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Impact resistance of hybrid fibre reinforced concrete containing sisal fibres

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Influence of sisal fibres on impact resistance of structural concrete was investigated and the performance was compared with that of Polypropylene (PP) and Steel fibres. Apart from Mono-fibre reinforced concrete (mono-FRC), resistance of hybrid fibre reinforced concrete (HyFRC) containing steel-Polypropylene (S-PP) and Steel-Sisal (S-Si) fibres to impact loading was also evaluated. Fibre dosages of 0%, 0.50%, 1.00%, 1.25% and 1.50% were used. Drop-weight test in accordance with ACI committee 544 was conducted and compressive strength was evaluated for curing periods of 7, 28 and 90 days. Furthermore, liner regression analysis was performed between the compressive strength and impact resistance. It was found that increase in fibre content improved the impact resistance of FRC. Steel fibre reinforced concrete (SFRC) outperformed and Sisal FRC (SiFRC) showed least performance among mono-FRC. Though S-Si HyFRC performed better as compared to sisal FRC, HyFRC containing S-PP at a fibre dosage 1.5% exhibited superior performance.

1. Literature review/introduction

Due to extended use of concrete structures in military applications and runways, concrete structures are subjected to impact loads that vary both in velocity and intensity. However, brittle nature of concrete is highly susceptible to impact loads. Being a quasi-brittle material, concrete looses its loading capacity once the cracks are formed and cracks are initiated. The energy consumed during impact loading is utilized for the process of development of cracks and their propagation in concrete. Microcracks are developed at relatively low stress levels and the fracture zone is formed when these microcraks propagate and link up into larger cracks. Controlling of cracks goes a long way in protecting the integrity of the structure.

This weakness of the concrete can be overcome by adding fibres (metallic, synthetic or natural) randomly to concrete. Addition of fibres helps concrete overcome its shortcomings such as low durability, high shrinkage and less resistance to impact loading [1]. Moreover, Substantial resistance to formation and propagation of cracks is achieved through FRC [2]. Fibres of various materials are available with different shapes and properties. Addition of steel fibres affects the impact strength positively to a great extent. Randomly distributes discontinuous fibers help bridging the cracks and improve post cracking behavior. FRC will be able to carry significant stresses over a relatively large strain capacity in the post-cracking stage if added fibres have sufficient strength and good bonding with cement matrix.

It has been reported [3] that steel and PP fibre are most commonly used fibres. Aspect ratio and dosage of fibres play important role in enhancing various properties. Fibres start bearing the load when cracks are initiated. The fibres start transmitting excess stresses to the matrix when the load is increased. Fibre pull-out or rupture of the fibre is noticed when these stresses exceed the bond strength between the fibre and the matrix.

Hooked end steel fibres were found to be effective in improving impact resistance of the concrete and the improvement is attributed to the good bond between the fibre and the matrix [3,4]. Steel fibres improved the impact resistance for initial crack and final

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fracture by 4 and 18 times respectively in the presence of silica fume [5]. Improvement impact resistance of SFRC was observed irrespective of type of concrete, w/c ratio, type of steel fibres, binding materials used and environment they were subjected to [3,6–8].

PP fibres have been interest of most of the researchers due to their resistance to shrinkage, enhanced roughness and low cost. [9]. Extensive research on influence of PP fibres on impact strength of concrete revealed that the type and content of fibres used influence the resistance of FRC to impact loading [4]. Length, tensile strength and bonding with cement matrix play important role in improving the resistance to impact loading [3]. Resistance to impact load was improved with increase in fibre dosage irrespective of w/c ratios [10,11]. As compared to cellulose fibres, PP fibres were effective in resisting impact loads [12]. PP fibres improved the impact strength irrespective of the fibre length and types concrete [8,13]. Addition of fibres to concrete improves mechanical properties of concrete apart from enhancing resistance to impact loads [14]. It was reported that the specimen geometry, fibre type and concrete mix could affect the impact strength of the concrete [15].

Steel fibres are manufactured by extracting the natural resources. Moreover, PP fibres are derived from hydrocarbons. Their continued usage will not only deplete the natural resources, but also add pollutants to greenhouse effect. Hence, fibres extracted from sisal, which is natural, is considered as an alternative to PP fibres. Not many research findings were reported on use of sisal fibres in cementitious materials especially in improving the impact resistance. In one of the studies [16], coconut fibre was used to verify its performance under impact loading in aggressive environments. It was reported that presence of the natural fibre improved the resistance to impact loading irrespective of the environment. Use of natural fibres has been gaining momentum due to lower cost, renewability and nonhazardous nature. However, use of natural fibres as reinforcement in cementitious composites needs further research [17].

Hybrid FRC has been a buzzword in concrete science. HyFRC is achieved when two or more types fibres are used in the same mix. HyFRC helps exploiting benefits of each of the fibres being used [18]. The hybrid fibre system requires combination of different types of fibres to bring in synergic effect and enhance the performance of the composite both in fresh and hardened state [19]. Among various hybrid fibre reinforced combinations, S-PP combination has been getting popularity. Although it shrinks and internal stresses are developed, S-PP FRC has ability to distribute the stresses in all directions through millions of PP fibres present [2]. In addition to steel fibres, PP fibres were found to be effective in enhancing resistance to impact loading [20]. Though the resistance offered by synthetic fibres is less as compared to that of steel fibres, the PP fibres are non-corrosive and light in nature. Hence, the concept of hybridization was developed to enhance the resistance to impact loading [21]. One advantage of using hybrid fibre system is that it reduces the dead load of the structure due to low density of the PP fibres as compared to those of steel fibres.

Synergic effect in hybrid combination of S-PP was reported as compared to mono FRC [1,2]. Hybrid fibre combination performed equally well in enhancing resistance to impact strength even under cyclic loading [19]. Moreover, the S-PP HyFRC outperformed as compared to mono FRC in the presence of oil palm shell in the concrete [22]. On contrary, it was reported [23] that S-PP HyFRC did not show any synergic effect and SFRC showed superior performance as compared to hybrid fibre combination.

Various investigators proposed different methods to assess the impact resistance of concrete and they include drop-weight test, Charpy pendulum test, an explosive test and a projectile impact test [24]. Among all the methods, the simplest method is the drop-weight test proposed by the ACI (American Concrete Institution) committee 544 [3].

Through numerous investigations have been reported on the performance of steel and PP as mono fibres and hybrid combination in enhancing impact strength of the concrete, availability of literature on impact resistance of concrete reinforced with natural fibres and its comparison with metallic or synthetic fibres is scarce. Hence, the objective of this experimental investigation is to evaluate the impact resistance of SiFRC and compare it with that of SFRC and PFRC. In addition, the performance of SSiFRC is compared with that of SPFRC.

2. Experimental program

2.1. Materials used

The experimental study used ordinary Portland cement confirming to IS 8112-2013 [25] and the properties are mentioned in Table 1. Crushed stone was used as coarse aggregate and natural river sand was used as fine aggregate. The properties of the aggregates are evaluated as per IS 2386 (Part 1 to part 8):1963 [26]. Specific gravity and water absorption of coarse and fine aggregate were 2.7 and 0.40%, and 2.3 and 1.00% respectively. Potable water was used for mixing. Fig. 1 shows the hooked end steel fibres, Staple type PP fibres and locally available sisal fibres used in the study. The properties of the fibres used are presented in Table 2.

2.2. Mixing proportions

Mix design was carried out based on the guidelines mentioned in IS 10262:2009 [27] and IS 456-2000 [28]. Mix proportion of 1:1.74:3.33 and w/c ratio of 0.50 were used in the experimental investigation. Napthalene sulphonate based superplasticizer by 1% weight of cement was used to maintain workability and it was procured from Fosroc. Various mix proportions used in the experimental study are mentioned in the Table 3.

2.3. Mixing procedure and preparation of specimen

Computed quantities of cement, coarse aggregate and fine aggregate were mixed thoroughly in a drum type mixer for 2 min. 50% of calculated water was added and mixed thoroughly. Calculated quantity of fibres was added to rest 50% of the water, mixed properly and added along with super-plasticizer. The mixing process was continued for 2 min to ensure uniform distribution of fibres. Each type of freshly mixed concrete was poured in cylindrical specimens of size 150 mm × 300 mm in three layers and each layer was compacted using machine vibration. The surface of the each specimen was leveled and coved with wet gunny bags for 24 hrs. The specimens were demoulded and kept in curing tank until the test date. Test specimens of size 150 × 64 mm were prepared from these cylindrical specimens for curing periods of 7, 28 and 90 days.

Table 1
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

Fig. 1. Different fibres used in the experimental study.

Table 2
Properties of fibres.

Name of property	Steel	PP	Sisal
Length (mm)	30	12	12
Thickness (mm)	0.5	0.022	0.09
Aspect ratio	60	545	133
Specific gravity	7.8	0.9	1.4
Modulus of elasticity (GPa)	200	4	16
Tensile strength (MPa)	1050	400	560

2.4. Impact test

Drop-weight test was conducted in accordance with ACI committee 544 to evaluate the impact resistance of FRC under dynamic loading. The drop-weight test apparatus and test setup are shown in Figs. 2 and 3. In addition, close view of the test set up at the bottom is shown in Fig. 4. Cylindrical disk specimens of size 150 × 64 mm were used. A 4.54 kg weight is dropped repeatedly from a height of 457 mm and it is allowed to a hit steel ball of diameter 64 mm, which is in contact with the top surface of the specimen, each time. Number of blows required for initial crack was recorded and the test was continued to record the number

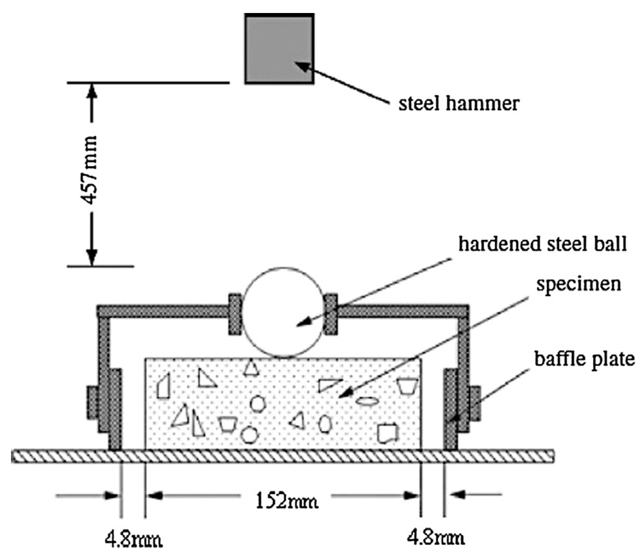

Fig. 2. Schematic diagram of drop-weight test set up.

Table 3
Mix proportions used.

Mix	Cement (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Total fibre vol. (%)	Steel fibre vol. (%)	PP fibre vol. (%)	Sisal fibre vol. (%)	Proportions of steel + PP fibre	Proportions of steel + sisal fibre
PCC	354.88	177.44	617.83	1183.35	–	–	–	–	–	–
S050	354.88	177.44	617.83	1183.35	0.50	0.50	–	–	–	–
S100	354.88	177.44	617.83	1183.35	1.00	1.00	–	–	–	–
S125	354.88	177.44	617.83	1183.35	1.25	1.25	–	–	–	–
S150	354.88	177.44	617.83	1183.35	1.50	1.50	–	–	–	–
P050	354.88	177.44	617.83	1183.35	0.50	–	0.50	–	–	–
P100	354.88	177.44	617.83	1183.35	1.00	–	1.00	–	–	–
P125	354.88	177.44	617.83	1183.35	1.25	–	1.25	–	–	–
P150	354.88	177.44	617.83	1183.35	1.50	–	1.50	–	–	–
Si050	354.88	177.44	617.83	1183.35	0.50	–	–	0.50	–	–
Si100	354.88	177.44	617.83	1183.35	1.00	–	–	1.00	–	–
Si125	354.88	177.44	617.83	1183.35	1.25	–	–	1.25	–	–
Si150	354.88	177.44	617.83	1183.35	1.50	–	–	1.50	–	–
SP050	354.88	177.44	617.83	1183.35	0.50	–	–	–	80 + 20	–
SP100	354.88	177.44	617.83	1183.35	1.00	–	–	–	80 + 20	–
SP125	354.88	177.44	617.83	1183.35	1.25	–	–	–	80 + 20	–
SP150	354.88	177.44	617.83	1183.35	1.50	–	–	–	90 + 10	–
SSi050	354.88	177.44	617.83	1183.35	0.50	–	–	–	–	80 + 20
SSi100	354.88	177.44	617.83	1183.35	1.00	–	–	–	–	80 + 20
SSi125	354.88	177.44	617.83	1183.35	1.25	–	–	–	–	90 + 10
SSi150	354.88	177.44	617.83	1183.35	1.50	–	–	–	–	90 + 10

Fig. 3. Drop-weight test apparatus.

Fig. 4. Close view of the test setup at the bottom.

of blows required for complete fracture of the specimen. Energy absorption capacity of the each specimen is calculated using the Eq. (1).

$$E_{imp} = (mV^2/2) \cdot n = (mgh) \cdot n \quad (1)$$

where variables m, V, g, h and n are drop mass, velocity at impact, gravitational acceleration, height of fall and number of blows respectively.

3. Results and discussion

3.1. Impact resistance to initial crack & fracture

Table 4 and shows the impact resistance of FRC for various mixes. As it can be seen that increase in fibre dosage enhanced the impact resistance to initial crack. SFRC continued to dominate both PFRC and SiFRC in resisting impact loading for initial crack. Though increase in fibre dosage improved the impact resistance for all mono-FRC, SFRC outperformed for a give fibre volume. It was observed that steel fibres improved the impact resistance as much as 10 times at a fibre dosage of 1.50%. This is inline with the finding reported by other investigators [3,4,12]. Substantial increase in impact strength of SFRC is attributed to good bond strength between the hooked end steel fibres and the concrete. In addition, greater tensile strength and larger length of the fibre contributed to enhanced impact resistance.

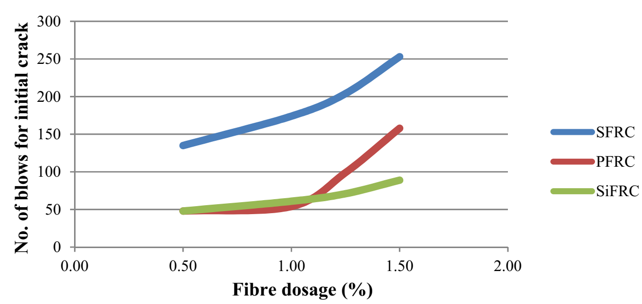

Fig. 5. Impact resistance of mono-FRC for initial crack after 90 days of curing.

Table 4
Impact resistance of various mixes.

Fibre dosage (%)	No. of blows for initial crack			No. of blows for final crack			Kinetic Energy (Initial crack) (N-m) (J)			Kinetic Energy (Final crack) (N-m) (J)			Difference in no. of blows (Between initial and final crack)		
	7d	28d	90d	7d	28d	90d	7d	28d	90d	7d	28d	90d	7d	28d	90d
PCC	18	22	25	25	30	32	364	445	506	506	607	648	7	8	7
S050	104	121	135	132	155	172	2105	2449	2732	2672	3137	3481	28	34	37
S100	143	168	174	171	197	208	2894	3400	3522	3461	3987	4210	28	29	34
S125	158	186	204	202	227	254	3198	3765	4129	4088	4594	5141	44	41	50
S150	206	234	253	264	293	329	4169	4736	5121	5343	5930	6659	58	59	76
P050	34	41	48	58	64	74	688	830	972	1174	1295	1498	24	23	26
P100	36	45	54	63	72	82	729	911	1093	1275	1457	1660	27	27	28
P125	68	81	99	103	118	135	1376	1639	2004	2085	2388	2732	35	37	36
P150	121	140	158	167	189	205	2449	2834	3198	3380	3825	4149	46	49	47
Si050	31	39	48	47	55	64	627	789	972	951	1113	1295	16	16	16
Si100	39	48	61	59	70	87	789	972	1235	1194	1417	1761	20	22	26
Si125	41	54	71	72	78	92	830	1093	1437	1457	1579	1862	31	24	21
Si150	62	73	89	88	96	104	1255	1478	1801	1781	1943	2105	26	23	15
SP050	104	121	153	142	165	192	2105	2449	3097	2874	3340	3886	38	44	39
SP100	252	285	312	284	320	334	5100	5768	6315	5748	6477	6760	32	35	22
SP125	278	314	336	346	386	403	5627	6355	6801	7003	7813	8157	68	72	67
SP150	319	362	387	434	487	512	6457	7327	7833	8784	9857	10,363	115	125	125
SSi050	116	134	164	152	173	187	2348	2712	3319	3076	3502	3785	36	39	23
SSi100	127	154	183	163	186	208	2570	3117	3704	3299	3765	4210	36	32	25
SSi125	139	161	192	173	196	223	2813	3259	3886	3502	3967	4514	34	35	31
SSi150	152	172	221	211	236	271	3076	3481	4473	4271	4777	5485	59	64	50

For instance, Fig. 5 shows the performance of SFRC as compared to PFRC and SiFRC in resisting initial crack after 90 days of water curing. Although it improved the impact resistance by about 3.5 times, SiFRC showed the least performance as compared to PFRC. Low performance of SiFRC is the result of weak interface between the fibre and the cement matrix. Additionally, porous microstructure and hydrophobic nature of the fibre resulted in less resistance as compared to SFRC and PFRC.

On the other hand, PFRC showed an improvement in impact resistance by about 6.3 times. Additionally, all mono-FRC showed slightly improved performance with curing period. Although, increase in fibre dosage improved the performance, low resistance of PFRC (in comparison with the SFRC) to impact loading is the result of less fibre length and smooth surface of the PP fibres. The weak interfacial zone between the matrix and the fibre make PFRC less resistant to impact loading. Presence of PP fibres delayed the fracture process more than contributing to prevent the failure. Moreover, ability of PP fibres in distributing the stresses helped improving impact resistance.

Fig. 6 shows the performance of all mixes after a curing period of 90 days. Tremendous improvement in performance was observed in case of HyFRC. Increase in fibre dosage improved the resistance to initial crack under impact loading. Furthermore, HyFRC gained more resistance to impact loading with increase in curing period as compared to mono-FRC. Out of all hybrid combinations, steel-PP at a fibre dosage of 1.50% improved the performance as much as by 15 times. Substantial increase in impact resistance is due to the synergic effect of steel and PP fibres. This is in contrast to the finding reported by [23]. Synergy between steel and PP fibres not only improved various static mechanical properties, but also showed tremendous increase in resistance to impact [1,2,19,22].

Although steel-sisal hybrid combination performed better as compared to Steel-PP at a fibre dosage of 0.50%, steel-sisal could not match the performance of steel-PP combination for other volume fractions. Maximum resistance to impact loading was found at a fibre dosage of 1.50%. This shows that at lower fibre dosages, the synergy between S-PP is at par with that of S-Si. However, with increase in fibre volume, SSiFRC showed inferior performance as compared to SPFRC. This effect is mainly due to lower synergic effect between steel and sisal fibres and intrinsic properties sisal fibres.

Similar trend was observed for resisting fracture of the specimens under impact loading. Among all combinations, SPFRC outperformed by improving the impact resistance to final crack by 16 times followed by SFRC, which improved the resistance by 10 times. Hybrid combination of S-PP continued to outperform in resisting fracture under impact loading.

3.2. Difference in number of blows between initial crack and fracture

It was observed as shown in Fig. 7 that the difference between number of blows for initial crack and fracture increase with increase in fibre dosage for both mono and hybrid FRC. In case of mono-FRC, SFRC continued to outperform and PFRC showed a better performance as compared to SiFRC. The superior performance of SFRC due to presence of hooked end fibres with high tensile strength, with better pullout resistance and having strong adhesion with cement matrix. Moreover, energy absorption capacity of steel fibres improved the resistance to impact loading. Among all fibre combinations, SiFRC showed a least difference of 15 blows between initial crack and final crack. Difference in number of blows between initial crack and fracture is mostly governed by the pullout resistance of the fibres. The poor performance of sisal fibres might be due to poor resistance to pullout and fibre fracture [29,30].

In hybrid combination, maximum difference of 125 blows was observed for SPFRC for fibre dosage of 1.50% at a curing period 90 days. On the other hand, control mix showed a very brittle failure and not much of the difference was observed between number of blows it took for developing initial crack and fracture.

A linear regression analysis was carried out between number of blows it took for initial crack and fracture. The result revealed a good correlation between them. For example, such relation after 90 days of curing is shown in Fig. 8. Hence, it is safe to conclude that more number blows for initial crack formation means it would take more number of blows for complete fracture in case of fibrous cement composites. Fig. 9 shows the failure pattern of fractured specimen. Specimens showed different fractured surfaces based on the fibre type and dosage. All fibrous cement composites failed due to pullout of fibres from and cement matrix. In addition, fracture of some fibres was also observed in case of sisal fibre.

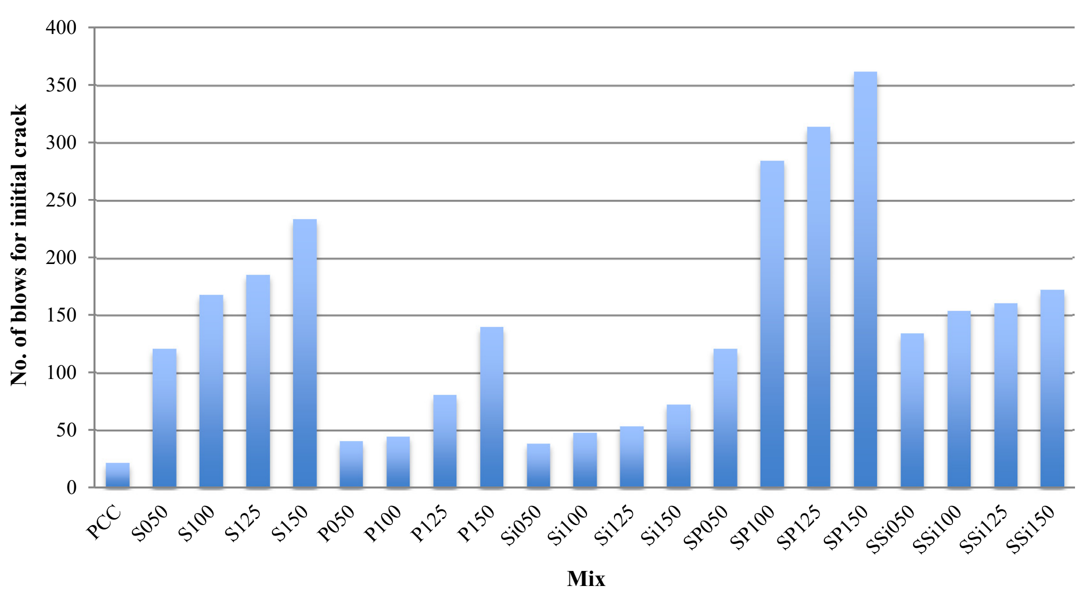

Fig. 6. Impact resistance for initial crack after 90 days of curing.

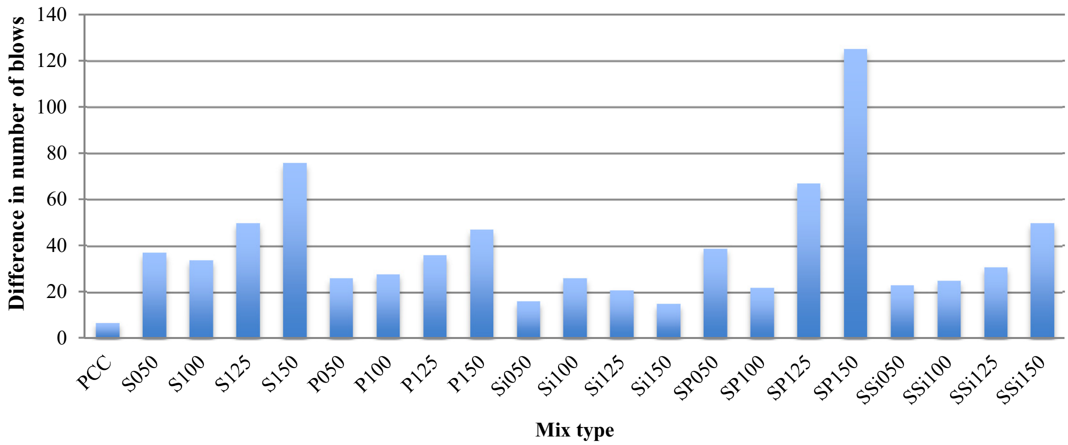

Fig. 7. Difference in number of blows after 90 days of curing.

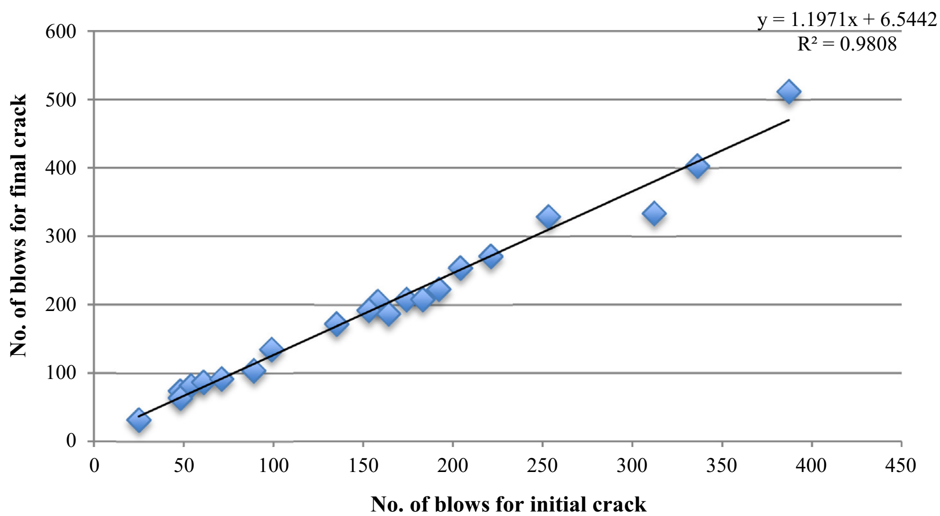

Fig. 8. Relation between number of blows for initial and final crack.

Fig. 9. Fractured specimen showing pull-out of the fibres.

3.3. Kinetic energy

It is the measure of energy absorption capacity of the FRC. Kinetic energy is directly proportional to number blows. Hence, all mixes showed the similar behavior as it showed for resting initial crack and final crack. SFRC, PFRC and SiFRC improved the kinetic energy for initial crack by 10, 6.3 and 3.6 times respectively. Among all fibre combinations, maximum kinetic energy was observed to be 7833 J for SPFRC when the fibre dosage was 1.50% at a curing period of 90 days. In addition, SSiFRC improved the kinetic energy for final crack by 8.5 times at a fibre dosage 1.50%.

3.4. Compressive strength

Table 5 shows the compressive strength and number of blows it took for complete fracture for various mixes. Compressive strength improved with increase in fibre dosage for SFRC, PFRC and SiFRC. However, SFRC, PFRC and SiFRC showed a maximum increase of about 10%, 4.2% and 5.6% respectively at a fibre dosage of 1.50% and curing period of 90 days. Some researchers reported that presence of steel fibres [7,31,32], or PP fibres [33–37] reduced compressive strength. On contrary, the test results are in complete agreement with the finding reported by [6,38]. Moreover, increase

Table 5
Compressive strength and number of blows for fracture of various mixes.

Fibre dosage (%)	Compressive strength (MPa)			No. of blows for final crack		
	7d	28d	90d	7d	28d	90d
PCC	36.31	40.62	42.54	25	30	32
S050	37.45	42.13	44.38	132	155	172
S100	39.23	43.71	45.32	171	197	208
S125	40.31	44.35	46.04	202	227	254
S150	41.08	45.07	46.85	264	293	329
P050	36.58	40.78	42.68	58	64	74
P100	36.93	41.87	43.81	63	72	82
P125	37.41	42.21	44.22	103	118	135
P150	38.14	42.62	44.34	167	189	205
Si050	36.39	40.76	42.80	47	55	64
Si100	37.31	41.68	43.62	59	70	87
Si125	37.85	42.49	44.26	72	78	92
Si150	38.32	42.96	44.91	88	96	104
SP050	38.41	42.32	45.36	142	165	192
SP100	39.70	43.86	46.42	284	320	334
SP125	40.86	45.12	47.10	346	386	403
SP150	41.08	45.07	46.85	434	487	512
SSi050	38.05	42.37	44.81	152	173	187
SSi100	39.46	43.92	46.69	163	186	208
SSi125	39.72	44.42	47.13	173	196	223
SSi150	41.08	45.07	46.85	211	236	271

in strength with curing period was observed for all fibrous cement composites.

Maximum increase of about 10% was observed for both SPFRC and SSiFRC at a fibre dosage of 1.25%. Though the increase in compressive strength was observed to the tune of 10% in case of SFRC, the same increase could be obtained at a fibre dosage of 1.25% when hybrid combination was used. This demonstrated the synergy between steel and PP/sisal fibres. This synergy is inline with findings reported by various investigators [39–41]. However, increasing fibre dosage beyond 1.25% reduced the compressive strength. This might be due to availability of more number of PP or sisal fibres at a volume fraction of 1.50% and thereby reducing the compressive strength.

3.5. Correlation between compressive strength and number of blows

Fig. 10 shows the relation between compressive strength and number of blows it took for complete fracture after curing for 90 days. Strong correlation between compressive strength and number of blows it took for fracture could not be observed. The linear regression analysis showed a R-squared value of 0.71 after a curing period of 90 days. The low R-squared value is attributed to basic function of fibres in concrete. Fibres contribute little to enhance the compressive strength. However, main role of fibres comes in to play in enhancing energy absorption capacity and ductility of the concrete. Therefore, increase in fibre dosage improved the resistance to impact loading significantly, but fibres did not improve compressive strength similarly. Moreover, resistance to impact loading has more to do with the resistance to pullout of fibres from cement matrix and fibres are good at it. On the other hand, fibres are less effective in transferring compressive stresses through ITZ.

4. Conclusions

The following conclusions can be drawn from the experimental investigation.

- Difference between number of blows for initial crack and final crack was observed for conventional concrete was not significant. Highly brittle nature of the non-fibrous concrete attributed to less resistance to impact loading.

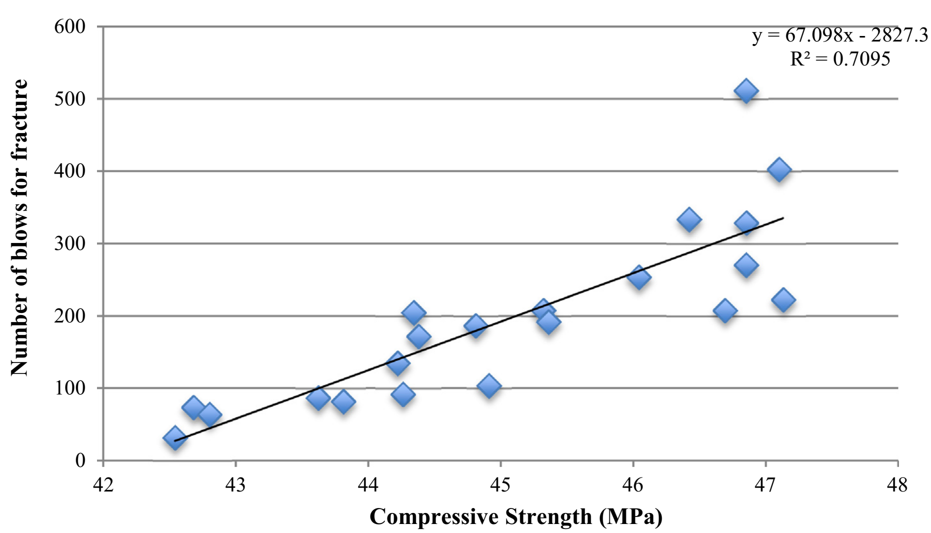

Fig. 10. Relation between compressive strength and no. of blows for fracture after 90 d of curing.

- Impact resistance to initial crack improved with increase in fibre dosage. Among Mono-FRC group, SFRC showed the superior performance followed by PFRC. SFRC improved the resistance to initial crack under impact loading by 10 times at fibre dosage of 1.50%. However, presence of sisal fibres could improve resistance to initial crack only by 3.5 times at the same fibre dosage.
- Hybrid combination of steel-PP exhibited superior performance as compared to steel-sisal combination and Mono-FRC. SPFRC improved the impact resistance to initial crack by 15 times at volume fraction of 1.50%. This improved performance is the result of synergy between steel and PP fibres.
- Impact resistance to complete fracture showed the similar trend as it was for initial crack formation. SFRC among mono-FRC group and SPFRC in hybrid combination outperformed in resisting repeated impact loading for the complete fracture.
- Though marginal improvement in impact resistance was observed between the curing periods 28 and 90 days for mono-FRC, noticeable improvement was observed in case of HyFRC.
- Difference in number of blows for initial and final crack increased with increase in fibre dosage. A maximum difference of 125 number of blows was observed for SPFRC for a volume dosage of 1.50%. SiFRC took less number of blows to become completely fracture from initial cracks. Strong correlation was observed between number of blows required for initial crack and for final crack.
- Compressive strength of fibrous concrete improved with the fibre dosage. Maximum compressive strength was observed for SPFRC and SSiFRC at a total fibre dosage of 1.25%. The compressive strength was improved by about 10% as compared to control mix. Role of the fibres in enhancing compressive strength was found to be limited.
- No strong correlation between compressive strength and resistance to impact loads could be observed. This is mainly due to the role of fibres in contributing to energy absorption capacity of the concrete.

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