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Research Paper

Investigation on the glass fiber reinforced geopolymer concrete made of M-sand

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A B S T R A C T

This research work investigates the effect of utilization of glass fibers in geopolymer concrete made of Manufactured sand (M-sand) over its fresh and hardened properties and understand the influence of fibers over reducing the brittleness of the matrix. Geopolymer concrete synthesized in this study is Fly ash- GGBS blend type with optimum molarity cured under heat condition. Fresh property of the fiber reinforced geopolymer concrete was accessed using compaction factor test. Mechanical properties such as compressive strength, split tensile strength, flexural strength, impact strength, ductility factor, first crack toughness, failure crack toughness and ultimate failure toughness were measured and their results are analyzed and discussed in this work. Later, SEM analysis was carried out over the optimum fiber reinforced geopolymer concrete samples to understand the bonding and the effectiveness of the fiber reinforced geopolymer concrete made of M-sand. Incorporation of glass fiber s proved to be more beneficial and yielded a hybrid concrete with increased strength properties. The performance of fiber s could be measured precisely in increasing the ductility and impact strength. Scanning Electron Microscopy (SEM) analysis showed better bonding between the fiber s and the matrix. This study unleashes an enormous scope for the practical implication of fiber reinforced geopolymer concrete as a building material.

1 Introduction

Geopolymer concrete has gained attraction now days due to its remarkable capability of being able to replace cement concrete in most of its vicinity. This has been made possible due to the proliferating awareness about the ill effects of cement production leading to the ozone layer depletion. Geopolymer concrete is typically formed as a result of the polymerization reaction between the aluminosilicate source materials in the presence of an alkaline medium [1]. These aluminosilicate materials can be either natural like Metakaolin or industrial by-product like Fly ash and Ground Granulated Blast Furnace Slag (GGBS) [2]. Few works by researchers report that Geopolymer concrete exhibit fair compressive strength, reduced shrinkage, better acid resistance and durability than the conventional cement concrete and its properties extremely depends on the type of aluminosilicate source material, curing condition and concentration of alkaline solution [3-7]. Duxan et.al.

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reports that GGBS based geopolymer attained strength earlier and processed greater acid resistance than the fly ash based geopolymer concrete whereas the latter conceded better durability properties than the former [8]. In spite of the exemplary characteristics of geopolymer concrete, the frailty lies in the brittle nature of the geopolymer concrete observed through the investigation of fracture planes [9]. The encumbrance for the practical applicability of Geopolymer concrete is its brittle demeanour [10]. Hence efforts can be focused towards enhancing the split tensile, flexural strength and ductility of the Geopolymer concrete to make it an absolute replacement for the cement concrete.

Utilization of fibers inside the concrete to increase its engineering properties has attracted rampant attention worldwide. Fibers increase the characteristic strength, split tensile strength, flexural strength, post cracking behaviour and strain hardening behaviour [11, 12]. Fracture toughness can be mitigated by the addition of fibers in the concrete [13]. Among the available fibers, glass fiber is found to have good bond with concrete and enhance the engineering properties of concrete [14]. Hence glass fibers can be utilized in the Geopolymer concrete to reduce its brittleness and increase the other engineering properties.

Demand for river sand is at its peak owing to the substantial developments made in the construction industry, making river sand costlier. Moreover mining of river sand leads to serious environmental issues affecting the ecosystem drastically in series ways like affecting the ground water table, aquatic life, local livelihood [15-19]. Pond ash, off shore sand, quarry dust can be proposed as a replacement for river sand. Manufactured sand was found to be advantageous than the other alternatives due to its easy availability and good bonding inside the matrix [18-20]. M-sand has been proved to behave well inside the geopolymer at elevated temperatures under all types of curing [21]. Hence it can be suggested to use M-sand as a replacement of river sand in the fibre reinforced geopolymer concrete.

Apart from the many research works which focused on either Geopolymer concrete using M-sand or fiber reinforced concrete, this research work focuses on the effect of utilization of glass fibers in Geopolymer concrete made of M-sand synthesized with optimum molarity and optimum Fly ash– GGBS content under heat curing. In order to enhance the split tensile strength, flexural strength, impact strength and achieve further improvement in engineering properties, it is proposed to incorporate glass fibers of high tensile strength in Geopolymer concrete. Further an approach has been made in this research by utilizing Manufactured sand (M-sand) instead of river sand.

This research work delineates the various material properties, methodology involved in measuring the fresh and hardened properties of fiber reinforced geopolymer concrete such as workability, compressive strength, split tensile strength, flexural strength, and impact strength. Measuring the ductility of the material will unleash the real effect of fibers in the Geopolymer concrete made of M-sand. A scrupulous discussion part is included in this paper analyzing and addressing the effects of incorporation of glass fibers in matrix of Geopolymer concrete made of M-sand. This discussion part is supported by the observation from the similar research works carried out by other researchers. Later Scanning Electron Microscopy (SEM) analysis was performed over the optimum specimens of fibre reinforced Geopolymer concrete made of M-sand to analyze its microstructure. Finally conclusions were interpreted from the inference of the various tests by analyzing the observations of the experimental data and scientifically declared facts.

2 Materials

Geopolymer concrete used in this study is the fly ash - GGBS blend Geopolymer concrete with optimum proportions as determined from the previous research works held by the author. Fibre reinforced Geopolymer concrete in this study was made from fly ash, GGBS, M-sand, coarse aggregate, glass fiber and fly ash -class F which has low calcium content. Specific gravity of the fly ash is determined to be 2.3. Specific Gravity of GGBS is found to be 2.9. M-sand used in this study was obtained as the by product from the quarry industry. Fineness modulus of M-sand is determined to be 2.36. M-sand falls under zone-3. Specific gravity of M-sand is found to be 2.9. The bulk density of the M-sand is found to be 1702 Kg/m3. Coarse aggregates used in this work are of size 20mm. Fineness modulus of coarse aggregate is found to be 6.10. Specific gravity of the coarse aggregate is found to be 2.7. Bulk density of the coarse aggregate is determined to be 1456 kg/m3. Glass fibers used in this work are of diameter 0.1 mm and length 6 mm. Aspect ratio of glass fiber used in this study is 60. A mixture of sodium hydroxide and sodium silicate solution is used as the alkaline activator solution. Sodium hydroxide solution of 13Molarity (M) is used in this work. Sodium hydroxide solution and sodium silicate solution is mixed one day prior to casting and kept ready in the beaker. Ratio of mixture of sodium hydroxide and sodium silicate solution is kept as 1:2.5The mix design is based on B.V. Rangan mix design [22].

3 Experimental Program

The experimental work aims at investigating the effect of incorporation of glass fibers in the Geopolymer concrete made of M-sand. The glass fibers are added in different dosages which are (0.25%. 0.5%, 0.75%, 1% and 1.25% to the Geopolymer concrete made of M-sand. The fresh properties and hardened properties of the Geopolymer concrete such as Workability, Compressive strength, Split tensile strength, Flexural Strength, Impact strength, first crack toughness, ultimate fracture toughness, post peak toughness and ductility factor were determined to investigate the effect of incorporation of glass fibers and determine the optimum proportions of fiber utilization. Microstructural study was conducted through SEM analysis to understand the bonding of fibers and M-sand with the alumino-silicate source materials.

Geopolymer concrete in this study was synthesized with optimum parameters ascertained from the previous works. 80 percent fly ash and 20 percent GGBS were used as alumino-silicate source material. Quantities of various materials used in this work are tabulated in Table 1. Molarity of the sodium hydroxide solution to be used in adjunction with the sodium silicate solution was fixed as 13M. Geopolymer concrete specimens were made by mixing the fly ash, GGBS and M-sand in a mixer followed by the addition of coarse aggregate. Then, the fibers and alkaline solution were added to the mixer and mixed for 5 minutes. There is no standard method available for mix design of Geopolymer concrete; hence the various ingredients of Geopolymer concrete were proportioned by the mix design proposed by the B.V. Rangan [22]. The geopolymer concrete were casted in cubical specimens of size 100 mm, cylindrical specimens of diameter 100 mm and length 200mm and prismatic specimens of 500 x 100 x 100 mm dimensions. Cylindrical specimens of diameter 400 mm and 40 mm thickness were also casted for performing the impact strength test. The Geopolymer concrete moulds were subjected to heat curing in the hot air oven at 150 degree Celsius for 6 hours. Specimen details of the Geopolymer concrete made of M-sand casted and different fibre dosages for various tests are tabulated in Table 1.

Table 1. Specimen details for various fiber dosage

Specimen Name	Fiber dosage percentage (%)	Fly Ash (Kg/m³)	GGBS (Kg/m³)	Fine Aggregate (Kg/m³)	Coarse Aggregate (Kg/m³)	NaOH (Kg/m³)	Na_2Sio_3 (Kg/m³)	Glass Fiber (Kg/m³)
GPC	0	440	110	505.97	956.74	95.85	239.14	0
FRGPCA	0.25	440	110	505.97	956.74	95.85	239.14	6.25
FRGPCB	0.5	440	110	505.97	956.74	95.85	239.14	12.5
FRGPCC	0.75	440	110	505.97	956.74	95.85	239.14	18.75
FRGPCD	1	440	110	505.97	956.74	95.85	239.14	25
FRGPCE	1.25	440	110	505.97	956.74	95.85	239.14	31.25

4 Results and Discussion

4.1 Workability

The effect of augmentation of glass fibers at the workability in the Geopolymer concrete made of M-sand was determined via using the compaction factor test as per IS-1199. Table 2 shows the compaction factor values of Geopolymer concrete without fiber and with glass fibers for the various dosages.

From figure 1, it is explicit that the workability of the Geopolymer concrete decreases with the increase in the fiber dosage. This was observed during the mixing as well in terms of easy of mixing. This is due to the reason that as the fiber dosage increases, the stiffness of the matrix increases, which increases the cohesiveness of the matrix. When the fiber dosage increases more than 1 percent agglomeration of fibers takes place during mixing ie) excess amount of fiber stick together and hinder proper mixing. Alomyri reported that viscosity of the matrix increases with the higher glass fiber content [23].Workability of the Geopolymer concrete reinforced with other fibers such as poly vinyl alcohol, steel, polypropylene fibers were also found to decrease with the increase in fiber content in the works conducted by other researchers [24-27]. It can also be inferred that the use of M-sand as the filler material does not play any odd role in the workability of the glass fiber reinforced Geopolymer concrete.

Table 2 Compaction factor test

Specimen Name	Compaction factor
GPC	0.89
FRGPCA	0.87
FRGPCB	0.85
FRGPCC	0.84
FRGPCD	0.82
FRGPCE	0.8

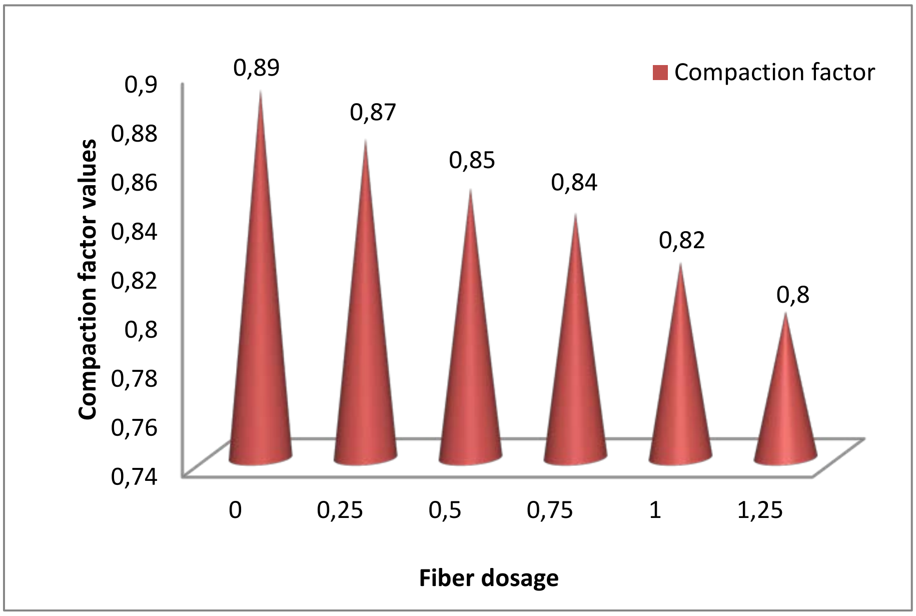


Fig. 1- Compaction factor test results

4.2 Compressive strength

The effect of glass fiber dosage at the characteristic strength of the Geopolymer concrete specimens made of M-sand was assessed at 7 days and 28 days using the compression testing machine of capacity 2000KN as per IS 516-1959. The average compressive strength values along with the standard deviation (SD) values are shown in Table 3.

Table 3. Compressive Strength and Split tensile strength test results

Specimen Name	Compressive strength 7 days (MPa)		Compressive strength 28 days (MPa)		Split tensile strength 7 days (MPa)		Split tensile strength 28 days (MPa)	
	Average	SD	Average	SD	Average	SD	Average	SD
GPC	24.50	1.8	41.30	2.2	2.4	0.15	3.8	0.21
FRGPCA	26.45	1.7	44.60	2.1	2.5	0.18	4.0	0.25
FRGPCB	27.12	1.9	45.7	2.6	2.8	0.21	4.4	0.23
FRGPCC	27.3	2.2	47.8	2.5	2.9	0.2	4.7	0.18
FRGPCD	30.1	2.1	50.85	2.4	3.3	0.22	5.2	0.20
FRGPCE	28.7	2.3	48.2	2.6	2.8	0.18	4.8	0.22

The variation of the compressive strength for the different dosages of glass fiber can be well understood from Figure 2.

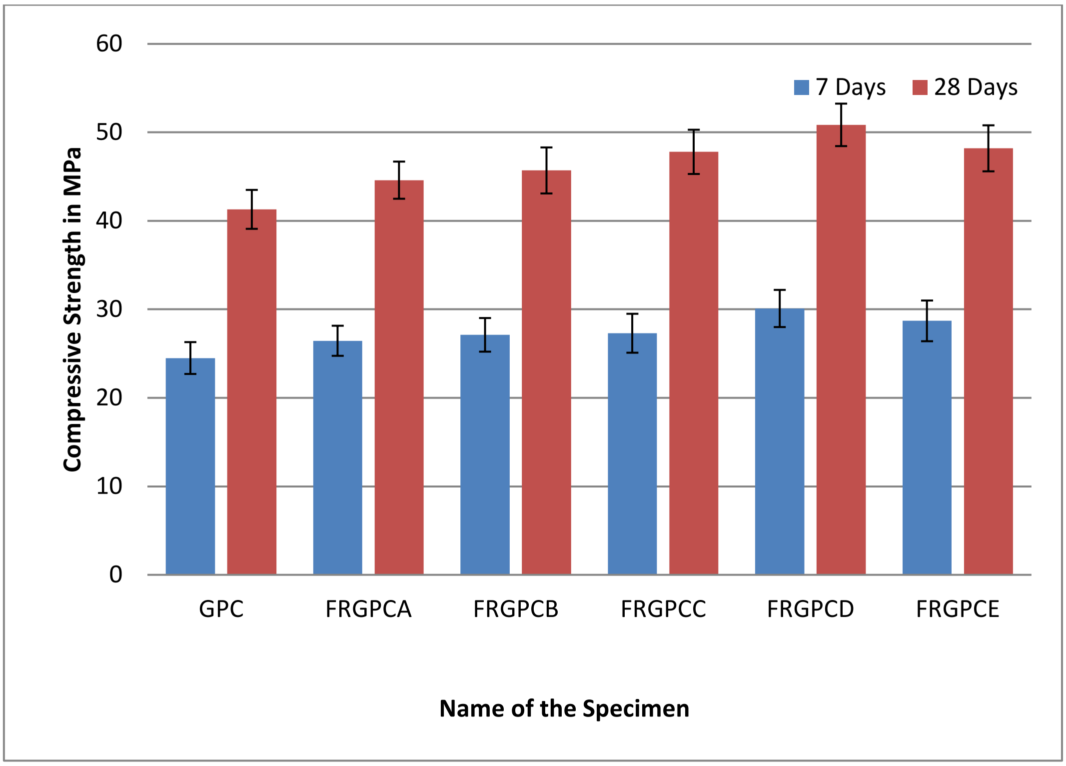


Fig. 2- Compressive strength test results

Figure 2 clearly shows that the compressive strength of the Geopolymer concrete made of M-sand increases with the increase in glass fiber dosage till one percent and then it decreases. The decrease in strength of the specimen beyond one percent dosage can be addressed due to the fact that the workability of the FRGPCE specimen is 0.80 leading to a stiffer mix. The stiffer mix when subjected to heat curing becomes dry and yields lesser characteristic strength. The specimen FRGPCD exhibits the optimum compressive strength with one percent of glass fiber. It is observed from figure.2 that about sixty percent of the 28days could be attained at seven days through heat curing by the fly ash - GGBS based Geopolymer concrete made of M-sand. Bhalchandra et.al, Balamurugan et.al, Sathanandamet.al [28-30] reported that addition of glass fibers increases the compressive strength in the fly ash based Geopolymer concrete under heat curing. The incorporation of glass powder in Geopolymer concrete also increases the characteristic strength [31]. It is inferred that the addition of glass fibers in Geopolymer concrete made of M-sand increases the compressive strength about 23% in the optimum dosage.

4.3 Split tensile strength

The effect of augmentation of glass fiber at the split tensile strength of the Geopolymer concrete made of M-sand was investigated by testing the cylindrical specimens in the Universal Testing Machine of capacity 2000 KN as per IS: 5816-1999. The average split tensile strength values and the standard deviation values are shown in Table 3. The variation of the split tensile strength is well depicted in Figure 3.

Figure 3 clearly states that the split tensile strength of the Geopolymer concrete using M-sand increases with increase in the glass fiber dosage till one percent and then it decreases. There was a significant increase in split tensile strength from 3.8MPa to 5.2MPa by the augmentation of glass fibers. It was evident that increase in split tensile strength of 37% could be achieved by the optimum addition of glass fiber which was 1%. Sachithanandam and Meikandaan [32] reported that augmentation of 0.03% glass fiber in Geopolymer paste increases the split tensile strength. Experimental works carried out by Vijai et.al [33] reported that there is a slight increase in the split tensile strength for the OPC (Ordinary Portland Cement) - Fly ash blend Geopolymer concrete reinforced with 0.03 % of glass fiber by the volume of concrete. The decrease in split tensile strength after the optimum percent could be attributed due to the reason that at high fiber volume dosage, the bond between the fiber and the matrix becomes weak.

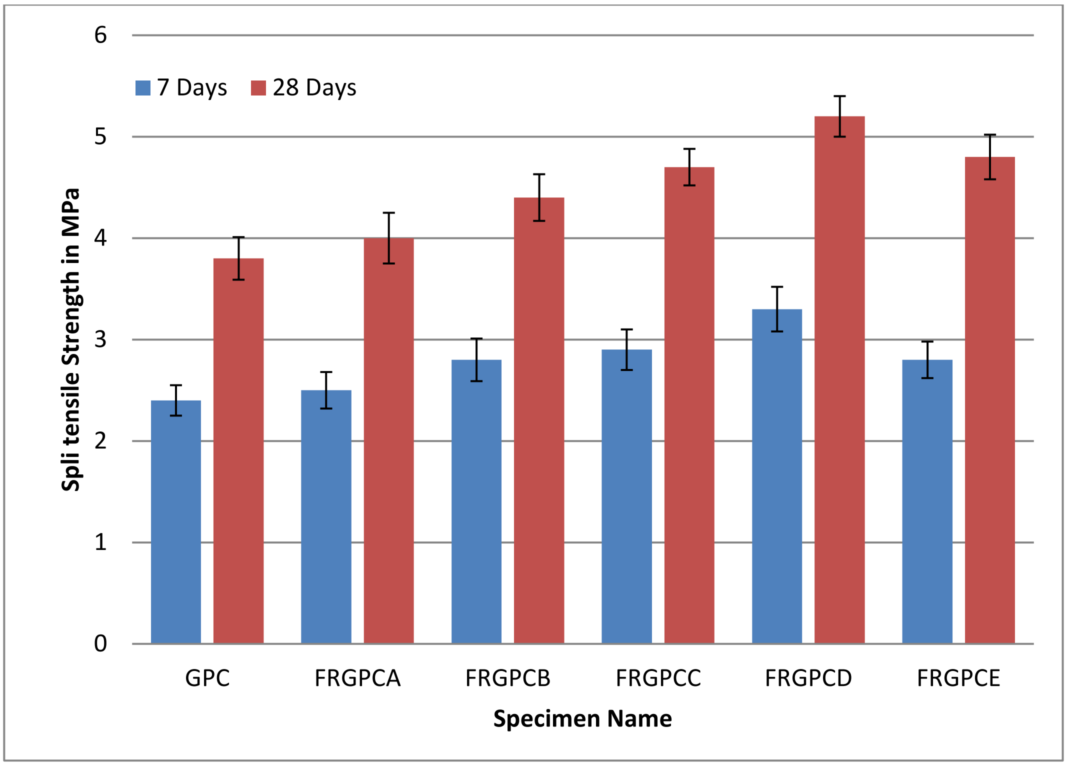


Fig. 3- Split tensile strength test results

4.4 Flexural Strength

Prism specimens of standard dimension were tested using Universal Testing Machine of 2000 KN as per IS:516- 1959 and the results are shown in Table 4 and Figure 4. The incorporation of glass fibers has significant effect on the flexural strength the Geopolymer concrete made of M-sand.

Table 4. Flexural strength test

Specimen Name	Flexural Strength 28 days (MPa)	
	Average	SD
GPC	5.3	0.31
FRGPCA	5.5	0.28
FRGPCB	6.1	0.33
FRGPCC	6.8	0.35
FRGPCD	7.5	0.34
FRGPCE	6.9	0.37

From Figure 4, it is evident that the flexure strength of the Geopolymer concrete specimen made of M-sand increases with the increase in glass fiber content until one percent and then it decreases. The increase in flexural strength of 42% was observed in the optimum percent of fiber utilization. Puertas et.al [34] claimed that the incorporation of glass fibers of 1.1% by weight of binder increases the flexural strength of the GGBS based Geopolymer mortar. Studies conducted by other researchers on fly ash based Geopolymer concrete were also found to be in accordance with the observed results [28-30]. Significant improvement was witnessed in flexural strength when compared to compressive and split tensile strengths of the Geopolymer concrete specimen made of M-sand.

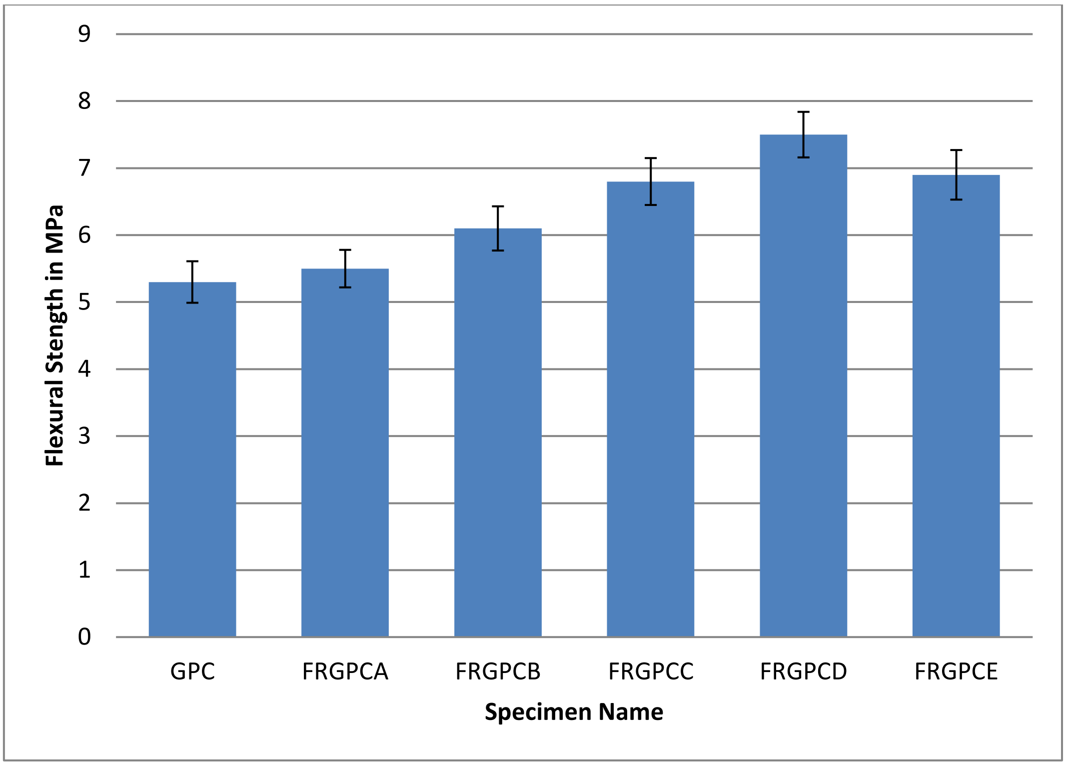


Fig. 4- Flexural strength test results

4.5 Ductility Factor

Ductility factor is the measure of the flexibility of the Geopolymer concrete specimen. The initial yielding deflection and the ultimate deflection of the Geopolymer concrete specimen made of M-sand from the flexural strength test through the Universal Testing Machine s per IS:516- 1959 are shown in Table5.

Table 5. Ductility Factor values

Specimen Name	Ultimate deflection (mm)	Initial yielding deflection (mm)	Ductility factor
GPC	3.62	2.5	1.41
FRGPCA	3.95	2.71	1.45
FRGPCB	4.33	2.95	1.46
FRGPCC	4.71	3.19	1.47
FRGPCD	5.15	3.49	1.47
FRGPCE	4.43	3.10	1.43

The variation of the ductility factor with reference to the ultimate deflection is shown in Figure 5.

From Figure 5, it can be observed that as the glass fiber dosage increases there is a significant increase in the ultimate deflection value compared to the initial yielding deflection and hence there has been a substantial increase in the ductility. It is evident that the addition of glass fibers increases the ultimate stress of the material. Novais et.al [35] in his research work claimed that addition of glass fibers of about 2% increased the ductility in the Metakaolin based Geopolymer concrete. It is found that glass fibre can serve vital role of reducing the brittleness of the Geopolymer concrete specimen made of M-sand.

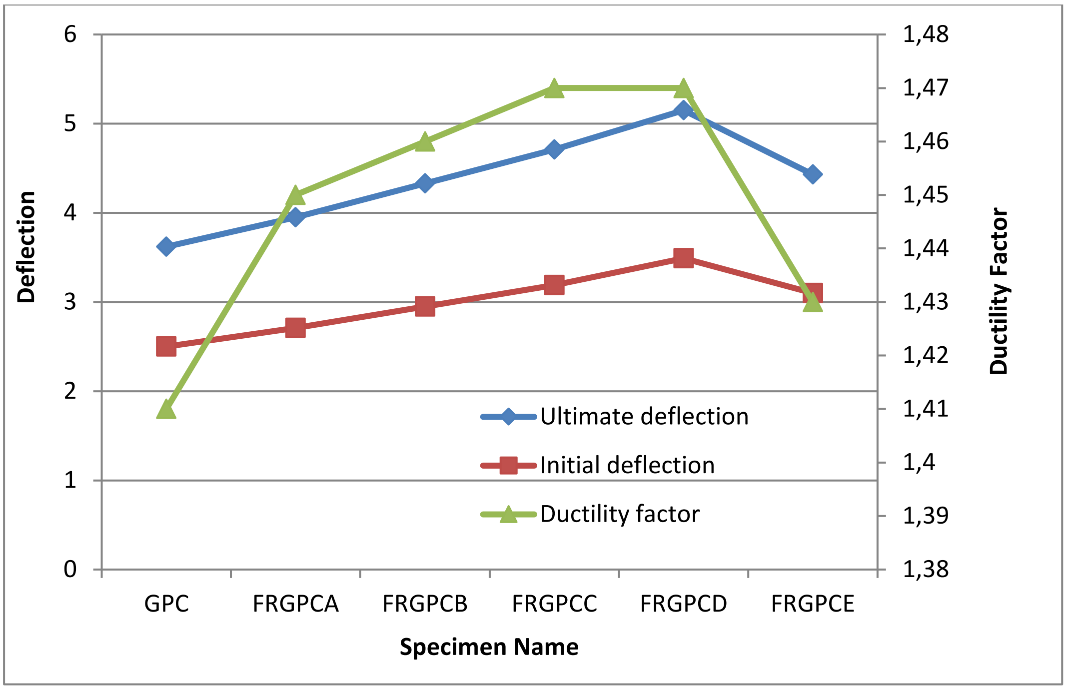


Figure5. Variation of Ductility factor

4.6 Impact Strength

Cylindrical specimens of diameter 400mm and thickness 40mm were subjected to impact through free fall of 4.5kg load at a height of 0.5m as per ACI Committee 544. Impact strength was calculated using the following relation,

$$\text{Impact Strength} = 9.81 \text{ X Load X Height X Number of Blows} \quad (1)$$

$$\text{First crack toughness} = 9.81 \text{ X Load X Height X Number of Blows to cause first crack (N1)} \quad (2)$$

$$\text{Ultimate Failure toughness} = 9.81 \text{ X Load X Height X Number of Blows to cause final crack (N2)} \quad (3)$$

$$\text{Post Peak toughness} = 9.81 \text{ X Load X Height X (N2} - \text{N1)} \quad (4)$$

The performance of the glass fibers in the Geopolymer concrete specimen made of M-sand is more significant in the impact test. The impact strength was calculated for different fiber dosages and is shown in Table 6.

Table 6. Impact Strength results

Specimen Name	Initial Crack (No. of Blows)	Ultimate failure (No. of Blows)	First Crack Toughness (Nm)	Ultimate Failure Toughness (Nm)	Post Peak Toughness (Nm)
GPC	9	9	209.68875	209.68875	0
FRGPCA	26	34	605.7675	792.1575	186.39
FRGPCB	32	51	745.56	1188.23625	442.6763
FRGPCC	52	74	1211.535	1724.1075	512.5725
FRGPCD	78	126	1817.3025	2935.6425	1118.34
FRGPCE	45	56	1048.44375	1304.73	256.2863

The variation of the toughness values for the different dosages of glass fiber is shown in Figure 6 and Figure 7.

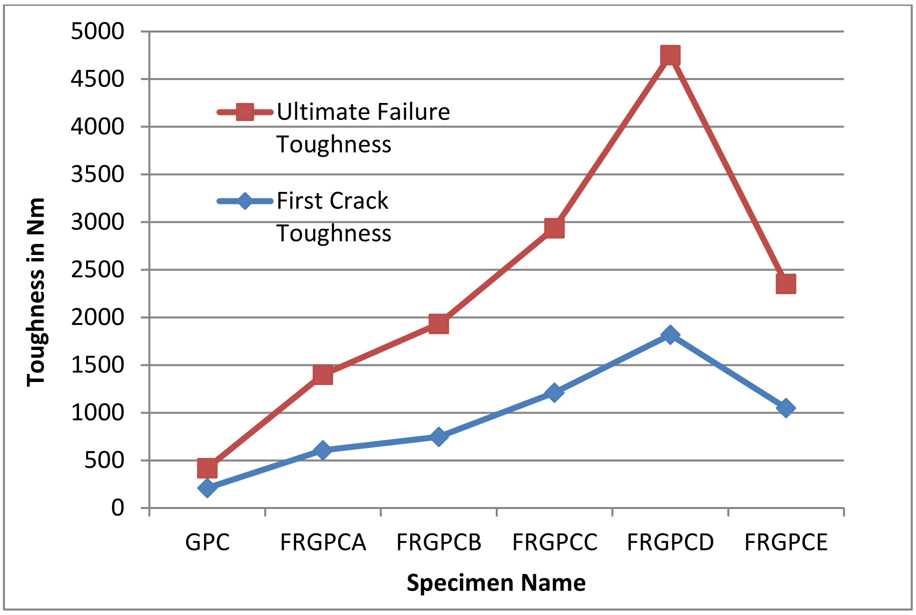


Fig. 6- Variation of Toughness values

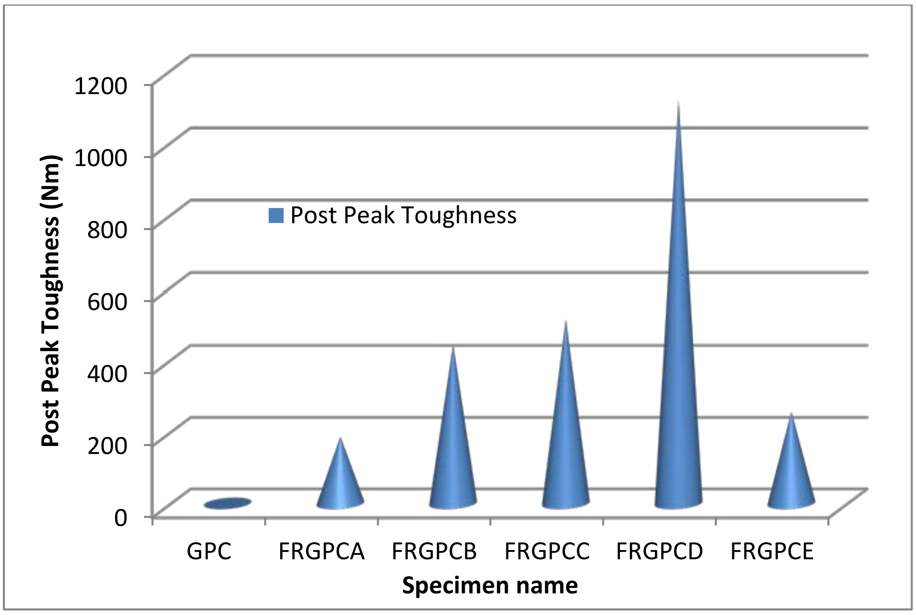


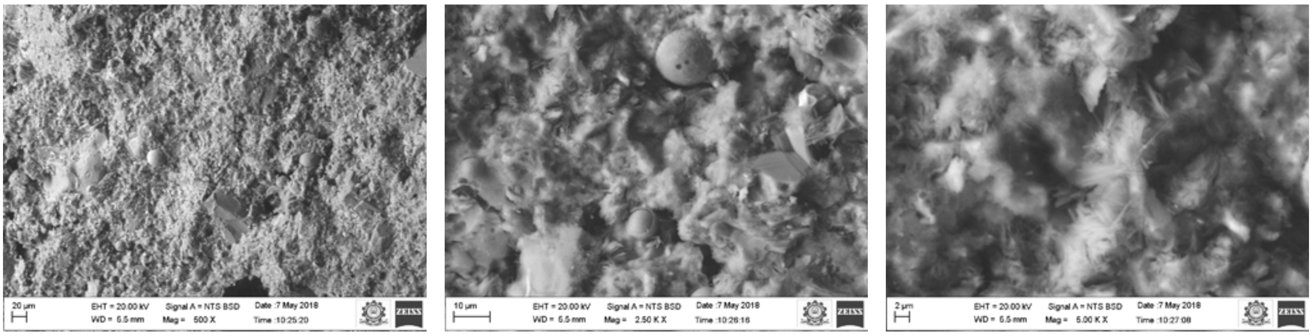
Fig. 7- Variation of Post Peak Toughness values

From Table 6, it is clear that number of blows required to initiate first crack and ultimate failure increases with the increase in the fiber content till one percent.

Figure 6 and Figure 7 shows that Geopolymer concrete specimens without fiber content suffer first crack and ultimate failure at the same number of blows indicating the more brittle nature of the specimen and poor energy absorbing capacity. As the fiber content increases, the energy absorption capacity increases. Post Peak Toughness of the Geopolymer concrete made of sand also increases with the fiber dosage. After attaining the optimum fiber content, the impact strength reduces due to the agglomeration of fibers during the mixing time. Beyond 1% the volume of the fiber is much excess that it results in a poor compaction to yield a concrete with less structural integrity. The impact test portrays the real performance of the fibers in the Geopolymer concrete as the increase in the impact strength is lot more than the other engineering properties like compressive strength, split tensile strength and flexural strength.

4.7 Microstructural Study

Scanning Electron Microscopy Analysis was performed at FRGPCD specimen with optimum glass fiber content to understand the microstructure of Geopolymer concrete made of M-sand and to analyze the bonding of fibers and the matrix. Figure 8 shows the various magnification levels of the image of 0.5mm cut piece of sample.



a) 20μm b) 10μm c) 2μm

Fig. 8- SEM Analysis of FRGPCD Sample

From Figure 8, it is evident that the fiber orientation is uniform and the fibers are well dispersed in the matrix with good bonding. There is no trace of un-reacted substance on the surface of the material making explicit that fly ash and GGBS has well reacted with the M-sand and the glass fiber. This can be observed in Figure 8 c). This unleashes a lot of scope for the utilization of fibers and M-sand in the Geopolymer concrete.

5 Conclusion

Fiber Geopolymer concrete have been synthesized using M-sand with various proportions of glass fiber and investigated for fresh and mechanical properties to understand the effect of fiber addition. Further SEM analysis was also carried out to understand the bonding of fibers and M-sand with the fly ash and GGBS in the presence of alkaline medium.

- Workability of the Geopolymer concrete was found to decrease with the augmentation of fibers in the matrix.
- Obtained results suggest that incorporation of 1 percent of glass fiber in Geopolymer concrete using M-sand was found to be more beneficial and optimum in increasing the engineering properties of the Geopolymer concrete such as compressive strength about 23%, split tensile strength about 37%, flexural strength about 42% and impact strength more than 100%.
- Incorporation of glass fibers further tends to increase the ultimate deflection of the material leading to the improvement of ductility of the material.
- Reports from the Microstructural studies indicate that there is good bond between the fiber and the matrix.
- Utilization of M-sand in the fibre reinforced Geopolymer concrete proved to be substantially beneficial without posing any defects to the structural integrity of fiber reinforced geopolymer concrete. This research work gives a free rein to the utilization of glass fibers and M-sand in the vicinity of Geopolymer concrete and fibre reinforced concrete.

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REFERENCES

[1]- J. Davidovits, Properties of geopolymer cements. In: Proceedings of First International Conference on Alkaline Cements and Concretes. Scientific Research Institute on Binders and Materials, Kiev State Technical University, Ukraine, 1994, pp. 131–149.

[2]- B. Singh, G. Ishwarya, M. Gupta, S.K. Bhattacharyya, Geopolymer concrete: a review of some recent developments. Constr. Build. Mater. 85 (2015) 78–90. doi:10.1016/j.conbuildmat.2015.03.036

[3]- P. Zhang, Y. Zheng, K. Wang, J. Zhang, A review on properties of fresh and hardened geopolymer mortar. Compos. Part B-Eng. 152 (18) (2018) 79-95. doi:10.1016/j.compositesb.2018.06.031.

[4]- A. Bhutta, M. Farooq, C. Zanotti, N. Banthia, Pull-out behavior of different fiber s in geopolymer mortars: effects of alkaline solution concentration and curing. Mater. Struct. 50 (2017) 80. doi:10.1617/s11527-016-0889-2

[5]- K.T. Nguyen, T.A. Le, J. Lee, D. Lee, K. Lee, Investigation on properties of geopolymer mortar using preheated materials and thermogenetic admixture. Constr. Build. Mater. 130 (2017) 146-155. doi:10.1016/j.conbuildmat.2016.10.110

[6]- A. Chithambar Ganesh, M. Muthukannan, A Review of Recent Developments In Geopolymer Concrete. Int. J. Eng. Technol. 7 (4-5) (2018) 696-699. doi:10.14419/ijet.v7i4.5.25061

[7]- K.H Mo, U.J. Alengaram, M.Z. Jumaat, Structural performance of reinforced geopolymer concrete members: A review. Constr. Build. Mater. 120 (2016) 251–264. doi:10.1016/j.conbuildmat.2016.05.088

[8]- P. Duxson, A. Fernández-Jiménez, J.L. Provis, G.C. Lukey, A. Palomo, J.S.J. Van Deventer, Geopolymer technology: the current state of the art. J. Mater. Sci. 42 (9) (2007) 2917–2933. doi:10.1007/s10853-006-0637-z

[9]- Z. Pan, J.G. Sanjayan, B.V. Rangan, Fracture properties of geopolymer paste and concrete. Magazine of Concrete Research. 63(10) (2011) 763–771. doi:10.1680/macr .2011.63.10.763

[10]- P. Nath, P.K. Sarker, Fracture Properties of Geopolymer Concrete Cured in Ambient Temperature. In: Proceedings of The Seventh International Structural Engineering and Construction Conference, ISEC-7, Manoa, Honolulu: University of Hawaii, Jun 18-23 2013, pp. 1061-1066. doi:10.3850/978-981-07-5354-2_M-53-430

[11]- K. Korniejenko, Er. Czek, E. Pytlak, M. Adamski, Mechanical properties of geopolymer composites reinforced with natural fibers. Procedia Eng. 151 (2016) 388 – 393. doi:10.1016/j.proeng.2016.07.395

[12]- S.F.U. Ahmed, H. Mihashi, Strain hardening behaviour of lightweight hybrid polyvinyl alcohol (PVA) fiber reinforced cement composites. Mater. Struct. 44 (6) (2011) 1179-1191. doi:10.1617/s11527-010-9691-8

[13]- S.A. Bernal, J. Bejarano, C. Garzon, R.M. de Gutierrez, S. Delvasto, E.D. Rodriguez, Performance of refractory aluminosilicate particle/fiber reinforced geopolymer composites. Compos. Part B-Eng. 43(4) (2012) 1919–1928. doi:10.1016/j.compositesb.2012.02.027

[14]- K. Korniejenko, J. Mikula, M. Lach, Characterization of mechanical properties of short glass fiber reinforced geopolymer composites. In: Proceedings of the 10th International Conference on Composite Science and Technology, Lisboa, Portugal, 2–4 September, 2015.

[15]- B.N.A. Aryee, Ghana's mining sector: its contribution to the national economy. Resour. Policy 27(2) (2001) 61–75. doi:10.1016/S0301-4207(00)00042-8

[16]- S. Sreebha, D. Padmalal, Environmental impact assessment of sand mining from the small catchment rivers in the southwestern coast of India: A case study. Environ. Manage. 47(1) (2011) 130–140. doi:10.1007/s00267-010-9571-6.

[17]- S. Sreebha, D. Padmalal, Environmental impact of sand mining. a case study in the river catchments of vembanad lake southwest India. J. Earth Sci. 3(1) (2008) 41-54. doi:10.1007/s00254-007-0870-z

[18]- M.A. Ashraf, M.J. Maah, I. Yusoff, A. Wajid, K. Mahmood, Sand mining effects, causes and concerns. A case study from Bestari Jaya, Selangor, Peninsular Malaysia. Sci. Res. Essays 6(6) (2011) 1216–1231. doi:10.5897/SRE10.690

[19]- S. Khan, A. Sugie, Sand mining and its social impacts on local society in Rural Bangladesh. A case study of a village in Tangail District. J. Urban Region. Stud. Contemp. India 2(1) (2015) 1–11.

[20]- Radhakrishna, K.P. Kumar, K. Venugopal, V. Sasalatti, Characteristics of Alternative building materials. In: Proceedings of the International Conference on Food Nutrition and Civil Engineering, ICFNCE’2015, Dubai, UAE, March 14-15, 2015. doi:10.15242/IAE.IAE0315405

[21]- A.C. Ganesh, M. Muthukannan, M. Rajeswaran, T.U. Shankar, M. Selvam, Comparative Study On The behaviour Of Geopolymer Concrete Using M-Sand and conventional concrete exposed to elevated temperature. Int. J. Civil Eng. Technol. 9(11) (2018) 981-989.

[22]- R. Anuradha, V. Sreevidya, R. Venkatasubramani, B.V. Rangan, Modified Guidelines For Geopolymer Concrete Mix Design Using Indian Standard. Asian J. Civil Eng. 13(3) (2012) 353-364.

[23]- T. Alomayri, Effect of glass micro fibre addition on the mechanical performances of fly ash-based geopolymer composites. J. Asian Ceram. Soc. 5(3) (2017) 334-340. doi:10.1016/j.jascer.2017.06.007

[24]- S.F.U. Ahmed, H. Mihashi, Strain hardening behavior of lightweight hybrid polyvinyl alcohol (PVA) fiber reinforced cement composites. Mater. Struct. 44(6) (2011) 1179-1191. doi:10.1617/s11527-010-9691-8

[25]- B. Nematollahi, J. Sanjayan, F.U.A. Shaikh, Tensile Strain Hardening Behavior of PVA Fiber -Reinforced Engineered Geopolymer Composite. J. Mater. Civil Eng. 27(10) (2015) 04015001-1- 04015001-12. doi:10.1061/(ASCE)MT.1943-5533.0001242.

[26]- Y.E.S. Antony, Experimental Investigation on Replacement of GGBS for Fly Ash in Steel Fibre Reinforced Geopolymer Concrete. Int. J. Appl. Civil Environ. Eng. 2(3) (2016) 14-18.

[27]- Z. Bayasi, J. Zeng, Properties of Polypropylene Fiber Reinforced Concrete. ACI Mater. J. 90(6) (1993) 605-610. doi:10.14359/4439

[28]- S.A. Bhalchandra, A.Y. Bhosle, Properties of Glass Fibre Reinforced Geopolymer Concrete. Int. J. Modern Eng. Res. 3(4) (2017) 2007-2010.

[29]- R. Balamurugan, R. Balachandran, S. Kalaiyarasi, Experimental investigation of glass fibre reinforced geopolymer concrete. Eng. Sci. Technol. 7(2) (2017) 15 – 19.

[30]- T. Sathanandam, P.O. Awoyera, V. Vijayan, K. Sathishkumar, Low carbon building: experimental insight on the use of fly ash and glass fibre for making geopolymer concrete. Sust. Environ. Res. 27(3) (2017) 146 – 153. doi:10.1016/j.serj.2017.03.005

[31]- H. Sethi, P.P. Bansal, R. Sharma, Effect of Addition of GGBS and Glass Powder on the Properties of Geopolymer Concrete. Iran. J. Sci. Technol. Trans. Civil Eng. 43 (2019) 607-617. doi:10.1007/s40996-018-0202-4.

[32]- P. Sachithanandam, T.P. Meikandaan, Properties and strength of glass fibre reinforced geopolymer concrete. Int. J. Innov. Res. Sci. Eng. Technol. 4(6) (2015) 4409 – 4416. doi:10.15680/IJIRSET.2015.0406219

[33]- K. Vijai, R. Kumutha, B.G.Vishnuram, Properties Of Glass Fibre Reinforced Geopolymer Concrete Composites. Asian J. Civil Eng. 13(4) (2012) 511-520.

[34]- F. Puertas, A. Gil-Maroto, M. Palacios, Alkali activated slag mortars reinforced with glass fibre. Performance and properties. Mater. Constr. 56(283) (2006) 79 – 90. doi:10.3989/mc.2006.v56.i283.10

[35]- R.M. Novais, J. Carvalheiras, M.P. Seabra, R.C. Pullar, J.A. Labrincha, Effective mechanical reinforcement of inorganic polymers using glass fibre waste. J Clean. Prod. 166 (2017) 343–349. doi:10.1016/j.jclepro.2017.07.242