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Hybrid fibre reinforced eco-friendly geopolymer concrete made with waste wood ash: A mechanical characterization study

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Abstract

On reducing greenhouse gas emissions by the cement industry, geopolymer with an amorphous polymer form was the best alternative. Geopolymer concrete (GPC) was weak in impact strength, brittle, ductile, and energy absorption than conventional cement concrete. Various property fibres with the capacity to improve the aforementioned properties of GPC can be added. Polypropylene fibre with low elastic modulus and waste tire rubber fibre with high elastic modulus was used in this research to improve energy absorption and impact strength. Different modulus fibres such as polypropylene and rubber was added by 0%, 0.5%, 1%, 1.5% and 2% of volume fraction. The effects of adding individual fibres on the mechanical property of eco-friendly geopolymer concrete were studied. In addition, the influence of hybrid fibres on the mechanical features of low-calcium geopolymer concrete was assessed. The research results revealed that the hybridization of 0.5% of polypropylene fibre and 0.5% of rubber fibre showed better performance and achieved maximum strength in all mechanical features such as compressive, flexural, and splitting tensile behaviour. Meanwhile, the optimum hybrid fibres increased the mechanical features by 23.9%, 12.0%, and 15.2%, respectively, at the 28 days of curing ages compared to geopolymer concrete without fibres.

Keywords: Eco-friendly geopolymer concrete, Waste wood ash, Polypropylene fibre, Waste tire rubber fibre, Hybrid fibre

1. Introduction

The best alternate for cement in the construction sector was geopolymer, an amorphous polymer form developed by the dissolution of alumina and silica from the waste by-products such as fly ash, ground granulated blast furnace slag, metakaolin, and wood ash. The dissolution rate of alumina and silica have related to the concentration of alkaline solutions [1]. Most of the studies were focused on utilizing fly ash for the production of geopolymer concrete [2-7]. The amount of alkaline solutions were the primary parameter of geopolymer concrete strength attainment [8, 9]. Besides achieving full strength, fly ash-based geopolymer concrete has to be cured at a temperature of 60 degrees Celsius in 24 hours [10, 11]. The fly-based geopolymer concrete strength was enhanced with the molarity of sodium hydroxide. In contrast, up to 12M of NaOH increased the strength and silica-alumina dissolution from the binder materials [12]. At the same time, the strength attainment was not enriched if the molarity exceeds 12M [13]. The availability of fly ash was not reduced due to increased awareness of fly ash utilization effectiveness. In 2017, the utilization of fly ash was increased to 69.68Mt to 107.1Mt, while the production decreased to 169.25Mt [14]. Therefore, the researchers needed to find an alternate binder material for the production of geopolymer concrete [15, 16]. GGBS (Ground granulated blast furnace slag) with high calcium was chosen as an alternate for fly ash in the geopolymer concrete production [17]. The early age strength and geopolymer reaction were enriched with the presence of high calcium [18]. However, the excess ions of unreacted silica and alumina were noticed with the disruption of geopolymer reaction by the calcium present in the GGBS [19]. Therefore, the alternate with less calcium and less requirement of alkaline solution could be favourable for the aforementioned problems [20-22]. The material with inbuilt composition of alkaline compounds oxide might be the solution to the aforementioned problem. Hence, in this study, waste wood ash with 14.49% of potassium oxide content in their chemical composition could be substituted for fly ash [23, 24]. The optimization study on substitution ratio of binders and concentration of NaOH and activator to binder ratio was performed and noted [25].

In general, geopolymer concrete was weak in impact resistance and ductility characteristics [26]. Meanwhile, it has less brittleness and energy absorption [27]. The addition of polypropylene (PP) fibres enhanced the first crack load of all the specimens and provides more bonding effect in the concrete structure due to its high aspect ratio and surface texture [28, 29]. The addition of PP fibre enhanced the flexural strength to 36.1 percent and limits the deformation due to shrinkage, and also enhanced the toughness of geopolymer concrete [30, 31]. The incorporation of polypropylene fibre enhanced the impact energy of geopolymer to 6.25 percent [32, 33]. The

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ductility of GPC was also enriched with the Polypropylene (PP) fibre addition, whereas it decreases the shrinkage deformation due to its less degree of compressibility [34, 35]. Therefore, incorporating PP fibre could help limit crack development and formation [36]. The resistance against the crack formation on the structural geopolymer concrete was enhanced with the 0.5 percent PP fibre addition [37]. However, the PP fibre didn't help to enhance the impact strength and energy absorption of the structural members to use in heavy load structures [38, 39]. Hence, there was a need for fibre which improves the impact strength and energy absorption. Durability and mechanical characteristics have increased with the addition of rubber fibre [40, 41]. Meanwhile, the strength properties such as impact and energy absorption were enhanced by the rubber fibre addition [42] and reduced the compressive strength and brittleness of GPC [43]. The impact strength of GPC was enhanced with the rubber fibre addition, which has the capacity of retaining its plastic state [44, 45]. Further, the impact strength, energy absorption, and ductility characteristics were enriched with the polypropylene and rubber fibre hybridization, and also it reduces the brittleness and cracks propagation [25].

Hence, this study assessed single fibre optimization and hybridization of polypropylene and rubber fibre with eco-friendly geopolymer concrete. Further, the influence of individual fibres and hybrid fibres on the mechanical characters of eco-friendly geopolymer concrete has been studied in detail.

2. Material properties

A waste residue obtained from electricity production in the thermal power plant station named Fly Ash (FA) was used in this study [46]. The fly ash type was confirmed by the amount of calcium oxide present in FA, ensuring that the type of fly ash was class F (less than 10% CaO) by the EDX analysis shown in Figure 1. The properties of raw materials such as specific gravity, fineness modulus, and consistency were found using ASTM C188 [47], ASTM C786 / C786M - 17 [48], ASTM C187 [49] standard procedures. The fineness modulus and consistency of fly ash were found as 38% and 6%, and other physical characteristics were tabulated in Table 1. The initial and final setting time was determined as 18 hours and 36 hours. The second binder material was the waste wood ash available in nearby hotels [50]. The amount of calcium oxide (CaO) present in the waste wood ash confirmed the waste wood ash was a low calcium waste wood ash (LCWA) [51]. The EDX analysis found the chemical compounds present in the LCWA were illustrated in Figure 2. The fineness modulus and consistency of LCWA were found as 58% and 9%, and other physical characteristics were tabulated in Table 1. In addition, the initial and final setting time of LCWA was found to be 2.30 hours and 3 hours. In geopolymer concrete, both sodium-based activator and potassium-based activator solutions can be used to develop the geopolymerization reaction. The EDX analysis found that the wood ash has 14.49% potassium oxide content which can help to reduce the requirement of alkaline activator solution [52]. The specific gravity of the constituents added in this study was listed in Table 1. The fineness modulus of fine aggregate and coarse aggregate was 2.91 and 7.6, found using ASTM C136 [53]. The fine aggregate and coarse aggregate unit weight was 1470 $kg/m^{3,}$ and 1590 kg/m^3 found using ASTM C29 [54]. Water absorption and weight loss from Los angles of coarse aggregate were found as 0.9 % and 38 %. The optimal size of fine aggregate and coarse aggregate used in this study was 1.18 mm and 10 mm. In this research, sodium-based activator solutions such as sodium silicate and sodium hydroxide were used [55]. Sodium silicate, which having chemical composition of $Na_2O.2SiO_2.5H_2O$ in powder form was used. 10M concentration of sodium hydroxide pellets was used to produce the activator solution [56].

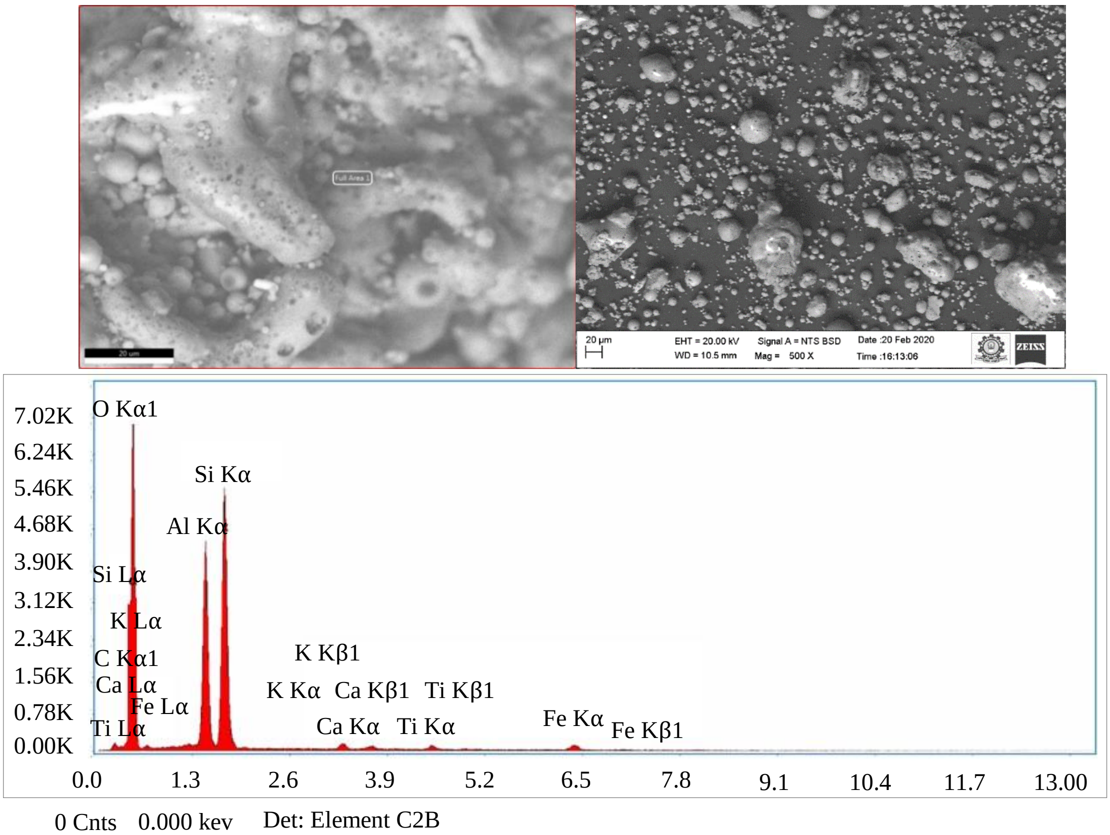


Figure 1 Microstructure analysis of FA through SEM and EDX

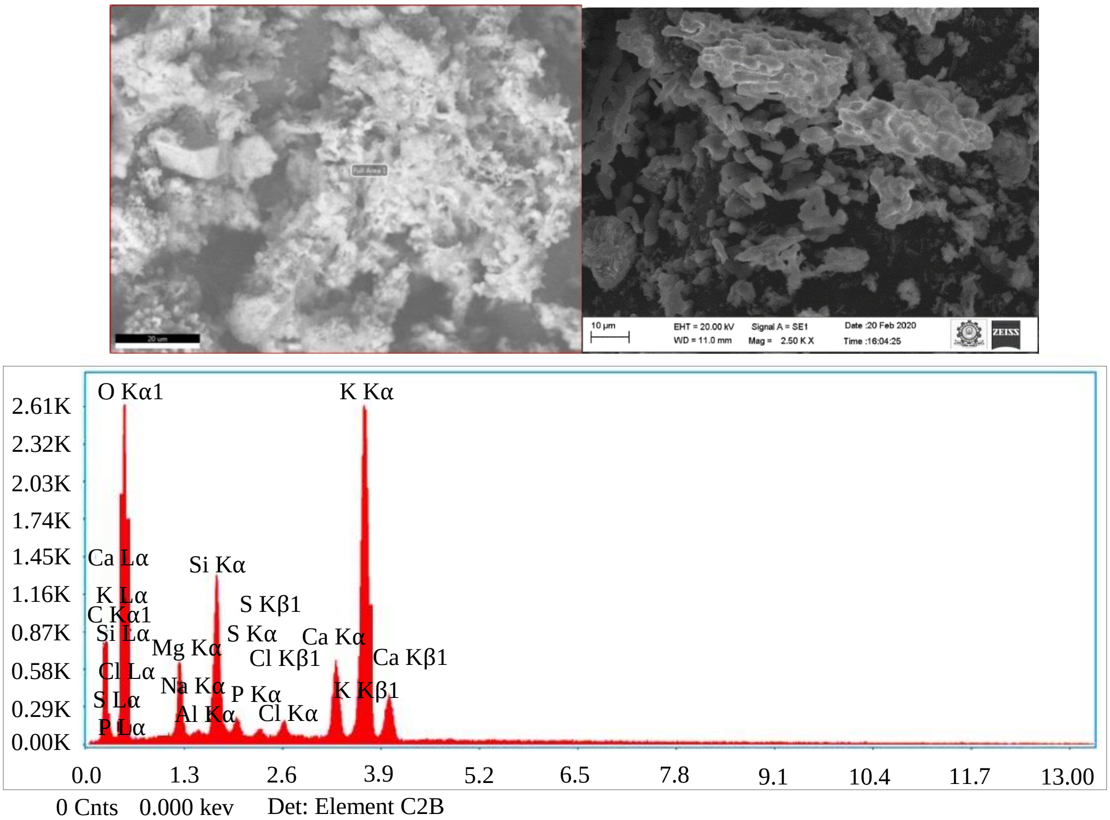


Figure 2 Microstructure analysis of LCWA through SEM and EDX

Low modulus polypropylene fibre [57] of length 20 mm was bought from the online suppliers. Waste rubber tire was purchased from the local workshops and cut into the required size. Rubber fibre [58] was one type of latex product that has high modulus was used and cut to the length of 20 mm. The addition of both the PP and rubber fibre was varied by 0%, 0.5%, 1%, 1.5% and 2% of volume fraction. The hybrid fibres such as polypropylene and rubber fibre were varied by 0, 0.25, 0.5, 0.75, and 1% volume fraction. Table 2 listed the chemical compounds present in the FA and LCWA. Figure 1 and 2 represented the scanning electron microscope image of fly ash and waste wood ash.

Table 1 Specific gravity of the constituents

Constituents	NaOH	Na_2SiO_3	FA	LCWA	Fine aggregate	Coarse aggregate	PP fibre	Rubber fibre
Specific gravity	1.61	1.47	2.3	1.7	2.62	2.42	0.91	1.05

Table 2 Chemical Composition of fly ash and LCWA (% by Mass)

Chemical compound	Al_2O_3	SiO_2	K_2O	CaO	Fe_2O_3	MgO	Gd	P_2O_5	TiO_2	C	Others
LCWA	20.32	47.56	14.49	3.61	2.22	3.02	0.51	3.06	1.01	10.22	3.98
FA	31.13	37.3	0.91	2.53	1.99	0.61	-	-	0.99	6.99	4.31

3. Mix proportion

In this study, the modified guidelines proposed for the design of the geopolymer concrete as per IS 10262-2009 were followed to design the mix proportions of eco-friendly geopolymer concrete [59]. The mix ratio for Binder: Sand: Coarse Aggregate was found as 1:1.05:1.57 with the activator to binder ratio of 0.45 [25, 60]. The rubber and polypropylene was added by 0%, 0.5%,1%, 1.5% and 2%, of volume fraction. In addition, the influence of single fibre addition on the mechanical features of eco-friendly geopolymer concrete was investigated. The quantity of materials required for different mixes was found in accordance with the mix proportion and tabulated in Table 3. Further, the percentage of both fibres was varied by 0%, 0.25%, 0.5%, 0.75%, and 1% of volume fraction to produce hybrid fibre reinforced eco-friendly geopolymer concrete. The quantity of materials required for rubber fibre reinforced geopolymer concrete was shown in Table 4. Table 5 illustrates the quantity required for hybridization.

Table 3 Material quantity required for polypropylene fibre reinforced geopolymer concrete in kg/m^3

Mix id	GC	0.5PFRG	1.0PFRG	1.5PFRG	2.0PFRG
FA	385	385	385	385	385
LCWA	96.3	96.3	96.3	96.3	96.3
NaOH	110.2	110.2	110.2	110.2	110.2
Na2SiO3	275.59	275.59	275.59	275.59	275.59
Sand	666.58	666.58	666.58	666.58	666.58
CA	993.7	993.7	993.7	993.7	993.7
Fibre		2.41	4.82	7.22	9.63

Table 4 Material quantity required for rubber fibre reinforced geopolymer concrete in kg/m^3

Mix id	GC	0.5RFRG	1.0RFRG	1.5RFRG	2.0RFRG
FA	385	385	385	385	385
LCWA	96.3	96.3	96.3	96.3	96.3
NaOH	110.2	110.2	110.2	110.2	110.2
Na_2SiO_3	275.59	275.59	275.59	275.59	275.59
Sand	666.58	666.58	666.58	666.58	666.58
CA	993.7	993.7	993.7	993.7	993.7
Fibre		2.41	4.82	7.22	9.63

Table 5 Material quantity required for hybrid fibre reinforced geopolymer concrete in kg/m^3

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

4. Experimental program

The standard mixing procedure followed the method of mixing to get a homogeneous mix. Before 24 hours of the mixing process, NaOH pellets were mixed with water to achieve the liquid solution of NaOH. The water required to dilute the NaOH pellets was calculated [61]. Then the raw binder materials were mixed in the dry state. The geopolymer concrete constituent materials such as a binder, fine aggregate, and coarse aggregate were mixed in the concrete mixer for 3 minutes. The prepared solution of NaOH and Na_2SiO_3 was added to the mix, and then it was adequately mixed for 5 minutes. In accordance with ASTM C109 [62], ASTM C496 [63], ASTM C78 [64] standards, the compressive strength, splitting 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 100 mm x 100 mm x 100 mm size cubes, and for computing splitting tensile strength, 100 mm x 200 mm size cylinder was cast. In addition, a 500 mm x 100 mm x 100 mm size prism was cast to compute flexural strength. In this study, ambient curing condition was chosen to cure the casted specimens for 3, 7, and 28 days. The influence of single fibre addition and hybrid fibres on mechanical features of eco-friendly GPC was assessed. Compressive, flexural and splitting tensile strengths test were performed to find the mechanical features. Figures 3-5 showed the testing of specimens.

Figure 3 Testing of the cube for compressive strength

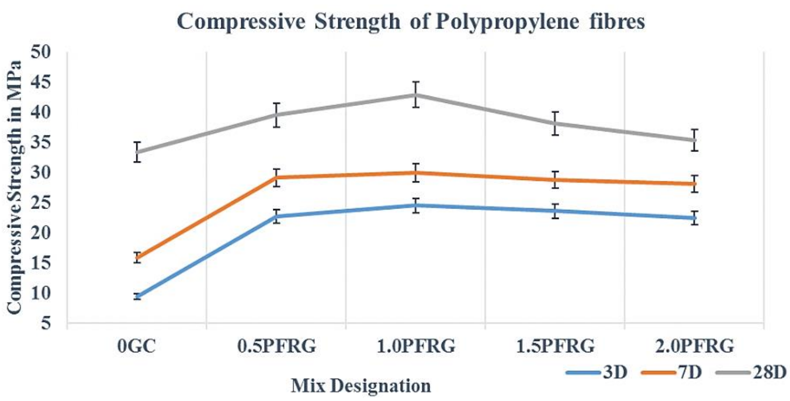
Figure 4 Testing of the cylinder for splitting tensile strength

Figure 5 Testing of prism for flexural strength

5. Result and discussion

5.1 Effect of polypropylene fibre

The influence of polypropylene (PP) fibre on the mechanical features of eco-friendly geopolymer concrete was illustrated in Figure 6-8. The PP fibre was added by 0, 0.5, 1, 1.5, 2% of volume fraction, and their influences on each mechanical character were assessed. There was a specified limit for the fibre addition noted from [25], and the study confirmed that 2% of fibre was only added. Exceeding the fibre addition could reduce the rigidity of the concrete medium. In this study, all the mechanical characters at all concrete ages were enhanced with the 1% fibre addition. The increasing trend was due to the easy spread of fibre matrix and its stiffened bonding over the concrete internal pores [38]. Further increasing the fibre addition beyond 1% reduced the strength attainment [36]. The reduction in strength was due to the augmentation of fibres in one place, which could develop the unstiffened matrix [29]. Compared to the control mixture, the compressive strength of the mixes in 3 days was increased by 58.3%, 61.4%, 60%, and 57.9%, whereas the strength in 28 days was increased by 15.5%, 22.2%, 12.5%, and 5.4% [31]. Thus it confirmed that PP fibre addition helped in enhancing the early age strength attainment. However, Comparing all mixes, the mix with 1% of PP fibre achieved the highest percentage of increment in compressive strength as 61.4%. Therefore, the mix with 1% of PP fibre achieved the maximum strength attainment. Moreover, the compressive strength of the mix with 1% PP fibre in 3, 7 and 28 days curing was enhanced by 61.4%, 47%, 22.2% respectively, compared to the control mixture.



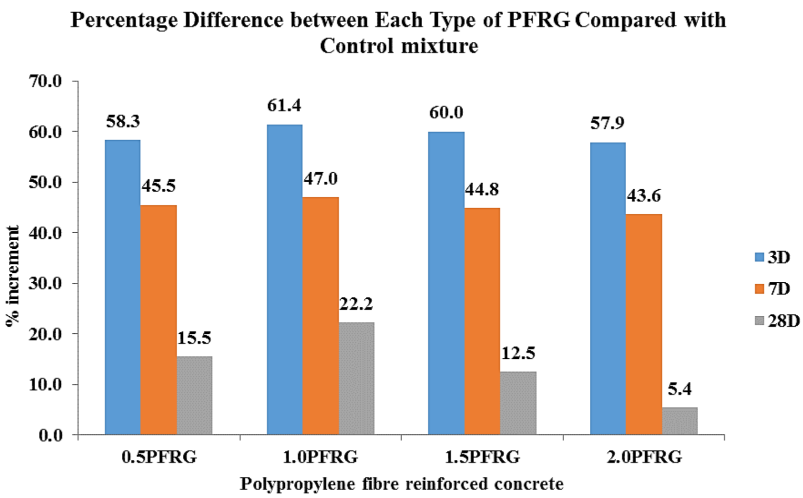
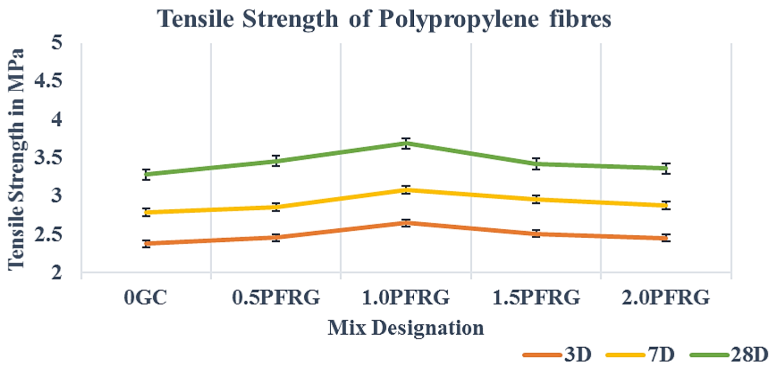


Figure 6 Influence of PP fibre in compressive strength

From Figure 7 it was observed that the splitting tensile strength in 28days was enhanced by 5.2% and 11.1% with the addition of 0.5% PP and 1% PP than the control mixture. The percentage increment in strength was not gradual, which means the addition of fibre up to 1.5% enhanced the splitting tensile strength of GPC [32]. Besides, the mix with 1.5% of PP fibre achieved a higher increment in strength at all age of concrete than the mix with 0.5% of PP fibre. However, the splitting tensile strength in 3, 7, and 28 days was enhanced by 10.2%, 9.4%, and 11.1% with the 1% PP fibre addition. The mix with 2% of PP fibre showed less percentage of increment in all ages of curing due to the large quantum of fibres which could augment the fibre in one place [65]. The maximum increment rate in splitting tensile strength was achieved with the 1% PP fibre addition than the other mixes. This improvement in strength was related to the capacity of PP fibre, which has enhanced the splitting tensile and flexural strength [28].



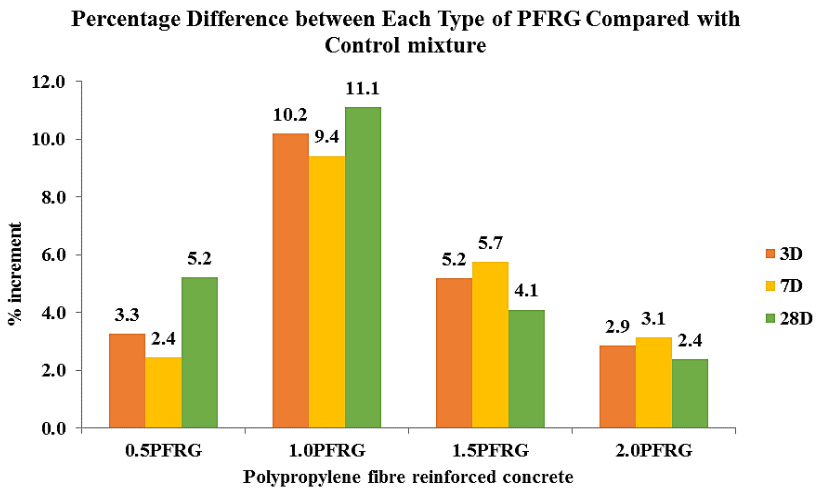


Figure 7 Influence of PP fibre in splitting tensile strength

From Figure 8 it was observed that the flexural strength in 28 days was enhanced by 5.13% and 11.46% with the addition of 0.5% PP and 1% PP than the control mixture [33]. On the other hand, the flexural strength in 3 and 28 days was enhanced by 8.38%, 10.75%, and 11.46% with 1% PP fibre addition. The strength increment was gradual up to 1% of PP fibre addition, and then the increment was decreased. The maximum increment rate in flexural strength was achieved with the 1% PP fibre addition than the other mixes [37].

The gradual increment in all strength aspects up to 1% of PP fibre addition was noticed due to the development of stiffened fibre matrix in the concrete medium. In contrast, the strength reduction was observed with the mix exceeding 1% of PP fibre due to the augmentation of fibres which developed the unstiffened matrix [26]. Hence, the result findings suggested that adding 1% of PP fibre could help improve the compressive, splitting tensile and flexural strength of the eco-friendly geopolymer concrete, which confirmed the previous research outcomes [36].

5.2 Effect of rubber fibre

Figure 9-11 illustrated the influence of rubber fibre on mechanical characters of eco-friendly geopolymer concrete. In previous research [43, 44, 66], the rubber was used as crumbed rubber replaced with fine aggregate in various percentages. The research shows that the strength was not enriched with the rubber addition exceeds 5 percent. The research findings also showed that the rubber could be added in smaller volume fractions to improve the strength properties. In this research, the rubber was added as fiber with a smaller volume fraction. In this study, all the mechanical characters at all concrete ages were enhanced with the 1% rubber fibre addition [51]. The strength increment was due to the easy spread of rubber fibre over the concrete pores and developed the stiffened bonding [40]. Further increasing the fibre addition beyond 1% reduced the strength attainment due to the development of an unstiffened matrix by the augmentation of fibres in one place [43]. Meanwhile, compared to the control mixture and other curing ages, the compressive strength of each mix attained the maximum percentage of increase over the early age of curing. Compared to the control mixture, the compressive strength of the mixes in 3 days was increased by 57.87%, 59.89%, 59.13%, and 57.32%, whereas the strength in 28 days was increased by 7.02%, 8.65%, 7.59%, and 6.68%. Thus it confirmed that rubber fibre addition helped in enhancing the early age strength attainment. Comparing all mixes, the mix with 1% of rubber fibre achieved the highest percentage of increment in compressive strength as 59.89%. The mix with 1% of rubber fibre achieved the maximum strength attainment. Moreover, the compressive strength of the mix with 1% rubber fibre in 3, 7, and 28 days curing was enhanced by 59.89%, 46.66%, 8.65%, respectively, compared to the control mixture. The gradual increment in all strength aspects up to 1% of rubber fibre was noticed due to the development of stiffened fibre matrix in the concrete medium [41]. In contrast, the strength reduction was observed with the mix exceeding 1% of rubber fibre due to the augmentation of fibres which developed the unstiffened matrix [66].

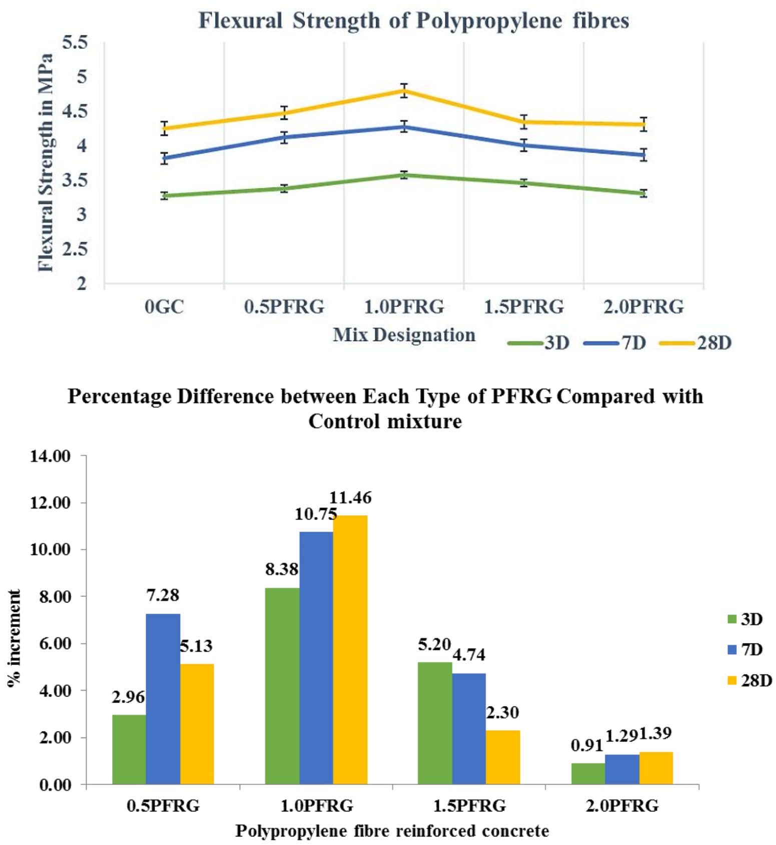


Figure 8 Influence of PP fibre in flexural strength

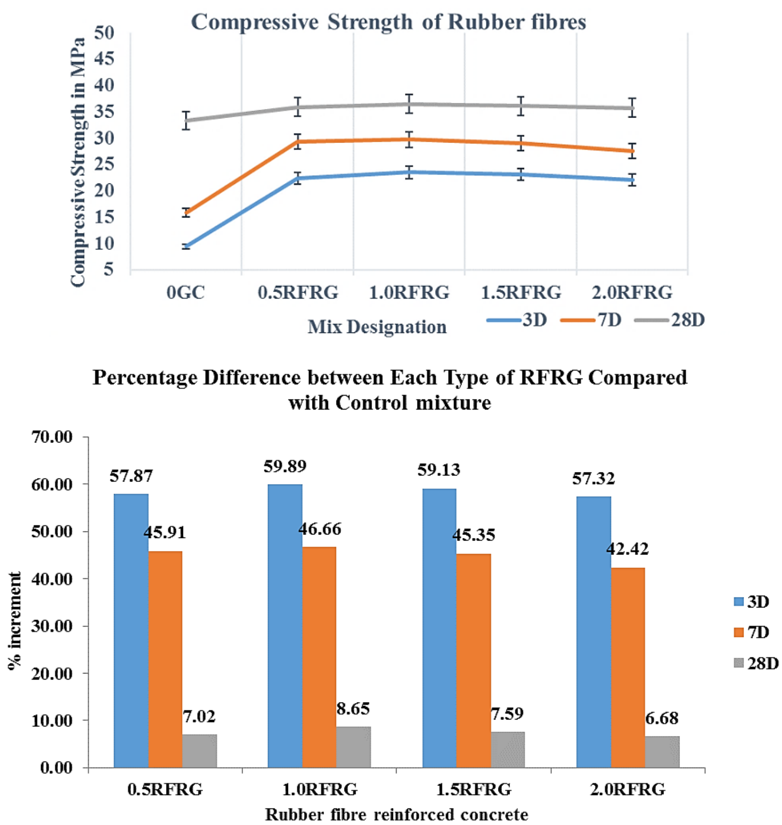
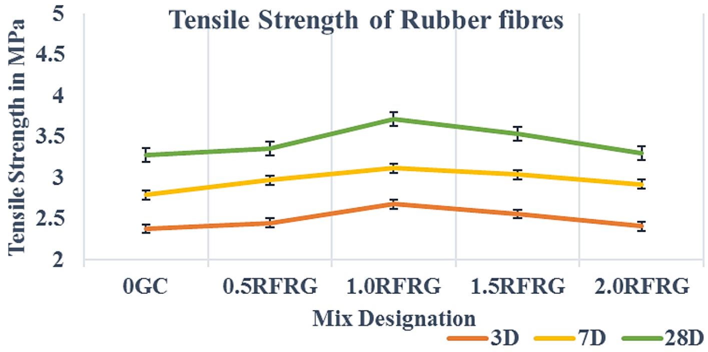


Figure 9 Influence of rubber fibre in compressive strength

The highest rate of strength increment was observed with the addition of PP fibre compared to the strength increment rate of rubber fibre addition [42]. This decrement was due to rubber, which could decrease the compressive strength [67].



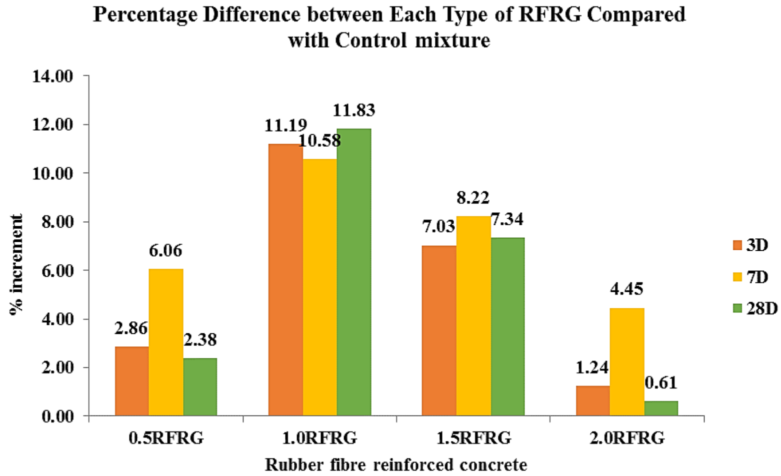


Figure 10 Influence of rubber fibre in splitting tensile strength

From Figure 10, it was observed that the splitting tensile strength in 28days was enhanced by 2.38% and 11.83% with the addition of 0.5% rubber fibre and 1% rubber fibre than the control mixture. Besides, the mix with 1.5% of rubber fibre achieved a higher increment in strength at all concrete ages than the mix with 0.5% of rubber fibre. However, the splitting tensile strength in 3, 7, and 28days was enhanced by 11.19%, 10.58%, and 11.83%with the 1.0% of rubber fibre. The mix with 2% of rubber fibre showed less percentage of increment in all ages of curing, such as 1.24%, 4.45%, and 0.61%, due to the large quantum of fibres which could augment the fibre in one place [45]. The maximum increment rate in splitting tensile strength was achieved with the 1% rubber fibre addition than the other mixes. This improvement in strength was related to the capacity of rubber fibre, which has enhanced the splitting tensile and flexural strength [29, 43, 51].

From Figure 11, it was observed that the flexural strength in 28days was enhanced by 1.85% and 3.19% with the addition of 0.5% rubber fibre and 1% rubber fibre than the control mixture [33]. However, the flexural strength of 3 and 7 days showed a higher %increment than 28 days due to the rubber fibre enhancing early age strength attainment. On the other hand, the flexural strength in 3 and 28 days was enhanced by 4.09%, 7.95%, and 3.19% with 1% rubber fibre addition. In contrast to the control mixture and other RFRG mixes, rubber addition up to 1% attained the highest increment in flexural strength due to the stiffened fibre matrix [41, 44]. The strength increment was gradual up to 1% of rubber fibre addition, and then the increment was decreased. The decrement in the percentage of increase was due to fibre augmentation in the mix with 2% of rubber fibre [67, 68]. Therefore, the maximum increment rate in flexural strength was achieved with the 1% rubber fibre addition than the other mixes. However, the increment in strength with rubber fibre addition was less than the rate of increment in strength with PP fibre addition [43, 69].

Hence, the result findings suggested that the addition of rubber fibre up to 1% could help in gradually improving the compressive, splitting tensile, and flexural strengths of the eco-friendly geopolymer concrete, which confirmed the previous research outcomes [51].

5.3 Effect of hybridization of polypropylene and rubber fibre

Mechanical characterization of eco-friendly geopolymer concrete by adding each fibre, such as rubber and polypropylene fibres, was performed earlier. The findings showed that all the strength parameters were enhanced by incorporating 1% fibre [27]. In addition, this research was extended to investigate the influence of hybrid fibres of PP and rubber fibres on the mechanical characters of eco-friendly geopolymer concrete. The graphical representation of the results of hybrid fibre addition was shown in Figure 12-14. In addition, the percentage increase of compressive, splitting tensile, flexural strengths of hybrid fibre reinforced eco-friendly geopolymer concrete mixtures was explored in Figure 12-14.

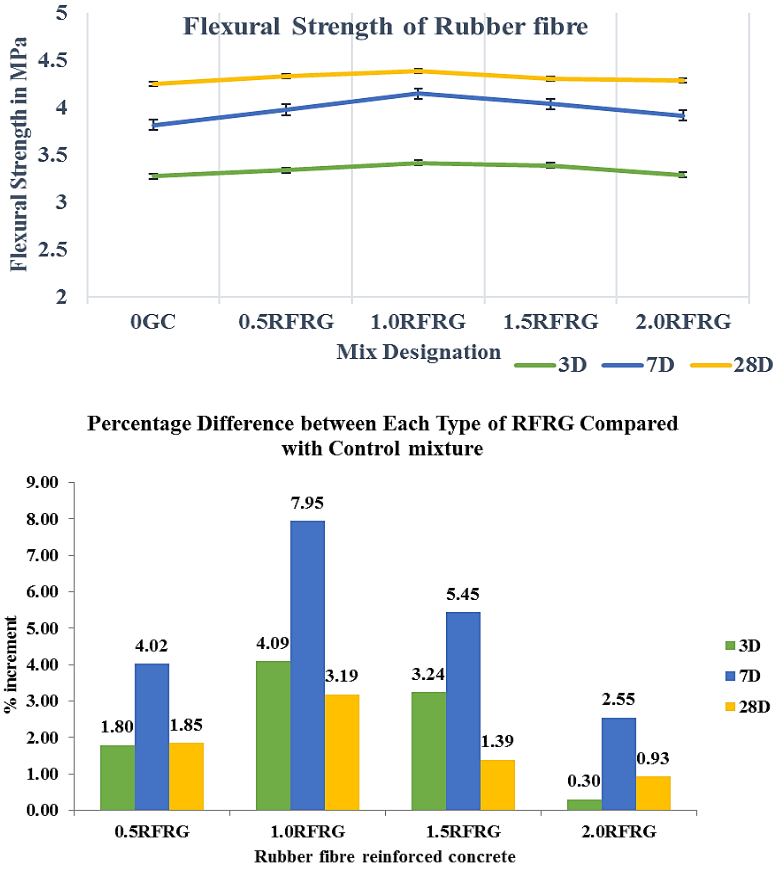


Figure 11 Influence of rubber fibre in flexural strength

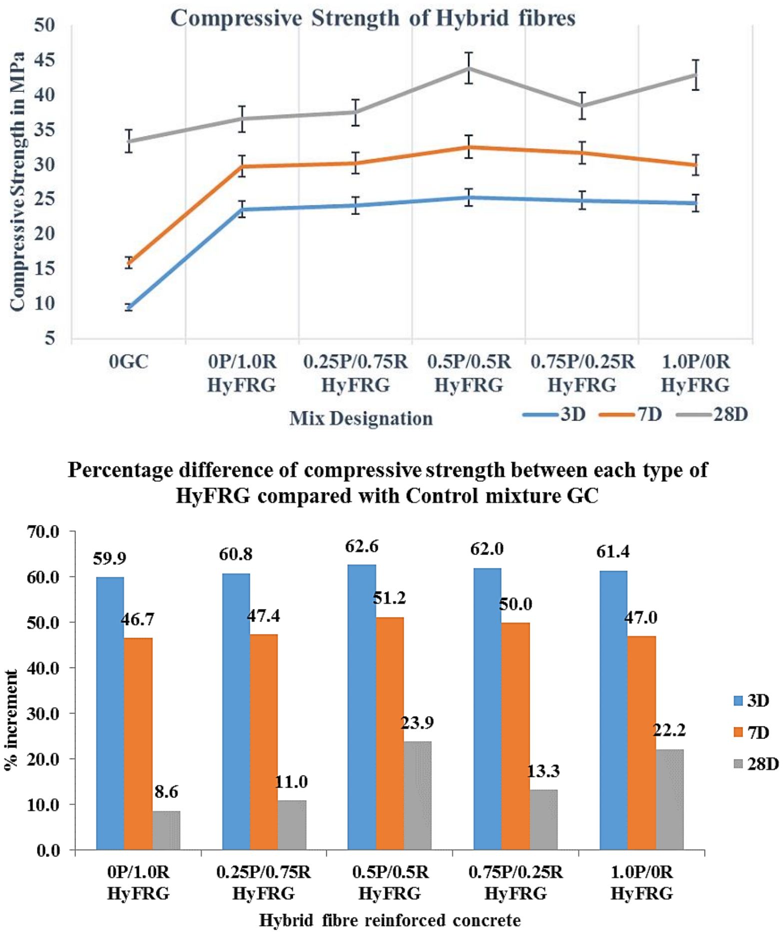


Figure 12 Influence of hybrid fibre in compressive strength

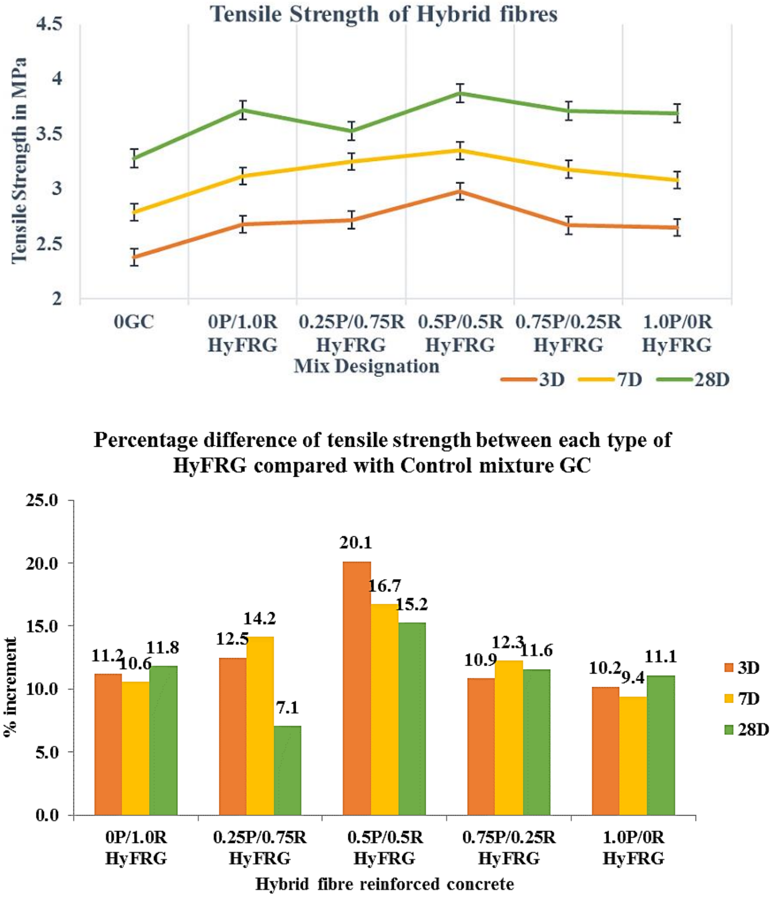


Figure 13 Influence of hybrid fibre in splitting tensile strength

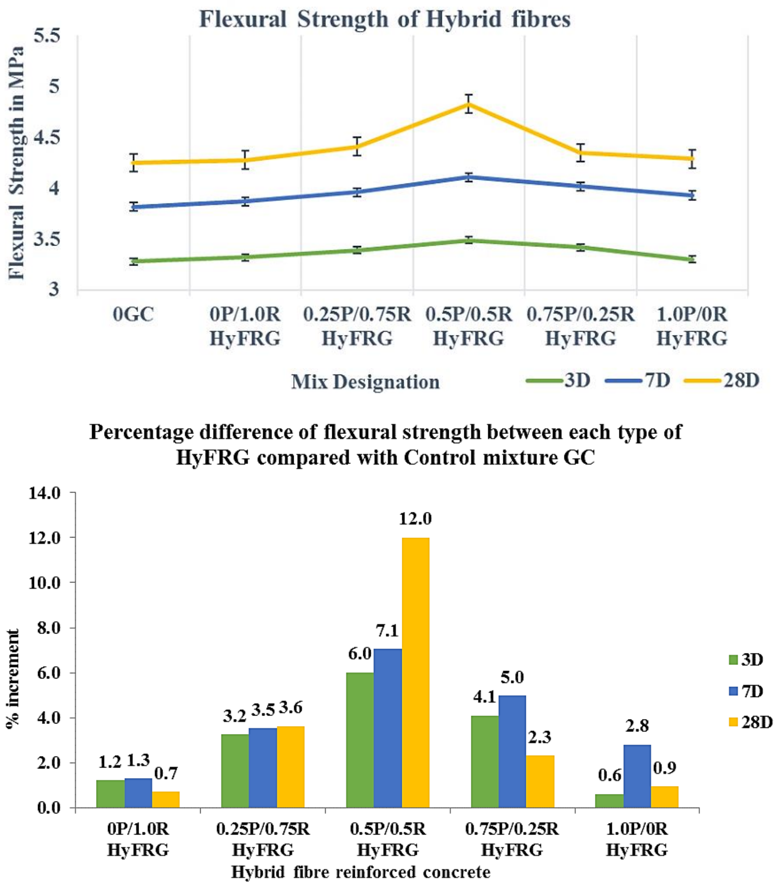


Figure 14 Influence of hybrid fibre in flexural strength

The maximum rate of increment in all the mechanical characters such as compressive, splitting tensile, and flexural strengths was enhanced with the mix with 0.5% of PP and 0.5% of rubber fibre. All the hybrid mixes achieved the highest rate of increment (46.7 to 62.6 percent) in compressive strength at early days of curing than the 28 days curing (8.6-23.9 percent) [70]. Meanwhile, the maximum compressive strength at 28 days was achieved using 0.5% PP and 0.5% rubber fibre. Compared to other mixes, the mix with 0.5% PP and 0.5% rubber fibre enhanced the compressive strength in 3, 7, and 28 days by 62.6%, 51.2%, and 23.9%. The reduction in compressive strength was noted with the rubber fibre addition exceeds 0.5% due to a high degree of compressibility of rubber fibre [28, 71]. Meanwhile, the strength enhancement at all ages of concrete was achieved with polypropylene fibre [26]. The mix with 1% PP fibre revealed good performance in compressive strength at all ages due to its lower degree of compressibility than the mix with 1% rubber fibre [51].

Compared to other mixes, the mix with 0.5 % PP and 0.5% rubber fibre enhanced the splitting tensile strength in 3,7 and 28 days by 20.1%, 16.7%, and 15.2% [36]. The increment rate in splitting tensile strength was higher with the addition of rubber fibre than the increment rate with PP fibre addition [34]. The strength increment was gradually increased by increasing the rubber fibre content up to 0.5% in the mix. The rubber fibre has a high elastic modulus which could help to improve the splitting tensile strength [24].

Compared to other mixes, the mix with 0.5% PP fibre and 0.5% rubber fibre obtained the highest rate of increment in flexural strength. The increment rate in flexural strength was less than the increment rate of splitting tensile strength [27]. Moreover, the addition of rubber fibre could improve the capacity of resisting flexural loading in all types of mixes [40, 67]. Compared to other mixes, the mix with 0.5 % PP and 0.5% rubber fibre enhanced the flexural strength in 3,7, and 28 days by 6%, 7.1%, and 12.0%. Similar to splitting tensile strength, strength increment was gradually increased with fibre incorporation [44]. The finding showed that increasing rubber fibre replacement with PP fibre up to 0.5% enhanced the flexural strength at 28 days from 0.9% to 12%. The pp fibre addition up to 0.5% also increased the flexural strength to 12%. The research findings suggested that the addition of different property fibres could help in enhancing the mechanical behavior of geopolymers. Besides, each fibre helped in improving each characteristics of eco-friendly geopolymer concrete which was confirmed by the previous research findings [26].

6. Conclusion

The study aimed to produce eco-friendly geopolymer concrete with major waste utilization and incorporating different property fibres and waste fibres to enhance the energy absorption, ductility, brittleness, and toughness characteristics. Mechanical characterization of eco-friendly geopolymer concrete by the addition of hybrid fibres was assessed. Further, the characterization was done with the influence of hybrid fibres on the mechanical behavior of eco-friendly geopolymer concrete. The research findings showed that incorporating polypropylene fibre and rubber fibre up to 1% enhanced all the mechanical characters at all ages of concrete. The compressive strength, splitting tensile strength, and flexural strength after 28 days of curing, was enhanced by 61.4%, 11.1%, and 11.46%, respectively, with 1% PP fibre. At the same time, the strength of the mix with 1% PP fibre in the earlier age of concrete (3days) was enhanced by 59.89%, 11.83%, and 4.01%, respectively. The reason behind the increment in strength was the formation of stiffened matrix inside the concrete medium. The mix with 1% rubber fibre enhanced the compressive strength, splitting tensile strength and flexural strength in 28 days by 8.65%, 11.83%, and 3.19%, respectively. It confirmed that the early age strength attainment with rubber fibre addition was higher than the later age strength attainment. Whereas the percentage of both fibres (rubber and PP) addition exceeds 1%, decreased all strength parameters due to the unstiffened fibre matrix developed by the augmentation of fibres in one place. Meanwhile, the compressive strength, splitting tensile strength, and flexural strength after 28 days of curing were enhanced by 23.9%, 15.2%, and 12% with the hybridization of 0.5% of rubber and 0.5% of PP fibre, compared to other mixes with and without fibres. Hence, this study admired that the optimum percentage of hybridization enhanced the mechanical properties of eco-friendly geopolymer concrete. The production of hybrid fibre reinforced eco-friendly geopolymer concrete was helped to utilize the wastes in concrete which was the major hypothesis of this research.

7. Future study

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

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