

Impact Toughness Properties of Polymer Latex Modified Concrete Composites

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Abstract

The paper focuses on the impact strength and toughness behaviour of SBR based polymer concrete reinforced with crimped polypropylene fibres. A total of 48 slab specimens were casted and tested on a manual type fabricated impact testing apparatus. Circular disc specimens of 400 mm diameter concrete slabs were used to test the impact strength. In the polymer modified concrete the dosage of fibre used were 0.1% and 0.3% to the volume fraction of the concrete. Toughness parameters such as first crack, ultimate, fibre concrete and post crack toughness were evolved from the experimental study. It is observed that ultimate toughness of polymer fibre concrete (372.78N-m) is higher compared to plain concrete (139.79Nm) due to absorption of energy by SBR latex polymer and bridging of polypropylene fibres compared to plain concrete. The effect of fibres in absorbing the impact load and cracks was shown in post crack toughness of polymer modified concrete with increase in the dosage of fibres from 0.1% to 0.3%.

Keywords: Fibres, Impact Test, Polymer Modified Concrete, Post Crack Failure, Toughness

1. Introduction

Polymer incorporated concrete finds a wide range of applications in the production of high strength concrete with superior mechanical properties. The addition of polymer based rubber latex provides increased bonding when polymeric fibres added with cement matrix acts as pore fillers in the concrete. In addition it provides excellent workability on the fresh concrete properties even at low water to cement ratio. Polymer impregnated concrete requires shorter curing days to initiate strength gain before latex film formation. Polymer concrete with fibres provides increased tensile strength and resistance to cracking. Also, it is understood from several studies that SBR polymer provides high resistance to corrosion; plastic shrinkage cracks and improves the aggregate matrix bonding¹⁻³. On the other hand, the presence of discrete polypropylene fibres provides adequate reinforcing efficiency and improves the stress strain properties of concrete. The combined addition of polymeric fibres and polymer latex suspensions provided synergistic improvements on

the concrete composites. The toughness of the polymer composites is exhibited by means of plastic deformation upon reaching ultimate load without failure and showed improved post cracking mechanical properties⁴. Fibre addition in concrete provides higher energy absorption capacity by increasing the load at failure, impact strength and fatigue endurance of the fibre reinforced concrete⁵. The effects of different dosage of polypropylene fibres have shown marginal or negligible increase in fracture toughness compared to plain concrete. In the load deflection curve up to the point of concrete failure is dominated by the matrix strengthening and after the peak load the residual strength is dependent on the fibres bridging the cracks. The residual load increases with the increase in fibre dosage and provides adequate stress smoothening mechanism⁶⁻⁹. The polymeric fibre addition has a significant influence on the fracture toughness, bonding strength and impact toughness of the composite^{10,11}. The toughness of flexural specimens depends upon the loading rate and accuracy of deflection in the testing machine¹². It is also noted from many studies that, the

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addition of fibres provides high resistance towards impact and punching load^{13,14}. The impact failure is highly influenced by composite stiffness and subsequent delay in the crack origination. The impact load transmitted and energy absorbed in the concrete is realized from type of failure pattern^{15,16}. Energy absorption capacity of unreinforced polymer composites showed marginal increase in the flexural bending capacity and lower energy absorption when subjected to punching load. The flexural and impact toughness was found to be improved with the fibre addition in polymer modified concrete and the energy absorption capacity increases with the increase in fibre volume fraction^{17,18}. The presence of discrete fibres provided significant resistance to localized damage compared to reinforced concrete slab due to the random distribution of fibres in concrete matrix. The punching capacity of fibre reinforced concrete is highly improved by the membrane action and the failure of slab showed the formation of shear cones at ultimate load¹⁹⁻²¹. Fibre addition in high performance concrete increases the ductility properties and showed favourable improvement on the ultimate strength capacity²². Addition of fibres is known to exhibit improvement in failure pattern from single crack to multiple cracks in the composite. However, the large presence of polypropylene fibres in cementitious matrix showed gradual self straining upon progressive failure of concrete²³. Glass fibre reinforced polymer sheet in beam element increases the resistance to the formation of cracks and have shown higher loading capacity compared to controlled beam²⁴. Literature review on the various experimental studies of polymer latex incorporated concrete showed favourable strength development with careful concrete mix design. However, limited studies were conducted to exhibit the synergistic improvements of polymer additions in cementitious system. Mechanical strength improvements in terms of impact toughness of polymer latex substituted polymer fibre concrete mixes necessitates more detailed experimental investigations.

2. Experimental Program

2.1 Materials

An ordinary Portland cement of 53 grade having 28 days compressive strength of 46.1 MPa, satisfying the requirements of IS: 12269-1987²⁵ was used. The specific gravity of cement was 3.13 with a fineness value of 312 m²/Kg. Fine aggregate consisting of river sand passing through

4.75 mm IS sieve, conforming to grading zone-II of IS: 383-1978²⁶ was used. The fineness modulus and specific gravity of fine aggregate was found to be 2.56 and 2.69 respectively. Machine crushed well graded granite stone with 12.5 mm maximum size conforming to IS:383-1978²⁷ was used as aggregate fillers. The specific gravity of coarse aggregate was found to be 2.7 with a fineness modulus of 6.6. Class F flyash with low calcium content was used as cement replacement material at 25% and 50% of the total binder content. The properties of flyash are given in Table 1. Crimped polypropylene fibres were used for matrix strengthening and were homogeneously distributed by effective mixing procedures. The properties and snapshot of the crimped polypropylene fibres are given in Table 1 and Figure 1 respectively. The polymers used in this study consisted of SBR latex in liquid form of specific gravity 0.9 and high range water reducing super plasticizer (Conplast 430) were used to improve the workability of concrete (slump range of 75-90 mm).

2.2 Mixture Proportions for Polymer Fibre Concrete

2.2.1 Conceptual Mix Design

The various polymer fibre concrete mixes evaluated in the present experimental study was based on conceptual mix design procedures with target strength of M40 grade concrete. The concrete proportions were arrived by varying the fine aggregate to coarse aggregate ratio of 0.6 and 0.8, with different volume fraction of polypropylene fibres. A low water to binder ratio of 0.3 was used for preparing all polymer concrete mixture and the SBR latex polymer dosage was optimized at 8% based on trial studies. The experimental study includes a total of eight different concrete mixture proportions, which consisted of four plain concrete mixes (without PP fibres and SBR latex) and four polymer fibre concrete mixes. The details of the mix proportions are given in Table 2.

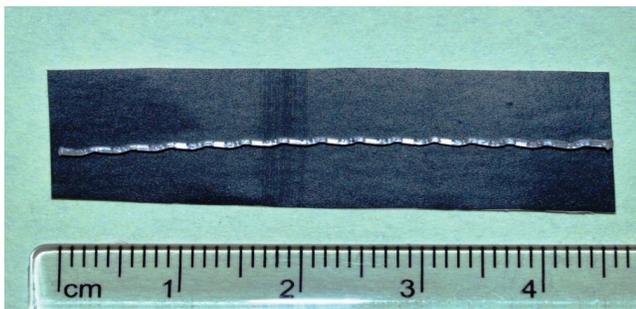
3. Experimental Test Methods

3.1 Impact Strength

Impact strength was performed on polymer modified concrete specimen of circular section with 400 mm diameter and 50 mm thickness. A total of 48 numbers of circular slab specimens were tested in the experimental study for each mix type. A small scale impact testing machine was

Table 1. Physical properties of Class F Flyash and PP fibres

Class F fly ash composition (%)	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	Cl	Loss on ignition	Insoluble residue	Moisture content
	59.30	34.60	5.87	1.02	0.38	0.10	1.28	0.01	0.49	1.90	-	0.73
PP fibres	Length (mm)		Diameter (mm)		Tensile strength (MPa)			Aspect ratio (L/d)		Density (Kg/ m ³)		
	47		0.60		450			80		910		

**Figure 1.** Crimped polypropylene fibre.

fabricated for the experimental work. Impact tests were conducted on concrete slabs with an impact weight of 4.5 Kg falling at a fixed height of 0.5 m from the top to observe the state of damage caused by impact loading. In order to secure the slab in restrained position at the time of impact adjustable screws were provided along the side of base plate to facilitate tightening of the circular slab. The test procedure was done manually by dropping the weight at a height of 0.5 m on the top of circular slab. The above process is continued until the ultimate failure of the slab occurs and the numbers of blows were noted for first crack and ultimate failure crack to determine the impact toughness of the slab. The schematic representation of impact test setup is shown in Figure 2 and snapshot of the tested specimen is shown in Figure 3.

4. Results and Discussions

4.1 Impact Strength and Toughness

Impact toughness represents the resistance of the material against cracking subjected to repeated impact force applied on the concrete surface. This exhibit the capacity of matrix to absorb the energy required to failure and the

test results obtained in various concrete mixes are provided in Table 3. The performance of the fibres on the energy absorption was calculated in terms of toughness parameters such as fibre concrete toughness and post crack toughness. First crack toughness in the case of fibre concrete mix (MS4) showed a maximum value of 139.79 N-m and a maximum ultimate toughness of 372.78 N-m. In the case of polymer concrete (MS2) with high volume fly ash addition, a maximum fibre concrete toughness of 69.90 N-m and a post crack toughness of 232.99 N-m observed for polymer concrete (MS4) were noticed. The energy absorbing capacity of fibre concrete specimens after the first crack shows the contribution of fibres in delaying the crack opening. It clearly indicates that compared to plain concrete, all fibre incorporated polymer concrete mixes showed maximum first crack resistance and ultimate failure. Also, the appearance of first crack was not visibly seen in plain concrete (without fibres) as it was the failure load which occurred immediately and the specimens showed complete failure. Whereas, the PP fibre substituted polymer concretes showed visible signs of fracture with the appearance of first crack and delayed occurrence of ultimate failure. The impact energy absorbed by the fibres present in the matrix was the difference in the ultimate and first crack toughness. Test results also indicate the fact that, the energy absorption capacity of polymer concretes was found to be higher which had PP fibre inclusions. The indication of energy absorption by the concrete matrix after first crack is truly exhibited when the fibres are present in the concrete system. In the case of plain concrete, the number of load repetition to failure was found to be lower and with the addition of fibres in polymer concrete mixes there was an apparent increase in the first crack resistance. This adequately defines the reinforcing properties of PP fibres in a high

Table 2. Mix proportions adopted for experimental study

Ingredients	Water+ Polymer composition					Binder + Aggregate composition				
	w/b ratio	F/c ratio	SBR Latex %	PP fibres (V _f) %	Super plasticizer %	Cement (Kg/m ³)	Flyash (Kg/m ³)	Fine aggregate (Kg/m ³)	Coarse aggregate (Kg/m ³)	Water (litres/m ³)
S1	0.3	0.6	0	0	1.5	400	100	713	1188	120
S2	0.3	0.6	0	0	1.5	400	200	675	1125	120
S3	0.3	0.8	0	0	1.5	400	200	800	1000	120
S4	0.3	0.8	0	0	1.5	400	100	844	1056	120
MS1	0.3	0.6	8	0.1	1.5	400	100	713	1188	120
MS2	0.3	0.6	8	0.3	1.5	400	200	675	1125	120
MS3	0.3	0.8	8	0.1	1.5	400	200	800	1000	120
MS4	0.3	0.8	8	0.3	1.5	400	100	844	1056	120

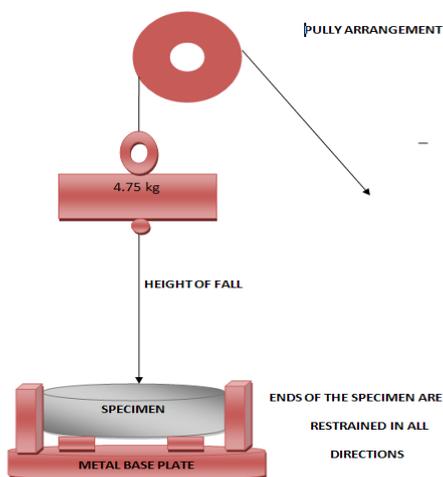


Figure 2. Schematic representation of impact toughness set up.

strength polymer matrix. From the comparative analysis of plain and polymer incorporated concrete mixes it can be drawn that the presence of fibres provides a possible crack arresting mechanism by means of inhibiting the crack origination and propagation. The subsequent delay in crack formation and widening could possibly lead to higher cracking resistance even after failure. In the case



Figure 3. Slab specimen placed in metallic base with restrained ends.

of plain concretes, the first crack was not visibly seen but rather developed complete failure upon reaching the ultimate capacity. Whereas, in the case of fibre substituted polymer concretes the first crack was noted at higher impact loading and showed a corresponding increase in ultimate load capacity at failure. The failure pattern

Table 3. Impact toughness properties for different polymer concrete mixes

Mix Id	S1	S2	S3	S4	MS1	MS2	MS3	MS4
PP fibre (V_p %)	0	0	0	0	0.1	0.3	0.1	0.3
F/C ratio	0.6	0.6	0.8	0.8	0.6	0.6	0.8	0.8
SBR Latex %	0	0	0	0	8	8	8	8
Fly ash %	25	50	50	25	25	50	50	25
Load (N)	46.60	46.60	46.60	46.60	46.60	46.60	46.60	46.60
Height of fall (m)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
No of blows (First crack)	0	0	0	0	4	5	4	6
No of blows (Ultimate crack)	2	2	3	4	8	12	10	16
First crack toughness (N-m)	0	0	0	0	93.26	116.49	93.20	139.79
Ultimate toughness (N-m)	46.60	46.60	69.90	93.20	186.39	279.59	232.99	372.78
Fibre concrete toughness* (N-m)	0	0	0	0	46.60	69.90	23.30	46.60
Post Crack toughness+ (N-m)	0	0	0	0	93.20	163.09	139.79	232.99

Note:

*Represents the difference between first crack toughness of polymer fibre concrete to the ultimate toughness of plain concrete.

+Represents the difference between ultimate crack toughness to that of first crack toughness of polymer fibre concrete.

represents the plain concrete in which a single crack occurred at ultimate and the crack growth was along the diametral direction. Whereas, in the case of fibre incorporated polymer concrete the tortuosity of crack growth occurred which resulted in multiple cracking. Also, most notably the crack growth propagated in radial direction originating from the centre of the concrete slab specimen. This shows that crack tortuosity can be anticipated in PP fibre substituted concrete mix compared to plain concrete specimens. Also, the difference in the first crack and ultimate crack provided an essential mechanism for energy absorption capacity in the case of PP fibre reinforced polymer concrete mixes. In general, the impact strength of polymer fibre concretes showed an appreciable increase in strength compared to plain concrete with higher

sustaining capacity even after repeated loading. Also, the crack width propagation in the concrete specimen is highly influenced by the dosage of fibres and increase in the fibre dosage increase the length and number of cracks before the ultimate failure load.

5. Conclusions

Within the limitation of experimental studies conducted the following significant conclusions are drawn.

- First crack toughness in the case of fibre concrete mix (MS4) showed a maximum value of 139.79 N-m and a maximum ultimate toughness of 372.78 N-m.

- A maximum fibre concrete toughness of 69.90 N-m (MS2) and a post crack toughness of 232.99 N-m (MS4) were noticed for polymer fibre concretes.
- The energy absorbing capacity of fibre concrete specimens after the first crack shows the contribution of fibres in delaying the crack opening.

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