

Effect of tempered glass fines in concrete at elevated temperature

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Abstract. Millions of tons of waste glass are produced every year. Solid waste management is one of the biggest environmental problems. Also, there is a need to discover alternative materials that can compensate for the depletion of natural resources. The purpose of this research is to assess the feasibility of waste tempered glass fines (TGF) as partial replacement of sand in concrete mix. Concrete cubes with four different replacement percentages (0%, 5%, 10%, 15% & 20%) and three different sizes of tempered glass fines (TGF) were tested for compressive strength at ambient and elevated temperature (790°C). The mass loss and elastic modulus were also inspected. The results indicated that waste TGF could be used as an efficient sand replacement material. An enhanced compressive strength was achieved for all of concrete mix design samples. Among all the mixes, 5% by weight replacement of sand with TGF (particle size= 1.7-4.75mm) gave the maximum enhancement of compressive strength. The same trend was observed for mass loss and modulus of elasticity.

Keywords. Temperature glass fines, concrete, solid waste management.

1. Introduction

Concrete is one of the most widely used construction material throughout the world because of its durability, strength, ease of fabrication and noncombustible nature. The rapidly growing use of concrete thus, puts an increased demand of the natural resources while leading to the depletion of the resources at the same time. Therefore, for the sustainability of the construction industry, new innovative, non-conventional cost-effective materials need to be employed which can compensate for the lack of such resources along with enhancement of the behavior of concrete structures under different loading conditions.

Moreover, waste reduction is also a global issue that needs to be addressed. Waste glass is a growing burden worldwide. Despite its ideal properties for recycling, it is not suitable for landfill [1]. Recycling of waste glass not only helps conserve earth's natural resources but also reduces demand of landfill spaces, while saving energy and money at the same time [2]. Glass can be used as a pozzolanic/cementitious material [3]. Various past researches have been dedicated to the use of waste glass as an aggregate and/or cement replacement material [4-7].

Glass has same physical properties as sand but it shows a lower rate of water absorption and therefore, is an interesting material for concrete development [8]. It has been reported in many past researches that with the inclusion of glass aggregates the compressive strength reduces [9,10]. Several other studies conducted in the last decade show that along with volume of glass aggregates used, particle size plays an important role in alkali silica reaction (ASR) [11,12]. The results indicate that ASR increases with the increased particle size. Expansion and subsequent cracking of concrete due to ASR can be eliminated if less than 20% of waste glass aggregates of particle size less than 1.18mm are used. Also reduced particle size increases pozzolanicity of the concrete mix. [13].

Fire resistance is an important natural attribute of concrete. When concrete is subjected to elevated temperature, strength and stiffness of concrete reduces due to several reasons such as evaporation of water from voids, aggregate decomposition and dehydration of cement paste etc. [14,15]. Also, higher



temperature and faster cooling rate produce negative impact on residual mechanical properties of concrete and strength reduces to almost zero at 600°C [16]. The volume and size of aggregates is another important factor that greatly influences the behavior of concrete at elevated temperatures [17,18].

Different materials can be employed to assess the fire-resistant properties of concrete. Poutos et al. proved that glass aggregates exhibit better temperature stability owing to its lower specific heat compared to its natural sand and due to pozzolanic activity of glass [19].

Tempering is a thermal process of glass strengthening by creating compressive stresses [20]. Tempered glass is a special glass type with enhanced features of high toughness and thermal resistance. It is extensively used in sliding doors and partitions in houses and offices, facades, car windshields etc. For a glass to be tempered, it is cut to required size and shape, before it is toughened and it cannot be re-toughened. Thus, broken tempered glass and wrongly fabricated sizes serve as a potential waste material that can be utilized in concrete. Moreover, the enhanced thermal resistance can lead to a better behavior when concrete is exposed to fire [21].

The described research program is aimed at improving the strength properties of concrete at normal and elevated temperature (790°C) on one hand. While to check the feasibility of using this material as sand replacement on the other hand. In this study, tempered glass fines (TGF) were used in concrete as partial replacement of fine aggregate and effect of size and dosage of TGF were studied.

2. Experimental Program

2.1. Materials

The concrete mix used in this study was prepared from Ordinary Portland Cement-Type I (OPC), natural coarse aggregates, locally available clean river sand (max. particle size 4.75mm), tap water and tempered glass fines. The bulk densities of cement, sand and coarse aggregate were 1440 kg/m³, 1463 kg/m³ and 1455 kg/m³ respectively. Tempered glass fines (TGF) were incorporated in the concrete mix as a partial replacement of sand in various sizes and percentages. The acronym of three types of TGF along with their respective sizes are listed in table 2.

2.2. Mix Proportion

A total of thirteen different concrete mixes were prepared with varying amount and sizes of TGF and a minimum compressive strength of 20 MPa. In all the mixes a constant W/C ratio of 0.42 was taken. Sand was replaced with TGF in four different amounts by weight as 5%, 10%, 15% and 20% respectively. The quantities of the constituent materials for all mix designs are summarized in table 1.

Table 1. Proportions of concrete mix designs

Mix Type	Cement (kg/m ³)	Sand (kg/m ³)	Aggregate (kg/m ³)	TGF (kg/m ³)
Control	205.71	418.12	831.77	0.00
CGF-5	205.71	397.21	831.77	19.51
CGF-10	205.71	376.31	831.77	39.02
CGF-15	205.71	355.40	831.77	58.53
CGF-20	205.71	334.49	831.77	78.04
MGF-5	205.71	397.21	831.77	17.52
MGF-10	205.71	376.31	831.77	35.04
MGF-15	205.71	355.40	831.77	52.56
MGF-20	205.71	334.49	831.77	70.08
FGF-5	205.71	397.21	831.77	14.44
FGF-10	205.71	376.31	831.77	28.88
FGF-15	205.71	355.40	831.77	43.32
FGF-20	205.71	334.49	831.77	57.76

Note: The numbers (5,10,15,20) in designation of specimen, %age replacement of sand by TGF

Table 2. Properties of TGF

TGF Type	Acronym	Passing sieve No.	Retaining sieve No.
Coarse Glass Fines	CGF	4	12
Medium Glass Fines	MGF	12	40
Fine Glass Fines	FGF	40	200

**Figure 1:** Test setup and test sample

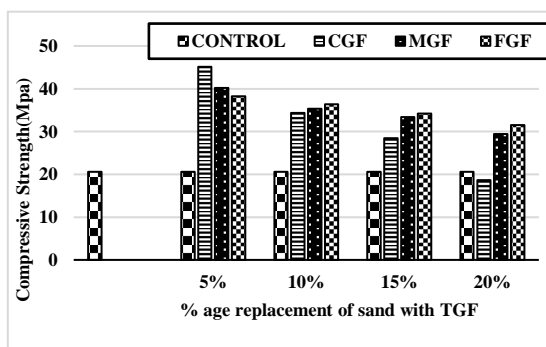
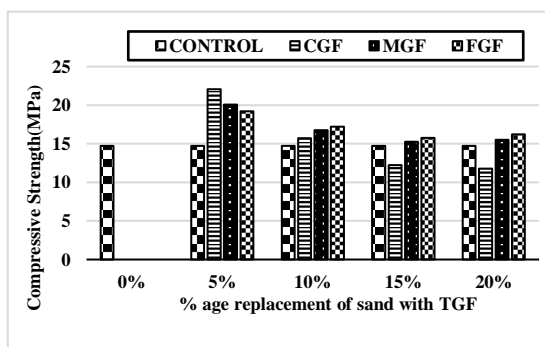
2.3. Specimen Detail & Testing Methodology

According to British Standard, 100 mm x 100 mm cubic specimens were prepared for compression test. Six specimens were prepared of each concrete mix. Three of them were tested at ambient temperature and three were tested after exposure to an elevated temperature of 790°C. Nabertherm LV 15/11 furnace was used to attain the 790°C temperature. The specimens were demolded after 24 hours of casting, cured for 28 days and were allowed to dry. Once the specimens were fully dried, half of them were one by one exposed to 790°C in a furnace at an approximate rate of 6.5°C/ temperature rise per minute. These samples were allowed to naturally cool down to room temperature before they were tested. The compression test was performed on Denison Universal Testing Machine of capacity 300Ton, figure 1. All the specimens were loaded at the rate of 5 Ton per minute up to the failure of the sample in Universal Testing Machine to get the compressive strength. The average of three tested samples has been reported in table 3. The strains were calculated from the readings of the dial gauge attached to the sample, Figure 1. Mass of each specimen was measured before and after exposing it to high temperature to find the mass loss.

3. Results and Discussion

3.1 Compressive Strength

The results of the compressive strength test carried out at ambient and elevated temperatures are presented in table 3 and figure 2a & 2b.

**Figure 2a.** Compressive strength at ambient temperature**Figure 2b.** Compressive strength at elevated temperature

It can be seen from the figure 2a & 2b that among the four different replacements of sand with TGF; 5% replacement of sand came out to be most efficient in improving the compressive strength. At the ambient temperature, CGF-5 mix delivered an increase of 119% (compared to control) in the ultimate compressive strength. In case of MGF-5 and FGF-5, this enhancement was up to 95% and 86% respectively. A similar trend was observed at the elevated temperature. Samples of CGF-5, MGF-5 and

FGF-5 mix showed a 49.9%, 16.6% and 10% enhanced ultimate compressive strength as compared to the samples of control mix (0% TGF). A decreasing trend was observed for the increased inclusion of TGF as replacement of sand. The specimens with 10%, 15% and 20% partial replacement of sand with TGF exhibited lesser enhancement in the respective ultimate compressive strengths as compared to the 5% replacement. But still the strength remained greater than control samples except for CGF-20.

This implies that although the coarser particle results in the maximum increase in compressive strength, but with the increased amount of CGF, the drop-in strength is also much more noticeable than the other two particle sizes. The reason is that the coarser TGF retain their original structure. The inherent surface compression in the structure of TGF, helps to resist much more compressive loads. On the other hand, the increased amount of CGF, being coarser, creates more voids and debonding in the concrete matrix. Such that the dominant advantage of the surface compression starts reducing. However, when the size of the particles is reduced, as the TGF structure is disintegrated and only the filling effect of the particles remains resulting in a more consolidated structure. And hence the compressive strength is increased but the effect is less pronounced for MGF and CGF concrete mixes.

Further, it can be said that use of TGF up to an optimum level results in enhanced compressive strength even at elevated temperatures. This highlights the advantage of TGF over annealed glass fines. The increase can be attributed to the improved thermal resistance, better crystalline structure, mechanical strength and surface compression, Table (1).

At elevated temperature of 790°C the moisture is dried up from the pores leaving voids, the hydration products of cement paste and C-S-H gel are considerably disintegrated. And as coarser particles have a lesser water absorption than the finer particles, CGF mixes show a lesser reduction in strength at the same replacement level compared to the MGF and FGF.

Table 3. Ultimate Compressive Strength

Mix Type	Ultimate Compressive Strength (MPa)		
	Ambient Temperature	790°C	%age Reduction
Control	20.60	14.72	29
CGF-5	45.13	22.07	51.1
CGF-10	34.35	15.72	54.2
CGF-15	28.45	12.25	56.9
CGF-20	18.64	11.77	36.9
MGF-5	40.22	20.07	50.1
MGF-10	35.32	16.77	52.5
MGF-15	33.37	15.28	54.2
MGF-20	29.39	15.50	47.3
FGF-5	38.26	19.19	49.8
FGF-10	36.38	17.21	52.7
FGF-15	34.23	15.78	53.9
FGF-20	31.51	16.21	48.6

3.2 Mass Loss

All the dried/cooled specimens were weighed before and after exposure to elevated temperature. The mass loss due to exposure to elevated temperature is reported in figure 3.

Mass loss is lesser in concrete specimens with smaller sized TGF as compared to the coarser TGF. This exactly complies with the expected behavior. Because coarser particles have more voids. And so for CGF, more porous concrete matrix is obtained as compared to the MGF and FGF mixes. The elevated temperature dries out the unreacted water and squeezes out the entrapped air. Fine particles produce denser concrete matrix with less voids in them. And lesser mass loss was witnessed.

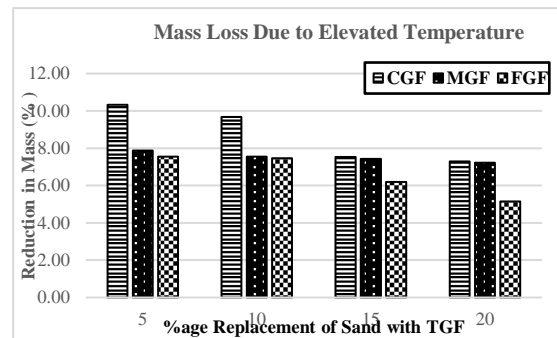


Figure 3. Mass loss due to elevated temperature

3.3 Modulus of Elasticity

Figures 4a & 4b show the effect of TGF on modulus of elasticity of concrete. At both the temperatures, the trend was similar as that of the compressive strength. The maximum improved strength was obtained for 5% replacement and coarser particles. The reason behind is that the higher MOE of TGF resulted in the higher MOE of the mix. Also, though elevated temperature caused a decrease in the MOE. But in case of concrete with TGF, the reduction was lower. Because between 600-800°C the melting and re-solidification of glass occurs. This process fills up the micro cracks and so the reduction in the MOE is lowered.

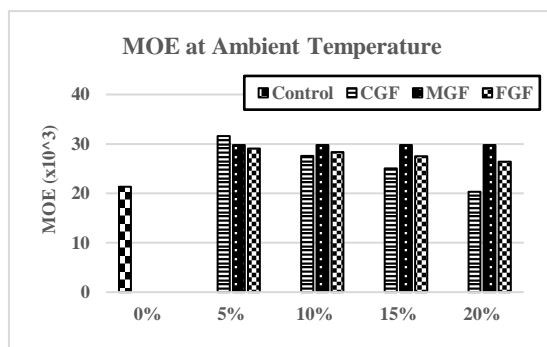


Figure 4a. MOE at ambient temperature

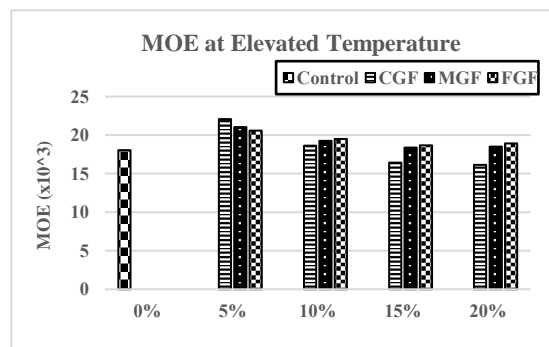


Figure 4b. MOE at elevated temperature

3.4 Mode of Failure

The samples failed by bulging and usual inclined cracks at ambient temperature. The bulging was more visible in case of CGF samples because of the weak bonding at the interface, figure 5. Spalling was pronounced in specimens after they were exposed to elevated temperature. The effect increased with the increased size and amount of TGF, figure 6. Hair like cracking was also visible in heated specimens before the application of any compressive load in figure 7. This is the sample that was exposed to heating prior to testing.



Figure 5. Bulging during Compression Test



Figure 6. Spalling compression test



Figure 7. Hair Line Cracks before Compression Test

4. Conclusion

The behavior of concrete with tempered glass was studied in the presented work. Based on the experimental investigation, following conclusions can be drawn.

- TGF can be used as an efficient sand replacement material with additional benefit of enhanced compressive strength. This will be beneficial from the solid waste management point of view as well as the exhaustion of natural resources.
- Among all the replacement percentages 5% replacement was found to be the most efficient in enhancing the compressive strength. Hence, it is the optimum dosage for the sand replacement.
- CGF-5 proves to be more efficient than MGF-5 and FGF-5 (12.2% and 17.9% respectively) in the improvement of compressive strength but at the same time the coarser particles result in greater mass loss i.e. 10.78%, 7.87% and 7.56% for CGF-5, MGF-5 and FGF-5 respectively. Therefore, it is recommended to carefully select the particle size especially when the concrete is frequently exposed to elevated temperature.
- TGF caused considerable increase in Modulus of Elasticity at ambient temperature and a lesser reduction in concrete stiffness at elevated temperature provided that the amount of TGF replacement does not exceed 10%. Therefore, it is an efficient sand replacement material especially for those structures having probability of being frequently exposed to elevated temperature and/or to fire.

5. Acknowledgements

The experimental work was conducted in Concrete Testing Laboratory of UET Lahore, Pakistan.

References

- [1] Heriyanto 2018 From waste glass to building materials – An innovative solution for waste glass. *Journal of Cleaner Production* 191:192-206.
- [2] Hogland W 2002 Remediation of an old landfill site *Environmental Science and Pollution Research* 9(S1):49-54.
- [3] Jani Y, Hogland W. 2014 Waste glass in the production of cement and concrete – A review *Journal of Environmental Chemical Engineering* 2(3):1767-1775.
- [4] Pike R, Hubbard D. Physicochemical studies of the destructive alkali-aggregate reaction in concrete. *Journal of Research of the National Bureau of Standards*. 1957;59(2):127.
- [5] Ducman V, Mladenović A, Šuput J. 2002 Lightweight aggregate based on waste glass and its alkali-silica reactivity. *Cement and Concrete Research* 32(2):223-226.
- [6] Tan K, Du H. Use of waste glass as sand in mortar: Part I – Fresh, mechanical and durability properties. *Cement and Concrete Composites*. 2013;35(1):109-117.
- [7] Shao Y, Lefort T, Moras S, Rodriguez D. Studies on concrete containing ground waste glass. *Cement and Concrete Research*. 2000;30(1):91-100.
- [8] Ismail Z, AL-Hashmi E. Recycling of waste glass as a partial replacement for fine aggregate in concrete. *Waste Management*. 2009;29(2):655-659.
- [9] Taha B, Nounu G. Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement. *Construction and Building Materials*. 2008;22(5):713-720.
- [10] Topçu İ, Canbaz M. 2004 Properties of concrete containing waste glass. *Cement and Concrete Research*. 34(2):267-274.
- [11] Takata R., Sato S., Nonaka T., Ogata H., Hattori K. 2004 Investigation on alkali-silica reaction utilizing waste glass in concrete and suppression effect by natural zeolite. *29th Conference on our world in concrete and structures*.
- [12] Corinaldesi V, Gnappi G, Moriconi G, Montenero A. Reuse of ground waste glass as aggregate for mortars. *Waste Management*. 2005;25(2):197-201.
- [13] Idir R, Cyr M, Tagnit-Hamou A. Use of fine glass as ASR inhibitor in glass aggregate mortars. *Construction and Building Materials*. 2010;24(7):1309-1312.
- [14] Nassif A. 2002 Postfiring stress-strain hysteresis of concrete subjected to various heating and cooling regimes *Fire and Materials* 26(3):103-109.
- [15] Nassif A. 2006 Postfire full stress-strain response of fire-damaged concrete *Fire and Materials* 30(5):323-332.
- [16] dos Santos CC, Rodrigues JPC 2016 Calcareous and granite aggregate concretes after fire. *J Build Eng* [Internet]. 8:231–42. Available from: <http://dx.doi.org/10.1016/j.jobe.2016.09.009>
- [17] Sideris KK. 2007 Mechanical characteristics of self-consolidating concretes exposed to elevated temperatures. *Journal of Materials of Civil Engineering ASCE* 19(8): 648–654.
- [18] Poutos K, Alani A, Walden P, Sangha C. 2008 Relative temperature changes within concrete made with recycled glass aggregate *Construction and Building Materials* 22(4):557-

- [19] To Q.D, He.Q.C, Cossavella M,Morcant K., Panait A., Yvonnet J. The tempering of glass and the failure of tempered glass plates with pin-loaded joints: Modelling and simulation.
- [20] Reynolds S. 2015 The Benefits of Glass Tempering and Strengthening. Swift Glass. *Archived from the original on 2017-12-14. Retrieved 2017-12-13*