension. The samples were vibrated using a needle vibrator and finished using a trowel. The samples were allowed for hardening. The hardened samples were then demoulded and placed in a steam chamber for curing. The temperature of curing was 100°C and the duration of curing was 24 h. The samples were allowed to cool to the room temperature and then tested for compression, split tensile and flexural strength. The rate of loading was maintained at 140 kg/cm^2 per minute. Apart from strength tests durability tests were also performed to analyse the properties like sorptivity and rapid chloride penetrability (RCPT). Sorptivity test is conducted on 5 cm cube samples which is coated with epoxy on all three sides. The top and bottom is not coated. The test set up of RCPT was as per ASTM C 1202 which was performed on a concrete disc of thickness 50 cm. The solutions that were used in the RCPT cells were 3% NaCl and 0.3 M NaOH. The test was conducted for 6 h by passing a current of 60 V

3. Results and discussion

3.1. Fresh concrete properties

Workability is the measure of the fluidity of the mix. To determine the workability of mixes, slump cone is used. Table 3 indicates the results of the slump flow test. It was observed that increasing the glass powder content also increased the workability. This is due to the fact that the fine surface texture of glass particles facilitated the flow of the mix thereby increasing the workability. It was also found that the addition of fibres have slightly increased the workability of the mix.

3.2. Strength properties

The bulk density of the material is plotted in the graph as shown in Fig. 4. It is observed that with the addition of basalt fibres there was a minor increase in the bulk density. But as the glass powder was added the bulk density reduced. This could be due to the low unit weight of the powdered glass. With increase in the replacement level, the bulk density further reduced. Bulk density of glass powder was 1525 kg/m^3 as compared to fine aggregate which was 1650 kg/m^3. Hence the decrease in the density would have been due to the reduction in bulk density of concrete. After the hardening process using steam curing, the materials were subjected to strength tests. The results of compressive test are shown in Fig. 5.

The conventional concrete cube exhibited strength of 76 MPa. And as the glass powder replacement level was increased the compressive strength increased substantially as shown in Fig. 5. The reason could be the pozzolanic reaction due to the use of glass powder containing reactive silica. This SiO_2 reacts with CaOH formed during the hydration of cement and results in the formation of additional C-S-H which contributes to the enhancement of the strength properties [23]. The split tensile strength which was performed on cylinders as given in Fig. 6 and it had the same trend. The flexural strength of concrete was also improved by the addition of glass powder (Fig. 7). It was observed that adding basalt fibres into the concrete mix, there was an enhancement in the flexural strength. The micro cracks formed during the loading as given in Figs. 8 and 9, was prevented from widening due to these fibres which prevents the propagation and growth of cracks.

Table 3
Workability of the mix in terms of slump flow (mm).

Mix	Slump (mm)
Mc	68
M1	72
M2	78
M3	82

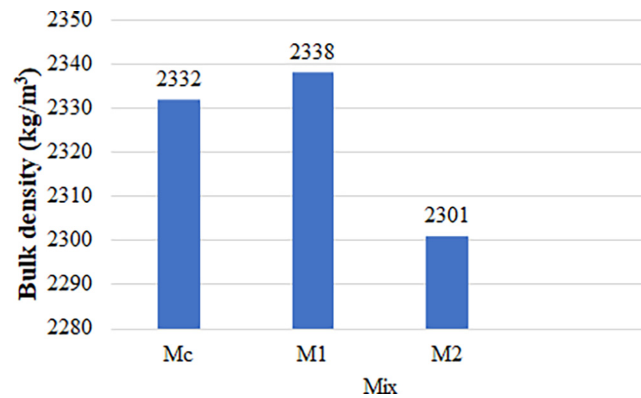

Fig. 4. Bulk density of the samples.

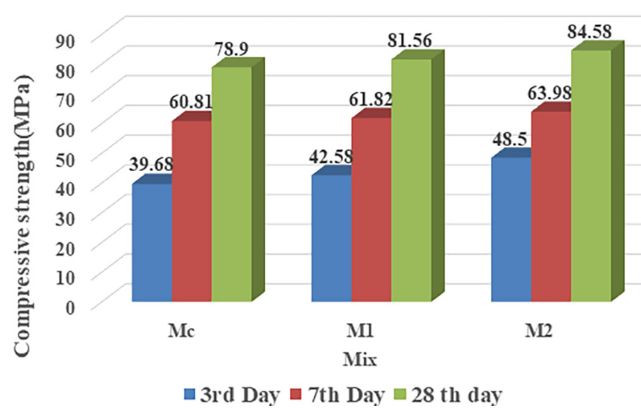

Fig. 5. Compressive strength of the samples.

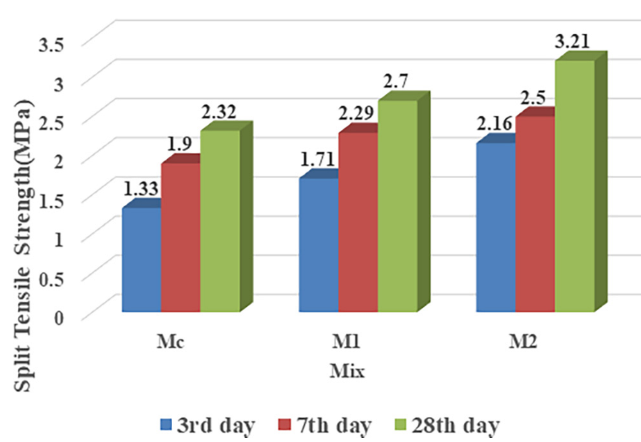

Fig. 6. Split Tensile strength of the samples.

3.3. Durability properties

Investigating the durability properties is as important as strength properties. Pore distribution and connectivity of pores are the main factors which contribute to the durability of the material. The durability parameters of the material can be ascertained by conducting sorptivity and RCPT which would give an idea of the absorption properties of the pores in concrete.

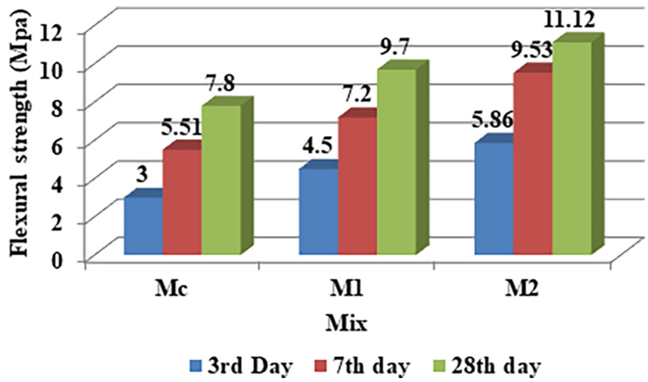

Fig. 7. Flexural strength of the samples.

Fig. 8. Split Tensile strength of the samples.

Fig. 9. Flexural strength of the samples.

The experimental arrangement for sorptivity test is shown in Fig. 10. The samples are placed on a sand bed which is saturated with water facilitating capillary absorption of water along one direction. The test results are plotted in Fig. 11. The test results showed that sorptivity reduces as the quantity of glass powder is increased. This is due to the dense microstructure and refinement of interfacial zone along the surface of the aggregate which prevents pore formation and connectivity of pores.

Fig. 10. Sorptivity Test set up.

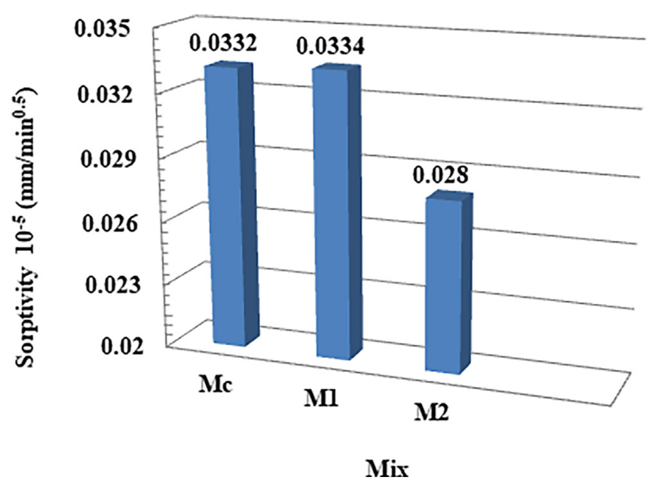

Fig. 11. Sorptivity of the samples.

The conductivity of charge through the concrete specimen is measured in coulombs as given in Fig. 13. The inference to find the quality of concrete based on RCPT value is given in Table 4. The performance of the RCPT experimental arrangement is shown in Fig. 12. The results show that the RCPT value reduces considerably as the amount of glass powder was increased in the mix. This could be attributed to the less pore connectivity.

4. Conclusion

The experimental data obtained from the study can be concluded as follows:

Table 4
Chloride ion penetrability Test Inference data.

Charge passed (Coulombs)	Chloride Ion Penetrability
greater than4000	High
2000–4000	Moderate
1000–2000	Low
100–1000	Very low
<100	Negligible

Fig. 12. Rapid Chloride Penetration Set up.

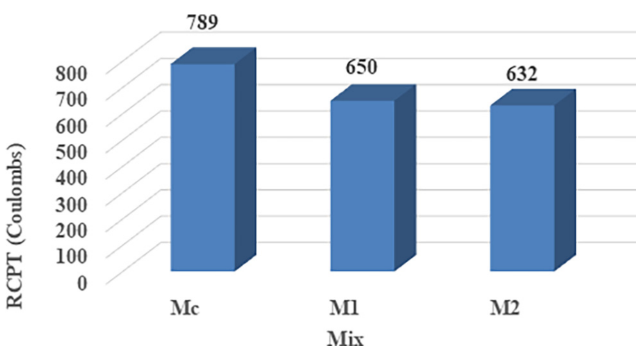

Fig. 13. Rapid Chloride Penetration Test values.

- Addition of glass powder as substitute to fine aggregate in this study has resulted in reduction of density and improvement in the workability properties.
- Strength properties have been considerably increased compared to the conventional concrete by inclusion of this supplement material and basalt fibres.
- Durability properties were improved with inclusion of glass powder which shows that there is much advantage in using this waste material in concrete. It will also help in reducing the cost of the concrete and make it a sustainable material as it consumes waste product.

CRediT authorship contribution statement

M. Selvakumar: Conceptualization, Methodology, Writing-review & editing. **S. Geetha:** Funding acquisation, Project administration, Original draft. **Sneha Kasturi Rangan:** Data curation, Investigation. **T. Sithrubi:** Investigation, Validation. **S. Sathyashriya:** Resources, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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