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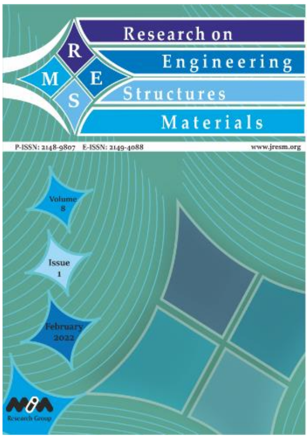

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Research Article

Mechanical and durability characterization of hybrid fibre reinforced green geopolymer concrete

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Abstract

Finding a suitable waste utilization approach to produce a cleaner environment is the most crucial aspect globally. Geopolymer is the most promising alternate for cement and source for major waste utilization. Disposal of waste rubber tires is a challenging task for the cleaner environment. Hence, abundant wastes, which create environmental pollution, such as wood waste ash and waste rubber, are used to invent the green geopolymer concrete in this research. The geopolymer is uncomfortable with carrying impact energy, ductility, and energy absorption. Fibre addition could enhance the above properties. Waste wood ash is replaced by 30 percent with fly ash. This research assesses the individual effect of adding polypropylene and rubber fibre by 0, 0.5%, 1%, 1.5%, and 2% of volume fractions. In addition, the effects of fibre hybridization on the mechanical and durability characteristics of green geopolymer concrete have also been analyzed. The study finds the maximum performance in mechanical and durability behaviors with the mix having 0.5% PP and 0.5% rubber. The microstructure characteristics are also assessed using SEM for understanding the phase development in green geopolymer concrete. The research hypothesis proves that an intellectual approach is made to utilize the waste materials such as rubber and waste wood ash in the invention of green geopolymer concrete, which can help to eliminate the environmental impact and can act as a sustainable concrete.

1. Introduction

An amorphous form of polymer (i.e., Geopolymer) was made in nature by dissolving silica and alumina from raw materials such as fly ash, metakaolin, and slag with extremely concentrated alkaline hydroxide and silicate solution [1]. Most of the researchers used fly ash as the binder for the production of geopolymer concrete [2–10]. Fly ash-based geopolymer concrete requires heat curing of 60^0C for 24hrs and needs a high alkaline solution to achieve the characteristic strength [11,12]. The molarity of NaOH played a vital role in the enhancement of GPC strength. The geopolymerization was formed easily with the molarity up to 12, whereas it was disrupted with the increased molarity beyond 12M. The geopolymer concrete with up to 12M promoted silica and alumina dissolution from raw materials [13]. The strength reduction was noted with the molarity exceeds 12M [8]. According to the fly ash production and use in 2017, while production fell to 169.25Mt, use increased to 107.10Mt. The demand for fly ash in forthcoming years was enlarged to high [14]. Hence, the researchers needed to find the alternate raw material to reduce the

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amount of fly ash utilization in geopolymer concrete. GGBS (Ground Granulated Blast furnace Slag), which has high calcium, was used as alternate source material for fly ash [15]. In GGBS, the high calcium was the threat that could take the alkaline compounds for producing the geopolymer reaction at earlier ages [16]. The formation of the geopolymeric reaction enhanced the strength at an early age. However, the silica and alumina were left unreacted with the disruption of calcium [17,18]. The reaction of silica and alumina with an alkaline solution was also a vital chemical formation in the geopolymer formation [19]. If the reaction was not formed properly, the alkali-silica expansion was formed on the prolonged ages. Therefore, the raw material with less calcium which requires a lower alkaline activator might be the solution. Moreover, the raw material with inbuilt alkaline compounds (K_2O) [20] was also suggested to substitute the fly ash.

The wood waste ash with inbuilt potassium composition was used as a binder material in conventional concrete, enhancing strength slightly [21]. Waste woods procured from timber industries are used to fuel food production in roadside hotels [21]. The wastes were burnt in the boiler but not limiting the temperature and resulted in the production of flyable ash [22]. The ash derived from the available local hotels was thrown into landfills, polluting the environment equally to global warming [23]. The chemical composition of wood ash was analyzed and showed the presence of potassium oxide in the inside matrix of wood ash [24]. Biomass Wood Ash was used to produce the geopolymer concrete, and it was limited to 10 percent due to the uncertainty of later age geopolymer reaction [25]. High Calcium wood ash was used as an aluminosilicate source material to produce geopolymer concrete, resulting in reduced strength in later ages due to high calcium [26]. When partially substituted, the waste wood ash with less calcium could be a promising binder material [27]. Hence, the waste wood ash procured from nearby hotels with less calcium was partially substituted for fly ash in this research to invent green geopolymer concrete.

Geopolymer concrete was weak in brittle, ductile, impact energy and energy absorption. The major solution invented for improving the above-mentioned properties of geopolymer was the incorporation of fibres within the specified limit. Incorporation of any type fibres had its capability of enhancing the properties. However, there was a specified limit of 2% of volume fraction for the incorporation of any type fibre. The most used type of low modulus fibre was polypropylene fibre which helped to enhance the bonding effect and first crack load. Due to its surface texture and bonding capacity, polypropylene fibre was chosen [28]. The flexural strength and toughness were increased with the addition of polypropylene fibre, and also it limits the deformation due to shrinkage. Meanwhile, the incorporation of polypropylene enhanced the impact strength of geopolymer concrete by 6.25 percent [29,30]. Ductility was increased, and the degree of compression was reduced by incorporating polypropylene [31]. Moreover, polypropylene fibre was specialized in limiting crack formation and propagation [32]. Enhancement in resisting the crack formation was observed with the 0.5 percent PP fibre addition [33]. However, the enhancement in the crack resistance and mechanical properties of GPC by incorporating polypropylene fibre was not efficient in using the GPC in heavy-loaded structural elements. Hence, hybridization of two or more different types of fibres could be adopted to improve the impact and energy absorption of GPC. This study aimed to choose one of the low modulus fibre which could enhance the GPC performances to use it in heavy loaded members.

Dumping waste rubber tires led to the formation of bacteria and fungus [34]. The burning of waste rubber tires produced some toxic gases, which led to death [35]. In the meantime, the burning of rubber tires releases an eminent amount of carbon di-oxides [36], and some developing countries banned it. Hence, disposal of that waste rubber tire was a challenging task for the cleaner environment. Awareness on utilizing waste rubber tires in concrete composites was increased, and it was used as a filler material and coarse aggregate [37]. Crumped rubber was replaced by 15percent with fine aggregate, which enhanced better performance; however, it reduces the compressive strength [36]. The strength reduction was due to the high amount of replacement of rubber tires. Hence, the addition of rubber as fibre instead of replacement, can be appropriate in the effective utilization of waste rubber [38]. The mechanical and durability properties were enhanced with the incorporation of rubber fibre [39]. Meanwhile, the increased amount of rubber fibre decreased the compressive strength of GPC, and enhancement in energy absorption was observed with the rubber addition [40,41]. The impact strength of GPC was also enhanced with the incorporation of rubber fibre, which can retain the plastic state [42]. The incorporation of rubber fibre was limited to a smaller volume fraction, which could also increase the mechanical properties of GPC [43]. There was a research gap on utilizing the rubber as a fibre with a smaller volume fraction in this study. Further, a combination of both PP and rubber fibre could allow enhancing the properties of GPC in all aspects to use in heavy-loaded structural elements [44].

In the author's previous study [45], the ratio of aluminosilicate binder materials, molarity optimization, and alkaline activators to binder ratio optimization was done. Hence the effect of individual fire addition on the mechanical properties of green geopolymer concrete was studied in this research. In addition, the effects of the hybridization of polypropylene and rubber fibre on the mechanical characteristics of green geopolymer concrete were investigated. Further, microstructural characterization analysis of hybrid fibre reinforced green geopolymer concrete was assessed by SEM.

2. Material Properties

In this research, Fly Ash (FA) derived from the thermal power plant station situated in Neyveli, was used as the raw binder [45]. Energy Dispersive X-Ray analysis was performed to find the chemical compounds present in the fly ash, as shown in figure 1, and also to define the class of fly ash type [46]. Standard ASTM procedures were followed to find the physical characters of FA [47]. The substitute raw material for FA was waste wood ash collected from the nearby hotels [48]. Figure 2 illustrates the Energy Dispersive X-Ray analysis performed to find the chemical compounds present in the waste wood ash and define the calcium present in the low calcium waste wood ash (LCWA) [26]. The composition of LCWA was found in EDX, which has 14.5% of K2O, which could help to reduce the requirement of alkaline solution [20] [24]. The required physical properties of constituent materials are illustrated in Table 1.

Table 1**.** Physical characteristics of the constituents

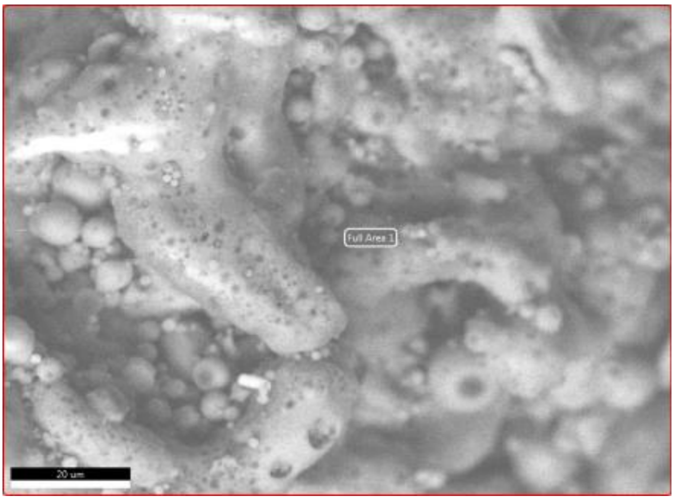
Properties / Constituents	Consistency	Initial Setting Time	Final Setting Time	Fineness Modulus	Specific Gravity
Fly ash	38%	18.00	36.00	6%	2.3
Waste Wood ash	58%	2.30	3.00	9%	1.7
Fine Aggregate	-	-	-	2.91	2.62
Coarse Aggregate	-	-	-	7.6	2.42
NaOH	-	-	-	-	1.61
Na_2SiO_3	-	-	-	-	1.47

In this research, fine aggregate and coarse aggregate [49] were also used, and their properties were tabulated in Table 1. The optimal size of FA and CA used in this study was

1.18mm and 10mm. Further polypropylene fibre and waste tire rubber fibre of length 20mm was added individually by 0%, 0.5%, 1%, 1.5% and 2% of volume fraction [50]. Hybridization of polypropylene and rubber fibre was also done by varying 0, 0.25, 0.5, 0.75, and 1% volume fraction. Table 2 lists the chemical compounds present in the FA and LCWA.

Table 2. Chemical composition of fly ash and LCWA [48]

Chemical compound	% by Mass	
	LCWA	FA
Al_2O_3	0.6	17.4
SiO_2	8.01	23.6
K_2O	14.49	0.9
CaO	3.61	1.8
Fe_2O_3	-	1.99
MgO	3.02	60
Gd	0.51	-
P_2O_5	3.06	-
TiO_2	-	0.99
MnO	-	-
C	10.22	2.99



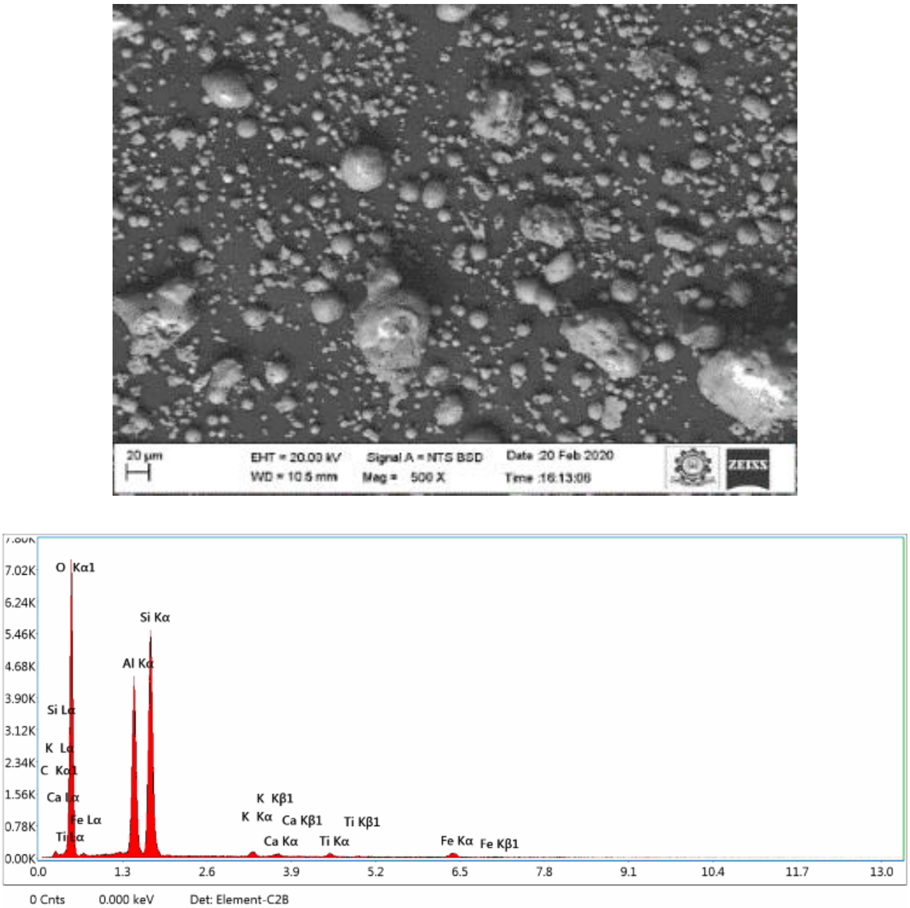
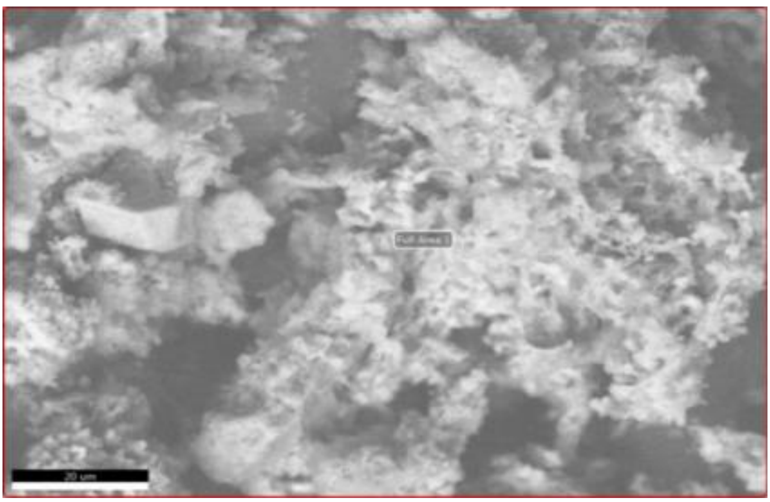


Fig. 1 Microstructure analysis of FA through SEM and EDX



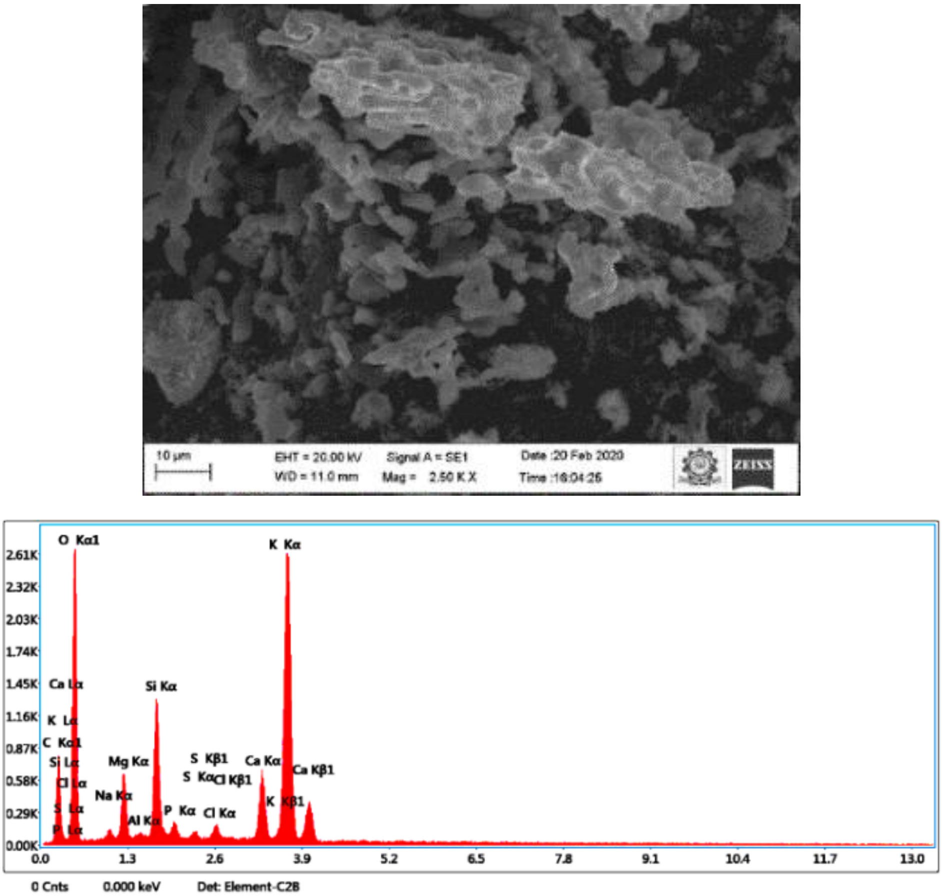


Fig. 2 Microstructure analysis of LCWA through SEM and EDX

3. Mix Proportion

In this research, the mix proportion for low calcium green geopolymer concrete was designed by the Indian standard modified guidelines for geopolymer concrete mix design [51]. The design mix was calculated as 1:1.05:1.57 with an activator to binder ratio of 0.61 [48]. The individual fibres such as polypropylene and rubber fibres were added by 0%, 0.5%, 1%, 1.5% and 2% of volume fraction [50]. The quantity of materials as per the mix design of individual fibre addition was tabulated in Table 3. This study found the influence of individual fibre on the mechanical characteristics of low calcium green geopolymer concrete. Table 3 shows the references of different mix id.

Further, the combination of rubber and polypropylene fibre was carried out by varying the percentage of both fibre at a variation of 0%, 0.25%, 0.5%, 0.75%, and 1% of volume fraction. Table 4 illustrates the quantity of material required for the hybridization of rubber and polypropylene fibre.

Table 3. Material quantity required for different fibre addition

Mix id (kg/m³)	GC	Polypropylene fibre			
		0.5PFRG	1.0PFRG	1.5PFRG	2.0PFRG
FA	385	385	385	385	385
LCWA	96	96	96	96	96
NaOH	110	110	110	110	110
Na_2SiO_3	276	276	276	276	276
Sand	667	667	667	667	667
CA	994	994	994	994	994
Fibre	0	2.41	4.82	7.22	9.63

Table 4. (Con.) Material quantity required for different fibre addition

Mix id (kg/m³)	GC	Rubber Fibre			
		0.5RFRG	1.0RFRG	1.5RFRG	2.0RFRG
FA	385	385	385	385	385
LCWA	96	96	96	96	96
NaOH	110	110	110	110	110
Na_2SiO_3	276	276	276	276	276
Sand	667	667	667	667	667
CA	994	994	994	994	994
Fibre	0	2.41	4.82	7.22	9.63

Table 5. Material quantity required for hybridization of fibre

Mix id	PP Fibre (kg/m³)	Rubber Fibre (kg/m³)	Fly ash (kg/m³)	LCWA (kg/m³)	NaOH (kg/m³)	Na_2SiO_3 (kg/m³)	Sand (kg/m³)	CA (kg/m³)
GC	0	0	385	96.3	110.2	275.59	666.58	993.7
0P/1.0R HFRG	0	4.82	385	96.3	110.2	275.59	666.58	993.7
0.25P/0.75R HFRG	1.21	3.61	385	96.3	110.2	275.59	666.58	993.7
0.5P/0.5R HFRG	2.41	2.41	385	96.3	110.2	275.59	666.58	993.7
0.75P/0.25R HFRG	3.61	1.21	385	96.3	110.2	275.59	666.58	993.7
1.0P/0R HFRG	4.82	0	385	96.3	110.2	275.59	666.58	993.7

4. Experimental Program

4.1 Mechanical Characterization

In accordance with ASTM C109 [52], ASTM- C215 [53], ASTM-C293 [54] standards, the compressive strength, tensile strength, and flexural strength of the mix was determined by testing the standard specimens in the Universal Testing Machine. The standard specimens for compressive strength testing were taken as 100mm x 100mm x 100 mm size cubes, and for computing tensile strength, 100mm x 200mm size cylinder was cast. 500mm x 100mm x 100mm size prism was casted for the computation of flexural strength. The specimens were cured at ambient temperature till the occurrence of testing ages of 3, 7 and 28 days. In this study, the effect of both rubber and polypropylene fibre on the compressive, flexural and split tensile strengths of low calcium based GPC was carried out at the required ages. Average of three specimens test results were taken as strength parameters for all ages of curing. The failure of specimens was shown in figure 3.

4.2 Durability Characterization

The water absorption of concrete specimens was a simple way of assessing the potential of concrete in durability aspects. In compliance with ASTM C 642 [55], the water absorption test was performed. For 24hrs, oven-dried specimens were soaked in water. Percentage growth in weight as water absorption was noted. According to time, the measurement of capillary water suction in a uniform direction was sorptivity. According to ASTM C267 [56], the resistance to acidic conditions was assessed. 3% sulfuric acid solution was used for submerging the specimens to find the reaction against the acidic environment. Initial specimen weights were determined.

Fig. 3 Failure of specimens

Mass loss, the residual strength of compression, and physical conditions of the tested specimen were noted after 30 days. Based on the procedure given in ASTM C1760[57], the electrical resistivity of the specimen was derived. While considering the determination of durability in terms of electrical resilience, this electrical conductivity method was easy and fast. The test was performed by measuring the variable voltage at the ends of the specimen using DC power. The current was measured for the average current for each applied voltage. Calculation of resistivity was done by using q = RA/L where R = V/I, L = In between distance of electrodes and A was c/s area of the specimen.

5. Result and Discussion

5.1 Mechanical Characterization

5.1.1 Effect of Polypropylene Fibre

The influence of polypropylene fibre incorporation on the mechanical characters of low calcium green geopolymer concrete is shown in figure 4 (a-c). The various proportion of polypropylene fibre incorporation was 0, 0.5, 1, 1.5, 2% of volume fraction and their effects on low calcium green geopolymer concrete were assessed. Table 5 represents the test results.

The specified limit of fibre incorporation was up to 2% of volume fraction due to augmentation of fibre in one place and reduced workability [50,58]. From the test result, at all ages of concrete, there was an enhancement in all strength noted with the 1% of PP fibre [59]. The strength parameters were started to decrease with the fibre addition exceeds 1% due to the augmentation of fibres in one place [31]. While comparing the testing ages, the specimens tested after 3 days of ambient curing was achieved the highest percentage of strength gaining than the control mix [60].

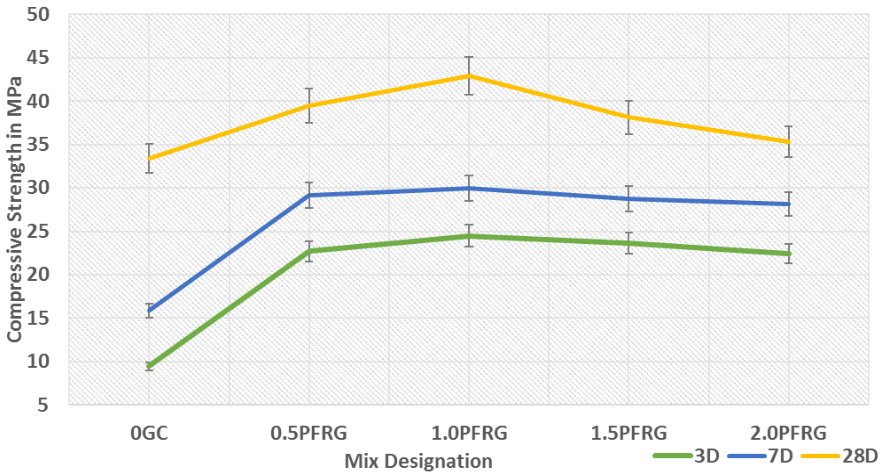


Fig. 4 a Influence of PP fibre in compressive strength

Table 6. Results of each mix

Mix ID	Compressive Strength (MPa)			Tensile Strength (MPa)		
	28D	7D	3D	28D	7D	3D
0GC (Control Mix)	15.9	33.4	9.45	2.4	2.8	3.3
0.5PFRG	39.5	29.1	22.7	3.5	2.9	2.5
1.0PFRG	42.9	30	24.5	3.7	3.1	2.7
1.5PFRG	38.1	28.8	23.6	3.4	3	2.5
2.0PFRG	35.3	28.1	22.4	3.4	2.9	2.5
0.5RFRG	35.9	29.3	22.4	3.4	3	2.5
1.0RFRG	36.5	29.8	23.6	3.7	3.1	2.7
1.5RFRG	36.1	29	23.1	3.5	3	2.6
2.0RFRG	35.8	27.6	22.1	3.3	2.9	2.4
0P/1.0R HyFRG	36.5	29.8	23.6	3.5	3.1	2.7
0.25P/0.75R HyFRG	37.5	30.2	24.1	3.7	3.3	2.8
0.5P/0.5R HyFRG	43.9	32.5	25.3	3.9	3.4	3
0.75P/0.25R HyFRG	38.6	31.7	24.9	3.7	3.2	2.7
1.0P/0R HyFRG	35.9	30	24.5	3.7	3.1	2.7

Table 7. (Con.) Results of each mix

Mix ID	Flexural Strength (MPa)		
	28D	7D	3D
0GC (Control Mix)	4.3	3.8	3.3
0.5PFRG	4.5	4.1	3.4
1.0PFRG	4.8	4.3	3.6
1.5PFRG	4.4	4	3.5
2.0PFRG	4.3	3.9	3.3
0.5RFRG	4.3	4	3.3
1.0RFRG	4.4	4.2	3.4
1.5RFRG	4.3	4	3.4
2.0RFRG	4.3	3.9	3.3
0P/1.0R HyFRG	4.3	3.8	3.3
0.25P/0.75R HyFRG	4.3	3.9	3.3
0.5P/0.5R HyFRG	4.4	4	3.4
0.75P/0.25R HyFRG	4.8	4.1	3.5
1.0P/0R HyFRG	4.4	4	3.4

The percentage of strength gaining of the specimens was noticed a gradual increment up to 1 % PP fibre, then a sudden drop down in strength was noticed in the mix with 1.5% PP fibre. While at the age of 28 days showed an increment in strength compared to the control mixture [33]. Compared to other curing ages, the increment rate was less. The maximum increment rate in compressive strength of 61.4% was observed with 1% PP fibre [61]. In the meantime, the fibre addition of 1% enhanced the compressive strength in 3, 7, and 28 days by 61.4%, 47%, 22.2%, respectively [29].

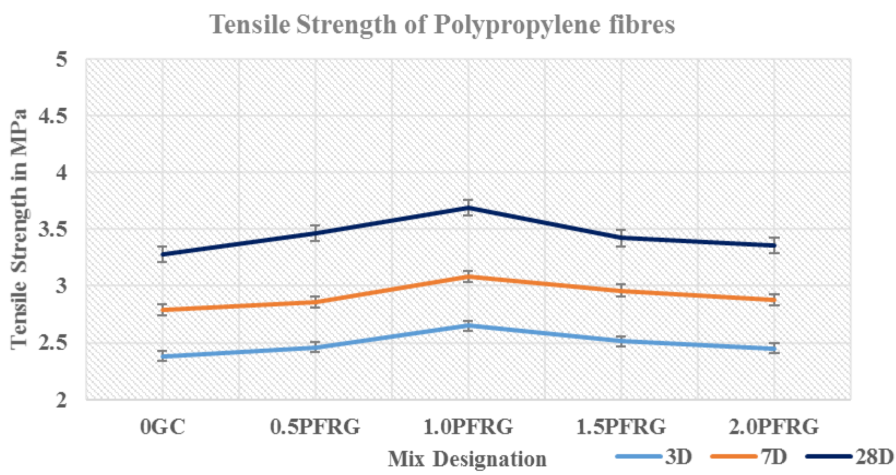


Fig. 4 b Influence of PP fibre in tensile strength

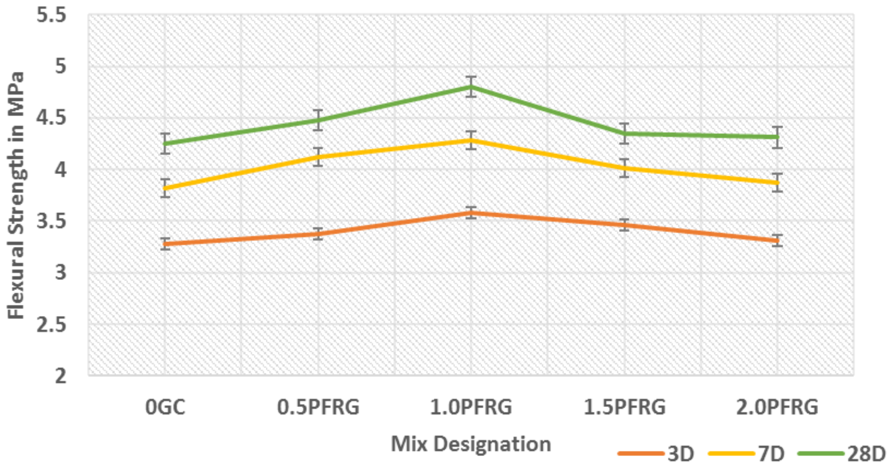


Fig. 4 c Influence of PP fibre in flexural strength

Meanwhile, the GPC incorporated with 0.5% polypropylene and 1% polypropylene achieved the maximum rate of increment in 28days tensile strength of 5.2% and 15.7%, compared to the control mixture [62]. The GPC mix incorporated with 1% polypropylene enhanced the tensile strength in 3, 7 and 28 days by 10.2%, 9.4% and 15.7% [50]. The findings showed that incorporation of polypropylene fibre up to 1 % achieved the maximum rate of increment compared to other mixes. Hence, the polypropylene fibre improved the tensile and flexural strength of GPC [28]. The GPC incorporated with 0.5% polypropylene and 1% polypropylene achieved the maximum rate of increment in 28days flexural strength of 5.13% and 11.4% compared to the control mixture [50]. On the other hand, The GPC mix incorporated with 1% polypropylene enhanced the flexural strength in 3, 7, and 28 days by 8.38%, 10.75%, and 11.46% [44]. incorporation of polypropylene fibre up to 1 % achieved the maximum rate of increment compared to other mixes. [32].

5.1.2 Effect of Rubber Fibre

The influence of various percentages of rubber fibre addition on the mechanical characters of low calcium GPC was illustrated in figure 5 (a-c). In the previous studies, the rubber was replaced with fine aggregate at various percentages [42], and rubber replacement up to 5 percent achieved equal performance related to the control specimen [39]. The studies stated that the addition of rubber in smaller volume fractions could help in improving mechanical performance. The rubber was incorporated with smaller volume fractions such as 0.5%, 1%, 1.5%, and 2% in this research. The 1% rubber fibre addition enhanced the compressive, flexural, and tensile strengths by 8.5%, 3.19%, and 11.83% [48]. The rate of increment in compressive strength at all curing ages was gradual with 1% rubber, compared to the control mixture [35]. The strength character was reduced with increasing the rubber fibre addition above 1% due to the unstiffened matrix developed by the augmentation of fibres [63]. The rate of increment in early age compressive strength was higher than the other ages [24]. The maximum increment rate in compressive strength of 59.89% was observed with 1% rubber fibre [36].

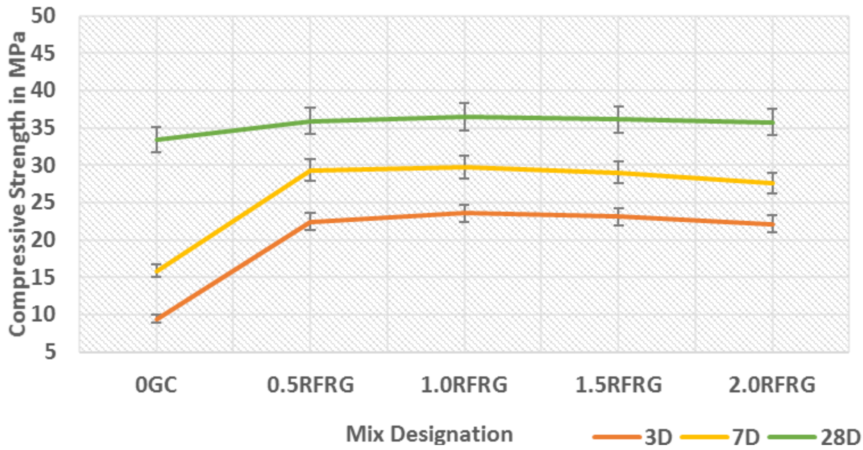


Fig. 5 a Influence of rubber fibre in compressive strength

In the meantime, the rubber fibre addition of 1% enhanced the compressive strength in 3, 7, and 28 days by 59.89%, 46.66%, 8.65%, respectively [48]. However, the addition of PP fibre enhanced the compressive strength than the rubber fibre addition due to the lower degree of compressibility of rubber fibre [64].

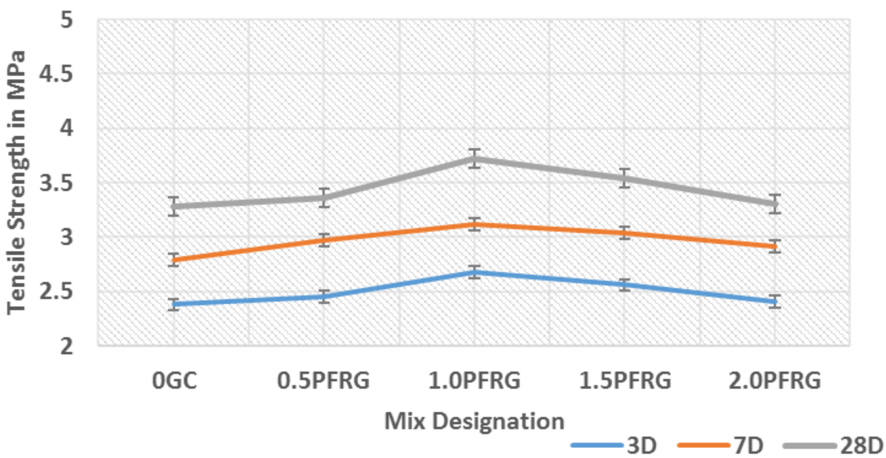


Fig. 5 b Influence of rubber fibre in Split Tensile Strength

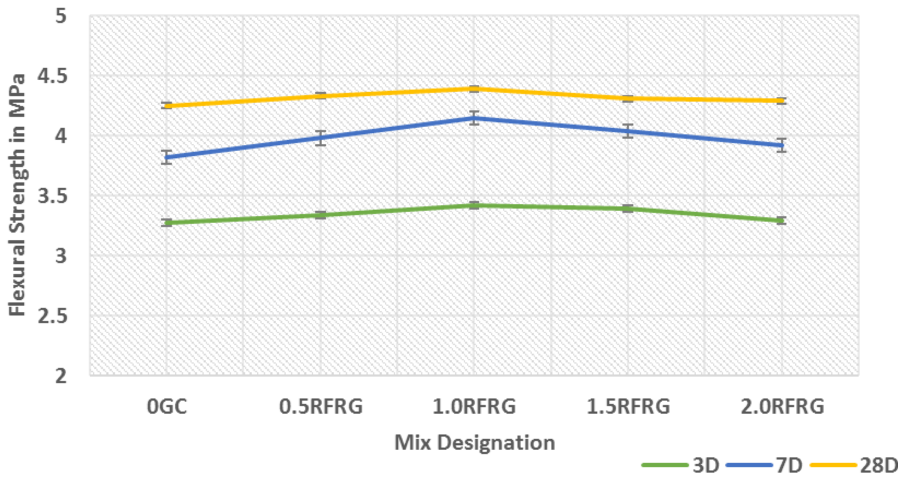


Fig. 5 c Influence of rubber fibre in flexural strength

The maximum rate of increment in 28 days tensile strength of 2.38% and 11.83% was attained by adding 0.5% rubber and 1.0% rubber fibre, and the rate of increment of each mix was illustrated in figure 5 b [48]. The GPC mix incorporated with 1% rubber enhanced the tensile strength in 3, 7, and 28 days by 11.19%, 10.58%, and 11.83% [42]. [50]. The findings showed that incorporating rubber fibre up to 1 % achieved the maximum increment rate compared to other mixes. Hence, the rubber fibre improved the tensile and flexural strength of GPC [37,42].

The GPC incorporated with 0.5% rubber and 1% rubber achieved the maximum rate of increment in 28days flexural strength of 1.85% and 3.19% compared to the control mixture [39,65]. On the other hand, The GPC mix incorporated with 1% rubber enhanced the tensile strength in 3, 7, and 28 days by 4.09%, 7.95%, and 3.19% [48]. The incorporation of rubber fibre up to 1 % achieved the maximum rate of increment compared to other mixes. [66,67].

5.1.3 Effect of Hybridization of Polypropylene and Rubber Fibre

The research found that the optimum percentage of individual fibre addition on the geopolymer concrete was 1% for both polypropylene and rubber fibre [44]. In addition, mechanical characteristics of hybrid fibre reinforced green geopolymer concrete due to the various percentage of hybridization of polypropylene and rubber were assessed [62]. The results are illustrated in figure 6 (a-c).

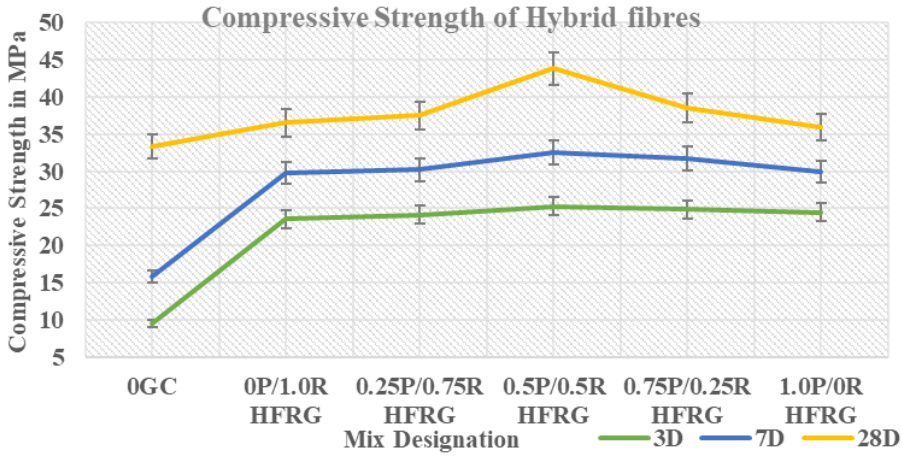


Fig. 6 (a) Influence of hybrid fibre in compressive strength

The maximum increment rate in all strength parameters was noticed with the mix having 0.5% rubber and 0.5% polypropylene [44]. The rate of increment in early compressive strength of the optimum mix (0.5P/0.5R HyFRG) was higher than the other curing ages. Meanwhile, the optimum mix attained the maximum compressive strength and high rate of increment at 28 days [17]. The optimum mix increment rate in 3, 7, and 28 days of compressive strength was enhanced by 62.6%, 51.2%, and 23.9% than the other mixes [32]. The findings explored a decrease in strength when the rubber fibre addition exceeds 0.5% [62]. In the meantime, compressive strength was enhanced with the addition of polypropylene fibre [50]. The GPC with 1% polypropylene fibre attained higher compressive strength than the mix with 1% rubber fibre [68].

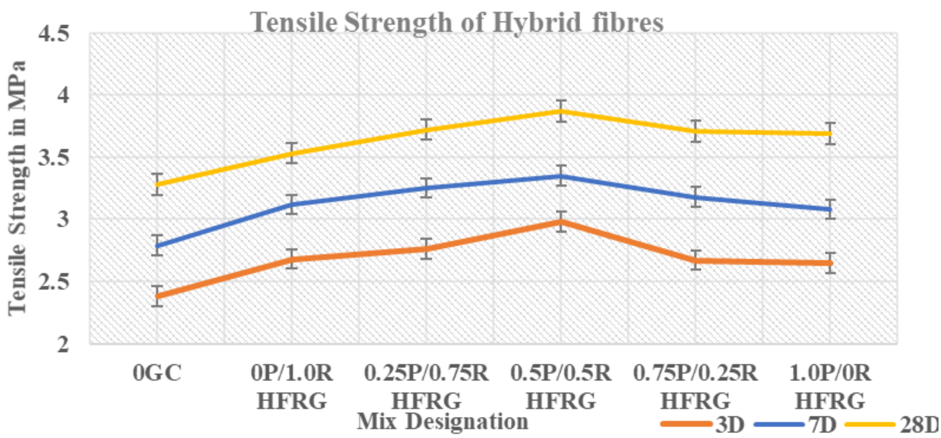


Fig. 6 (b) Influence of hybrid fibre in split tensile strength

The maximum rate of increment in 3, 7, and 28 days tensile strength of 20.1%, 16.7%, and 15.2% were attained by the optimum mix (0.5P/0.5R HyFRG), and the rate of increment of each mix was illustrated in figure 6 b [66]. The enhancement in tensile strength was higher with the rubber fibre addition than the polypropylene fibre addition [39]. The maximum rate of increment in early age tensile strength was higher than the other curing ages [33].

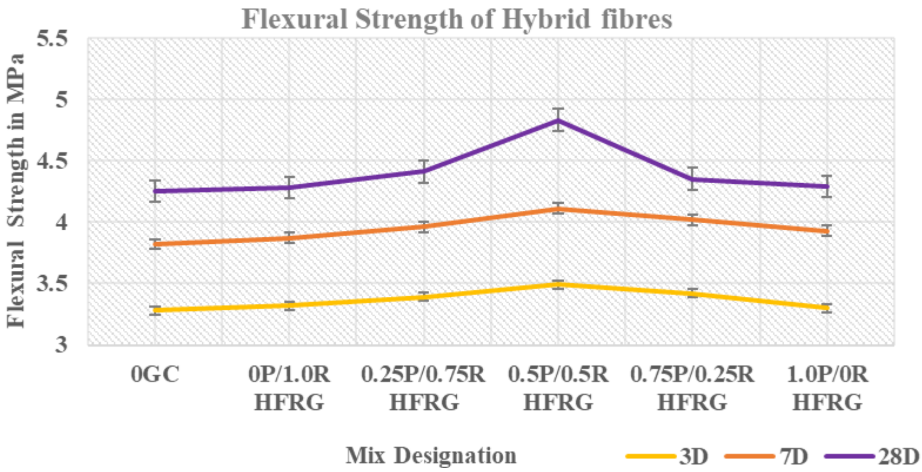


Fig. 6 (c) Influence of hybrid fibre in flexural strength

The maximum rate of increment in flexural strength was achieved with the optimum mix (0.5P/0.5R HyFRG). In the increase of flexural strength, the percentage increment was much higher than that of tensile strength. The maximum strength was achieved by adding 0.5% polypropylene fibers and 0.5% rubbers [44]. The maximum rate of increment in 3, 7, and 28 days of tensile strength of 6%, 7.1%, and 12.0% were attained by the optimum mix (0.5P/0.5R HyFRG), and the rate of increment of each mix was illustrated in figure 6 c [33]. The enhancement in flexural strength was noticed with the increasing the rubber fibre.

5.2 Durability Characteristics

5.2.1 Water Absorption

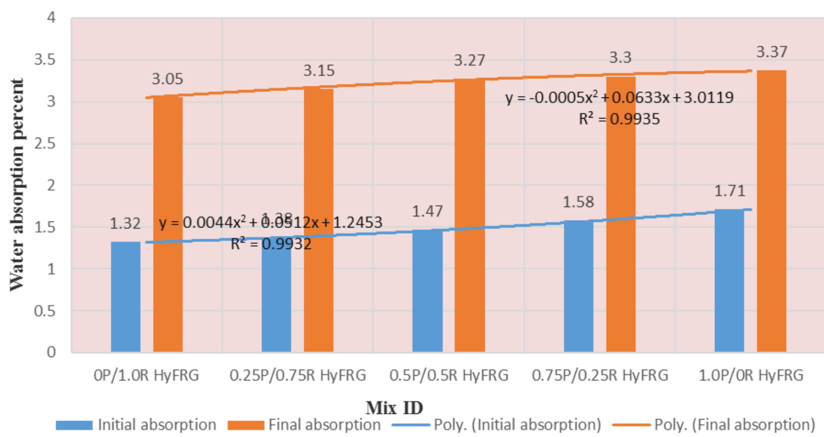


Fig. 7 Initial and final water absorption capacity of each specimen

The water absorption capacity of each specimen was evaluated by comparing the wet weight to the oven-dried weight. For the initial capacity to absorb water, the specimen was weighed 60 minutes after immersion, and the final capability for water absorption was quantified 24 hours later [66]. The chart in Figure 7 depicts the absorption capacities of each specimen. Initial and final water absorption was lower for the control mix (0GC). The control mix absorbed water at 1.32 and 3.05 at the start and end. The 1P/0R HyFRG mixture absorbed 3.66 percent of the total water [20]. The optimal 0.5P/0.5R HyFRG mix observed 3.27 closer to the control mix. The percentage of hybrid fibre added increased the capacity of the geopolymer concrete to absorb water. Incorporating hybrid fibre may allow for greater water absorption than the control mix. The greater water absorption was because of the large surface area and porous medium of the mix, which allows it to absorb more water [69]. However, the mix with 0.5 percent PP+0.5R absorbs less water than the mix with 100% PP and can be used for efficient hybridization [70]. Relation between the replacement percentage of hybridization(x) to the water absorption of each mix(y) obtained from regression analysis was y=-0.0005x2+0.0633x+3.0119, R^2 = 0.9935 [71].

5.2.2 Electrical Resistivity

Each specimen's electrical resistivity was measured in K-Ohm-cm [69] per ASTM C1760 [57] standards. The electrical resistivity of various mixtures is shown in Figure 8. Adding PP and rubber fibres reduced the electrical resistivity of GPC beyond the optimum limit. The optimum 0.5PP/0.5R HyFRG mix had the highest electrical resistivity of 440 compared to other mixes [72]. The control mix had 375K-Ohm-cm resistivity. The 0.5PP+0.5R hybridization displayed superior resistivity to the control sample. The super resistivity was due to rubber fibre with a greater surface area and higher specific electrical resistance [73]. The relation between the hybridization of fibre (x) to the electrical resistivity of each specimen was obtained by regression analysis. The relation is $y=--13.214x^2+78.786x+311$, R^2 = 0.9142 [27].

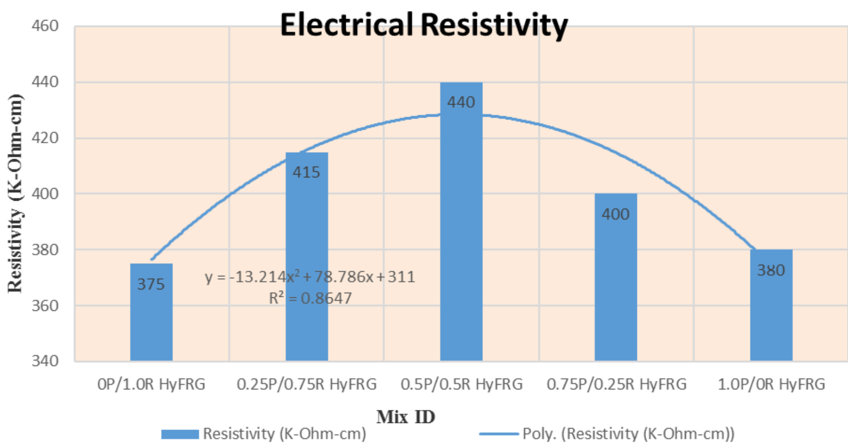


Fig. 8 Electrical resistivity of LCGPC mixes

5.2.3 Acid Attack Resistance

Figure 9 shows the resistance to sulphuric acid attack for each mix, and Figure 10 shows the percent weight loss and percent compressive strength loss for each mix. The sample weight was determined and compared to the starting weight of oven-dried samples after immersion in sulfuric acid for 1 day [69]. Its compressive strength was also measured. The findings showed that the addition of 0,5PP+0,5R in the acidic medium was most responsive [74]. The increase in the replacement percentage of GPC fibre increased the mass loss percentage [20]. With a mix of 1 percent PP fibre, maximum losses were observed in 6.39

percent. The 1% rubber fibre mix lost 4.28 percent weight. Thus, rubber fibre may be able to withstand acidic environmental conditions. The regression analysis was performed for the % loss in weight of each mix under the sulphuric acid environment. The relation between hybridization of fibre (x) to the percentage loss in mass of the specimen(y) was determined as $y = -0.0025x^2 + 0.2565x + 3.9504$, $R^2 = 0.9882$. The value of R2 closer to 1 showed that there is a good correlation of results.

Fig. 9 Specimens after exposure to the acidic environment

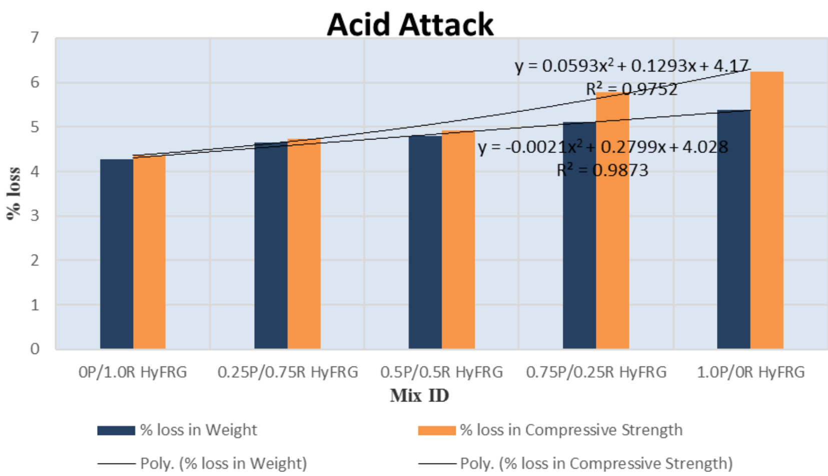


Fig. 10 Percentage loss in mass and compressive strength of LCGPC mixes due to acid attack

In the meantime, for each specimen, there was a percent loss in compression strength. Control specimens were sufficiently capable of resisting the reaction in acidic environments [66]. After being attacked by sulphuric acid, the specimens suffered a 4.28-4.79 percent reduction in compressive strength. The loss of compressive strength, when exposed to acidic conditions, has increased due to the addition of PP fibre [75]. However, adding PP at a concentration of 0.5 percent resulted in a loss of compressive strength comparable to that of the control mixture [22]. It demonstrates that the rubber fibre has enhanced compressive strength performance and resistant to compression strength loss in acidic conditions. The relation between hybridization of fibre (x) to the percentage loss in compressive strength(y) was determined as $y=0.0339x^2+0.1442x+4.0967$, $R^2 = 0.9944$. The value of R2 closer to 1 showed that there is a good correlation of results.

5.3 Microstructural Characterization

5.3.1 Scanning Electron Microscope

HyFRG-specimens were analyzed microstructurally with the aid of a scanning electron microscope (SEM) and shown in Fig 11. (a-f). Figure 10 shows the pores bridging of PP fibre (a-c). The PP fibre micrograph shows a heterogeneous and cracked matrix with a nonremoved solvent after being cured. These findings indicate a greater linkage among reacted and unreacted microspheres [68]. On the other hand, the particle pore bridging determines the results. The 0.5P/0.5R HyFRG mix has good porosity and microcracks, but the early strength production is limited. Replacing LCWWA results in a better geopolymerization and microstructure reaction [11].

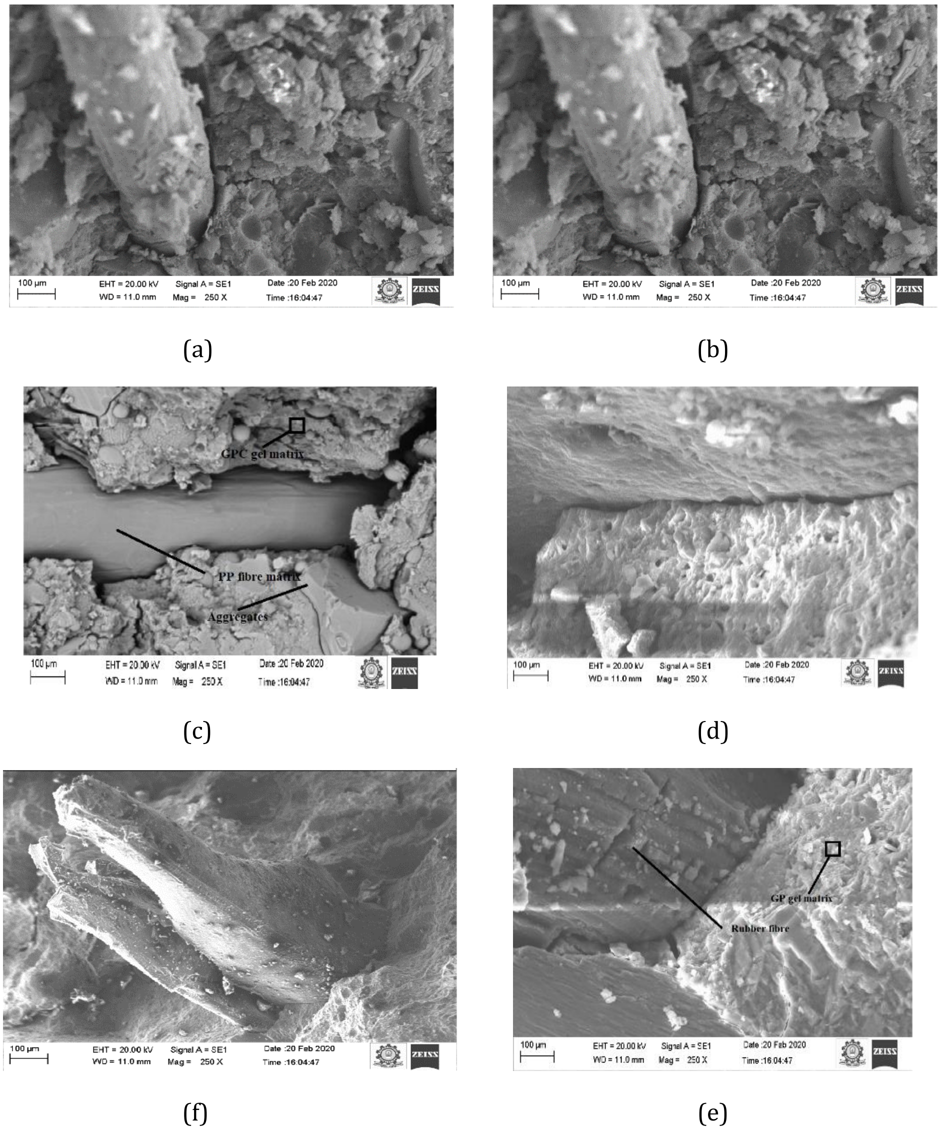


Fig. 11 Microstructure Analysis of HyFRG Mixes (a-c) PP fibre (e-f) Rubber Fibre

The ITZ zone of the geopolymer matrix and rubber fibre presence was established in Figure 10 (d-f). More homogeneous and dense gel matrices were observed when the optimum mix of 0.25P/0.75R HyFRG was used compared to a PP fibre-containing mixture [76]. The pore bridging impact among both fibres was enhanced by adding a small number of fibres to the mixture.

6. Conclusion

In this research, an intellectual approach for the utilization of wastes in the invention of green geopolymer concrete was made for a clean and sustainable environment. Influences on the mechanical characters of the green geopolymer concrete by rubber and polypropylene fibre have been studied. In addition, the mechanical and durability characteristics of green geopolymer concrete were characterized by the effects of the hybridization of polypropylene and rubber fiber. In contrast to the control mixture, the addition of PP up to 1% exhibited an increasing trend in all mechanical strengths at all curing periods. While increasing the addition of fibre over 1% resulted in decreasing all strength parameters. In the age of 28days curing period, the mix with 1% PP attained a maximum increase in compressive, flexural, and tensile strength as 61.4%, 47.0%, and 22.2%, respectively. The mix with 0.5%PP and 1%PP showed the maximum percentage of increase as 5.13% and 11.4% compared to the control mixture cured for 28 days. On the other hand, up to 1% rubber addition enlarged the highest strengths in all mechanical characterizations. Compared with the control mixture, the compressive strength, tensile strength, and flexural strength were increased by 8.65%, 11.83%, and 3.19%, respectively. Meanwhile, rubber addition over 1% results in decreasing the strength attainment. While hybridization of fibres, the compressive, tensile, and flexural strength of mix with 0.5% of PP fibre and 0.5% of rubber fibre had increased by 23.9%, 15.2%, and 12% at the age of 28 days compared to other mixes with and without fibres. The mix with 0.5P+0.5R performed better in water absorption, electrical resistivity, and acidic environmental exposure in the durability characteristics. The optimum mix of 0.5P/0.5R HyFRG was observed water absorption of 3.27, which was nearer to the control mix. The optimum mix 0.5PP/0.5R HyFRG observed the electrical resistivity of 440, which was the maximum resistance value compared to other mixes. Also, the mix 0.5P/0.5R HyFRG showed the most reactive and retained its compressive strength in the acidic environment. In the microstructure of the optimum mix 0.5P/0.5R HyFRG showed increased homogeneity and density of gel matrices. The bore bridging effect of both the fibres was enhanced with the limited addition of fibres. The replacement of LCWWA leads to improving the geopolymerization reaction and also the microstructure. Hence, the research hypothesis was proven that waste materials like rubber tire fibre and wood ash could be effectively utilized to produce green geopolymer concrete, and it paved the way for a clean and sustainable environment.

7. Future Study

In the future study, the study will be extended by investigating low calcium fibre reinforced Ferro-geopolymer concrete paver block. The optimization of size, shape, and surface texture of the paver block will be studied in detail.

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