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Performance Evaluation of Hybrid Glass Wastes Incorporated Concrete

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Abstract

Electronic-based Hybrid Glass Wastes (EHGW) cover computer, television, and mobile display screens. Although Hybrid Glass Waste is recycled to create a valuable new glass product, the vast majority of Hybrid Glass Waste is still disposed of in landfills. In the present study, the prime objective is to assess EHGW as a fine aggregate and filler in concrete composites. Physical and chemical assessments of EHGW are performed in detail. Thermogravimetric analysis revealed EHGW is more sensitive regarding temperature variation. Specifically, 344 °C is the observed melting point of EHGW. Predominantly, a concrete mix of M40 grade is designed with EHGW as a partial replacement to fine aggregate with the incremental rate of 5% and limiting to 20%. Slump and mechanical properties of concrete composite reveal that 10% of EHGW replacement to fine aggregate gives optimal results. In addition, the mechanical performance of all EHGW based concrete composite is observed and evaluated at 28 °C (ambient temperature), 115 °C (-H_2O) and 344 °C (liquefaction state). Compared with control mix, the overall findings revealed a maximum loss of mechanical properties for 20% EHGW based concrete composites which is about 10.26% to 30.97% at 115 °C and 27.25% to 71.89% at 344 °C. Also, the polynomial regression represents significant relation between mechanical properties and EHGW replacement percentage with 0.82 to 0.85 R^2 values.

Keywords: Electronic-based Hybrid Glass Wastes; Thermo-physical properties; Mechanical performance; Thermogravimetric analysis.

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1. Introduction

Non-biodegradable wastes which can be recycled or reused as a value-added material in any construction application are a globally oriented challenge.[1–7] Specifically, after plastic, glass is the major non-biodegradable waste. In addition, the collection of glass is a major challenging process as the glass waste is available in the broken form mixed with foreign material.[8–10] Due to the non-biodegradable nature of glass wastes, it is usually dumped or consumed for landfilling which would adversely affect the environment and ecosystem.[11] Also, the collection and disposal of glass wastes are categorized under solid waste management and the quantity of solid waste production is quite proportional to per capita income and urbanization.[11–13] In developing countries like India overall 1.3 million tons of glass waste per year has brought a burden to the solid waste management system.[14] Moreover, regarding global waste generation, 5% of wastes are contributed by the glass and it is 1% more than the global metal waste contribution.[12,14–16] The control over the solid waste management system which tracks the promotion to sustainability aspects has prompted the utilization of waste glass as an aggregate for the production of concrete.

A promising line of research has been proposed on the utilization of waste glass as a concrete ingredient, with several studies in countries like the United States, Hong Kong, Australia and Singapore, where conclusive and promotive results on mechanical property of concrete modified incorporating waste glass have been reported.[12,17] Lee *et al.*[18] studied the effect of four different glass fractions (un-sieved, < 2.36mm <1.18mm < 0.6mm) of post-consumer bottle's on concrete blocks with a partial replacement technique to sand at a replacement incremental rate of about 25%. The findings revealed that the results changed with regards to reduced compressive strength mainly due to the increase in water

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demand and porous structure of concrete. In addition, due to unforeseen pozzolanic reaction, a slight increase in compressive strength was observed while utilizing 0.6mm below sized aggregate fractions. Carsana *et al.*[19] experimented to analyze the pozzolanic reaction of glass powder while subjecting it with two different fractions having a specific surface of about 400 m^2/kg and 600 m^2/kg, which was compared to natural pozzolana, coal fly ash and silica fume. Results showcase a high reactive phase for finer glass fractions (600 m^2/kg) with improved strength. Many researchers[8,9,19–26] investigated the effect of alkali-silica reaction which promotes pozzolanic reactivity owing to the presence of high silica content in glass fractions, by utilizing fine glass fractions as supplementary cementitious material to cement. Findings validated the investigated theory concerning improved mechanical properties which were identified through alkali-silica reaction and dense packing. This declares that chemical composition and average fine fractions of glass were found to be more advantageous to ascertain pozzolanic reactivity and particle airtight packing between the coarse aggregates. Overall, the research findings utilize glass waste as a pozzolanic reaction phase promoter material. From the few research findings studied, it is observed that glass waste is used as an aggregate ingredient in concrete, but there is no evidence regarding examining the performance of electronic-based hybrid glass waste (EHGW) in concrete mixes.

EHGW are majorly generated due to the production of Liquid Crystal Displays (LCD) and Mobile displays. Usually, these LCDs are made up of 80.5% of hybrid glass and 25% polarizer foils.[16,27] Though hybrid glass is tough to manage as a recycled ingredient, the material exhibits much better tensile, flexural properties than ordinary glass wastes.[28–31] Usually the composition of EHGW includes polymers like polyethyl- ene (low and high density),[32] polypropylene,[33] polyvinyl chloride[34] and polystyrene[35] which imparts less water absorption properties, resistance to biochemical attack, shape stability, better stiffness, more strength, good abrasion resistance during production process and low density. It is found to be economical with respect to fine aggregate replacement in terms of mineral filler applications.[36] In other words, it may be advantageous to utilize it as fine aggregates in concrete which may contribute to improvement in concrete properties and other advancements as well. In the present research, EHGW is utilized in concrete as a replacement for fine aggregate and its mechanical performance is analysed for different working temperature conditions.

2. Material characterization and mix proportion

The study was based on concrete composite as a two-phase material consisting of aggregate skeleton and binder. Locally crushed igneous rock source-based aggregate with size 20mm and down was utilized as a coarse aggregate ingredient, followed by river sand with size 4.75 mm down as a fine aggregate ingredient along with Ordinary Portland Cement (OPC) and Class-F Fly Ash (FFA) as the major binder agents. In addition, EHGW was utilized with size 4.75 mm down as a partial replacement to natural river sand.

The EHGW particles having 0.6mm downsize would also come into the alkali-silica reaction phase thereby promoting the pozzolanic reaction in the concrete composite. Hence EHGW particles were categorized as both aggregate skeleton and binder ingredients.

X-Ray Diffraction (XRD) characterization of EHGW as shown in Fig. 1, represents the amorphous structure along with crystalline structure foams which had more than 70% of polystyrene sphere.[37,38] The identified peaks recognized the cristobalite (JCPDS-01-076-0939) and devitrite (JCPDS-00-023-0671).

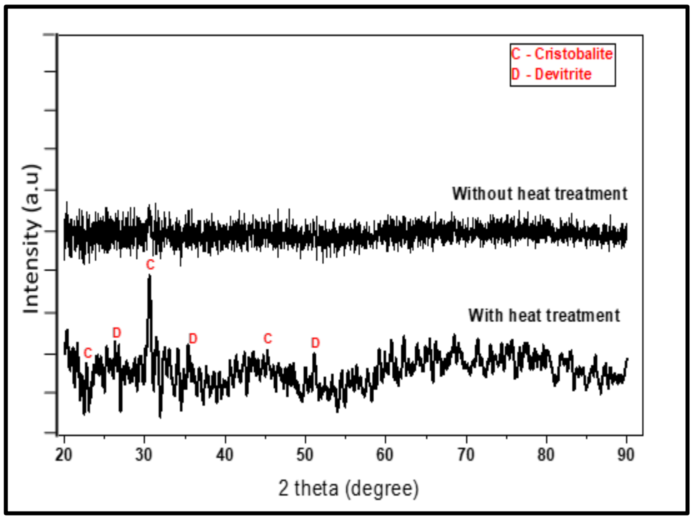


Fig. 1 X-Ray Diffraction characterization of EHGW sample.

Scanning Electron Microscope (SEM) characterization shown in Fig. 2 represented uneven EHGW crystalline texture with sharp edges proving to be advantageous to provide a good interlock between the binder and aggregate particle in a concrete composite. This observation was confirmed through the presence of Si, Ca, Mg and Al elements in EHGW sample as found from Energy Dispersive X-ray Spectroscopy (EDS) results shown in Figs. 3(a) and (b).

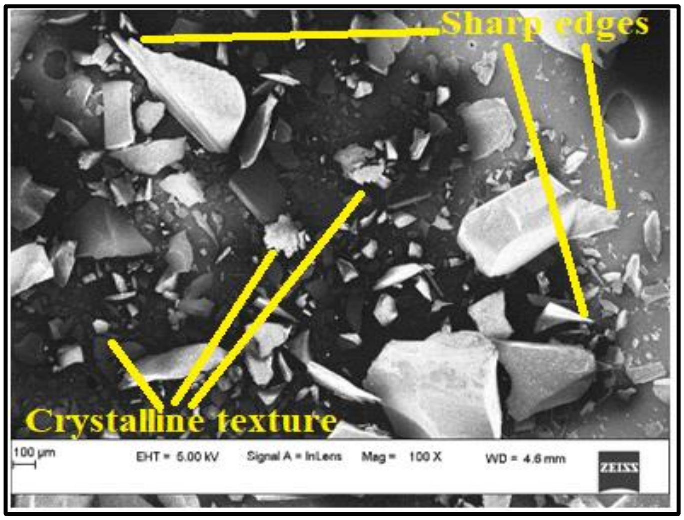
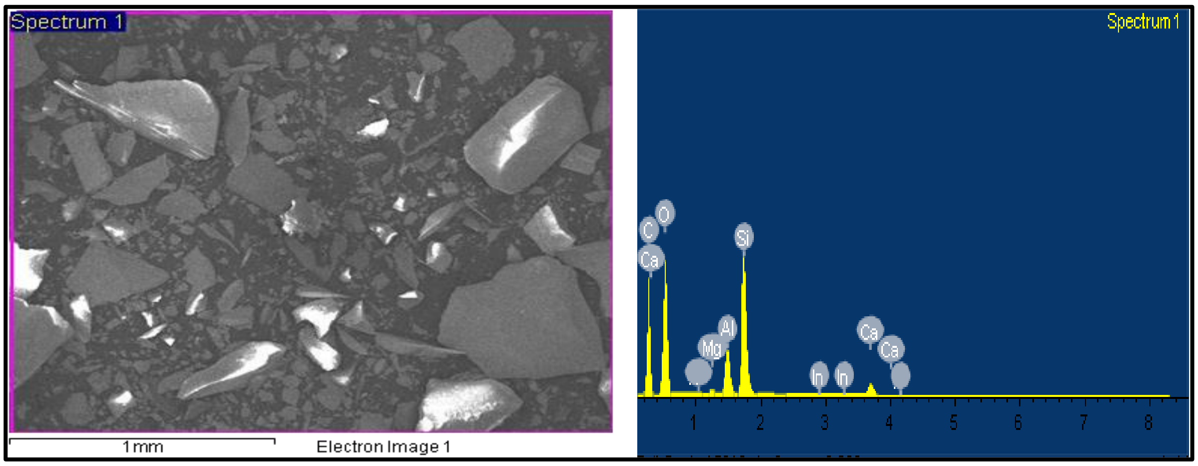


Fig. 2 Scanning electron microscope image of EHGW sample.



(a) (b)

Fig. 3 Energy Dispersive X-ray Spectroscopy image of EHGW sample.

Thermo-gravimetric analysis (TGA) performance represented the escape of H_2O between 25 °C to 115 °C. The carbon loss was observed up to 344 °C which is also the melting point of EHGW as shown in Fig. 4(a). Thus, from thermal analysis of EHGW, three major peaks were observed which were due to moisture loss at 25 °C, carbon loss at 115 °C and the melting point at 344 °C. Even the derive weight percent represented the EHGW disturbance with an uneven pattern as in Fig. 4(b).

The methodology plan of the study focused on understanding the characteristics of EHGW as composite input in concrete. Initially, the aim was to develop M40 grade of concrete with EHGW as a partial replacement to river sand at an increment of 5% and limited up to 20%. Table 1 represents the mix proportions and quantities of material used for various concrete mixes considered. For the mixes considered, the workability and mechanical characteristics were analysed with regards to slump value (as per IS -1199 - 1959[39]), compressive strength (as per IS - 516 – 1959[40]), flexural strength (as per IS - 516 – 1959[40]) and modulus of elasticity (as per IS - 516 – 1959[40]).

As thermal analysis of EHGW showed three major peaks which were due to moisture loss at 25 °C, carbon loss at 115 °C and the melting point at 344 °C, to understand thermal characteristics of concrete composites with EHGW as a replacement for fine aggregate, tests were performed specifically by exposing samples to 115 °C and 344 °C in the oven (4 °C/minute) for a duration of 8-hour conditioning, and later analysed through the mechanical characteristics based on IS - 516 – 1959.[40]

3. Performance of EHGW based concrete composites.

The workability of mixes considered was analysed by slump flow test and is as shown below in Fig. 5. The concrete slump flow characteristics indicated an increment of 13mm and 8 mm slump value at 5% and 10% replacement of river sand by

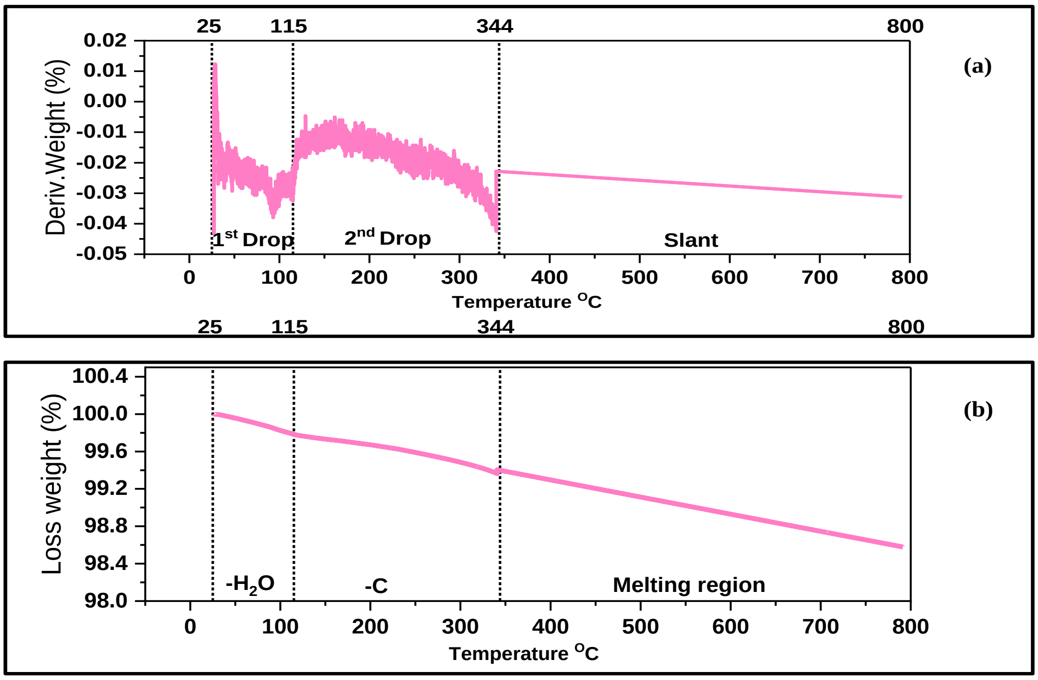


Fig. 4 (a) Thermogravimetric analysis of EHGW sample, (b) Thermogravimetric analysis of EHGW sample.

Table 1. Concrete mix proportions and quantities of material used.

Mixes	OPC (kg/m^3)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)	Water (kg/m^3)	Fly Ash (kg/m^3)	EHGW (kg/m^3)
CF (Cement & Fly Ash)	358.31	597.18	1194.37	191	39.81	0
CF-EHGW-5	358.31	567.33	1194.37	191	39.81	29.86
CF-EHGW-10	358.31	537.47	1194.37	191	39.81	59.72
CF-EHGW-15	358.31	507.61	1194.37	191	39.81	89.58
CF-EHGW-20	358.31	477.75	1194.37	191	39.81	119.44

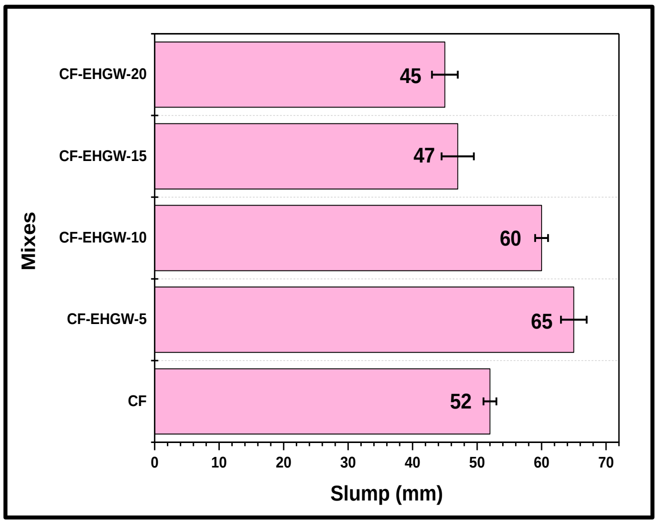


Fig. 5 Slump flow of various concrete mixes.

EHGW when compared with the slump values of control CF mix. From Fig. 5, it has been observed that further replacement of river sand by EHGW reduces the workability characteristics of concrete which is represented by the reduced trend in slump value. Even though mixes like CF-EHGW-5 and CF-EHGW-10 represented similar performance with the least slump difference of about 5mm, CF-EHGW-15 and CF-EHGW-20 were representing EHGW as an obstacle by obtaining a slump difference of about 7mm in comparison with the CF mix. This has been achieved due to acceleration in hydration by EHGW finer particles having a size of 0.6mm or less (presence of SiO_2 of about 73% and CaO 10% in EHGW imparts accelerated hydration).[41,42]

Also, larger particles of EHGW (more than 0.6mm) having flaky nature and uneven structure as observed from SEM image in Fig. 2, improved the aggregate locking characteristics which resulted in poor workability of concrete. The mechanical characteristics of various concrete mixes were examined through compressive strength and the obtained results were evaluated at the age of 7 and 28 days as shown in Fig. 6. For EHGW replacement up to 10% (CF-EHGW-10), an increase of 19.5% in the compressive strength at 28 days is observed as compared to the 28 days strength of CF mix. Also, a further replacement of EHGW represented a decremented trend due to the presence of more void structures in concrete. Particularly at the age of 28 days, a 27.20% decrease with regard to compressive strength was observed for CF-EHGW-20 as compared to the CF mix. In addition, regression analysis represented polynomial relation with a 0.85 R^2 value as shown in Fig. 7 indicating significant relation between compressive strength and EHGW replacement.

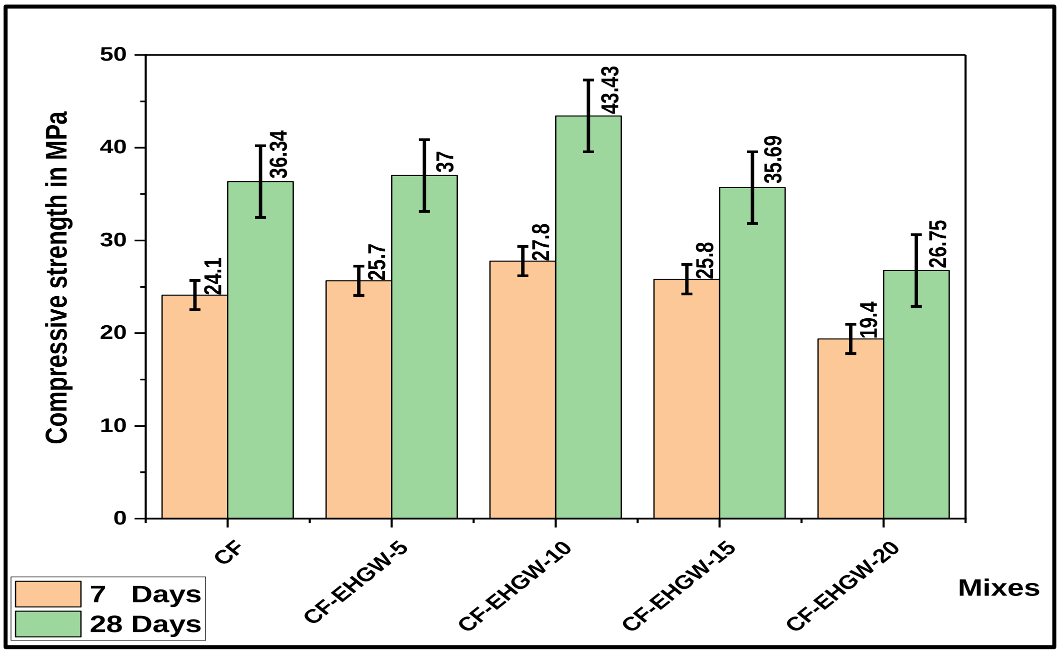


Fig. 6 Compressive strengths of EHGW concrete composite.

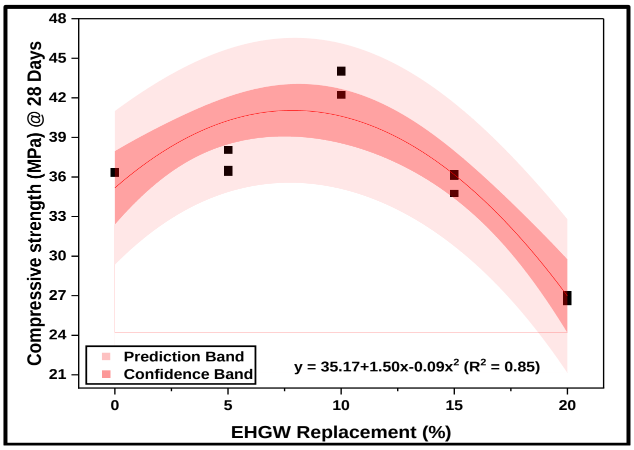


Fig. 7 Polynomial relation for compressive strength of EHGW concrete composite.

Fig. 8 indicates the split tensile strength of concrete mixes and the obtained results revealed a similar trend as that of compressive strength characteristics of concrete. At the age of 28 days, the mix CF-EHGW-10 gave an optimum performance, which in comparison with CF mix revealed an increase of 17.69% in split tensile strength. The flexural strength tests that followed were also indicative of the optimized performance of EHGW replacements in CF-EHGW-10 mix as shown in Fig. 10. Comparison of mix CF-EHGW-10 with CF mix revealed an increase of 12.61% in flexural strength at the age of 28 days. Moreover, significant relation was found between split tensile strength vs EHGW replacement percentage, and flexural strength vs EHGW replacement percentage with 0.83 (Fig. 9) and 0.82 (Fig. 11) R^2 values respectively.

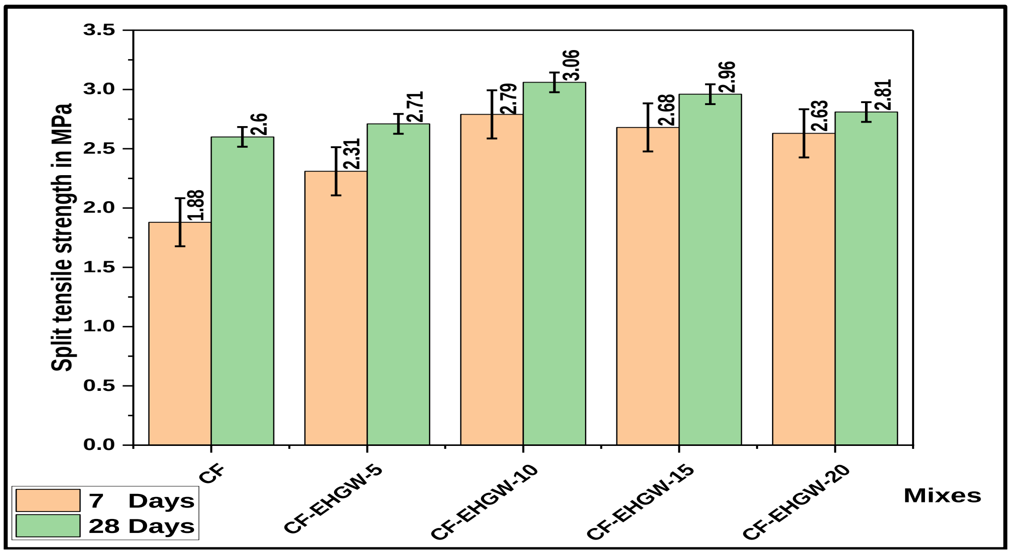


Fig. 8 Split tensile strength of EHGW concrete composite.

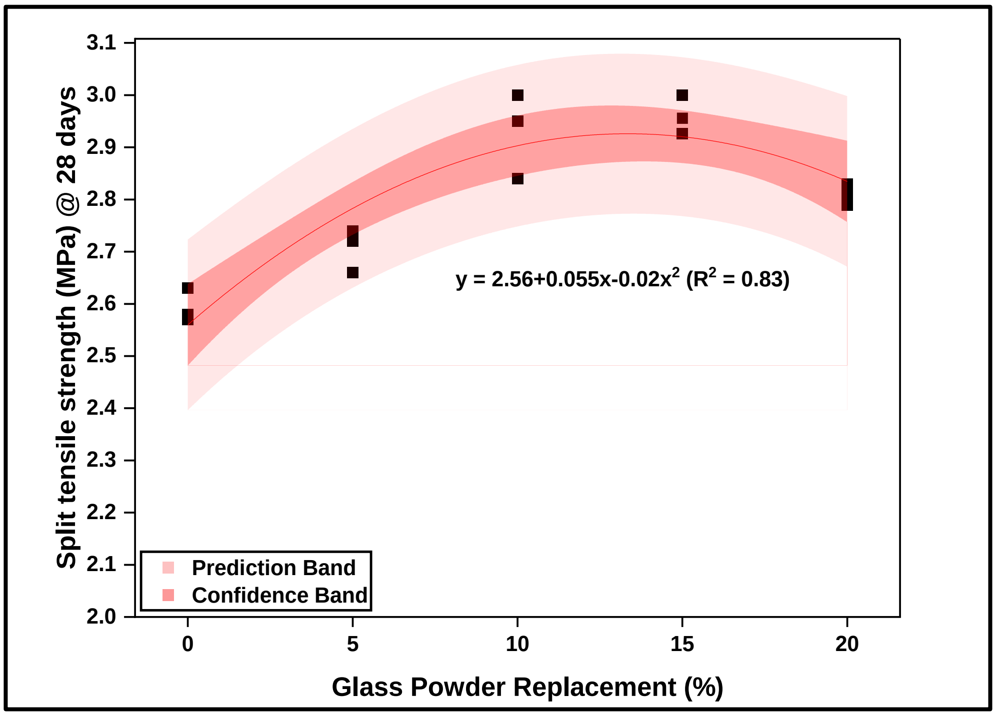


Fig. 9 Polynomial relation for split tensile strength of EHGW concrete composite.

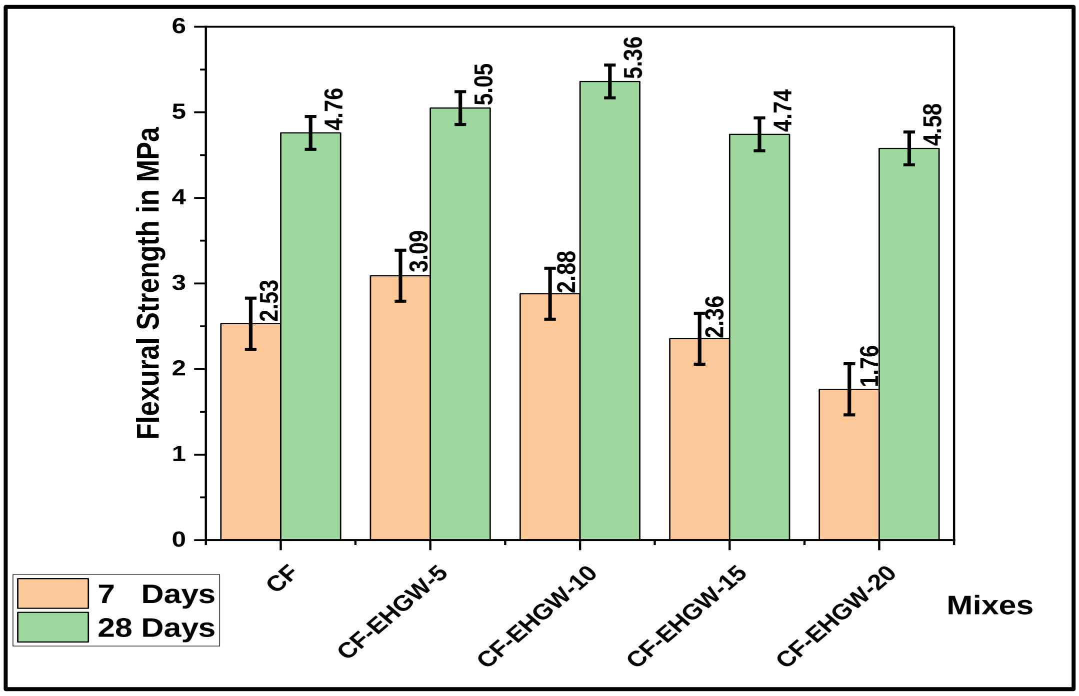


Fig. 10 Flexural strength of EHGW concrete composite.

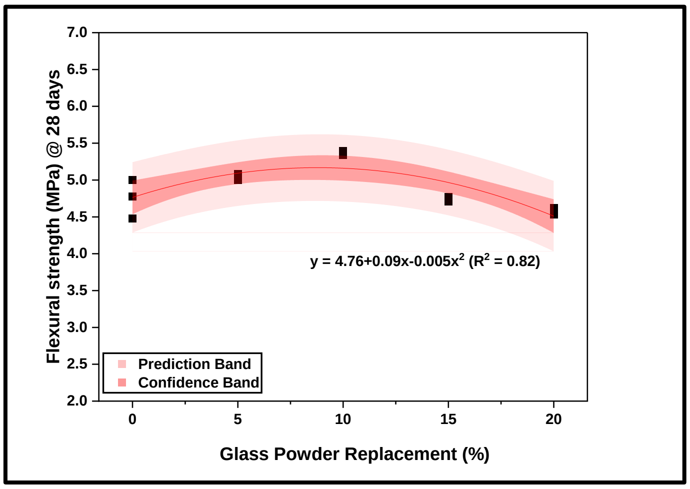


Fig. 11 Polynomial relation for flexural strength of EHGW concrete composite.

The elasticity of concrete mixes was examined and relationships developed between stress vs strain parameters are shown in Fig. 12. It observed that CF and CF-EHGW-5 more or less represent the same stress vs strain pattern and achieved an equivalent modulus of elasticity of about 31 GPa, indicating that the replacement of 5% EHGW in concrete is found to be insignificant. Regarding CF-EHGW-10 as an optimum mix, it represented more strain in the initial loading period as compared to CF-EHGW-15 and CF-EHGW-20. The CF-EHGW-10 optimum mix after 14 MPa showed strain behaviour that leaned closer to CF-EHGW-5 and CF mixes, and after 29 MPa it represented the least strain compared to all other mixes. Even the CF-EHGW-15 and CF-EHGW-20 represented similar strain behaviour with the least variance and precisely CF-EHGW-20 represented a huge strain of about 5. The overall effect of EHGW as a partial replacement in concrete composite represented complex behaviour with regards to stress-strain relation. Also, CF-EHGW-10 can be considered as an optimum performing mix in comparison to conventional concrete (CF). The study revealed that a partial replacement of EHGW of 10% is recommended for achieving almost change free strain behaviour as compared to CF concrete, even though CF-EHGW-10 performed with the highest modulus of elasticity of about 33GPa.

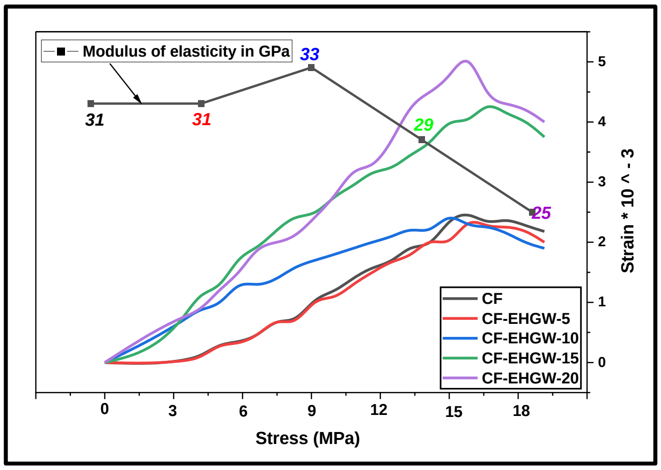


Fig. 12 Modulus of elasticity and stress-strain relation of concrete composites at 28 days.

The mechanical behaviour of temperature conditioned concrete samples indicated that the compressive strength, split tensile strength and flexural strength of concrete showed decreasing trends with the increase of temperature. Compressive strength of CF mix represented the least difference regarding 115 °C and 344 °C which were found to be 18.73% and 36.61% in comparison to 28 °C performance. From the study, it was also observed that the compressive strength performance of CF-EHGW-20 mix with temperature conditioning at 115 °C and 344 °C revealed a maximum decrease of about 30.97% and 71.89% in comparison to 28 °C which is shown below in Fig. 13.

The split tensile strength of CF mix at 115 °C and 344 °C temperature conditioning represented the least difference of about 15.38% and 36.36% in comparison to the results at 28 °C curing. Also, the split-tensile strength performance of CF-EHGW-20 at 115 °C and 344 °C temperature conditioning in comparison to 28 °C curing revealed a maximum difference of about 17.08% and 41.20% as shown in Fig. 14.

Figure 15 shows the variation in flexural strength of concrete, and it is observed that the flexural strength of CF mix at 115 °C and 344 °C of temperature conditioning represented the least difference of about 9.24% and 23.61% in comparison to results at 28 °C curing. Moreover, flexural strength performance of CF-EHGW-20 in regards to temperature conditioning at 115 °C and 344 °C in comparison to 28 °C curing revealed a maximum difference of about 10.26% and 27.25% respectively.

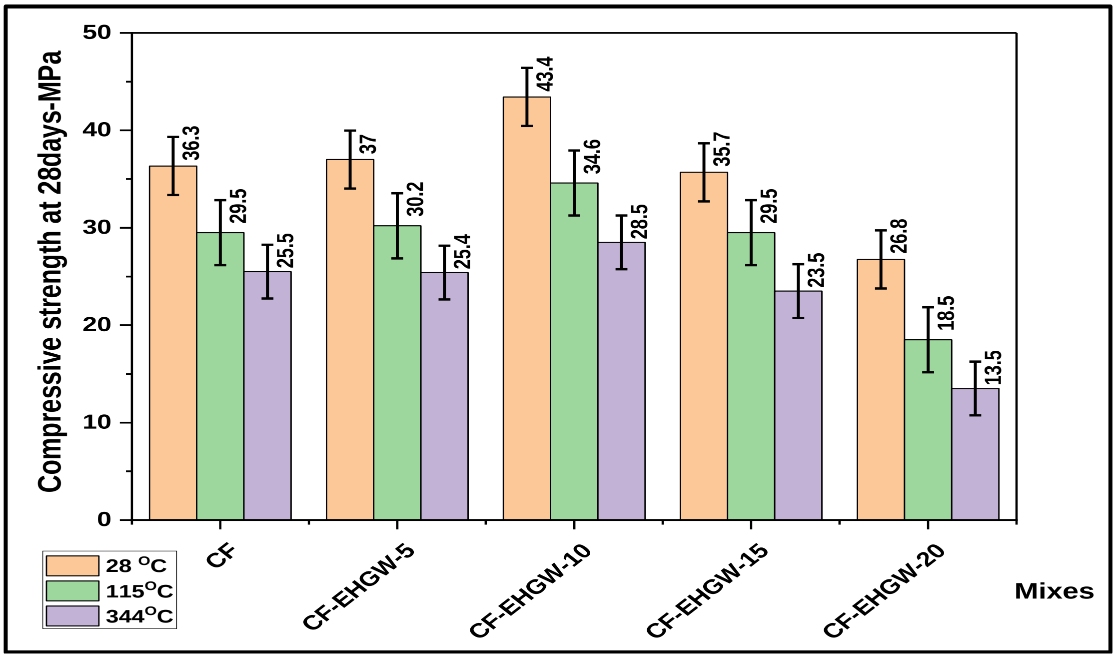


Fig. 13 Variation in compressive strength of concrete composites at different conditioned temperatures.

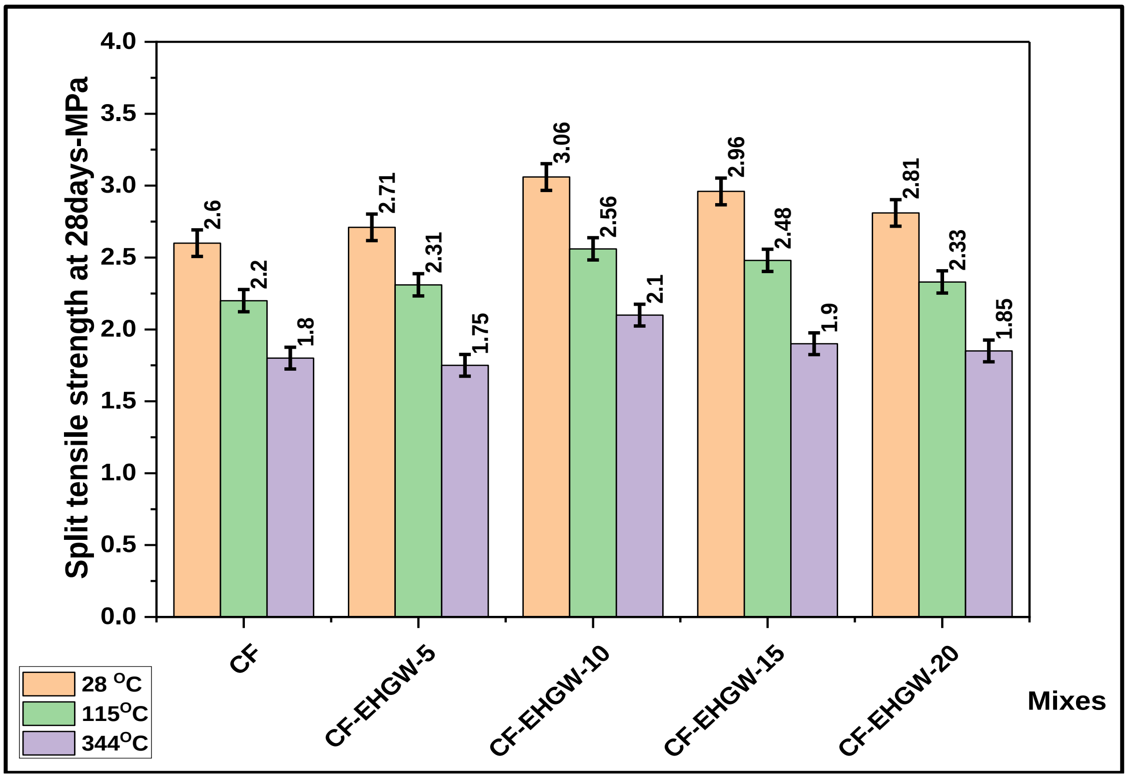


Fig. 14 Variation in split tensile strength of concrete composites at different conditioned temperatures.

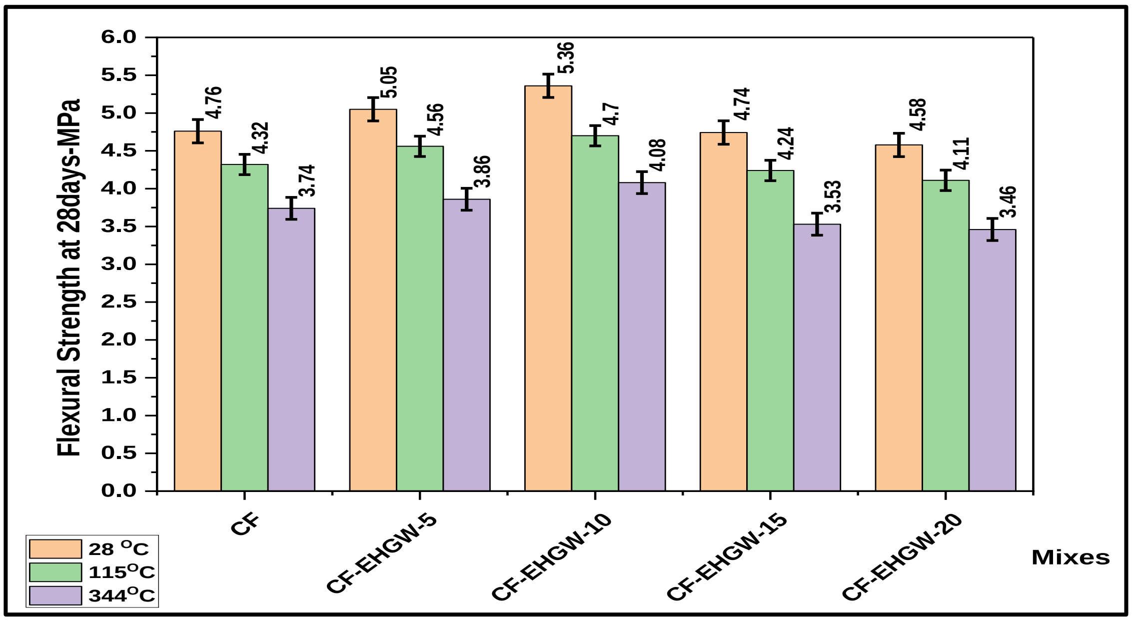


Fig. 15 Variation in flexural strength of concrete composites at different conditioned temperatures.

A huge drop of about 17.36% to 30.97%, 14.76% to 17.08% and 9.24% to 12.31% with regards to compressive strength, split tensile strength and flexural strength of concrete respectively performed at temperature conditioning of 115 °C in comparison to 28 °C were observed for the various concrete mixes.

From the concrete perspective, huge drop in mechanical properties is due to rehydration of calcium silicate hydrate and portlandite, which imparts imbalance and uncertainty in the porous structure of concrete resulting in a more brittle concrete composite.[43–45] Overall, the EHGW based mixes represented poor mechanical properties while performing at a higher temperature. The EHGW thermal characteristics as observed from TGA in Fig. 4, represented more derive. weight disturbance at 115 °C. It is evident that implication of volume change by promoting pore structure in concrete results in poor mechanical properties. Also at 344 °C slant, observed derive. weight percentage represented liquefaction of EHGW which imparted huge voids in concrete thereby resulting in sudden failure of concrete, as observed from the mechanical results obtained.

4. Conclusions

Based on the detailed study Slump value revealed more workable concrete with 5% and 10% EHGW replacement but the further increment of EHGW made concrete stiffer. With regards to mechanical properties of concrete, compressive strength, split tensile strength, flexural strength and modulus of elasticity, the CF-EHGW-10 mix is found to be optimum. Reason being presence of SiO_2 of about 73% and CaO of 10% in EHGW imparts accelerated hydration. In addition, significant relations between mechanical properties and EHGW replacement percentage were identified with 0.82 to 0.85 R^2 values. Although Mechanical performance of concrete at different conditioned temperatures revealed poor behaviour of EHGW based concrete composite, specifically the mix CF-EHGW-20 looses 10.26% to 30.97% at 115 °C and 27.25% to 71.89% at 344 °C in comparison to CF mix. Overall CF-EHGW-10 mix can be recommended for real-time practices at normal (28 °C) working temperature.

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Conflict of Interest

The authors declare no conflict of interest.

Supporting information

Not applicable.

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