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Performance of Polymer Optical Reinforced Granite Concrete

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ABSTRACT

The present study focuses on the results of experimental research on steel-fiber-reinforced metakaolin concrete. An investigation is done to state how these fibers affect various concrete strengths. The fiber percentage in cement varied from 0.5 to 5% by weight at intervals of 0.5. The bond strength, split tensile strength, flexural strength, and compressive strength were considered for investigation. A 100 mm cube and beams measuring 500 mm by 100 mm by 100 mm were cast for flexural strength. Before being assessed, each sample was water-cured for 7 or 28 days. To evaluate workability, we proceeded with the slump cone test. The observations on the fiber-reinforced concrete from the load-deflection were then investigated. The static and dynamic moduli of concrete are examined. When the results of steel fiber-reinforced metakaolin concrete were compared to those of ordinary concrete, it was clear that the results at various strengths had significantly improved.

Keywords: Polymer Optical fibers, Hooked End Polymer Optical fibers, FRC, Workability, Strengths, Elastic constants, NDT, Plasticizer

1. Introduction

The most widely used construction material in the world is probably cement concrete. Because it offers good workability and can be molded into any shape, it is widely used. An estimated 10 billion tons of concrete are consumed annually, or one ton for each person. [1] Due to the release of CO2 and dust particles into the atmosphere, the production of cement and steel poses environmental risks. Therefore, the wise use of cement and steel has different effects on the economy and the environment. Simple concrete is a brittle substance. Under impact and dynamic loading plain concrete exhibits extensive cracking and undergoes brittle failure. Because the concrete is weak in tension, it is strengthened with steel bars and is referred to as reinforced cement concrete as a result (R.C.C.) Civil engineering projects today must meet specific structural and durability standards. Every structure has a specific purpose, so it is now necessary to modify conventional cement concrete in order to achieve that purpose. The aforementioned discussion sparked extensive research on concrete, which gave rise to the development of mineral admixtures (such as fly ash, silica fume, rice husk, granite, etc.) that can partially replace cement, superplasticizers to increase workability, and various types of fibres that can be incorporated into concrete to enhance its mechanical properties, durability, and serviceability. Hydraulic cement, aggregates, and discrete reinforcing fibres make up the majority of the components of Fiber Reinforced Concrete (FRC), a composite material. Numerous engineering characteristics of concrete, mortar and cement paste are improved by fibre incorporation, including fracture toughness, flexural strength, resistance to fatigue, impact, thermal shock, and spalling. It is a kind of building material whose use is expanding. The need to update knowledge on the use of fibre reinforcement in such concrete grows as new types of concrete are continuously developed. It's not particularly novel to use fibre reinforcement. Fibers made from organic material were used in antiquity.

Reinforced with Fiber In the 1960s, concrete began to be used in modern industrial settings. The initial uses of FRC were mostly related to defense, and they included a number of shelter structures. The FRC's use as a building material has increased as a result of research development. Today, it is frequently used in precast components, shotcrete, pavements, industrial floors, and bridge decks. Technically, FRC with a high fibre content can be produced with very high tensile strength, but for structural applications, this is not practical. Several different types of fibres are used to create fiber-reinforced concrete. Metallic and non-metallic fibres are the two main categories into which the fibres are divided. We'll primarily talk about polymer optical fibre reinforced concrete here (POFRC). The POFRC is a composite material made of cement, fine and coarse aggregates, and discontinuous discrete Polymer Optical fibres. Only after the Polymer Optical fibre breaks or is pulled out of the cement matrix does POFRC fail in tension. The properties of POFRC when it is freshly mixed and hardened can be attributed to the composite nature of the material. [2] The type of fibre, aspect ratio, volume fraction, and size of the aggregates all affect the mechanical properties of POFRC. The ability of POFRC to transfer stresses across a cracked section increases the toughness of concrete in the hardened state, making this one of the material's most significant properties. For predicting the various mechanical properties of Polymer Optical fiber-reinforced concrete, Ramaswamy and Thomas [3] proposed models. Regression analysis of the test data was used to create the models. The proposed models' predictions of Polymer Optical fiber-reinforced concrete's strength were compared to test results from the current study and to a number of other test results that were reported in the literature.

The test data were accurately predicted by the proposed model. The study found that, contrary to both existing models and formulations based on the law of mixtures, the interaction of the fiber matrix significantly contributes to the improvement of mechanical properties brought about by the introduction of fibers. In order to determine the effectiveness of fiber inclusion in improving the mechanical performance of concrete with regard to the concrete type and specimen size, Balendran, Zhou, Nadeem, and Leung [4] carried out a series of experiments. According to the experimental results, the low volume of fiber improves splitting tensile strength, flexural strength, and toughness but has little impact on compressive strength. For lightweight concrete, the increase in splitting tensile strength, flexural strength, and toughness index was significantly greater than for normal aggregate concrete. They hypothesized that splitting and flexural strengths appeared to decline with specimen size and fracture behavior became more brittle.

In three types of SRFC specimens with 0.0%, 3.0%, and 6.0% (percentage by volume) of ultra-short Polymer Optical fibers, impact compression tests were conducted on 74-mm-diameter split Hopkinson pressure bars by Wang, Liu, and Shen [5]. (SHPB). A dynamic damage constitutive model of POFRC composite under compression was proposed based on the stress-strain curves of various strain rates and the random statistical distribution hypothesis for POFRC strength. It was determined that the POFRC strength is significantly influenced by both the volume fraction of steel fiber and the strain rate of loading. Theoretical findings and experimental findings agreed well. The impact of polymer optical fibre reinforcement and polymer modification on the Young's modulus of lightweight concrete aggregates was investigated by Kurugo, Tanacan, and Ersoy [6].

The mixtures' properties and volume fractions of their constituents were determined through experimental measurements of composite property models. Additionally, qualitative research was done on the connections between different composite properties and the mixtures used to create lightweight concrete. Granju and Balouch [7] looked into polymer optical fibre corrosion in the cracked area. In the cracked section, the durability of the material depends on the performance of the bridging capacity of the fibres embedded in the concrete. In addition to causing the concrete to spill, fibre corrosion also poses a threat to structural durability by reducing the sectional area of the fibres. The findings demonstrated how little POFRC is sensitive to corrosion. In cracked, Polymer Optical fiber-reinforced concrete, Rapoport, Aldea, Shah, Ankenman, and Karr [8] investigated the relationship between permeability and crack width. Additionally, it examined how polymer optical fibre reinforcement affected the permeability of the concrete. The findings demonstrated that specimens with relaxed cracks larger than 100 m had less permeability due to the Polymer Optical fibers.

Using either uniaxial compression or tension, Jin and Li [9] conducted an experimental study to determine how mineral admixtures like silica fume, slag, fly ash, and granite affected the mechanical behavior of young concrete. The experimental findings demonstrated that the various mineral admixtures do affect the properties of young concrete in a variety of ways. Young concrete's mechanical properties improved the most in granite. Potgieter and Vermaak [10] Kaolinite is thermally activated to produce granite, a pozzolanic substance. It has several important advantages when used as an extender for Portland cement. This note describes the increase in strength seen in mortars with additions of granite ranging from 10% to 30%. Compressive strengths were discovered to increase with longer curing times and to be highly dependent on the chosen activation temperature. They suggested that the concentration of Granite addition had little to do with strength improvements. In some cases, there have been significant increases in the compressive strengths of cement mortars of up to 80% or more.

The effects of granite and silica fume on various properties of concrete were researched and compared by Ding and Li [11]. With 0, 5, 10, and 15% of the cement replaced by either granite or silica fume, seven concretes were poured at a water-to-binder ratio of 0.35. Slump, compressive strength, free shrinkage, restrained shrinkage cracking, and chloride diffusivity were tested for in the concretes through ponding. Concrete modified with granite performed better than concrete modified with silica fume. The strength of the concrete modified with granite increased at all ages in a manner similar to that of the concrete modified with silica fume as the replacement level was raised. Both mineral admixtures constrained the shrinkage cracking width and decreased free drying shrinkage. The objective of this paper is to investigate the behavior of Polymer Optical fiber Reinforced Granite Concrete (POFRGC) composite with various volume fractions and to investigate various properties.

2. Experimental Results & Analysis

The tests on hardened concrete are conducted in accordance with the relevant standards. The strength of the material theory is used to compute the results of various strengths. The results of the test on wet and hardened concrete are tabulated in the following manner. Results of hardened POFRGC are later compared to those of regular concrete.

2.1 Workability and Density

The slump cone test is used to determine whether concrete with or without fibre is workable. The weight and volume of cube moulds are measured in order to determine the density. Table 1 displays the outcomes of these properties. According to Table 1, fiber-reinforced concrete has slightly more wet and dry density at 7 and 28 days than regular concrete. This could be as a result of granite replacing some of the cement, which densifies the concrete due to its microfilter effect from the relatively smaller particle size. Figure 1 depicts the variation in wet and dry density in relation to the percentage fibre volume fraction.

Table 1 - Physical Properties of Concrete.

Sr. No.	Mix designation	Granite (%)	% of Polymer Optical fiber	Water cement ratio	Wet. Density (kg/m3)	Dry Density (kg/m3) at 7 days	Dry Density (kg/m3) at 28 days	Workability by a slump (mm)
1	M0	12.5	0	0.40	2700	2603	2620	70
2	M1	12.5	0.5	0.40	2711	2590	2600	68
3	M2	12.5	1.0	0.40	2718	2616	2650	65
4	M3	12.5	1.5	0.40	2720	2620	2673	65
5	M4	12.5	2.0	0.40	2723	2623	2673	60
6	M5	12.5	2.5	0.40	2730	2643	2690	60

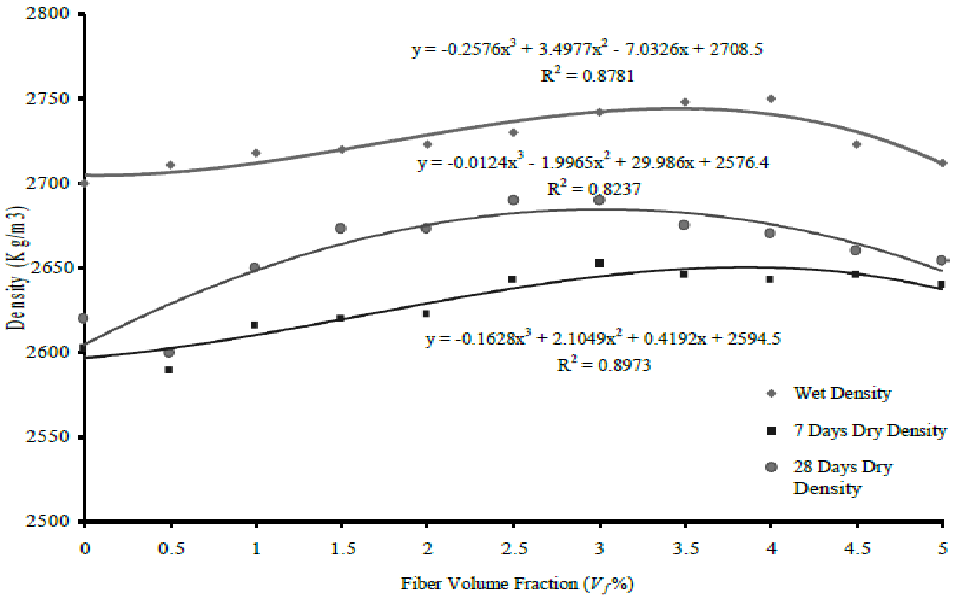

Fig 1: Variation of Wet Density And dry Density (7 Days and 28 Days) With Respect to Percentage Fiber Volume Fraction.

2.2 Slump loss and fiber factor

Table 2 displays the calculated slump loss with respect to fibre factor for various fibre volume fractions. The values of slump loss show that the workability decreases and the slump loss increases as the fibre factor rises.

Table 2 - Slump loss and Fiber factor

Sr. No.	Fiber Volume fraction Vf (%)	Fiber Factor Vf.(l/d)	Slump (mm)	Slump Loss
1	0	0	70	0.00
2	0.5	0.4	68	2.86
3	1	0.8	65	7.14
4	1.5	1.2	65	7.14
5	2	1.6	60	14.29
6	2.5	2	54	22.86

2.3 Compressive strength test on cube

Table 3 - Compressive Strength of Normal and SFRM Concretes, MPa

Sr. No	Granite (%)	Fiber Content (%)	Compressive Strength (fcu) MPa		% Variation in Compressive Strength Over Control Concrete	
			7 Days	28 Days	7 Days	28 Days
1	12.5	0.0	29.21	34.18	00.00	00.00
2	12.5	0.5	31.48	35.65	07.77	04.30
3	12.5	1.0	36.66	39.18	25.50	14.62
4	12.5	1.5	37.12	40.67	27.07	18.98
5	12.5	2.0	38.33	39.84	31.22	16.55
6	12.5	2.5	38.67	42.62	32.38	24.69

Table 3 indicates that the optimum volume fraction of fibers which gives maximum strength at 28 days is 3.0%. The percentage increase in strength at this volume fraction of fibers over normal concrete at 7 and 28 days is 28.02% and 8.74% respectively

2.4 Flexural strength test on beams

Table 4 - Flexural Strength of Beam, MPa

Sr. No	% of Polymer Optical fiber	Flexural strength in N/mm2		% variation in flexural strength over control concrete	
		7 Days	28 Days	7 Days	28 Days
1	0	4.16	4.64	00.00	00.00
2	0.5	4.35	4.96	04.56	06.89
3	1.0	4.78	5.15	14.90	10.99
4	1.5	5.1	5.36	22.59	15.51
5	2.0	5.42	6.16	30.28	32.75
6	2.5	5.76	6.82	38.46	46.98

From above Table 4, it is observed that the flexural strength increases with an increase in fiber content upto 3.0% and then it decreases. The maximum values at 7 and 28 days are 6.02 and 7.17 respectively. Thus, there an enhancement in the flexural strength of concrete from 4.56% to 44.71% at 7 days and from 6.89% to 54.52 % at 28 days.

2.5 Flexural Shear strength

Flexural shear strength is obtained for various fiber volume fractions and results are presented in Table 5.

Table 5 - Flexural Shear Strength of Beam, MPa

Sr. No	% of Polymer Optical fiber	Flexural Shear strength in MPa		% variation in flexural shear strength over control concrete	
		7 Days	28 Days	7 Days	28 Days
1	0	0.520	0.580	00.00	00.00
2	0.5	0.544	0.620	04.61	06.89
3	1.0	0.598	0.644	15.00	11.03
4	1.5	0.638	0.670	22.69	15.51
5	2.0	0.678	0.770	30.38	32.75
6	2.5	0.720	0.853	38.46	47.06

2.6 Equivalent cube compressive strength test

Table 6 - Comparison of Equivalent Cube Compressive Strength from Prism

Sr. No	Fiber content (Vf) %	Equivalent cube Compressive Strength (MPa)		% Variation in Compressive Strength over Control Concrete	
		7 Days	28 Days	7 Days	28 Days
1	0	0.0	40.30	42.33	00.00
2	0.5	0.5	41.83	44.33	03.79
3	1.0	1.0	41.33	44.96	02.55
4	1.5	1.5	42.33	46.00	05.03
5	2.0	2.0	44.66	47.83	10.81
6	2.5	2.5	46.67	48.67	15.80

Results of Equivalent cube compressive strength from prism are shown in Table 6 . Percentage increase in compressive strength at 7 days for 3.0% fiber content is 19.10% at 7 days and 20.08% at 28 days over control concrete.

2.7 Split tensile strength on cylinder

Table 7 - Split Tensile Strength on Cylinders, MPa

Sr. No	Fiber Content %	Split Tensile Strength (N/mm2)		% variation in split tensile strength over control concrete	
		7 Days	28 Days	7 Days	28 Days
1	0	1.52	2.40	00.00	00.00
2	0.5	1.96	2.65	28.94	10.41
3	1.0	2.12	2.44	39.47	01.67
4	1.5	2.20	2.68	44.73	11.67
5	2.0	2.32	2.93	52.63	22.08
6	2.5	2.40	2.96	57.89	23.33

From Table 7, the maximum increase in split tensile strength is 67.76% for 7 days and 25% for POFRGC at 28 days. The split tensile strength increases upto 3.0% fiber content and then again starts decreasing marginally for both 7 and 28 days respectively.

2.8 Pull out test on cubes

Table 8 - Bond Strength (MPa) and Work Done on Pullout Test

Sr. No	Fiber Volume fraction Vf (%)	Max. pull out force		Max. slip mm		Work done kN-mm		Bond strength (τbd)	
		7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
1	0	1.60	1.65	6.35	6.85	10.17	11.31	4.25	4.38
2	0.5	1.49	1.58	5.10	6.08	07.62	09.62	3.96	4.21
3	1	1.45	1.53	4.62	5.33	06.70	08.16	3.85	4.08
4	1.5	1.41	1.51	5.22	5.56	07.37	08.40	3.76	4.01
5	2	1.46	1.49	4.66	4.56	06.81	06.80	3.89	3.97
6	2.5	1.47	1.56	5.38	5.81	07.92	09.07	3.92	4.16

From Table 8, it is observed that bond strength has decreased marginally with the addition of fibers over normal concrete. It is also observed that maximum work done occurs at 4.0% fiber addition. The bond strength at 28 days decreases marginally upto 2.0% fiber addition and starts increasing upto 4.0% and then it again reduces.

3. Elastic Constants

Table 9 shows the results of determining the POFRGC's elasticity modulus using the Law of Mixtures, the I.S. code equation, and the Halpin-Tsai equations. Figure 2 illustrates how the static modulus obtained using the aforementioned formulae varied in relation to the fibre volume fraction.

Table 9 - Static Modulus of Elasticity (E) (GPa) of POFRGC

Sr. No	Fiber content (Vf) %	Compressive Strength (fcu)	Modulus of elasticity (E) GPa		
			IS Code	Law of mixture	Halpin-Tsai
1	0.0	34.18	29.23	29.23	29.23
2	0.5	35.65	29.85	29.28	30.34
3	1.0	39.18	31.29	29.32	32.28
4	1.5	40.67	31.88	29.37	33.36
5	2.0	39.84	31.55	29.42	33.53
6	2.5	42.62	32.64	29.47	35.12

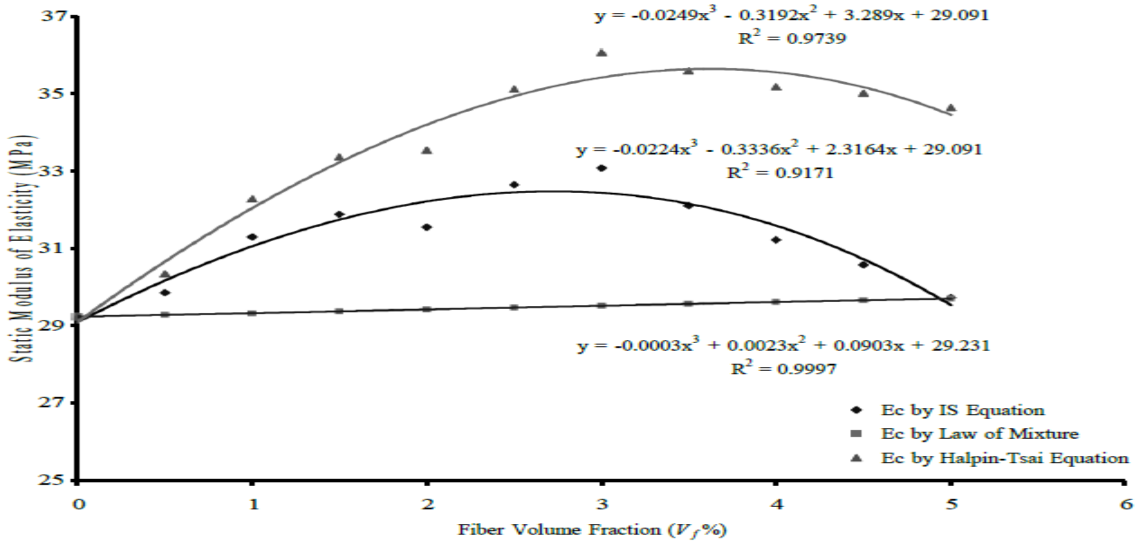

Fig 2: Variation of Static Modulus of Elasticity of Concrete with Respect to Percentage Fiber Volume Fraction.

4. Failure Pattern of Concrete & Rebound Hammer and Ultrasonic Pulse Velocity Test

The first vertical crack in POFRGC cubes was found at the coroners, and a mesh of cracks was then found around the edges of the concrete cubes. The mesh of cracks created on the periphery exhibits slicing on the cubes' sides. In POFRGC cubes, concrete spalling was discovered. Due to the bonds' strength, plain concrete cubes exhibited spalling and pyramidal failure. Due to the bond strength of concrete in the fibre, the diagonal tensile stresses increased. The compressive strength of POFRGC cubes is increased as a result of the fibers on the failure plain. The first vertical crack was noticed at the coroners, and a mesh of cracks was then noticed on the concrete cubes' perimeter.

Table 9 - Rebound Hammer Test on Cube at 28 days

Sr. No	Fiber Content (Vf)%	Face 1	Face 2	Face 3	Face 4	Mean Strength (MPa)
1	0.0	21.76	20.14	12.9	25.70	20.12
2	0.5	32.16	28.9	21.8	29.73	28.14
3	1.0	20.46	21.8	28.76	-	23.67
4	1.5	23.76	23.53	28.00	-	25.09
5	2.0	26.10	24.76	25.86	-	25.57
6	2.5	19.76	20.33	24.23	19.25	20.89

5. Mathematical Analysis

5.1 Compressive strength

Table 10: Comparison of Compressive Strength by Regression Analysis

Sr. No	Polymer Optical fiber content (%Vf)	Compressive strength, MPa			
		Exp. Value 7 days	From Eqn (4) at 7 days	Exp. Value 28 days	Exp. Value 28 days
1	0.0	29.21	25.77	34.18	30.79
2	0.5	31.48	27.53	35.65	32.35
3	1.0	36.66	29.22	39.18	33.81
4	1.5	37.12	30.82	40.67	35.17
5	2.0	38.33	32.32	39.84	36.44
6	2.5	38.67	33.72	42.62	37.59
7	3.0	40.24	35.00	43.76	38.62
8	3.5	40.33	36.16	41.24	39.54
9	4.0	38.56	37.19	39	40.33
10	4.5	35.33	38.08	37.38	40.98
11	5.0	32.66	38.81	35.33	41.50

Table 10 showcases the mathematical analysis done considering the compressive strength by Regression analysis. Similarly, various other tests like Flexural strength, flexural shear strength test, Split tensile strength test, bond strength test, tests on Modulus of elasticity, ultrasonic pulse velocity for cubes test, and ultrasonic pulse velocity for beams test are calculated using mathematical analysis and are omitted considering the length of the paper. On the basis of results obtained from the experimental analysis and mathematical analysis the following comparison is drawn.

6. Comparison between Experimental and Mathematical Analysis

The results of the experimental work are in excellent agreement with the results of the analytical method, it can be inferred from the results of the analytical and experimental work. The values of bond strength, split tensile strength, and flexural strength discovered through experimental research are more in line with those discovered through the analytical method. Compared to analytical results, only a small percentage of these strengths' values are undervalued.

Table 11: Optimum Fibre Content for Maximum Strength

Strength (MPa)	POFRGC		
	Steel Fibre content (%)	Max. Value of Strength, MPa	Percentage Variation of Strength over normal concrete
Compressive Strength	3.0	43.76	28.02
Flexural Strength	3.0	7.17	54.52
Split Tensile Strength	3.0	3.00	25.00
Bond Strength	4.0	4.36	0.00

7. Conclusion

From the experimental analysis carried out, the following conclusions are drawn,

- The wet and dry density of fiber-reinforced concrete has slightly risen over that of regular concrete at 7 and 28 days. Due to inadequate bond formation between the fibers and cement matrix, the density slightly decreased after the fibre content reached 3.5% at 28 days.
- Several techniques are used to obtain the elastic constants of the POFRGC. Empirical expressions for the static and dynamic moduli of elasticity have been developed in terms of the POFRGC fibre volume fraction and cube compressive strength. The predicted values of the modulus of elasticity and the law of mixtures agree very well.
- The optimum percentage fiber volume fraction for compressive strength, flexural strength, and split tensile strength is 3.0% while for bond strength is 4.0%.

- Satisfactory workability was maintained with increasing volume fraction of fibers by using a superplasticizer, The width of cracks is found to be less in POFRGC than that in plain cement concrete beam. The pullout force is increased with an increase in fibre content.
- Static Poisson’s ratio (μc) varies from 0 .20 to 0.35 and dynamic Poisson's ratio (μd) varies from 0.30 to 0.37 at 28 days. It is observed that μd is greater than μc and also μd is on the higher side for fiber-reinforced concrete over normal concrete.

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