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Evaluation of Fiber Type and Water-Binder Ratio Influence on Concrete Properties

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Abstract: *This paper enumerates the experimental study on workability and strength properties of concrete containing different dosage of polypropylene fiber from 0.1% to 0.6% and 1.0% to 3.5% of steel fiber. Water - binder ratio, fiber type and fiber dosage influence on flow behaviour, compressive strength, flexural strength and brittleness ratio were analysed. Experimental results were substantiated by linear regression analysis considering 95% confidence level. Reference mixes with 0.34 and 0.36 water- binder were prepared for results comparison with polypropylene and steel fiber reinforced concretes. Test results showed comparatively higher workability reduction in polypropylene fiber reinforced concrete. Compressive strength test results of fiber reinforced concrete indicted an optimum fiber content of 0.30% of polypropylene fiber and 2.50% of steel fiber. Steel fiber reinforced concrete displayed continuous increase in flexural strength with 44.46% average increase. Brittleness ratio, which was the ratio of flexural strength and compressive strength showed maximum value of 0.24 for concrete with 3.5 % steel fiber and 0.36 w/B ratio. Linear regression analysis revealed good correlation of flow properties with w/B ratio irrespective of fiber type. Though the compressive strength had low correlation with fiber type and w/B ratio, steel fiber reinforced concrete indicated up to 0.987 coefficient of determination with flexural strength.*

***Keywords** : Brittleness ratio, fiber reinforced concrete, flow properties, linear regression analysis.*

I. INTRODUCTION

In 21st centaury the concrete is one of the most widely used construction material due to its usage in all type of infrastructural projects. Decade's prior developed concrete is represented as conventional concrete in the present scenario and a step ahead concrete is being emerged as application oriented construction material. The fiber reinforced concrete (FRC) is one among those due to its immense benefit towards serviceability and durability aspects of concrete structures. Fibers in plain concrete withstand the tensile stress developed and prevent the development of microcracks. The production of FRC is intricate and multidimensional with varied grades of material and selection of fiber content. Many fibers are available in the market: polyvinyl fiber, carbon fiber, basalt fiber are successful in imparting one or other required performances in concrete. The studies show that the fresh property and mechanical behaviour of concrete are mainly influenced by fiber amount, fiber geometry, fiber orientation, fiber dispersion, concrete matrix mix design and concrete placement. The fiber amount and the concrete matrix mix design are two vital parameters which can be engineered in contrast to other crucial factors.

Concrete with fibers are tends to reduce the workability. Reduced V-B time and slump were observed for concrete with 0.05%, 0.10% and 0.20% of polypropylene fiber [1]. Steel fiber reinforced concrete with 0.0%, 0.5% and 1.0% fiber dosages, displayed a slump values of 12cm, 10cm and 7 cm [2]. Fiber reinforced concrete exhibited better results for all ranges of workability [3]. Good correlation was exist between slump test and flow table test and a linear regression correlation was exist between them with a correlation coefficient of 0.88 [4]

Considerable amount of works were carried on optimization of fiber type and content based on specific performance. Polypropylene fiber amount in lightweight high-strength concrete was optimized to prevent spalling when exposed to hydrocarbon fire [5]. Varied polypropylene fiber dosage considered in design of fiber reinforced mortar mixes to control the plastic shrinkage cracks [6]. [7] Fiber fractions of 0.05%, 0.1%, 0.2% and 0.3% were considered to analyze the compressive strength, toughness and impact resistance of polypropylene fiber reinforced concrete. The pre-cast fiber reinforced concrete elements are also characterised based on the performances in different tests. [8] Durability, micro- structural analysis and strength test results were utilized for characterization of polypropylene fiber reinforced concrete sleeper. Influences of polypropylene fiber on plaster mortars were analyzed based on strength test results. Among considered fiber dosage of 1.0 kg/m3, 1.5 kg/m3, 2.0 kg/m3 and 3.0 kg/m3, the specimens with 1.5 kg/m3 exhibited enhanced compressive and flexural tensile strength compared with controlled concrete and other fiber reinforced concrete specimens [9]. Concrete with polypropylene fiber contents of 2 kg/m3 and 3 kg/m3 indicated reduced compressive and splitting tensile strength losses at temperature higher than 200°C [10]. Among considered different fiber contents, 0.1% of polypropylene fiber displayed beneficial performances by improving tensile strength by 39% and reducing shrinkage cracks by 50% [11]. The flexural strength and brittleness index of the 1% polypropylene fiber reinforced concrete was increased up to 54% and 145% [12].

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The improvement in failure load, reduction in number of cracks and width of cracks clearly indicated beam specimens with 1.0 % of synthetic fiber performed better compared to 0.5% specimens [13].

The influence of fiber and optimization of fiber dosage are analysed by different methods and statistical tools. Different lengths polypropylene fibers were considered to optimize the wet shotcrete mix by Taguchi method. Analysis of variance (ANOVA) analysis was conducted to determine the influence of water- binder ratio and fiber on wet hardened properties [14]. Taguchi and ANOVA analysis were utilized to realize the influence of polypropylene fiber dosage, temperature and curing period on the test results [15]. [16] Regression analysis using response surface method (RSM) indicated the fiber properties greatly influences the fracture energy of steel fiber reinforced concrete. [17]Three level full factorial experimental design and response surface method were used to analyze the effect of aspect ratio and volume fraction of fiber on fracture properties of steel fiber reinforced concrete. Results indicated optimal design variable values of 0.64% volume fraction and an aspect ratio of 76.44. [18]Taguchi analysis technique in the form of Taguchi orthogonal array confirmed the noticeable effect of curing period and binder type among, age of testing, binder type, binder amount, curing type and steel fiber volume fraction, on compressive strength of steel fiber reinforced concrete. [19]Combination of trained ANN (artificial neural network) and PSOA (particle swarm optimization algorithm) were used to investigate the effect of polypropylene sulfide and steel fiber on workability and mechanical properties of self compacting concrete (SCC). Obtained results displayed decrease of workability with increase in fiber content and better influence of steel fiber on strength performances of SCC.

The performances of FRC is mainly depends on the type and geometry of fiber in concrete. Studies revealed the optimization of fiber dosage based on three parameters. First, to cater the specific requirement like resistance to spalling, plastic shrinkage cracks and other. Workability, strength and durability test results provides an authoritative information on FRC performances for varied fiber content. In this case the selection of fiber dosage range plays a pivotal role in deciding the FRC performance, since test results indicate no or less influences at lower dosages. Finally the test results can be validated thorough different statistical tools. Past researchers apprehended Taguchi method provides realistic confirmation on the influences of study parameters on workability and strength results. The present study aims to evaluate the effect of water-binder (w/B) ratio, polypropylene fiber and steel fiber on workability and strength. Linear regression analysis was employed to validate the test results.

II. EXPERIMENTAL PROGRAMME

A. Materials and Methods

In this experimental programme, FRC were made of ordinary Portland cement (OPC) conforming to Indian standard code IS 12269 [20]. Ground granulated blast furnace slag (GGBS) confirms to IS 12089 [21] with surface area 423 m^2/kg, specific gravity 2.90, and bulk density 1225 kg/m^3 was used as mineral admixture. Puntke test [22] results indicated an optimized binder (OPC:GGBS) content of 80:20 in total binder volume. The manufacture sand in accordance with zone-II requirement mentioned in IS 383 [23] having physical properties tabulated in table-I was used as fine aggregate. Locally available crushed granite single size coarse aggregate as per the requirement of IS 383 [23] was used in two size classes: 20mm - 4.75mm and 12.5mm - 4.75mm. The ideal combination (60% of 20mm - 4.75mm and 40% of 12.5mm - 4.75m size) of coarse aggregate was determined by dry packing test. Ideal all aggregate combination was again determined based on the dry packing [24] test results. Marsh cone test was carried out to determine the superplasticizer dosage and its properties are depicted in table-II. Monofilament polypropylene fiber shown in Fig. 1 is of diameter 0.036mm, cut length 12mm with aspect ratio of 334 was used to produce polypropylene fiber reinforced concrete (PFRC). Hooked end steel fiber with cut length 30mm, diameter 0.50 mm, density 7850 kg/m^3 and tensile strength 1345 kg/m^2 were employed as macro fiber.

Table-I: Properties of fine aggregate

Specific gravity	Fineness modulus	Water absorption, %	Material type	Particle size distribution
2.62	2.98	1.20	Granite	4.75mm to 150µm

Table-II: Characteristics of superplasticizer

Aspect	Relative Density	pH	Chloride ion content
Light brown	1.08	>6	< 0.2%

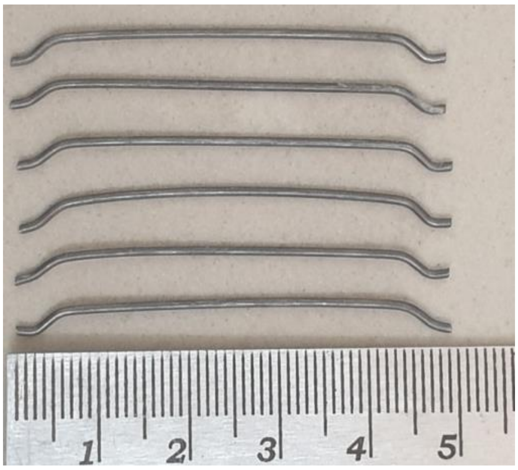

Fig.1 Polypropylene fiber and steel fiber use in the study

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B. Test Methodology

The reference concrete (RC) mix of compressive strength 40 N/mm^2 was designed in accordance to the guidelines of IS 10262 [25] for moderate exposure conditions. Two w/B ratio: 0.34 and 0.36 were selected to study its influence on fiber dosages. Two FRC series based w/B ratio consist of twenty four FRC mixes depicted in table-III were prepared with six polypropylene fiber dosage varies from 0.1 % - 0.6 % and steel fiber of 1.0 %, 1.5 %, 2.0 %, 2.5 %, 3.0 % and 3.5% dosage. Each FRC mixes were coded to represent w/B ratio and fiber dosage. The coarse aggregate had maximum nominal size of 20 mm. Mass of OPC, GGBS, fine aggregate, coarse aggregate, water and superplasticizer were kept constant based on w/B ratio. Flow table test as per the guidelines of IS 1199 [26] was employed to understand the variation in workability of PFRC and steel fiber reinforced concrete (SFRC).

Cube specimens of 150mm x 150mm x150mm were casted and tested to record the compressive strength as per IS 516. Flexural strength test was carried out in accordance with IS 516, on prism specimens of 150mm x 150mm x 700mm. All the specimens were moist cured for 7 and 28 days. To understand the influences of fiber and fiber dosage, brittleness index of PFRC and SFRC specimens were discussed which represented as the ratio of flexural strength to compressive strength [12].

Linear regression analysis was adopted for validation of experimental results. These models were used to propose the mathematical equations to find the volume of mixing fiber with influencing factors like flow percent, compressive strength and flexural strength.

Table-III: Proportion of fiber reinforced concrete mixes

w/B ratio	Mix code	Fiber dosage, %	Fiber mass, kg/m^3	Mass of other ingredients, kg/m^3
0.34	RC034	-	-	OPC-372 GGBS-93 Fine aggregate-724 Coarse aggregate: 20mm-684 12.5mm456 Water-158 SP-5.11
	PFRC03401	0.10	2.5	
	PFRC03402	0.20	5.0	
	PFRC03403	0.30	7.5	
	PFRC03404	0.40	10.0	
	PFRC03405	0.50	12.5	
	PFRC03406	0.60	14.9	
	SFRC03410	1.00	24.9	
	SFRC03415	1.50	37.4	
	SFRC03420	2.00	49.8	
	SFRC03425	2.50	62.3	
	SFRC03430	3.00	74.7	
	SFRC03435	3.50	87.2	
0.36	RC036	-	-	OPC-352 GGBS-88 Fine aggregate-731 Coarse aggregate: 20mm-690 12.5mm460 Water-158 SP*-4.84
	PFRC03601	2.5	2.5	
	PFRC03602	5.0	5.0	
	PFRC03603	7.4	7.4	
	PFRC03604	9.9	9.9	
	PFRC03605	12.4	12.4	
	PFRC03606	14.9	14.9	
	SFRC03610	24.8	24.8	
	SFRC03615	37.2	37.2	
	SFRC03620	49.7	49.7	
	SFRC03625	62.1	62.1	
	SFRC03630	74.5	74.5	
	SFRC03635	86.9	86.9	

III. RESULTS AND DISCUSSIONS

A. Workability

Compare to slump and Vee-Bee tests, the workability of FRC were well represented in flow table test [27]. The flow table test results of PFRC and SFRC for different w/B ratio and fiber dosage are tabulated in table-IV.

The flow table test results indicated inclusion of fiber either polypropylene or steel fiber resulted in reduction in workability [8] [28] [29]. Among 0.34 w/B ratio mixes, compared to SFRC mixes, the PFRC mixes displayed more workability reduction. The flow percent was reduced by 72% between PFRC03401 and PFRC03406. This may be due the "meshing effect" of polypropylene fiber with increased dosage. On the other hand, due to aspect ratio and geometry of fiber, less workability reduction of 58% was observed for SFRC mixes with 0.34 w/B ratio. Similar trend was observed for 0.36 w/B ratio mixes. Among PFRC mixes, highest flow percent of 110% was observed for PFRC03601 and the value decreases as the fiber dosage increases.

Table-IV: Flow table test results

Mix code	Flow Diameter	Flow Percentage, %
RC034	600	140
PFRC03401	490	96
PFRC03402	450	80
PFRC03403	380	52
PFRC03404	360	44
PFRC03405	345	38
PFRC03406	310	24
SFRC03410	550	120
SFRC03415	515	106
SFRC03420	495	98
SFRC03425	460	84
SFRC03430	445	78
SFRC03435	405	62
RC036	650	160
PFRC03601	525	110
PFRC03602	485	94
PFRC03603	445	78
PFRC03604	410	64
PFRC03605	390	56
PFRC03606	350	40
SFRC03610	575	130
SFRC03615	560	124
SFRC03620	510	104
SFRC03625	485	94
SFRC03630	465	86
SFRC03635	430	72

Though the similar trend of workability reduction appeared in SFRC mixes, but the rate of reduction was less compared to PFRC mixes. Overall flow percent reduction of 70% and 58% was noticed in PFRC and SFRC mixes with 0.36 w/B ratio. Due to availability of comparatively higher amount of water, 0.36 w/B ratio mixes exhibited higher flow percent than 0.34 w/b ratio mixes. This variation indicated the better dispersion of fiber at higher w/B ratio mixes.

Table-V and Fig. 2 indicate the results of linear regression analysis to understand the relationship between the flow percent and fiber dosages. Strong correlation was exist between the flow percent and SFRC mixes. Among PFRC, mixes with 0.36 w/B ratio exhibited less error compared to its counterpart. Considering w/B ratio, 0.36 influenced more on the flow percent because of higher correlation.

Table-V: Results of linear regression analysis for flow percent and fiber dosage

Mix code	w/B ratio	Regression coefficients		Standard error	Coefficient of determination, R^2
		A	B		
PFRC034	0.34	-141.14	105.07	7.019	0.946
PFRC036	0.36	-136.57	121.47	2.611	0.991
SFRC034	0.34	-22.1	141.22	2.382	0.989
SFRC036	0.36	-23.6	154.90	3.271	0.982

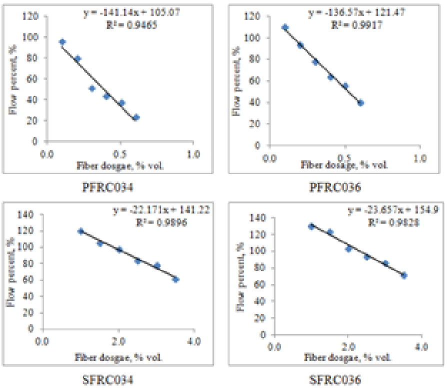

Fig. 2 Variation of flow percent with fiber dosages

B. Compressive Strength

The strength test results of concrete mixes were recorded to the nearest 0.05 N/mm^2. The normalised strength test results of RC, PFRC and SFRC mixes are tabulated in table-VI. The compressive strength, results of PFRC mixes with 0.34 w/B ratio indicated mixed variations at 7 days and 28 days of moist curing. Increase in strength was observed up to the fiber content of 0.30%. The PFRC03403 displayed highest compressive strength of 53.50 N/mm^2. Even PFRC mixes with 0.36 w/B ratio indicted increasing trend up to 0.30% fiber dosage. Later the value decreases with further increase in fiber content [11] [8]. This reduction may be due to the air entrapment around the polypropylene fiber, redistribution of void structure due to the inclusion of fiber and weak interfacial bonds between the fiber and paste matrix [1]. Among 0.36 w/B ratio, mix PFRC03603 exhibited highest compressive strength both at 7 and 28 days of curing. The standard deviation of test results were 2.15 N/mm^2 and 0.55 N/mm^2 [30] for 7 and 28 days of curing. An highest increase of 7.21% and 5.91% was observed in 0.34 and 0.36 w/B ratio mixes when compared to reference mixes [31].

SFRC mixes displayed gradual increase in compressive strength up to 2.5% fiber content. This increase in the compressive strength may be attributed to the confining effect and arresting of cracks growth [32]. Later the strength reduction was observed for both SFRC034 and SFRC036 mixes. Highest strength value of 42.05 N/mm2 and 55.65 N/mm2 was noticed in SFRC025 mix. The maximum increase was restricted to 11.52% [28]. Least compressive strength was observed for mix with 1.0% of fiber.

The maximum strength for SFRC036 mixes indicated better dispersion of fibers due to the availability of more water. Peak value of 54.85 N/mm^2 was observed at 2.5% and minimum compressive strength was observed for SFRC03610 mix. Further increase in fiber content resulted in gradual reduction strength [33]. Influence of fiber at 1.0% on reference mixes displayed negligible increase 2.72% and 4.64% for SFRC034 and SFRC036 mixes at 28 days [34]. Both SFRC034 and SFRC036 mixes recorded higher compressive strength compared to reference mixes RC034 and RC036 [27] . The SFRC034 mixes exhibited a standard deviation of 1.52 N/mm^2. Where as its value was 1.49 N/mm^2 for SFRC036 mixes.

Table-VI: Strength test results of concretes

Mix code	Normalised compressive strength at 7 days, N/mm^2	Normalised compressive strength at 28 days, N/mm^2	Normalised flexural strength at 7 days, N/mm^2	Normalised flexural strength at 28 days, N/mm^2
RC034	34.75	49.9	2.75	6.6
RC036	33.55	48.45	2.2	5.45
PFRC03401	34.9	50.75	2.85	6.75
PFRC03402	37	51.9	3.1	7.15
PFRC03403	40.65	53.5	4.05	8.2
PFRC03404	37.8	52.05	3.8	7.95
PFRC03405	35.7	50.6	3.25	7.1
PFRC03406	34.65	50.2	2.9	6.85
PFRC03601	33.75	50.05	2.45	5.55
PFRC03602	34.25	51.3	2.95	5.85
PFRC03603	39.35	52.85	3.85	6.85
PFRC03604	36.3	51.6	3.6	6.5
PFRC03605	35.15	50.6	3.25	6
PFRC03606	34.15	49.95	2.65	5.6
SFRC03410	37.65	51.35	3	6.85
SFRC03415	38.7	52.85	3.35	7.75
SFRC03420	40	53.65	4.05	8.15
SFRC03425	42.05	55.65	4.95	9.75
SFRC03430	39.6	52.55	5.65	10.7
SFRC03435	37.85	51.9	6.15	12.2
SFRC03610	34.25	50.7	2.5	5.65
SFRC03615	36.55	52.3	3.2	6.25
SFRC03620	38.85	53.25	3.85	7.95
SFRC03625	40.55	54.85	4.3	8.75
SFRC03630	38.9	52.85	5.45	9.65
SFRC03635	36.1	51.25	5.95	10.95

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Low correlation between compressive strength and FRC were evidenced from the linear regression analysis depicted in table-VII and Fig. 3. Results displayed minimal influence of fiber on compressive strength results at 28 days of moist curing. FRCs compressive strength was impacted by parameters other than fiber dosages.

Table-VII: Linear regression analysis results of compressive strength and fiber dosage

Mix code	Regression coefficients		Standard error	Coefficient of determination, R^2
	A	B		
PFRC034	-2.31	52.31	1.283	0.124
PFRC036	-1.10	51.44	1.204	0.035
SFRC034	0.22	52.49	1.687	0.018
SFRC036	0.34	51.76	1.622	0.046

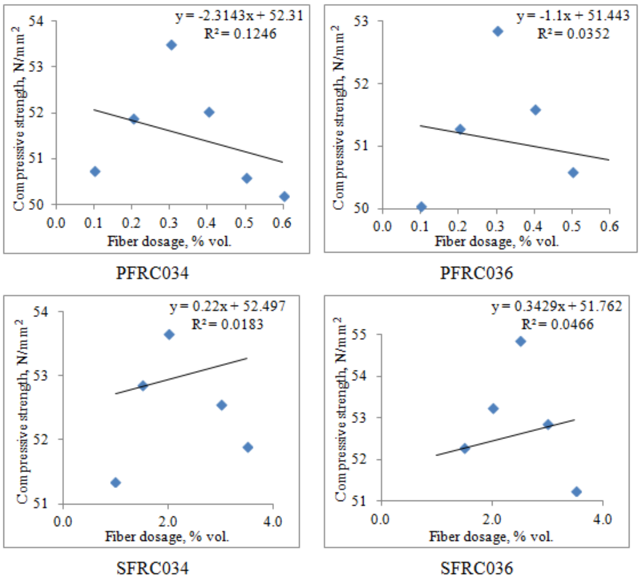

Fig. 3 Variation of compressive strength with fiber dosages

C. Flexural Strength

The flexural strength is a direct way of determining the tensile strength of concrete. Flexural strength of PFRC mixes with 0.34 w/B ratio increases first and then decrease with higher fiber content [8]. The least and highest strengths were noticed for PFRC03401 and PFRC03403 mixes. An increase of 24.24% was observed in PFRC03403 compared to RC034 at 28 days age [35]. Due to higher w/B ratio, PFRC036 mixes displayed lower strengths than PFRC034 mixes. But the values were higher than RC mixes. Highest flexural strength was again noticed for PFRC03603 mix. The PFRC03601 registered less increase in strength compared to RC mixes. Both mixes displayed steady increase up to 0.30% fiber dosage. Later gradually decreases.

Flexural strength of SFRC mixes indicated continuous increase with fiber contents both for 7 and 28 days of moist curing [27] [29] [36] [37]. SFRC034 mixes displayed variation in flexural strength from 3.00 N/mm^2 to 12.20 N/mm^2. Similarly SFRC036 mixes exhibited highest strength of 10.95 N/mm^2. But the values were lesser than 0.34 w/B ratio mixes [32]. Due to transfer of tensile stress from cement matrix to fibers and these transfer resulted in arrest of macro crack propagation led the SFRC mixes to exhibit tensile strength increase up to 84.84% [33]. The 7 and 28 days results indicated a standard deviation of 1.24 N/mm^2 and 2.00 N/mm^2. Flexural strength were in the range of 11.14% to 23.50 % of compressive strength.

Results of regression analysis results tabulated in table-VIII displayed no or low correlation between PFRC and flexural strength. Low tensile strength, flexural rigidity and weak bonding with matrix, the polypropylene fibers had minimal influence on tensile properties of reference concrete as shown in Fig.4.

Table-VIII: Linear regression analysis results of flexural strength and fiber dosage

Mix code	Regression coefficients		Standard error	Coefficient of determination, R^2
	A	B		
PFRC034	0.02	7.32	0.669	0.000079
PFRC036	0.10	6.02	0.577	0.001309
SFRC034	2.12	4.45	0.355	0.975
SFRC036	2.14	3.37	0.247	0.987

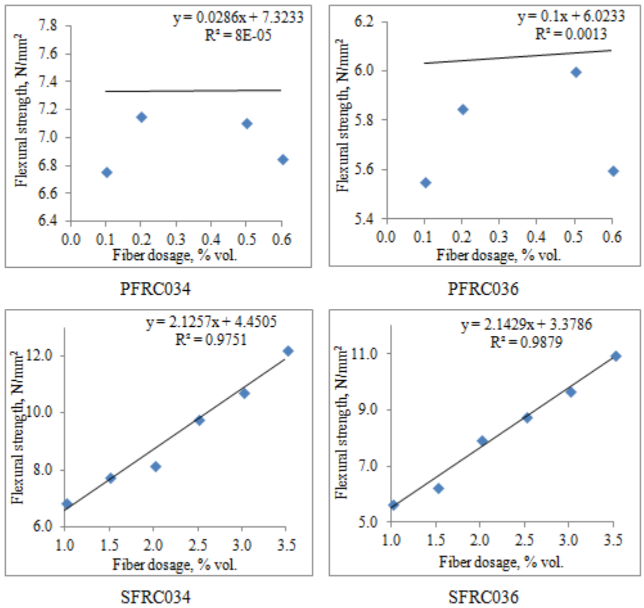

Figure 4 Variation of flexural strength with fiber dosages

On the other hand, strong matrix bond of steel fibers resulted in high flexural strength of SFRC mixes. Its higher tensile strength and end hook geometry increases the resistance for fiber debonding. The w/B ratio influence was minimal on fiber type and concrete tensile strength.

D. Brittleness Index

The ratio of flexural strength and compressive strength indicates the brittleness index [12] and it was analysed to assess its relationship with fiber dosages. This ratio was calculated for 28 days strength results of both PFRC and SFRC mixes. The influence of fiber type and fiber volume on brittleness are depicted in Fig.5 and 6. The brittleness index of PFRC and SFRC mixes indicated improvement with increase in fiber dosages. [29] [12]. PFRC034 mixes with 0.10%, 0.20%, 0.30%, 0.40%, 0.50% and 0.6% displayed 0.56%, 4.16%, 15.88%, 15.48%, 6.09% and 3.17% increase in brittleness index compared to RC034.

An increase of 15.22% was noticed for PFRC03603 which was highest among PFRC036 mixes. SFRC mixes with w/B ratio 0.34 indicated continuous increase in brittleness index varies from 0.86% to 77.73%. Even the SFRC036 mixes exhibited continuous improvement which was ranged between 0.11 to 0.21. The brittleness index of FRC mixes were dependent on w/B ratio. It was observed the 0.34 w/B ratio mixes irrespective of fiber type indicated higher index compared to 0.36 w/B ratio mixes. Among steel fiber and polypropylene fiber, steel fiber exhibited higher values for both w/B ratio. In general both FRC mixes exhibited higher brittleness index than RC mixes.

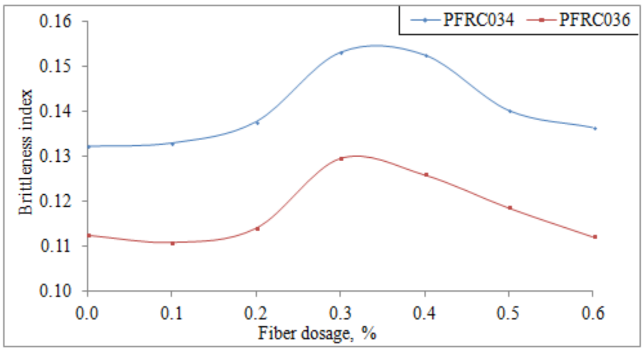

Fig. 5 Brittleness index of PFRC mixes

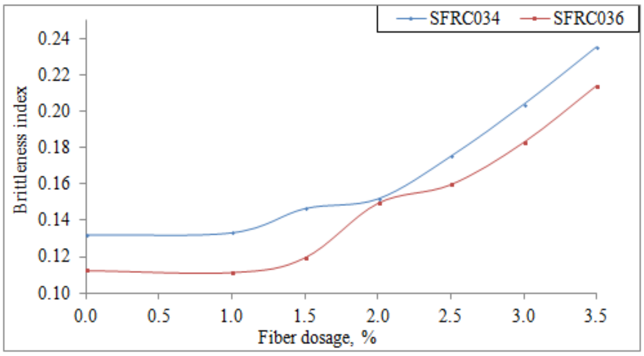

Fig. 6 Brittleness index of SFRC mixes

IV. CONCLUSIONS

Many inferior behaviours of regular concrete can be effectively overcome by using fibers. Ideal fiber content plays vital role in determining the required performances of concrete. Conclusions were drawn based on experimental study and linear regression analysis to understand the influence of fiber dosage and w/B ratio on concrete properties.

• Flow properties of PFRC and SFRC were sensitive to the variation in fiber dosage. Due to fiber meshing effect and higher aspect ratio, PFRC mixes exhibited more workability reduction compare to SFRC.

• Compressive strength test results were decisive in finding the optimized fiber in PFRC and SFRC. It was dependent on w/B ratio and fiber type. Average increase of 4.27% and 7.27 % was observed between RC, PFRC and SFRC. Similarly, mixes with 0.34 w/B ratio exhibited marginal increase of 0.63 N/mm2 over the 0.36 w/B ratio mixes. The polypropylene fiber dosage of 0.30% displayed highest compressive strength at both w/B ratio. Highest values were noticed for 2.50% steel fiber dosage.

• PFRC mixes exhibited highest flexural strength of 8.20 N/mm2 for 0.30% of fiber at 0.34 w/B ratio. But, SFRC mixes for both w/B ratio displayed continuous increase in flexural strength. SFRC03435 mix indicated maximum value of 12.20 N/mm2. PFRC mixes achieved average increase of 11.11%, whereas SFRC indicated an enhancement of 44.61 % compared to RC mixes. Results indicated greater influence of steel fiber on flexural strength. Studies can be extended with higher fiber dosages and other fiber types to understand the influence on strength properties.

Brittleness index of reference concrete was less influenced by the presence of polypropylene fibers. Maximum increase of 15.88% was noticed in PFRC03403 mix. Random distribution of hooked end steel fibers in concrete exhibited positive influence on the brittleness index. Highest increase of 89.94% was witnessed for SFRC with 3.5% fiber dosage and 0.36 w/B ratio.

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