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Mechanical Properties of Geopolymer Concrete Reinforced with the Natural and Waste Plastic Fibers

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Abstract: The flexural and splitting tensile strength were investigated on the specimens prepared with the geopolymer concrete (GPC) reinforced by the combined usage of coir and metalized plastic fibers. The combined addition of natural and artificial fibers has not been explored extensively into the GPC. The objective was to obtain the optimum combined dosage of the artificial and natural fibers to prepare a sustainable construction composite. The results showed excellent improvement of the properties of the GPC at the combined addition of 1% of the fibers for all test conditions.

Keywords ***: Fiber reinforced geopolymer concrete; Flexural strength; Splitting tensile strength; Sustainability.***

I. INTRODUCTION

In the past few years, the geopolymer concrete (GPC) has been explored to increase the cracking resistance and ductility improvement by the addition of the fibers. The efforts have been made to utilize the artificial as well as the natural fibers. The objective of the addition of the fibers is to increase the resistance of the composite under the tensile forces and crack formation in the hardened mass. It is well known that fibers are capable to improve the tensile strength of the concrete composites. However, the intensity of the strength improvement has subjected the type, geometry, and dosage of the fibers. The natural and artificial fibers have been explored into the GPC namely steel and polypropylene and coir, cotton, basalt and agricultural products respectively. The observations of the test results of the previous studies on the topic revealed that strength improvement is influenced by the type of fiber primarily namely natural or artificial. The artificial fibers show better strength of material than the natural fibers tough, the sustainability attributes of preparing the GPC with waste materials may not be satisfied completely. On the other hand, the natural fibers are useful in making the GPC more eco-friendly but lack the excellence of strength improvement.

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In the present study, the artificial (waste metalized plastic fibers) and natural fibers (coir fibers) have been combined to avail the dual advantage of the sustainability and strength improvement simultaneously.

II. LITERATURE SURVEY

The steel fibers are the most commonly utilized artificial fibers into the GPC as reflected by some of the recent studies. The addition of 0.5% of steel fibers was reported to improve the splitting tensile strength by 38% and the flexural strength by 44%. The impact resistance was also increased up to 3.5times that of the unreinforced GPC [1]. The fiber addition and response was influenced by the alkaline concentration also. The reduced molar intensity of the alkaline solution for the sodium hydroxide increased the inter-molecular binding of the galvanized steel fibers in the hardened matrix of GPC [2]. The combined usage of the basalt and steel fibers has been reported. The high-temperature exposure and flexural behavior was studied. The test showed the behavior of the basalt and steel fibers under elevated temperature for the flexural response was excellent at the 800^0C. The failure mechanism for the members with basalt and steel fibers was explored and found satisfactory for the performance of the GPC [3]. In another study, the combination of steel and polypropylene fibers has been investigated. However, the steel fibers were in the micro size fibers. The energy absorption and flexural response were improved due to the combined addition of the fibers. However, both were artificial fibers [4]. There are studies on the addition of the natural fibers in the GPC namely oil palm fibers [5], woven cotton fibers [6], sweet sorghum fibers [7]. For the given dosage of the fibers by the volume fractions in the GPC mix, the properties namely splitting tensile strength, flexural and impact strength were found better and improving due to the fibers. However, the rate of improvement was not as significant as in the case of the artificial fibers. In another study, the carbon and the basalt fibers were mixed into the GPC to avail the reinforcement benefits [8] and the combination provided excellent improvement of the member behavior in case of the elevated temperature. The combination of natural and artificial fibers namely polypropylene and raffia fibers experimented as the combined fiber dosage in the GPC [9]. The flexural behavior of the GPC was reported with excellent improvement for the 1% the volume fraction of the fibers. However, the polypropylene fibers contributed better in terms of the mechanical strength while the natural raffia fibers improved the inter-molecular bonding behavior of the GPC.

From another study on the polyvinyl alcohol fibers into the GPC, the results reported the improvement of the tensile strain hardening, crack propagation and the ductility of the material [10]. As the explorations with the modern fibers, the carbon fibers were mixed into the GPC as the reinforcement fillers and were reported for the increase in the splitting tensile strength, flexural strength and the toughness of the specimens containing the fiber-reinforced GPC [11]. Referring to the literature available on the topic of reinforcing the GPC with natural and artificial fibers, the need for the study was felt for the combined usage of the fibers into the GPC. The present study is an effort to explore the feasibility of the combined addition of the varying nature of the fibers into the composite to avail the optimum resistance against the tensile strength and the flexural response.

III. EXPERIMENTAL

A. Materials

A total of four GPC mixes designated as GPC0, GPC1, GPC2 and GPC3 were prepared. The results of GPC0 were taken as the reference for the comparison between the reinforced and unreinforced GPC specimens. The coir fibers were mixed in GPC and designated as GPC1. The metalized plastic waste (MPW) fibers were added into the GPC2 mixes and the GPC3 mix was prepared with blending of coir and metalized plastic waste fibers. All the fibers were added in the 0%, 0.5%, 1%, 1.5 % and 2% by volume of the mixes. The quantities were determined from the density values of the fibers. The blending was done for both fibers by taking the equal proportions. The binder material was consisting of the fly ash and grounded granulated blast furnace slag (GGBFS) mixed with the alkaline solution prepared with sodium silicate and sodium hydroxide in the ratio of 2.25. The sodium hydroxide was prepared with the 14M concentration. The GGBFS was added to initiate the polymerization process between the binder and alkaline solution. The natural aggregates and sand with 2.78 and 2.63 specific gravity and water absorption of 30% and 47% respectively were utilized into the GPC mix. The coir fibers were rendered into the fibers of 20mm long as average length. Similarly, the MPW fibers were rendered from the plastic packaging films of an average width of 1mm and 20mm length. The fibers are shown in the Fig.1. The general properties of MPW fibers are shown in Table 1. The coir fibers are natural fibers containing cellulous and wood plant substances and bears 10 to 20 micron diameter with 1.3mm length.[13]. Unlike the coir fibers, the metalized plastic fibers are macro fibers and may be rendered into the variety of the lengths namely 5mm, 10mm and 20mm [14]. However, for the present study the 20mm long fibers were selected. The mix proportions of the constituents are shown in Table 2.

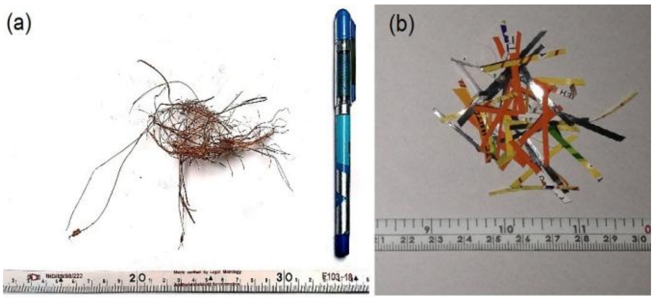

Fig. 1 Samples of the Coir fibers and the MPW fibers

Table 1 General Properties of metalized plastic films

Property	Values	Unit
Resin category	Polypropylene	--
Plastic type	LDPE	--
Density range	0.925-0.94	g/cm^3
Thickness	0.08	mm
Water vapor resistance	Good	--
Oxygen permeability	High	--
Tensile strength (Tested)	800	N/mm^2
Elongation	10-Aug	%
Co efficient of friction	0.45 – 0.55	--
Metalized layer material	Aluminum	--

Table 2 GPC mix proportions

Batch	Fly ash	GGBFS	Alkaline Liquid	Natural Agg.	Sand	Coir fibers	MPW fibers
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	%	%
GPC0	350	200	190	950	700	0	0
GPC1	350	200	190	950	700	0.5, 1,1.5,2	0
GPC2	350	200	190	950	700	0	0.5, 1,1.5,2
GPC3	350	200	190	950	700	0.25,0.5, 0.75,1	0.25,0.5,0.75,1

B. Specimens and tests

The specimens namely cylinders and beams of 150mmx300mm and 100mmx100mmx700mm sizes respectively were prepared for all four mixes. The cylinders were utilized to obtain the splitting tensile strength and the beam members were utilized for the flexural strength in accordance with the IS: 5819-1999[15] and IS: 516-1959 [16] respectively. The splitting tensile strength tests were conducted in the compression-testing machine of 2000kN capacity and the flexural strength tests were performed in the universal testing machine of 400kN capacity.

IV. RESULTS AND DISCUSSION

A. Splitting tensile strength results

Fig. 3(a) and 3(b) shows the effect of the presence of the coir fibers and the MPW fibers into the GPC mix on the resistance to the splitting actions of loads respectively. Fig.3 (c) shows the effect of the combined addition of the coir and MPW fibers.

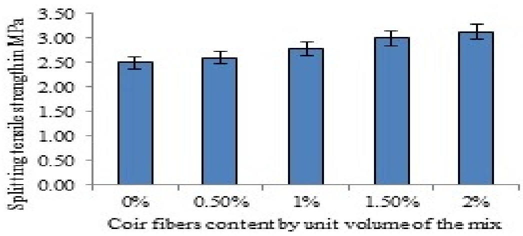

Figure 3 (a) Effect of the coir fibers on the splitting tensile strength of GPC

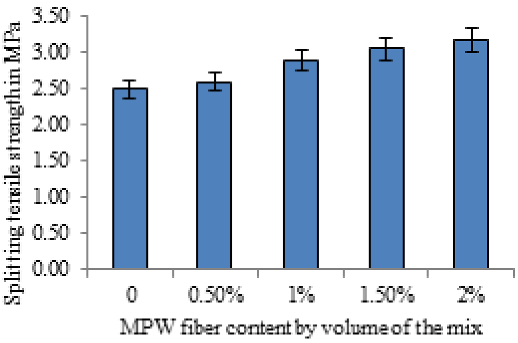

Figure 3(b) Effect of MPW fibers on the splitting tensile strength of GPC

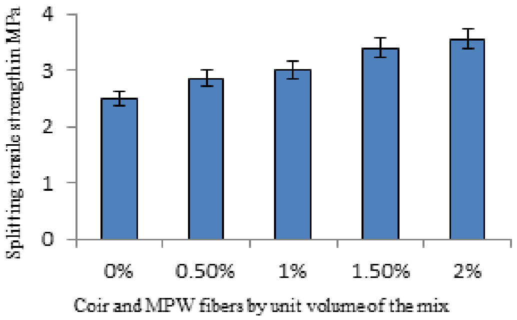

Figure 3(c) Effect of Coir and MPW fibers on the splitting tensile strength of GPC

The addition of the fibers influenced the splitting tensile strength extensively. The coir fibers improved the strength by 6%, 11%, 18%, 21% and the MPW fibers by 8%,12%,16% and 29%. As reported in the previous study [13] on the coir fibers in the composite, the coir fibers showed limited strength improvement compared to the MPW fibers. This may be due to the bonding limitations of the fibers with the constituents. However the combination of the 50% coir and 50% MPW fibers showed excellent improvement of the strength by 12%,22%,32% and 38% for the increment of 0.5%,1%,1.5% and 2% fibers by the unit volume of the mix. The coir fibers were nearly micro- sized fibers contributed into the better intermolecular bonding of the GPC binder gel when added as the only fibers in the mix. On the other hand, the MPW fibers being the macro fibers in size contributed to mitigate the crack propagation during the loading and failure of the inter-facial gel to aggregate bonding. The increased resistance to the splitting action by the GPC reinforced with both the fibers in the equal proportions may be explained as the combined and supplementary effects by the micro and macro fibers to each other's responses. Though the fiber sizes are the visible difference, the materials of the fibers however may have worked as intended. The micro coir fibers were of less tensile strength but finer in the size, contributed to increasing the ductility of the hardened binder gel of GPC, while the MPW macro fibers fulfilled the requirements to restrict the larger size cracks in the GPC mass. The experimental results evidently ensured the advantages of the addition of the fibers in as a combined dosage than their utilization as the single fiber entity.

B. Flexural strength test result

The flexural strength as the flexural modulus was obtained for each mix and member prepared as the beam element. The results are shown in Fig.4 for the mixes prepared with the coir fibers, MPW fibers and the combination of the fibers into the GPC. The trend of the increment in the flexural strength found nearly similar to that of the splitting tensile strength of the GPC mixes. The coir fibers increased the strength by 12%, 21%, 28% and 34% and the MPW fibers by 23%, 32%, 46%, and 55% as the only fibers into the GPC mix. However, the combined usage of the fibers increased the strength significantly by 28%, 39%, 55%, and 68% on the addition with equal proportions of 50% each. The flexural response of the GPC composite primarily depends on the intermolecular bonding and the adhesion capacity of the hardened gel of the binder material with the aggregates. However, the flexural action in the member creates the cracking of the bonding with increased load and exhibited by the cracks eventually. Therefore, the resistance to the cracking by the composite is of great importance. The addition of the fibers in varying fraction and in the combination increases the strength of the GPC composite against the cracking resulted in the flexural actions on the specimens. This is a similar response observed from the other researcher [5] in the case of oil palm shell fibers, used for the improvement of the flexural strength of geopolymer concrete. In the study carried out on the addition of coir fibers [13] into the concrete, it is suggested to explore the response by the reinforced composite to understand the contribution by the natural fibers to the flexural resistance. The macro fibers tend to influence the flexural response more than that of the microfibers owing to the fact that the crack propagation of the composite subjected to the increment of the tensile forces is larger and with a faster rate of the occurrence. In that scenario of the cracking, the macro fibers have more significance to resist the growth of the cracks in the hardened mass. However, the area of influence of the fibers in the combined format requires investigations based on the micro structural explorations. The present study shows the primary investigations and the discussions based on the results obtained from the tests.

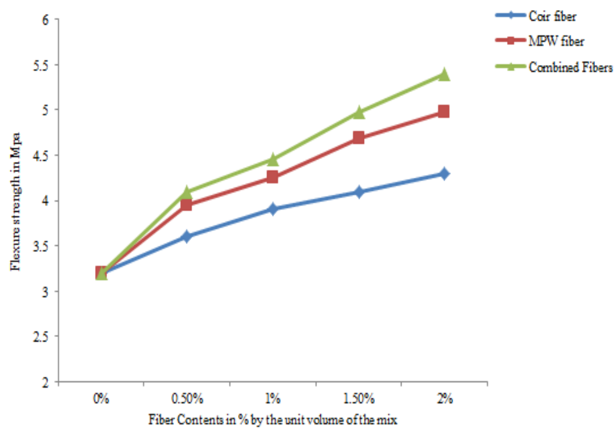

Figure 4 Effects of fibers on the flexural strength of the GPC beam specimens

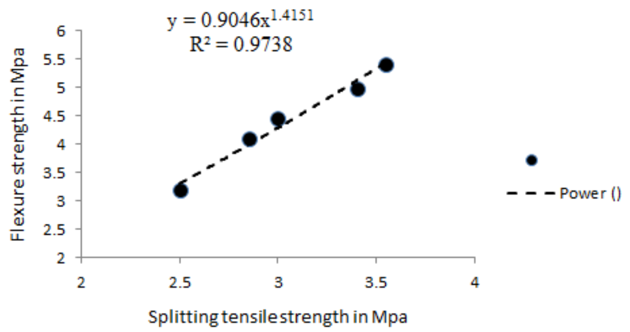

Figure 5 Relationship between the splitting tensile strength and the flexural strength of GPC with combined fibers

The results of the tests showed that the combination of the natural and artificial fibers namely coir and MPW fibers exhibited excellent improvement of the strength properties. The correlation between the test results of splitting tensile strength and flexural strength for the GPC containing the combined fibers was obtained as shown in Fig.5. The empirical or the constitutive prediction model was referred from the literature [17]. Though the exact or similar work on the relation between the splitting tensile strength to the flexural strength was seldom available to refer, the most appropriate relationship model expressing the relation of the strength was compared with the results of the experimental work and found satisfactory. The regression analysis of the results showed the value of the R^2 =0.9738, indicating a good confirmation of the experimental results with the empirical relationship. Fig.6 shows the comparison of the experimental values with the predicted values.

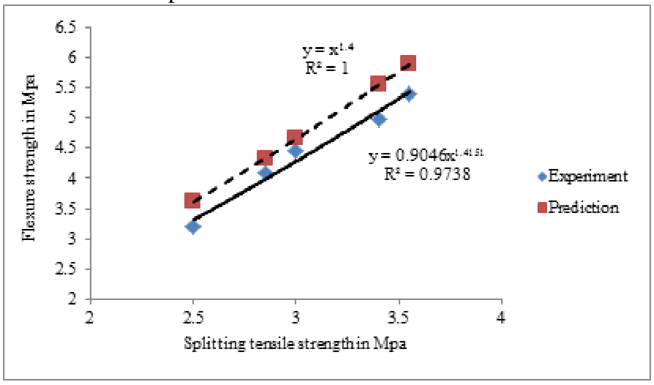

Figure 6 Comparison of the predicted and experimental values of the strength relationship of GPC with fibers

V. CONCLUSIONS

The experimental study on the effect of natural and artificial fibers on the GPC specimens subjected to the splitting and flexural actions revealed the following important observations;

1) The combined addition of the coir and MPW fibers improved the crack resistance capacity of GPC.
2) The splitting tensile and flexural strength were largely influenced by the combined addition of the coir and MPW fibers compared to the GPC mixes containing a single type of fiber.
3) The blended fibers of equal (50% coir and 50% MPW) proportions showed maximum increase in the strength properties at the 2% of the dosage.
4) The coir fiber exhibited a reduced rate of strength improvement beyond 1% and the MPW as the only fibers showed maximum rate of increase up to 1.5% of the dosage into the GPC for all test conditions.
5) The preliminary investigations on the effect of the blending of the natural with artificial fibers on the crack resistance capacity and the flexural strength of the GPC confirmed the potential of the combined usage of the fibers in the development of the fiber reinforced geopolymer concrete as the futuristic area of investigation.

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