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A Comparative Performance of Sisal and Polypropylene Fibres in Enhancing Tensile Strength of Concrete

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Abstract— **Use of polypropylene (PP) fibres in concrete has been found to be effective in improving various engineering properties of concrete. However, PP fibres cause depletion of natural resources and add pollutants to the greenhouse effect as they are derived from hydrocarbons. Hence, Sisal fibre was considered as an alternate fibre to improve the tensile strength properties of conventional concrete. Manually extracted 12 mm long local sisal fibres were used to evaluate their influence on the tensile strength properties of M30 grade concrete. Fibre dosages of 0.5%, 1.00%, 1.25% and 1.50% of volume of concrete were used. Split tensile and flexural strength of PP Fibre Reinforced Concrete (PFRC) and Sisal Fibre Reinforced Concrete (SFRC) were evaluated for the ages of 7, 28 and 90 days. Linear regression analysis confirmed good correlation between tensile strength properties of PFRC and SFRC. Additionally, scanning electron microscopy (SEM) tests on fractured surface of the specimens were conducted. Presence of PP fibres marginally increased the tensile strength of concrete due to absence of dense hydrated products on the surface of the PP fibres. However, SFRC could not achieve as much strength as PFRC did due to mineralization and migration of hydrated products in SFRC.**

Keyword- Fibre reinforced concrete; Polypropylene; Sisal; Tensile strength; SEM.

I. INTRODUCTION

Though conventional concrete has good compressive strength, its brittle behavior makes it susceptible to tensile loading conditions. Short discrete fibres are added to control mix to enhance desired strength and durability properties. The resulted concrete is known as Fibre Reinforced Concrete (FRC). Added fibres could be metallic, synthetic or natural. Fibres are designated using aspect ratio, which is the ratio of length to diameter of the fibre.

A detailed review of literature reveals that polypropylene (PP) fibres improved the tensile and flexural strength properties irrespective of curing conditions [1]. Furthermore, it was concluded that addition of PP fibre dosages of 0.2%, 0.3% and 0.5% resulted in enhanced tensile strength property for water cement ratios of 0.36 and 0.46 [2]. Even small fibre dosages of 0.15% and 0.3% have shown improvement in tensile strength properties [3]. However, the increase in tensile strength was not restricted to conventional concrete alone. The effect of multi-filament PP fibres of length 19 mm and 12mm on tensile strength properties of oil palm shell concrete and found that both fibres affected the split tensile and flexural strength properties positively [4]. Moreover, Addition of PP fibres to high performance concrete resulted in increase in split tensile strength [5]. Furthermore, Addition of PP fibres along with partial replacement of cement with silica fume showed increase in tensile strength properties of PFRC as well [6]. Results of flexural tests conducted on fibrillated PFRC and monofilament PFRC for different combinations of fibre lengths showed that flexural strength had increased for all combinations [7].

It is proved beyond doubt that addition of PP fibres enhances tensile strength properties irrespective of w/c ratio, curing conditions, grade of concrete and type of PP fibre used. However, increase in PP fibre dosage had adverse effect on both split tensile and flexural strength properties of PFRC [8]. Hence, it was decided to use fibre dosages of 0.5%, 1.00%, 1.25% and 1.50% restricting maximum fibre dosage to 1.50%. Furthermore, the addition of PP fibres for combinations of different lengths and fibre dosages showed decrease in flexural strength [9]. Hence, it necessitated evaluating the performance of PFRC for fibre length of 12 mm under tensile loading.

The performance of continuous sisal fibre cement composites under tensile and bending loading conditions and concluded that sisal fibres were able to bridge and arrest the cracks within the tensile region of response [10]. The tensile and flexural strength properties of sisal fibre composites were comparable with glass mat PP composites [11] and long aligned sisal fibres could be used in cement-based laminates for semi-structural and structural applications [12]. The evaluated performance of PP fibres and natural fibres such as sisal fibres in lime plasters and suggested that sisal fibres can be used as a valid alternative to PP fibres [13]. The influence of interfacial adhesion on mechanical properties of sisal fibre reinforced polymer composites for various lengths of sisal fibres was used and found that addition of sisal fibres enhanced the tensile and flexural strength properties [14]. It is clear that addition of sisal fibres showed improvement in tensile strength property of SFRC.

However, change in aspect ratio has impact on degree to which it affects the mechanical properties of FRC ([15]- [16]). Hence, it was decided to use 12 mm length fibres for both PFRC and SFRC so that comparative performance could be studied. Additionally, linear regression analysis was performed to establish relation between split tensile strength and flexural strength for both PFRC and SFRC.

II. EXPERIMENTAL PROGRAMME

A. *Properties of the Materials*

Ordinary portland cement (OPC) of grade 43 confirming to IS 8112 (2013) [17] was used. Properties of the cement used are given in Table I. Locally available crushed angular stone aggregates as coarse aggregates and locally available river sand as fine aggregate confirming to IS 383:1970 (2002) [18] were used. Maximum size of the coarse aggregate used was 20 mm.

TABLE I
Properties of cement

Name of Property	Value
Type	OPC
Grade	43
Specific Surface (m^2/Kg)	275
Specific Gravity	3.15
Soundness (Lechatelier method) (mm)	1.5
Initial setting time (Minutes)	180
Final setting time (Minutes)	230
Compressive strength (MPa)	55

Sieve analysis was performed on fine aggregate and grading limits were determined according to IS 383:1970 (2002) [18]. Based on the grading limits the fine aggregate was classified as grading zone II. Properties of coarse and fine aggregate are shown in Table II. Naphthalene based superplasticizer (SP) confirming to IS 9103:1999 (2004) [19] at 1% by weight of cement was used to maintain the workability of FRC.

TABLE II
Properties of aggregates

Name of the property	Coarse Aggregate	Fine Aggregate
Specific Gravity	2.7	2.3
Water absorption (%)	0.40%	1.00%

Staple type PP fibres of length 12 mm were used for experimentation and sisal fibres were obtained from locally available sisal plants. Fibres were manually extracted, air-dried and cut into a length of 12mm. The Properties of PP and sisal fibres are shown in Table III.

TABLE III
Properties of fibres ([20]-[21])

Name of the Property	Polypropylene	Sisal
Length (mm)	12	12
Diameter (μm)	20-400	10-50
Specific gravity	0.9-0.95	1.5
Modulus of elasticity (MPa)	3.5-10	18
Tensile strength (GPa)	0.45-0.76	0.8
Elongation at break (%)	15-25	3

B. Mixing Proportions

Mix design for M30 grade concrete was obtained by using IS 10262 (2009) [22] and IS 456 (2000) [23]. Out of computed weight of coarse aggregates, a combination of 60% of 20mm size and 40% of 10 mm size coarse aggregates was used for better strength. Two initial trails were made based on the mix design proportions so as to get the compressive strength near to target mean strength. The final mix proportion was arrived at 1:1.94:3.87 based on the results from trail mixes.

C. Mixing Procedure and Preparation of Specimens

Drum mixer was used to mix the ingredients for uniform concrete. Initially, calculated quantity of coarse aggregates and fine aggregates were mixed for 2 minutes. Cement and half of the calculated water along with SP were added and continued mixing for 2 minutes. The remaining water containing calculated PP or sisal fibres was added to the concrete mix and continued mixing for 2 minutes. Balling effect was observed during mixing when the fibre dosage was beyond 1.00%. A constant SP dosage of 1.00% of weight of cement was used to maintain the workability. Specimens were cast for fibre dosages of 0.50%, 1.00%, 1.25% and 1.50% to evaluate strength properties at the ages of 7, 28 and 90 days. Fibre dosages used for various test specimens are mentioned in Table IV. A curing period of 90 days was selected to verify if SFRC shows any degradation in strength after being in highly alkaline environment for such duration.

TABLE IV
Specimens and mix proportions used

Mix	Fibre dosage (%)	
	PP	Sisal
PCC	-	-
P1	0.50%	-
P2	1.00%	-
P3	1.25%	-
P4	1.50%	-
S1	-	0.50%
S2	-	1.00%
S3	-	1.25%
S4	-	1.50%

Cylinders of size 150 mm x 300 mm and flexural beams of size 100 mm x 100 mm x 500 mm were used to evaluate the split tensile strength and flexural strength of FRC respectively. Steel moulds were used to prepare the specimens. Moulds were filled in three layers and each layer was compacted using machine until the desired condition was attained. After the top layer was compacted, the surface of the concrete was leveled to the top of the mould, using a trowel, and covered with metal plate to prevent evaporation. The samples were demoulded and kept in curing chambers to test the strength at the ages of 7, 28 and 90 days. Three samples were tested for each combination of fibre dosage and age, and the average values are reported.

III. RESULTS AND DISCUSSION

PFRC and SFRC specimens with fibre dosage of 0.50%, 1.00%, 1.25% and 1.50% were tested for split tensile strength and flexural strength as per IS 5816 (2004) [24] and IS 516 (2004) [25] respectively and compared them to those of the control mix. The results are tabulated in Table V and VI.

TABLE V
Split tensile strength of PFRC and SFRC at different ages

Specimen	7 days		28 days		90 days		Average change (%)
	Split Tensile Strength (MPa)	% Change	Split Tensile Strength (MPa)	% Change	Split Tensile Strength (MPa)	% Change	
PCC	2.80	-	3.13	-	3.39	-	-
P1	2.86	2.14	3.19	1.92	3.46	2.06	2.04
P2	2.96	5.71	3.29	5.02	3.59	5.88	5.54
P3	3.01	7.50	3.38	7.99	3.65	7.67	7.72
P4	3.09	10.37	3.46	10.54	3.74	10.32	10.41
S1	2.83	1.07	3.18	1.60	3.42	0.88	1.18
S2	2.87	2.50	3.24	3.51	3.46	2.06	2.69
S3	2.91	3.93	3.27	4.47	3.51	3.54	3.98
S4	2.93	4.64	3.31	5.75	3.54	4.42	4.94

A. Split Tensile Strength

Increase in split tensile strength of PFRC was observed with the increase in fibre dosage for all curing periods as shown in Fig. 1. Only about 10% increase in split tensile strength was observed for the maximum fibre dosage of 1.50%. Growth rate of PFRC did not change even after curing it for 90 days. However, mode of failure of fibre composites depends on bond strength between the fibre and the matrix. Only slight improvement in split tensile strength is attributed to smooth surface of PP fibres and weak interfacial zone between PP fibres and cement matrix. Concrete specimens failed due to pullout of the fibre and no fracture of fibres was observed from the fractured surface of the test specimen.

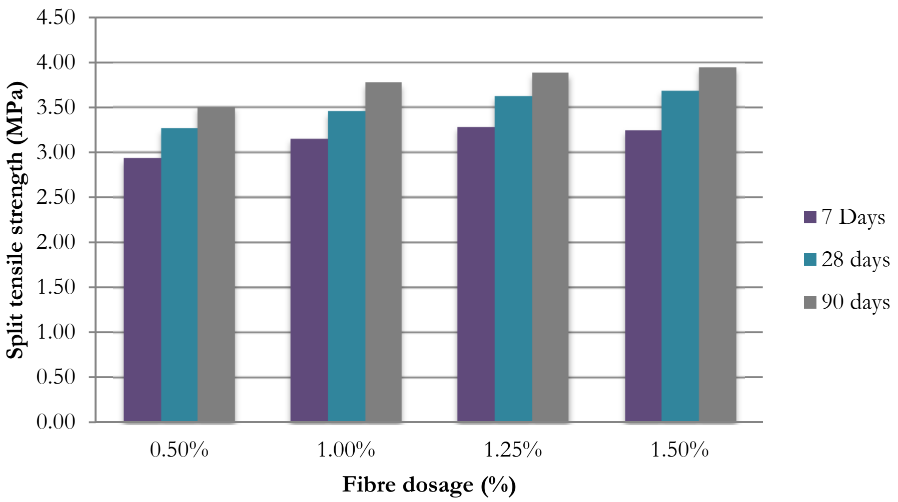

Fig. 1. Split tensile strength of PFRC at various ages

Split tensile strength of SFRC was slightly improved by the presence of sisal fibres. The strength variations for different fibre dosages and curing periods are shown in Fig. 2. Growth only to a tune of 5% was observed even at a fibre dosage of 1.50%. Although PP of same length improved the split tensile strength to a tune of 10%, sisal fibres could not enhance the strength to the same extent. Furthermore, it can be observed from Table 5 that percentage change in split tensile strength for SFRC at 90 days was much less as compared to PFRC for all fibre dosages. The reduced capacity of tensile strength is due to aging of natural fibre being in contact with portland cement matrix. Aging process occurs due to mineralization, which is the result of migration of hydration products (particularly $Ca(OH)_2$) to the fibre surface. This process reduced the tensile strength of SFRC at later ages.

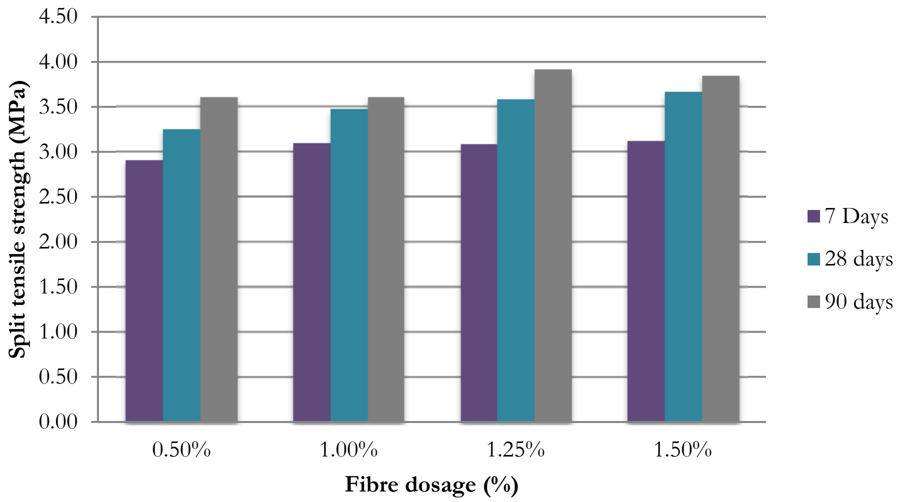

Fig. 2. Split tensile strength of SFRC at various ages

B. *Flexural Strength*

Performance of PFRC for different fibre dosages and ages is shown in Fig. 3. Increase in flexural strength was observed with increase in fibre dosage for all fibre dosages. Maximum increase of about 8% in flexural strength was observed for the fibre dosage of 1.50%. Ability of the fibres to bridge the cracks and arresting crack propagation under flexural loading were the reasons for enhancement in flexural strength of PFRC. More fibre dosage contributed to the availability of more fibres for the given volume of concrete. Hence, more fibres facilitated arresting the propagation of cracks and enhancing the post cracking capacity of the PFRC. As the length of the PP fibre was 12 mm, their significant contribution was in arresting prorogation of micro cracks under flexural loading. Fractured surface showed that the specimen failed mostly due to pullout failure of the PP fibres.

TABLE VI
Flexural strength of PFRC and SFRC at different ages

Specimen	7 days		28 days		90 days		Average change (%)
	Flexural Strength (MPa)	% Change	Flexural Strength (MPa)	% Change	Flexural Strength (MPa)	% Change	
PCC	3.98	-	4.38	-	4.66	-	-
P1	4.01	0.75	4.45	1.60	4.71	1.07	1.14
P2	4.06	2.01	4.47	2.05	4.76	2.15	2.07
P3	4.21	5.78	4.63	5.63	4.87	4.57	5.33
P4	4.27	7.39	4.77	8.90	5.06	8.66	8.32
S1	4.01	0.75	4.42	0.91	4.68	0.43	0.70
S2	4.04	1.51	4.47	2.05	4.72	1.29	1.62
S3	4.11	3.27	4.56	4.11	4.77	2.36	3.25
S4	4.13	3.77	4.61	5.25	4.81	3.22	4.08

On the other hand, Fig. 4 shows the variation of SFRC for different fibre dosages at three different curing periods. Slight increase in flexural strength was observed for increase in fibre dosage. Maximum average growth of about 4% was observed for a fibre dosage of 1.50%. The poor performance of SFRC as compared to PFRC could be attributed to high density and vulnerability to alkaline environment of the sisal fibres. Higher density of sisal fibres resulted in availability of less number of fibres to arrest propagation of cracks for the given volume of concrete as compared to PFRC. As the hydration process continues in concrete, sisal fibres get degraded as they are in constant contact with Portland cement matrix. Fractured surface of the failed specimen showed the combination of pull out and fractured failures of the sisal fibres.

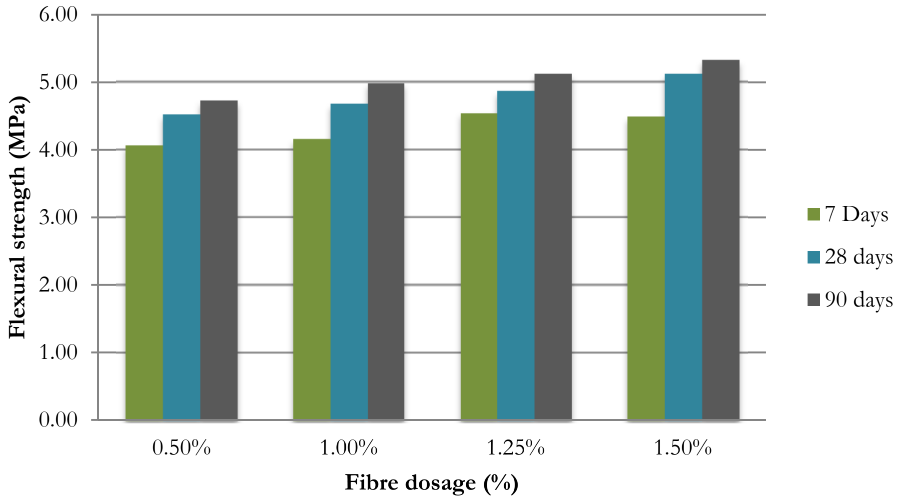

Fig. 3. Flexural strength of PFRC at various ages

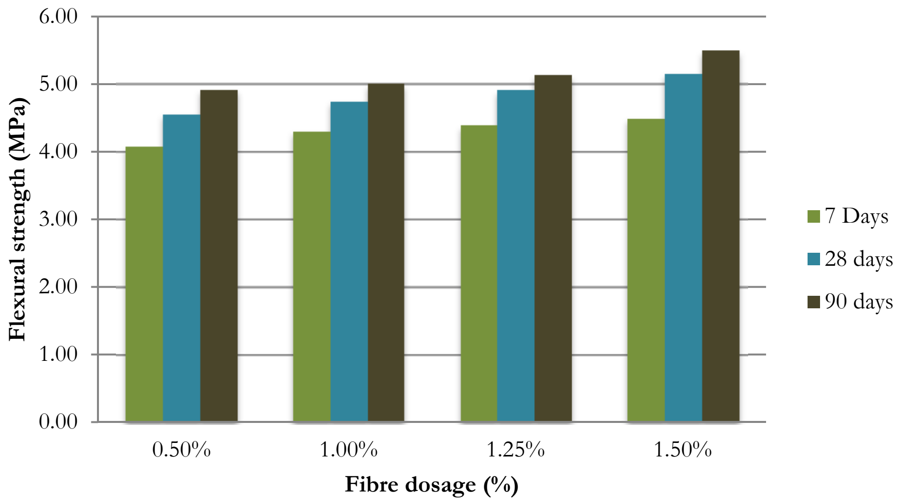

Fig. 4. Flexural strength of SFRC at various ages

C. Correlation between Split and Flexural Strength

Linear regression analysis was performed between split tensile strength of PFRC and SFRC as shown in Fig. 5. Although PFRC outperformed SFRC, good correlation exists between them. Split tensile strength of PFRC and SFRC are connected through a power relation with R-squared value of 0.96. Furthermore, good correlation was observed between flexural strength of PFRC and SFRC as shown in Fig. 6 through a power relation with R-squared value of 0.95. It is evident from the analysis that a high degree positive correlation exists between PFRC and SFRC for tensile strength properties.

Following equations are proposed to predict the split tensile strength (f_{ss}) and flexural strength (f_{fs}) of SFRC based on split tensile strength (f_{sp}) and flexural strength (f_{fp}) of PFRC respectively.

$$f_{ss} = 1.062 * f_{sp}{}^{0.925}$$

$$f_{fs} = 1.153 * f_{fp}{}^{0.894}$$

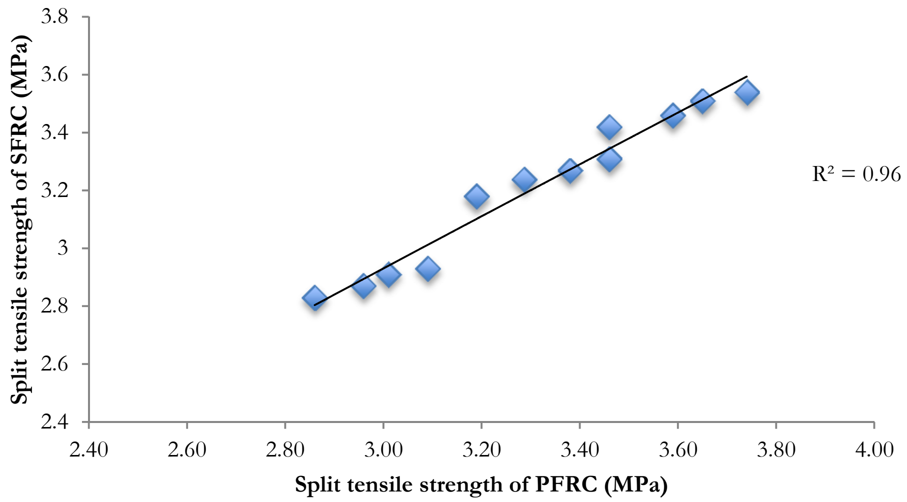

Fig. 5. Correlation between split tensile strength of PFRC and SFRC

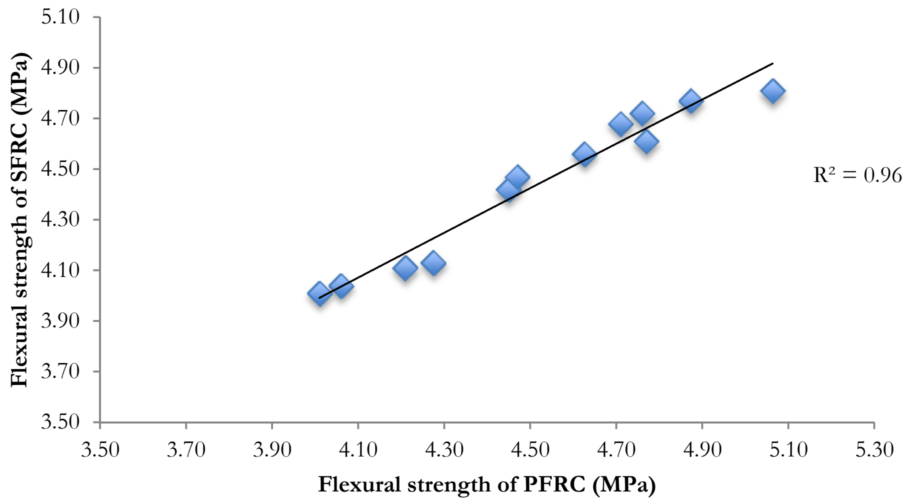

Fig. 6. Correlation between flexural strength of PFRC and SFRC

D. Microstructural Studies

Scanning electron microscope (SEM) tests were conducted on fractured surfaces of flexural test specimens of PFRC and SFRC. Only occasional asperities are observed for PFRC as shown in Fig. 7 with smooth fibre surface. These asperities have sharp edges and they are believed to be crystals of calcium hydroxide. Only moderate increase in tensile strength of PFRC is explained by the presence of low crystalline precipitation on the surface of the fibre. PFRC arrest the propagation of micro-cracks while retaining its elasticity. However, PP fibres contribute only in delaying the propagation process instead of preventing them.

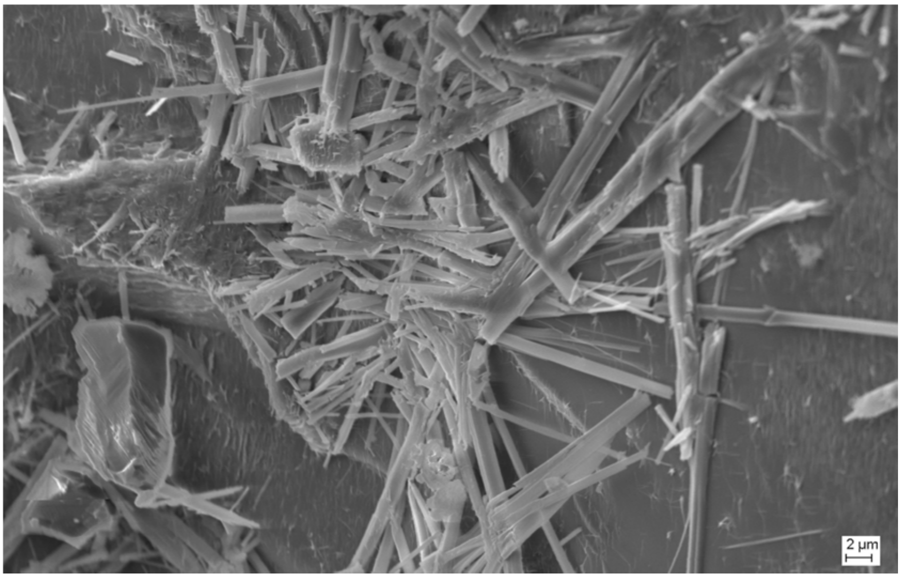

Fig. 7. SEM micrograph of fractured surface of PFRC

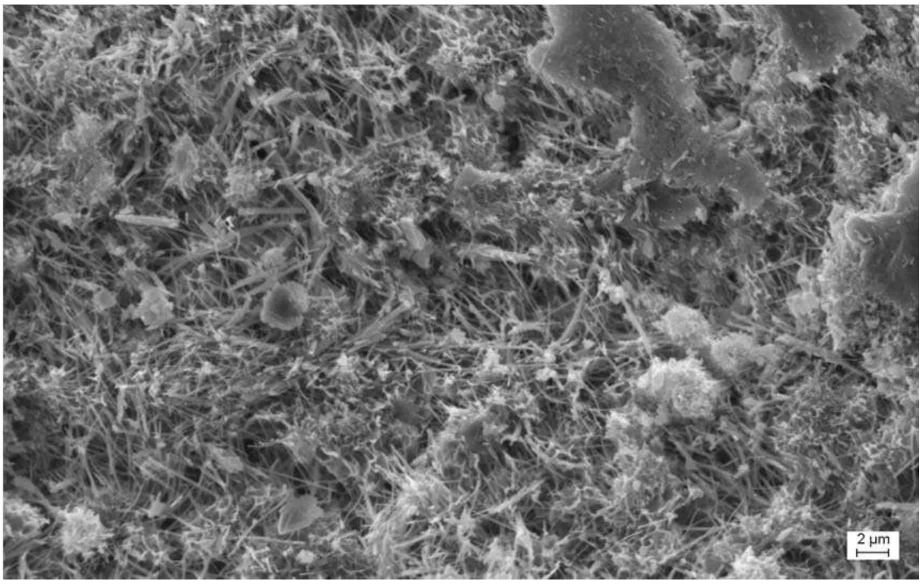

Fig. 8. SEM micrograph of fractured surface of SFRC

SEM analysis of failure surface of SFRC is presented in Fig. 8. Calcium hydroxide ($Ca(OH)_2$) and calcium silicate hydrate (CSH) along with fractured fibre surface are observed. The presence of $Ca(OH)_2$ causes the mineralization of sisal fibre and it leads to reduced tensile strength of fibres. SEM micrograph supports the only slight improvement in tensile strength of SFRC even at a fibre dosage of 1.50%.

IV. Conclusions

Following conclusions can be drawn from the experimental study.

- Addition of PP fibres improved the split tensile and flexural strength properties
- Increase in fibre dosage of sisal fibres slightly improved the split and flexural strength properties
- Linear regression analysis revealed a good correlation between tensile strength properties of PFRC and SFRC
- Micro structural analysis revealed that absence of asperities on the surface of PP fibres and weak interfacial zone caused lower growth in tensile strength properties of PFRC
- Mineralization and migration of hydrated products in highly alkaline portland matrix resulted only slight improvement in tensile strength properties of SFRC

Although SFRC did not perform at par with PFRC from split tensile and flexural strength stand point, further research is in progress to evaluate durability properties of PFRC and SFRC to recommend the suitability of using sisal fibres in durable structures.

REFERENCES

[1] A. J. Al-Tayyib, M. M. Al-Zahrani, Rasheeduzzafar & G. J. Al-Sulaimani, "Effect of polypropylene reinforcement on the properties of fresh and hardened concrete in the Arabian Gulf environment," *Cement and Concrete Research*, Vol. 18, pp. 561-570, 1988.
[2] A. A. Nia, M. Hedayatian, M. Nili & V. A. Sabet, "An experimental and numerical study on how steel and polypropylene fibres affect the impact resistance in fibre-reinforced concrete," *International Journal of Impact Engineering*, Vol. 46, pp. 61-73, 2012.
[3] C. X. Qian, & P. Stroeven, "Development of hybrid polypropylene-steel fibre-reinforced concrete," *Cement and Concrete Research*, Vol. 30, pp. 63-69, 2000.
[4] S. P. Yap, U. J. Alengaram & M. Z. Jumaat, "Enhancement of mechanical properties in polypropylene and nylon fibre reinforced oil palm shell concrete," *Materials and Design,* Vol. 49, pp. 1034-1041, 2013.
[5] K. Behfarnia & A. Behvaran, "Application of high performance polypropylene fibres in concrete lining of water tunnels," *Materials and Design*, Vol. 55, pp. 274-279, 2014.
[6] M. Nili & V. Afroughsabet, "The effects of silica fume and polypropylene fibres on the impact resistance and mechanical properties of concrete," *Construction and Building Materials*, Vol. 24, pp. 927-933, 2010.
[7] Z. J. Grdic, G. A. T. Curcic, N. S. Ristic, & I. M. Despotovic, "Abrasion resistance of concrete micro-reinforced with polypropylene fibres," *Construction and Building Materials*, Vol. 27, pp. 305-312, 2012.
[8] A. A. Ramezanianpour, M. Esmaeili, S. A. Ghahari & M. H. Najafi, "Laboratory study on the effect of polypropylene fibre on durability, and physical and mechanical characteristics of concrete for application in sleepers," *Construction and Building Materials*, Vol. 44, pp. 411-418, 2013.
[9] M. S. Meddah & M. Bencheikh, "Properties of concrete reinforced with different kinds of industrial waste fibre materials," *Construction and Building Materials*, Vol. 23, pp. 3196-3205, 2009.
[10] F. A. Silva, B. Mobasher, & R. D. T. Filho, "Cracking mechanisms in durable sisal fibre reinforced cement composites," *Cement and Concrete Composites*, Vol. 31, pp. 721-730, 2009.
[11] P. Wambua, J. Ivens & I. Verpoest, "Natural fibres: can they replace glass in fibre reinforced plastics?," *Composites Science and Technology*, Vol. 63, pp. 1259-1264, 2003.
[12] F.A. Silva, R. T. D. Filho & J. A. M. Filho, "Physical and mechanical properties of durable sisal fibre cement composites," *Construction and Building Materials*, Vol. 24, pp. 777-785, 2010.
[13] G. D. Bella, V. Fiore, G. Galtieri, C. Borsellino & A. Valenza, "Effects of natural fibres reinforcement in lime plasters (kenaf and sisal vs polypropylene)," *Construction and Building Materials*, Vol. 58, pp. 159 -165, 2014.
[14] K. Joseph, S. Varghese, G. Kalaprasad, S. Thomas, L. Prsannakumari, P. Koshy & C. Pavithran, "Influence of interfacial adhesion on the mechanical properties and fracture behavior of short sisal fibre reinforced polymer composites," *European Polymer Journal*, Vol. 32, No. 10, pp. 1243-1250, 1996.
[15] S. Abbas, A. M. Soliman, & M. L. Nehdi, "Exploring mechanical and durability properties of ultra-high performance concrete incorporating various steel fibre lengths and dosages," *Construction and Building Materials*, Vol. 75, pp. 429-441, 2015.
[16] R. S. Olivito & F. A. Zuccarello, "An experimental study on the tensile strength of steel fibre reinforced concrete," *Composites: Part B*, Vol. 41, pp. 246-255, 2010.
[17] IS 8112. Indian standard ordinary Portland cement, 43 grade – specification (bureau of Indian Standards), New Delhi, 2013.
[18] IS 383-1970 (Reaffirmed 2002). Indian standard specification for coarse and fine aggregates from natural sources for concrete (bureau of Indian Standards), New Delhi, 2002.
[19] IS 9103-1999 (Reaffirmed 2004). Indian standard specification for concrete admixtures – specification (bureau of Indian Standards), New Delhi, 2004.
[20] F. A. Silva, N. Chawla & R. D. T. Filho, "Tensile behavior of high performance natural (sisal) fibres," *Composites science and Technology*, Vol. 68, pp. 3438-3443, 2008.
[21] A. Bentur & S. Mindess, "Introduction", *Fibre Reinforced Cementitious Composites*, 2nd ed. New York: Taylor & Francis, 2007, Ch. 1, pp. 2.
[22] IS 10262-2009. Indian standard concrete mix proportioning – guidelines (Bureau of Indian Standards), New Delhi, 2009.
[23] IS 456. Indian standard plain and reinforced concrete code of practice (Bureau of Indian Standards), New Delhi, 2000.
[24] IS 5816:1999. Indian standard splitting tensile strength of concrete – Method of tests (Bureau of Indian Standards), New Delhi, 2004.
[25] IS 516:1959. Indian standard Method of tests for strength of concrete (Bureau of Indian Standards), New Delhi, 2004.

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