Experimental Study on Enhancement in Modulus of Elasticity of Concrete with Inclusion of Hybrid Fiber Reinforcement

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Abstract

This article provides the experimental result in enhancement of modulus of elasticity of concrete by inclusion of discrete fibers. Researchers have successfully demonstrated that the addition of fibers to concrete strengthens the concrete by fostering interactions between the fibers and matrix. Concrete's elastic modulus, which affects the stiffness of the material and is a reliable measure of strength, must be taken into consideration in order to maintain the material's maximum serviceability. The tests on M20 and M25 grade conventional and Hybrid Fiber Reinforced Concrete (HFRC) are carried out in laboratory to examine the improvement in modulus of elasticity. The combination of hooked end steel fiber ranging from 0.5% to 1.00% by volume of concrete and fibrillated polypropylene (PP) fibers from 0.3% and 0.6% is added in concrete.The study reveals that the addition of 1.00% hooked end steel fibers + 0.3% fibrillated polypropylene fibers by volume of concrete significantly improves the HFRC's experimental modulus of elasticity by 52.23% and 55.60% for M20 and M25 concrete respectively and also helps prevent excessive deformation by avoiding the most cost-effective designs.

KeyWords: Modulus of Elasticity; Compressive Strength; Fibrillated Polypropylene fiber; Hooked end steel fiber; Hybrid fiber reinforced concrete

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Introduction

Concrete is adaptable, has desirable strength characteristics, and can be shaped into any shape or size using the most economical resources. Hybrid fibers, which are discontinuous, discrete, and uniformly scattered fibers, are added to concrete to boost its modulus of elasticity [4]. Hooked end steel fibers improve compressive strain under maximum load, provide superior crack management, boost tensile strength, and serve as crack arrestors. Contrarily, fibrillated polypropylene fiber has high tensile strength and relatively high elastic modulus. For constructions that demand stringent control of deformability, it is highly necessary to get an accurate estimate of the modulus of elasticity of concrete. The modulus of elasticity is often used in situations involving the determination of the amount of reinforcement, the computation of stress based on observable strain, and, in essence, the measurement of the stiffness of a material.

In addition, structures made of high-strength concrete have a tendency to be more slender and need for a higher elastic modulus to maintain their stiffness. This is necessary in order to make full use of the compressive strength potential. The use of standard reinforced steel bars may raise the tensile strength of concrete; nevertheless, these bars do not increase the tensile strength of concrete on their own. In members made of reinforced concrete, cracks may freelyexpand until they come into contact with a reinforcing bar. Because of this, it is necessary for concrete to have reinforcement in multiple directions and at near interval [1].

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The ratio of the stress to the strain experienced by the concrete as a result of the application of loads is known as the concrete's modulus of elasticity. Different methods, such as the initial tangent modulus, secant modulus, or tangent modulus, may be used in conjunction with the stress-strain curve to calculate the elastic modulus [2]. Experiments may be performed to determine the elastic modulus, or approximations could be made using formulae supplied by a variety of algorithms [3]. The criteria that determine the compressive strength of concrete are also the ones that determine its elastic modulus [4]. The fibers are able to maintain their strength which includes the transmission of stress from the matrix to the fibers either by interfacial shear or, if the fiber surface is distorted, through interlock between the fiber and the matrix. When the matrix is under strain, the fiber and the matrix both experience stress; however, as the matrix begins to break, the whole of the stress is gradually transferred to the fibers [5]. On the other hand, in contrast to plain concrete, the presence of fibers in concrete has the potential to produce qualities that are both strain-softening and strain-hardening. Because of this, it is challenging to estimate the elastic modulus of strain-hardening for Fiber Reinforced Concrete (FRC), given that the equations that are now in use may not be appropriate. Some of the researchers have hypothesized that the addition of discrete fibers to concrete would result in an increase in the material's modulus of elasticity [6-10]. The modulus of elasticity is referred to as the secant modulus of elasticity, and it is determined by the slope of the limit linking the origin to any point on the stress-strain curve. This slope is used to determine the point at which the deformations are to be computed. [2] The components that have an effect on the modulus of elasticity include the moisture state, the aggregate characteristics, the cement matrix, and the transition zone. The elastic modulus was favorably impacted by polypropylene or steel fibers, and it rises with the increment of fiber content, according to the experimental test findings of FRC's elastic modulus that were conducted with various fiber contents [11]. This study is to determine the HFRC's modulus of elasticity as well as the combination of greatest fiber percentage and highest modulus of elasticity. This paper could be helpful to promote the wider applications on HFRC in civil engineering. The percentage of steel fiber used is 0.5%, 0.75% and 1.00% for every 0.3% and 0.6% percent of polypropylene fiber respectively.

Objectives Of The Study

The objectives of this study are

Experimental study on enhancement in modulus of elasticityof HFRC with inclusion of hooked end steel and fibrillated PP fibers in predefined proportions to concrete.

Comparative investigation of the percentage improvement in modulus of elasticity of HFRC at workable mix with maximum fiber content with reference to conventional concrete.

Factors Affecting Modulus Of Elasticity Of Concrete

The factors affecting the modulus of elasticity of concrete are presented in Fig. 1.

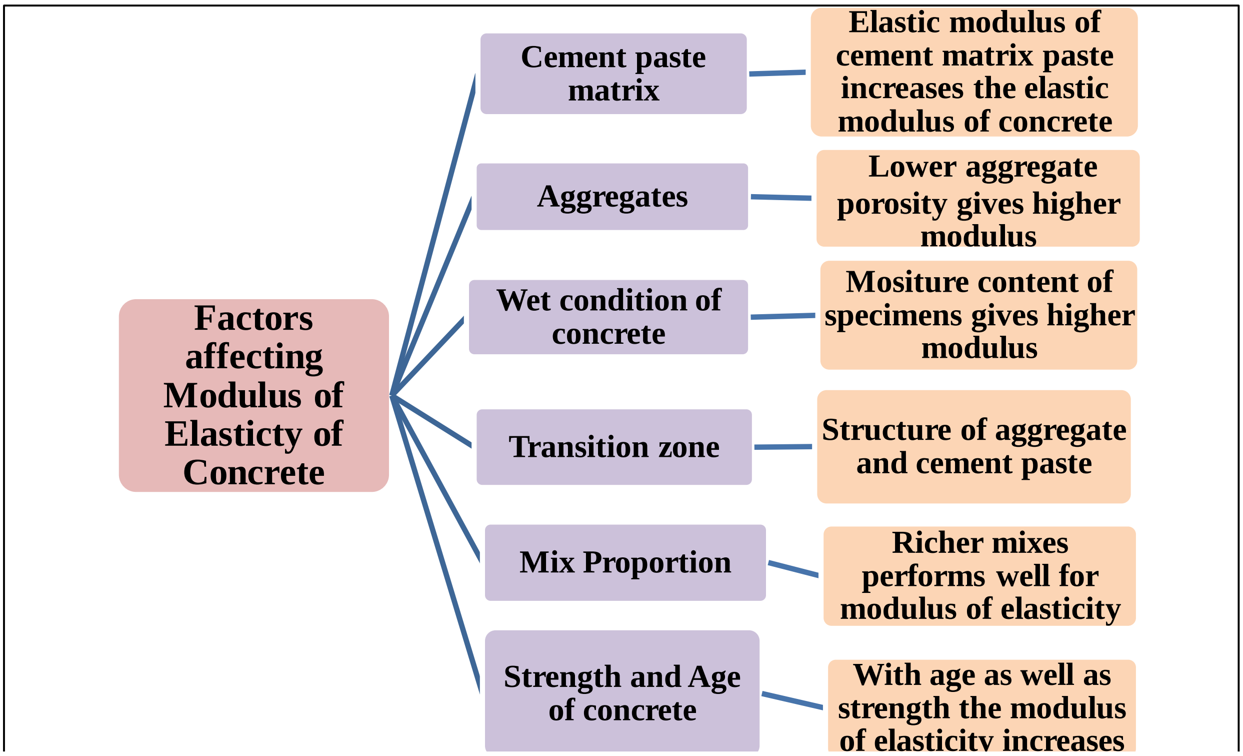

Fig 1: Factors affecting Modulus of Elasticity of Concrete

Experimental Program

Materials Used

53 grade OPC cement is used and tests are conducted conforming to IS 12269:1987. Artificial sand is used as fine aggregate conforming to zone-I of I.S. 383-2016 and locally available 20mm coarse aggregate is used. Two types of fibers are used, namely hooked end steel fiber [Fig. 2] and fibrillated polypropylene fiber [Fig.3].

Fig2: Hooked end Steel fiber

Fig3: Fibrillated Polypropylene fiber

Hooked end steel fibers used are of length, diameter and aspect ratio equal to 60 mm, 0.75mm and 80 respectively. In addition the polypropylene fibers used are of length, diameter and aspect ratio equal to 20mm, 50 micron and 400 respectively.In addition, the tensile strength and elastic modulus of hooked end steel fiber is 1100 MPa and 200 GPa, and those of PP fiber is 453 MPa and 3.5 GPa.

Mix Proportions

A mix design is carried out as per I.S. 10262:2019 and mix proportions obtained are as follows:

For M20 grade - 1:1.795:3.25, w/c ratio = 0.51
For M25 grade - 1:1.967:2.997, w/c ratio = 0.485

Study of properties of concrete

The concrete is cast precisely in accordance with the specifications of the concrete mix design. Fibers are added into the mix in small amounts at a time to avoid balling up while it is being mixed. For evaluating the quality of the concrete, I.S. cylinders are made from each mix.

Workability

Hybrid fiber reinforced concrete does not respond well to slump test due to stiffness simulated by fibers used in it. The compaction factor (CF) test is therefore adopted, and workability iscomputed in terms of the compaction factor. According to I.S. 456:2000, 0.85 to 0.92 is the range for compaction factor of concrete with medium workability.

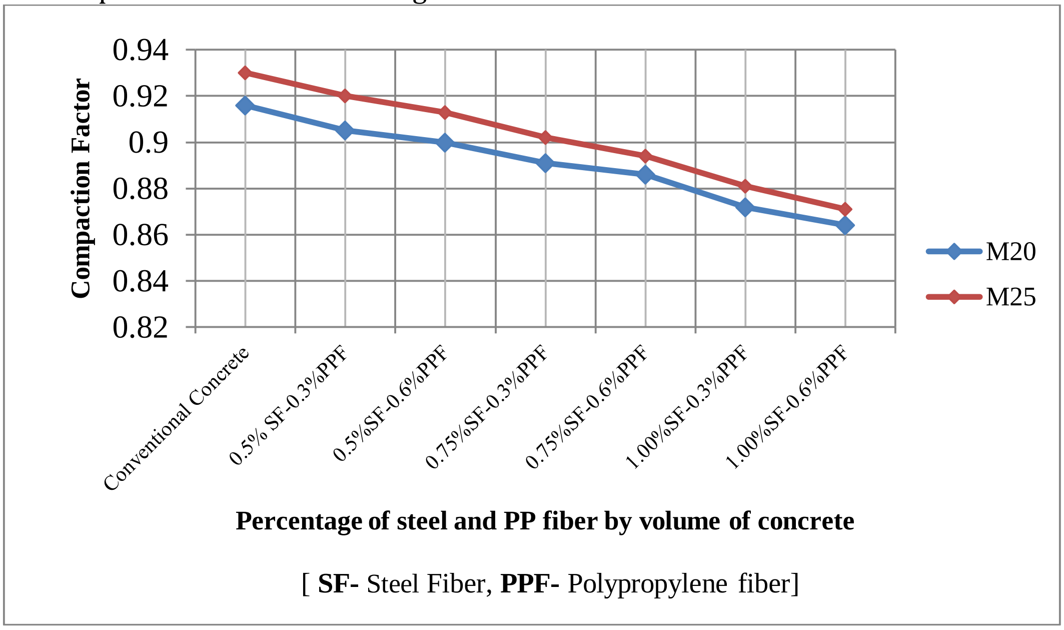

Fig 4:Variation in workability of M20 and M25 grade concrete with varying percentages of steel & PP fibers

We can observe that workability of concrete decreases as the percentage of fibers increases which depicts that fibers acts as obstruction for workability of concrete. Fig. 4 shows the variation in workability of M20 and M25 grade of conventional concrete and HFRC withvarying percent of steel and PP fibers. At maximum fiber content of 1% steel + 0.6% PP fiber, for M20 grade concrete, compaction factor is 0.864 which comes under medium workability range as per I.S. 456:2000. Similarly for M25 grade with same fiber content the compaction factor is 0.871. There is no need of super plasticizer for workability up to this mix. Even though fiber content of 1% steel + 0.6% PP is workable its strength is lower than 1% steel+ 0.3% PP fibers. Hence, it is found that HFRC mix with 1% steel fiber + 0.3% PP is the suitable workable mix with maximum fiber content [14].

Test Specimen, Casting and Curing

According to I.S516-1959(Reaffirmed 2018), the cylindrical specimen 300mm long and 150mm diameter are cast for M20 and M25 grade conventional as well as HFRC mixes.Total 42 test specimens were cast.
Specimens were kept under 90% humidity for 24 hours, there after de-molded and immersed in water for 28 days of curing.

Experimental set-up and Test Procedure

The strain was measured using the Video Gauge Measurement System [Table 1] which gives strain and deformation readings in microns.

Table 1:Specifications of Video Gauge Measurement System

Sr. No.	Description	Specifications
1.	Application	Simultaneous measurement of deformations like strain, displacement, rotation, shear strain etc. on various materials including metals and alloys, plastics, composites, concrete etc.
2.	General Features	Non-contact continuous measurement and direct strain output without any need for calibration
		Real time measurement for more than 100 target points
3.	Hardware	Camera GigE PoE camera, 50fps, 2048 x 1088 or better
		Lenses Lenses for various applications. Offers fixed focal length lenses of 50 mm and 8mm, resolution range of 0.5 μm to 5 μm (depending upon working distance).
4.	Software	Complete software package with test setup and control tools
		Video Zoom in/zoom out facility in measurement setup and calibration mode
		Post process mode to analyse various parameters using recorded video

After 28 days of curing, test specimens are tested immediately for Modulus of Elasticity of concrete in accordance with I.S. 516:1959.Fig. 6 shows a flowchart forthe test procedure specified by I.S 516:1959 which is followed meticulously in the present investigation during test in laboratory. The strain readings are taken in the central 150 mm portion of the specimen, away by 75mm from both the edges as specified by I.S. 516:1959 [Fig. 5(a)].

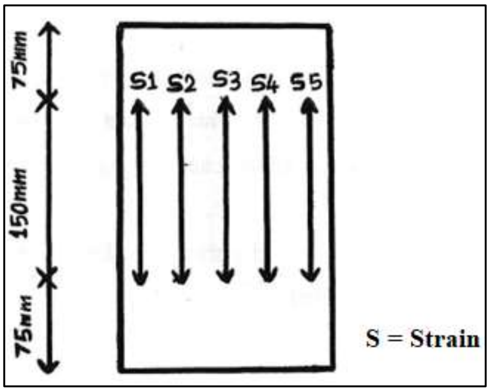

Fig 5(a): Strain measurement at different regions on specimen

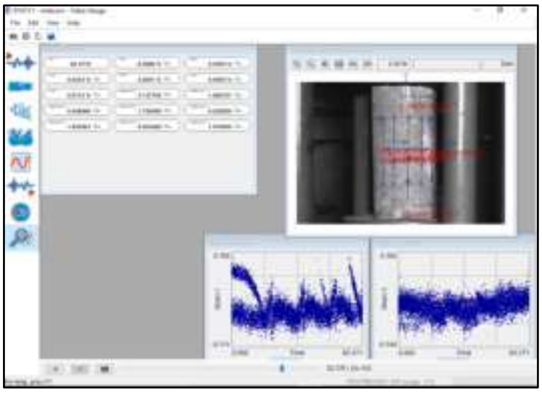

Fig. 5(b): Strain readings by Video Gauge Measurement System

1. Application of load and strain measurement is started simultaneously. The load is applied continuously and without any shock at a rate of 14 N/mm²/min until an average stress of (C+0.5) N/mm² is reached, where C is one third of compressive strength of cubes calculated to the nearest 0.5 N/mm².
2. Further this load is maintained for one minute and is reduced to 0.15 N/mm²/min. The load is applied again until the average stress rate is reached to (C+0.15) N/mm². The load is again reduced gradually and again readings are taken at 0.15 N/mm².
3. The load is then applied a third time and readings taken at ten approximately equal increments of stress up to an average stress of (C+0.15) N/mm².
4. If the overall strains observed on the second and third readings differ by more than 5%, the loading cycle is repeated until the difference in strain between consecutive readings at (C+0.15) N/mm² does not exceed 5%.
5. Finally the readings are taken at each stage. In the software, strain readings are recorded since the process began and also stress readings are computed concurrently.
6. Load v/s deformation readings are recorded and the Modulus of Elasticity is obtained by plotting the graph of stress vs. strain.

Fig 6:I.S. 516:1959 procedure for computation of Modulus of Elasticity of Concrete in Laboratory

The experimental test set up to test thespecimens in laboratoryis shown in Fig. 7.

Fig 7: Use of Video Gauge Measurement Software for strain measurement in testing for modulus of elasticity of concrete

Results And Discussion

Table 2 shows modulus of elasticity results for M20 and M25 grade of conventional concrete and HFRC with inclusion of hybrid fibers.

Table 2- Experimentalresults of modulus of elasticity of conventional concrete and HFRC

Grade of Concrete	Type of concrete	% of fibers by volume of concrete		Compressive Strength of cylinder (MPa)	Experimental Modulus of elasticity (MPa)	Average Experimental Modulus of elasticity (MPa)	% increase in Experimental Modulus of Elasticity of HFRC w. r. t conventional concrete
		Steel fiber	PP fiber				
M20	Conventional Concrete	-	-	21.06	1.98×104	2.01×104	-
					2.04×104		
					2.00×104		
	HFRC	0.50	0.3	23.12	2.28×104	2.31×104	14.92
					2.35×104		
					2.30×104		
			0.6	23.42	2.47×104	2.45×104	21.89
					2.42×104		
					2.46×104		
		0.75	0.3	24.92	2.69×104	2.66×104	32.33
					2.61×104		
					2.66×104		
			0.6	25.01	2.84×104	2.80×104	39.30
					2.77×104		
					2.81×104		
		1.00	0.3	25.49	2.99×104	3.06×104	52.23
					3.10×104		
					3.12×104		
			0.6	24.11	2.92×104	2.89×104	43.78
					2.86×104		
					2.90×104		
M25	Conventional Concrete	-	-	25.92	2.35×104	2.32×104	-
					2.28×104		
					2.33×104		
	HFRC	0.50	0.3	27.58	2.49×104	2.43×104	4.74
					2.40×104		
					2.44×104		
			0.6	28.70	2.66×104	2.60×104	12.06
					2.61×104		
					2.55×104		
		0.75	0.3	29.97	2.84×104	2.89×104	24.56
					2.95×104		
					2.87×104		
			0.6	31.02	3.26×104	3.23×104	39.22
					3.20×104		
					3.22×104		
		1.00	0.3	31.95	3.64×104	3.61×104	55.60
					3.58×104		
					3.63×104		
			0.6	29.90	3.37×104	3.33×104	43.53
					3.29×104		
					3.34×104		

Modulus of elasticity is the ratio of linear stress to linear strain. Hence, as the stress increases and/or the strain decreases the modulus of elasticity of concrete increases. Steel and PP fibers, due to their high tensile strength and percent elongation respectively, are instrumental in stress as well as strain improvement of concrete. Fibers contribute to improved ductility and help the matrix bind together and control creep. Due to inclusion of hybrid fibers in concrete, its stiffness improves considerably. The interface between the matrix and the fibers becomes stronger as the stress increases, increasing the stress-strain relationship with a higher elastic limit. Delay in crack initiation and also reduction in micro cracking at the interface is as a result of strain improvement in HFRC. Consequently this strain rate is relatively slower than stress rate of concrete. Since, the rate of increase of stress is higher than rate of increase of strain, the modulus of elasticity improves. The fibers are deliberate in increasing the ultimate stress. Results show that there is continuous increment in modulus of elasticity of HFRC with addition of steel and PP fibers.

The percent increase for M20 grade is 52.23% and for M25 grade the increment is 55.60% by the inclusion of 1% steel + 0.3% PP fibers respectively [Table 2]. Modulus of Elasticity for highest percent combination of 1% steel + 0.6% PP fiber is found to get decreased because the compressive strength isdecreased and relatively pre-cracking is observed during the testing due to excessive fibers in it

Table 3:Comparison of theoretical modulus of elasticity asper IS 456:2000 with experimental values

Grade of Concrete	**Type of concrete**	**% of fibers by volume of concrete**		**Modulus of Elasticity of concrete as per IS 456:2000**	**Average Experimental Modulus of elasticity (MPa)**	**% increase in Experimental Modulus of Elasticity of HFRC w. r. t I.S. 456:2000**
		Steel fiber	PP fiber			
M20	Conventional concrete	-	-	5000 √ f ck= 5000 √ 20 = 2.23×104MPa	2.01×104	-9.86
	HFRC	0.5	0. 3		2.31×104	3.58
			0.6		2.45×104	9.86
		0.75	0.3		2.66×104	19.28
			0.6		2.80×104	25.56
		1.00	0.3		3.06×104	37.21
			0.6		2.89×104	29.59
M25	Conventional concrete	-	-	5000 √ f ck= 5000√25 = 2.50×104MPa	2.32×104	-7.20
	HFRC	0.5	0. 3		2.43×104	-2.80
			0.6		2.60×104	4.00
		0.75	0.3		2.89×104	15.60
			0.6		3.23×104	29.20
		1.00	0.3		3.61×104	44.40
			0.6		3.33×104	33.20

Table 3 presents the test results of the percent increase in modulus of elasticity of concrete with respect to the theoretical value. The theoretical value of modulus of elasticity is computed using formula given by I.S 456:2000. The maximum increase in modulus of elasticity of concrete is observed at 1% steel + 0.3% PP fiber content for M20 and M25 grade HFRC. This improvement is 37.21%and 44.40% for M20 and M25 grade of HFRC respectively.

Graph shows the variation in the modulus of elasticity for M20 and M25 grade of Conventional concrete and HFRC [Fig. 8]. Graph shows continuous increase in the modulus of elasticity of concrete with addition hybrid fibers. But for 1% steel and 0.6% PP fiber there is decrease in modulus of elasticity. The curve for modulus of elasticity of M25 grade is at higher level than M20 grade HFRC.

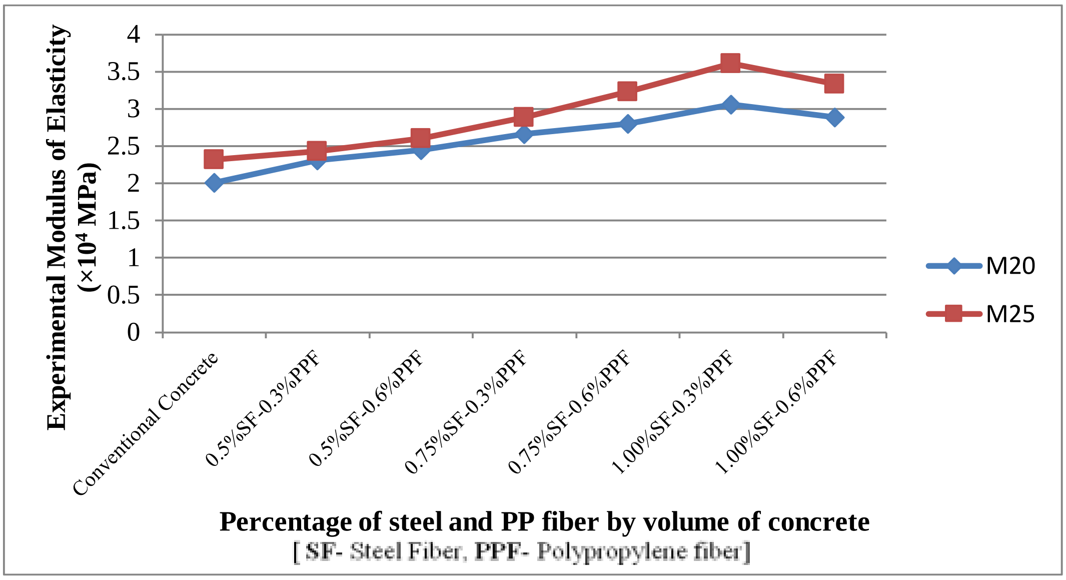

Fig 8: Variation in Experimental Modulus of elasticity for M20 and M25 grade conventional concrete and HFRC

Conclusion

The effect of combination of hooked end steel fiber and fibrillated PP showed a good performance in the increment of modulus of elasticity of concrete under uni-axial compression test. The theoretical value of modulus of elasticity is computed using formula given by I.S 456:2000. Based on the experimental results, following conclusions are drawn:

A workable mix with maximum fiber content is 1% hooked end steel fiber + 0.3% fibrillated PP fiber without superplasticizers.

According to the experimental values, HFRC is a strain-rate-dependent material, and both steel and PP fibers clearly have a strengthening and toughening influence on concrete strength.

Substantial improvement in modulus of elasticity of HFRC is observed due to inclusion of hybrid fibers in it. In case of M20 HFRC with 1% steel + 0.3% PP fiber content, experimental modulus of elasticity is observed to be maximum and equal to 3.06×104 MPa which is respectively 52.23% and 37.21% greaterthan theexperimental and theoretical value of conventional concrete.

In case of M25 HFRC, experimental value of the modulus of elasticity is equal to 3.61× 104MPa, which is respectively 55.60% and 44.40% greater than the experimental and theoretical value of conventional concrete.

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