Journal of Mines, Metals and Fuels, 71(7): 984-989; 2023. DOI: 10.18311/jmmf/2023/34783

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

Mechanical Properties of Steel and Polypropylene Fiber Reinforced Geopolymer Concrete

Bhargavi C[1], Sreekeshava K S[1], Prashant Sunagar[2], Manishh S Dharek[3] and Ganesh C R[1]

[1]*Department of Civil Engineering, Jyothy Institute of Technology, Bengaluru, Karnataka, India;*
E-mail: bhargavi.c@jyothyit.ac.in / sreekeshava.ks@jyothyit.ac.in / ganesh.cr@jyothyit.ac.in
[2]*Department of Civil Engineering, Ramaiah Institute of Technology, Bengaluru, Karnataka, India;*
E-mail: prashant.sjce@gmail.com
[3]*Department of Civil Engineering, BMS College of Engineering, Bengaluru, Karnataka, India;*
E-mail: manish.shashikant@gmail.com

Abstract

Fiber reinforced geopolymer concrete using granulated blast furnace slag, activated with alkali solution and incorporating different quantity of polypropylene fiber (PF) and steel f iber (SF) was studied in this research. A group of control mixtures was prepared with volume fraction of 0% fibers. A second batch of mixtures with volume fraction of 0.5%,1% and 1.5% of PF and SF was used to observe the effect of the fibers on various mechanical properties. Compressive strength test results showed that introducing steel fibers at volume fraction of 1.5% showed the highest compressive strength and same quantity of polypropylene fiber exhibited lower strength. The results indicated that as quantity of fibers in the binder increased, there was a reduction in workability of the mixture. It was seen that inclusion of polypropylene fibers with the binder changes the pattern of failure from brittle to ductile, an advantageous property in engineering applications. Incorporation of polypropylene fibers did not change the elastic modulus due to the possibility of entrapped voids which may have occurred because of fiber balls formed during mixing. Scanning electron microscopy analysis was performed which exhibited the bonding and mechanism of crack propagation based on micromorphology.

Keywords: *Steel Fiber, Polypropylene Fiber, GGBS, Geopolymer Concrete, SEM Analysis, Alkali Activator.*

1.0 Introduction

Manufacturing of cement has a significant contribution to large emissions of greenhouse gases. It has been reported that 7.35% of total carbon dioxide releases in the world is due to manufacturing of cement[1,2]. Further, faster methods like construction of walls of houses using a mixture of recycled material and cement are being adopted which are both economic and environment friendly as compared to conventional methods[3]. There is thus an absolute requirement for a replacement to the ordinary cement with better mechanical properties and lesser impact on environment and economy.

Geopolymers constitute a group of inorganic polymers. Aluminum and silicon source materials are dissolved in an alkaline solution that will cause polymerization reaction. This will lead to formation of geopolymers which are ring structures that consist of silicon-oxygen-aluminum-oxygen bonds. Thus, a geopolymer is a chemical mixture of compounds that consists of repeated units[4]. GPs result in reduction of demand for Portland Cement.

The effect of variation in polyethylene fiber content and water to binder fraction on high toughness geopolymer concrete and its fracture properties is studied with 6 volume

*Author for correspondence

fractions of polyethylene fibers and varying lengths of the same were considered. Results indicated increasing fiber factor will lead to bell curve that exhibits the result of fracture toughness (FT). It was found that the FT of PPFRG with water to binder fraction of 0.35 was greater than 0.38[5]. The effect of steel fibers on characteristics detailing was studied and the results showed that, an increase in fiber quantity till 2% exhibited the strength in compression value to increase. The splitting tensile strength and flexural strength showed a considerable value when volume content of the fiber was 2.5%[6]. Another study indicated that incorporation of minimal content volume of basalt fiber along with flyash geopolymer concrete showed an enhanced fracture toughness and better crack propagation mechanism[7,8]. Hybrid mixture incorporating both SF and PF was investigated indicating that the mixture showed an enhanced durability but reduced mechanical property[9,10]. The performance of geopolymer concrete was studied where the experiments were conducted to find fresh concrete properties, MOE and splitting tensile strength. It indicated that the workability of the mix reduced when fiber content increases[11]. Impact tests on FRGPC was performed and found that 0.75% of crimpled stainless-steel fiber increased the impact load resistance of the specimen[12].

2.0 Material Characteristics

2.1 Geopolymer Concrete

Industrial production leads to wastes such as silica fume and GGBS have geopolymer base of silicon and aluminum. These are activated using basic solution which leads to a reaction called polymerization further resulting in formation of binder material. Geopolymer concrete is prepared by mixing the binder material, coarse aggregates with crushed stones having a nominal size of 20mm and manufactured sand as fine aggregates. Chemical characteristics of silica fume and GGBS are illustrated in Table 1.

Table 1: Chemical compounds of Silica Fume and GGBS

Compound	GGBS (%)	Silica Fume (%)
Silicon Dioxide	35.8	94.9
Ferric Oxide	1.52	0.948
Aluminum Oxide	10.8	1.19
Magnesium Oxide	11.98	0.948
Calcium Oxide	38.7	0.588
Sodium Oxide	0.718	0.418
Potassium oxide	0.759	1.118
Manganese Oxide	1.677	-

2.2 Steel Fiber and Polypropylene Fiber

The mechanical property enhancers that are to be used must exhibit good bond strength, higher resistance to thermal conditions, better under corrosive environment and should be environment friendly[16]. Crimped steel fibers are used in this study (Figure 1). The specifications of steel fiber included length of 30mm, diameter of 0.6mm and aspect ratio of 50. It has a nominal tensile strength of 1100N/mm^2. Monofilament polypropylene fibers of natural white color, having a diameter of 0.5mm and length of 12mm was used for the study (Figure 2).

The alkali activator solutions were prepared by diluting NaOH flakes using water and rested in room temperature for a day after which Na_2SiO_3 solution is added. The dry components comprising GGBS, micro silica and manufactured sand were mixed in a blender till light gray colored mixture was formed. Activator solution that was previously prepared was gradually added to the mixture. Fibers were then added progressively to avoid balling or lumps till a uniform mixture was obtained. The mix was placed in the mold and tested as per the requirements. The mix ratio of the finalized volume content of mixes are tabulated in Table 3.

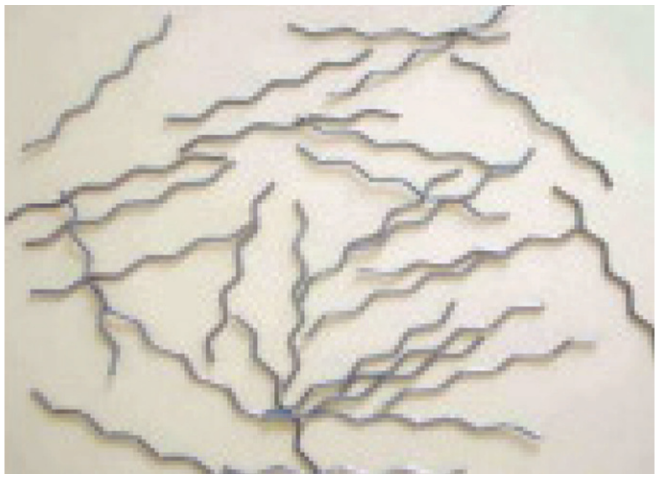

Figure 1: Crimped Steel Fibers

Figure 2: Monofilament Polypropylene Fibers

Table 2: Mix Ratio-Batch 1

Micro silica (kg per cubic meter)	GGBS (kg per cubic meter)	Na_2SiO_3/ NaOH ratio	Molarity of Sodium Hydroxide	Manufactured Sand (kg per cubic meter)
285	860	1.5	6	832
285	860	1.5	10	832
285	860	2.5	6	845
285	860	2.5	10	845
285	860	3.5	6	850
285	860	3.5	10	850

Figure 3: Design Mix Preparation

3.0 Methods of Testing

The impact of addition of fiber on the fresh concrete property that is workability was measured using flow test as per IS 1199-1959 immediately after mixing every batch. Compressive strength of various mixes was determined using specimens with size 100mm×100mm×100mm as per IS 516-1959. The splitting tensile strength was determined using cylindrical specimen of dimeter 150mm and height 300mm as per IS 5816-1999. The flexural strength is obtained using prism specimen of sizes 700mmx150mmx150mm as per IS 516-1959. (Figure 4 and Figure 5)

Figure 4: Flexural Strength Test Specimen

Figure 5: Flexural Strength Test

Table 3: Mix Ratio- Batch 2

Mixture Volume Percentage (% SF or %PF)	Micro silica (kg per cubic meter)	GGBS (kg per cubic meter)	Na_2SiO_3/ NaOH ratio	NaOH (M)	Manufactured Sand (kg per cubic meter)
0.5% Steel Fiber	285	860	3.5	10	832
0.5% Polypropylene Fiber	285	860	3.5	10	832
1.0% Steel Fiber	285	860	3.5	10	845
1.0% Polypropylene Fiber	285	860	3.5	10	845
1.5% Steel Fiber	285	860	3.5	10	850
1.5% Polypropylene Fiber	285	860	3.5	10	850

4.0 Results and Discussions

4.1 Workability

Increase in volume fraction of SF resulted in decrease in flow diameter. It was observed that harsher mixes were produced on incorporation of higher volume fraction of SF. It was observed that since the density of fibers is low, higher quantity of fiber was included even for very low volume fraction. This led to more fiber matrix interaction causing higher resistance to flow.

4.2 Compressive Strength

Table 2 shows the results for first batch of mix ratios. Aluminates and silicates dissolve in alkaline solution at a certain rate and polymerization depends upon this rate of dissolving. A new gel product was seen to develop throughout all mixes. This was due to enhanced polymerization which increased the dissolve rate of aluminosilicates. It was observed that rise in Na_2SiO_3/NaOH ratio (from 1.5 to 3.5) led to reduction in water binder ratio (5 to 7), thus increasing the compressive strength (6% to 12%). It thus indicated that molarity and Na_2SiO_3/NaOH ratio are directly proportional to 28 days compressive strength.

The mix that incorporated SS/SH option of 3.5 and 10 molar sodium hydroxide showed largest value in compressive strength. The same was selected as control mix for batch 2. It was in general noted that fibers' inclusion increased the value of strength in compression of all the mixes in the batch[13]. It was also noticed that maximum compressive strength of all the percentage volume content mixes were that of SF. It was inferred that as the volume percentage of the fibers was raised, a progressive growth in the strength of the mix was observed in steel fibers. 28 days strength in compression values are graphically represented in Figure 6.

4.3 Splitting Tensile Strength

It was observed that the propagation of cracks in control mix was abrupt indicating a straight crack as soon as the specimen fails. This indicated brittle mode of failure as expected. It was further noticed that incorporation of SF and PF exhibited slower crack propagation. It also showed many micro split cracks near main crack, indicating a ductile mode of failure. An elastic deformation phase of the specimen was observed initially where crack width of specimen is zero. Further increase of loading will exhibit cracks and gradual expansion is seen. It was observed that after concrete matrix cracks, the fibers take up the load along with gradual increase in cracks. At this point, capacity of the member to carry load slightly decreases and then increases rapidly. As the loading value reaches peak stress, crack width increases at higher rate finally resulting in failure by splitting longitudinally. Also, the fiber gaps between polypropylene fiber in the matrix is very less. This ensures that PF can avoid formation of cracks due to shrinkage or bleeding. PF exhibits good crack suppression initially but steel fibers exhibit crack arresting at higher loading conditions as the corresponding elastic property of fibers made of steel is much higher than those made of polypropylene. The split tensile strength values of the tested mixes are graphically represented in Figure 7.

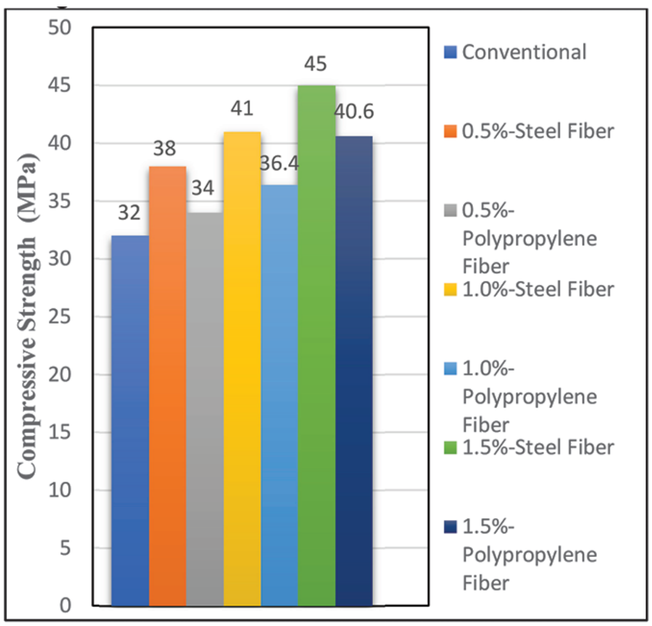

Figure 6: Compressive Strength

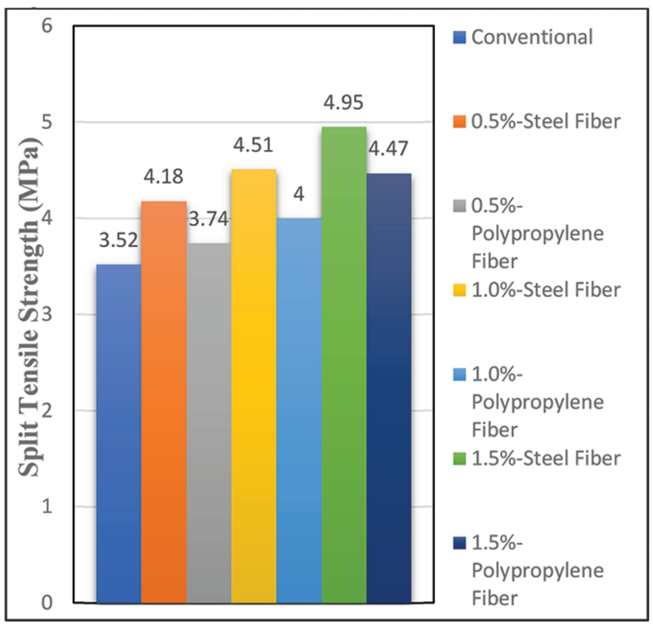

Figure 7: Split Tensile Strength

4.4 Flexural Strength

The results indicate that 1.5% SF mix with flexural strength 5.4MPa has the highest value. Tiny cracks are created in contact area between binder and SF during tensile pull-out. Whereas, PF cause lesser abrasion as they are more susceptible to breakage. It has been observed that PF can be easily withdrawn from the binder without any cracks or abrasions to the surface[14] Ductility increased with fiber incorporation[15]. The surface of steel fibers has tougher texture than aggregates and hence forms a good binding between the fiber and binder. GPs constitute gel, large number of gaps and aluminum and silicate crystallized elements [17,18]. The fibers hold with its two ends, the polymer matrix, in turn increasing its stiffness. It is hence observed that the FRGP exhibit higher splitting tensile strength and strength in flexural than the control mix. A possibility of microfracture was observed as well. This indicated the effect of length and size of the fiber on the flexural strength of the specimen. 28 days flexural strength of the specimens is depicted graphically in Figure 8.

4.5 Modulus of Elasticity

It was observed that as volume content of fibers were increased, an enhancement in Elastic modulus in comparison with plain polymer concrete mix was seen. Results indicated that the value of elastic modulus for various mixes were in the same range stating that the effect of fibers was not much to be seen on this property of the FRGPC.

4.6 Scanning Electron Microscopy (SEM) Analysis

SEM depicted small scale structure of FRGPC. FRGPCs performance was an effect of the microstructure. It was observed that FRGPC showed thicker structural appearance which further improved the behaviour mechanically. It was seen that undissolved crystallized hydro aluminosilicates were present (Figure 9). As we see in Figure 10, a good bonding between steel fiber and matrix was observed. This in turn will have a reliable benefit on enhancement of mechanical properties of the FRGPC as compared to conventional geopolymer concrete matrix (Figure 11).

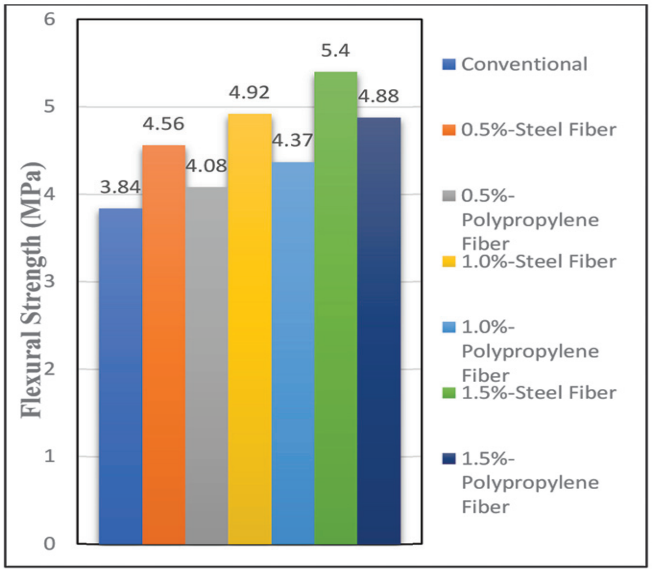

Figure 8: Flexural Strength

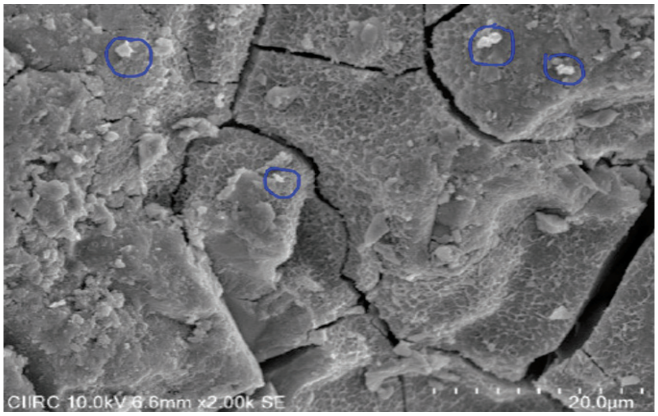

Figure 9: Crystallized undissolved Aluminates and Silicates

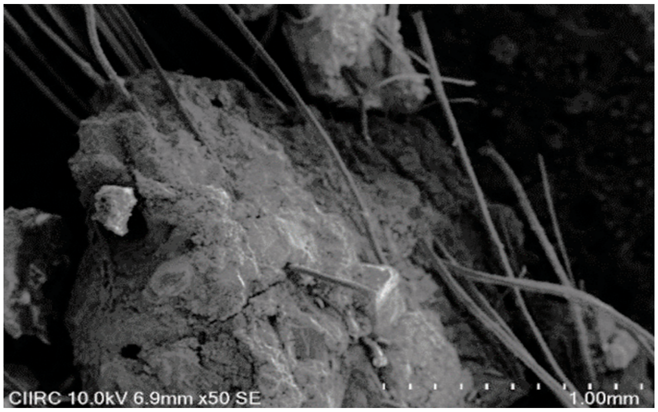

Figure 10: SEM Analysis showing bonding between Geopolymer and Steel Fiber

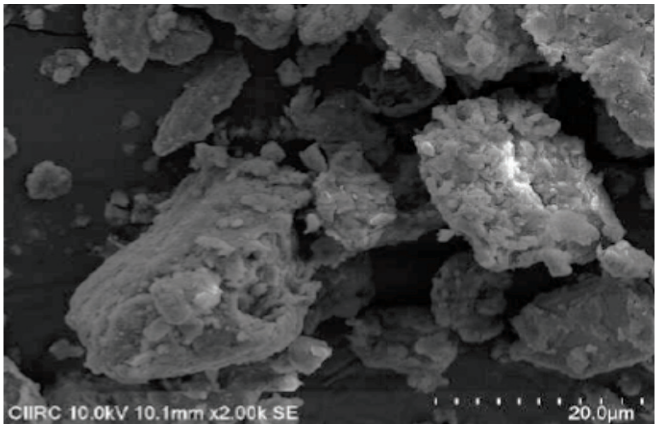

Figure 11: SEM Analysis showing conventional geopolymer concrete

5.0 Conclusions

The final conclusion of the study is as follows

Fiber inclusion, irrespective of the volume content reduced the workability of the mix. Further increase, made the mix even harsher and less workable.

Steel fibers showed a considerable increase in mechanical properties and exhibited better range compared to the polypropylene fiber characteristics.

A 40% and 27% increase in flexural strength was observed with incorporation of 1.5% steel fiber and polypropylene fiber respectively in comparison with conventional mix.

Highest 28 days compressive strength value was found to be that of 10M solution GPC with steel fibers incorporated in them.

Higher split tensile strength was observed in both FRGPC that indicated lesser crack propagation and formation of microcracks.

Undissolved crystallized aluminosilicates were found in the SEM analysis indicating thicker micro structures.

Enhanced bonding between fiber and matrix was observed in SEM analysis.

6.0 References

1. Mehta, P.K., (2002): Greening of the Concrete Industry for Sustainable Development. *ACI Concrete International,* 24(7): 23-28.
2. McCaffrey, R., (2002): Climate Change and the Cement Industry. *Global Cement and Lime Magazine* (Environmental Special Issue): 15-19.
3. Avinash Nair, S D Aditya, R N Adarsh, M Nandan, Manish S Dharek, B M Sreedhara, Sunagar C Prashant and K S Sreekeshava," (2020): Additive Manufacturing of Concrete: Challenges and opportunities", IOP Conf. Ser.: Mater. Sci. Eng. 814 012022
4. Davidovits, J. (1988b). Geopolymer Chemistry and Properties. Paper presented at the Geopolymer '88, First European Conference on Soft Mineralurgy, Compiegne, France.
5. Ning Zhang, Chenyu Yan, Li Li, Mehran Khan, "Assessment of Fiber Factor for The Fracture Toughness of Polyethylene Fiber Reinforced Geopolymer "*Construction and Building Materials.*319(2022), 126130
6. Peng Zhang, Jia Wang, Qingfu Li, Jinyi Wan and Yifeng Ling, "Mechanical and fracture properties of steel fiber-reinforced geopolymer concrete "*Science* 28(1):299-313: June 2021
7. KS Sreekeshava, KAS Arun ," Experimental studies on response of biaxial geo-grid proportioned cement concrete." *i-Manager's J Civ Eng* 8 (2): 15-2018
8. Yamin Wang, Shaowei Hu, Xiping Sun, "Experimental investigation on the elastic modulus and fracture properties of basalt fiber–reinforced fly ash geopolymer concrete "*Construction and Building Materials*, 338, (2022), 127570
9. K. S. Sreekeshava, A. S. Arunkumar, C. R. Ganesh, Manish S Dharek, Prashanth Sunagar," Influence of Steel Fiber with Polypropylene (PP) Geo–Fabric on the Performance of Concrete", *Emerging Technologies for Sustainability*, 2020
10. Bassam A. Tayeh, Mahmoud H. Akeed, Shaker Qaidi, B.H. Abu Bakar, "Influence of micro silica and polypropylene fibers on the fresh and mechanical properties of ultra-high performance geopolymer concrete (UHP-GPC)" *Case Studies in Construction Materials* 17 (2022) e01367
11. Meera Jacob, B. H. Bharatkumar, M.G. Rajendran studies on the impact behaviour of fiber reinforced geopolymer concrete, *International Journal of Advanced Technology in Engineering and Science,* Volume No 03, Special Issue No. 01, March 2015
12. H.U. Ahmed, A.A. Mohammed, S. Rafiq, A.S. Mohammed, A. Mosavi, N.H. Sor, S. Qaidi, Compressive strength of sustainable geopolymer concrete composites: a state-of-the-art review, *Sustainability* 13 (24) (2021) 13502
13. J. Mejía, R. Mejía de Guti´errez, F. Puertas, Rice husk ash as silica source in fly ash and ground blast furnace slag cementitious alkali activated systems, Mater.Constr. 63 (311) (2013) 361–375
14. Janhavi Desai, KS Sreekeshava, R Chandana, G Jeevan, Bheemsen Gogi," Investigations on Compressive Strength, Internal Structure and Composition of Concrete Casted and Cured using Marine Water", *Emerging Technologies for Sustainability*, 2020
15. S. Abbas, A.M. Soliman, M.L. Nehdi, exploring mechanical and durability properties of ultra-high-performance concrete incorporating various steel fiber lengths and dosages, *Constr. Build. Mater.* 75 (2015) 429–441.
16. P.S. Ambily, K. Ravisankar, C. Umarani, J.K. Dattatreya, N.R. Iyer, Development of ultra-high-performance geopolymer concrete, *Mag. Concr. Res*. 66 (2) (2014)82–89
17. Sreekeshava, K.S., Arunkumar, A.S., Dharek, M.S., Sunagar, P. (2021). Studies on Inclusion of Polypropylene (PP) Geo-fabric in Concrete. In: Dasgupta, K., Sudheesh, T.K., Praseeda, K.I., Unni Kartha, G., Kavitha, P.E., Jawahar Saud, S. (eds) Proceedings of SECON 2020. SECON 2020. Lecture Notes in Civil Engineering, vol 97. Springer, Cham.
18. Z.-h Zhang, X. Yao, H.-j Zhu, S.-d Hua, Y. Chen, Preparation and mechanical properties of polypropylene fiber reinforced calcined kaolin-fly ash based geopolymer, J. Cent. South Univ. Technol. 16 (1) (2009) 49–52.