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Investigating the effect of polypropylene fibres and curing parameters on the workability and mechanical properties of concrete

ABSTRACT

Polypropylene fibres possess certain characteristics that make them an ideal counterpart to attain explicit advantages when used for building works, more specifically, when added to concrete. In this investigation, polypropylene fibres were added by weight of cement (0.25%, 0.5% and 0.75%) in M20 grade of concrete and their impact on workability, compressive strength and flexural strength was assessed and analyzed. The slump test revealed that as the polypropylene fiber loading in the concrete mix was increased, the workability of the mixture continued to decrease; the workability decreased by 11.11%, 19.44% and 45.83% upon addition of 0.25 %, 0.5%, and 0.75% fibres respectively in the concrete. The compressive strength as well as the flexural strength of the concrete increased monotonously with increase in the curing time and fibre loading. For instance, in case of acidic water curing, the compressive strength enhanced from 19.08 MPa to 22.85 MPa upon increasing the fibre content from 0.25% to 0.75%. Adding 0.25% polypropylene fibre resulted in an increase in the flexural strength of conventional concrete mix by 15.78% and 10.29% when cured in normal water for 28 days and 56 days, respectively. Both compressive and flexural strength of the samples cured in normal water was found to be higher than the samples cured in acidic water and it was observed that the fibre reinforced concretes were more resistant to acids than the normal unreinforced concrete.

Keywords: *Cement, curing time, slump behavior, compressive strength, flexural strength*

1. INTRODUCTION

In the construction sector, concrete is the most popular building material. It consists of a carefully selected mixture of binders such as cement, well-classified fine and coarse aggregates, water and additives. To improve the qualities of conventional concrete, short, discrete fine fibers are randomly dispersed throughout the material [1-3]. The strength properties, aspect ratio, orientation, volume, shape, spacing and dispersion of the fibers affect how well a structure performs. A variety of fibers, including asbestos, steel, glass, carbon, nylon, and others, have been employed to enhance the characteristics of typical concrete [4-6]. Off late, a novel development in concrete related research has been the reinforcement of various fibers, which has displayed excellent outcomes in the form of enhanced compressive and flexural strength of the concrete. Polypropylene (PP), also known as polypropene, is a fiber that is used for strengthen concrete and for protection of concrete against micro cracks [7-10]. The durability of concrete has been found to improve by adding polypropylene fibers. Zhang et al. [1] noted that the compressive strength of concrete increased with increase in fiber dosage up to 0.3%. However, additional upsurge in the fibre content caused a reduction in the compressive strength. The incorporation of chopped basalt fibers to concrete mixtures exerted a positive impact on both compressive and flexural strength without compromising on the workability. Addition of 1% basalt fibers led to an upsurge in the flexural and tensile strength by 64% and 46%, respectively [2]. Toutanji [10] investigated the consequence of adding polypropylene fibers and silica fume on the mechanical properties of cement

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concrete. The silicon fume contents used were 5 and 10%, and the fiber volume fractions were 0.10, 0.30, and 0.50%. The findings showed that 5% fumed silica in combination with 0.30% fiber volume fraction provided the best mix design for repair applications in terms of processability, bonding, strength, elongation, and permeability. However, it is noteworthy that adding silica fume alone ensued a substantial reduction in permeability. Curing is essential to the development of the dense microstructure and pore structure, which in turn controls the concrete's moisture loss during cement hydration and leads to the achievement of desired properties. Yan and Cui [11] discovered that grinding fine slag powder with cement, fly ash, silicon ash composite, and gelled material at curing temperatures over 50°C greatly increases the reactivity of cement. However, a high curing temperature exerts a detrimental impact on adhesion and mechanical properties [12].

In this investigation, polypropylene fibres were added by weight of cement (0.25%, 0.5% and 0.75%) in M20 grade of concrete to assess their impact on the various properties of the concrete. Concrete specimens reinforced with and without polypropylene fibres were casted and subsequently cured in normal and acidic water for 7, 28 and 56 days. The impact of polypropylene content, curing medium and curing time on workability, compressive and flexural properties were determined, analyzed and discussed during the investigation.

2. MATERIALS AND METHODOLOGY

2.1. Materials Used

Materials utilized in the production of concrete mixtures include cement, aggregates (coarse and fine), polypropylene fibers, and sodium sulfate. Each material has been tested and its physical properties are described below. Digital photograph of polypropylene fibre used in this work.

Cement: Grade 43 ordinary Portland cement (OPC) was used as recommended by IS-8112 [13]. A cement plant was used throughout the JK OPC experimental work. Table 1 shows the characteristics of OPC.

Table 1. Properties of cement

Properties of Cement	Experimental value
Normal consistency (% by weight of cement)	35
Setting time (minutes) Initial Final	 45 350
Specific gravity	3.14

Fine Aggregate: **S**and present in the nearby locality was utilized as the fine aggregate. The physical properties of these aggregates enumerated in Table 2 were determined according to the test procedure described in IS-383 [13].

Table 2. Properties of fine sand aggregates

Physical properties	Values
Grading zone	III
Specific gravity	2.7
Moisture content (%)	2.5

Coarse Aggregate: Natural crushed stone with a maximum size of 20 mm were used as coarse aggregate. The aggregates were tested in accordance with IS-2386 [13] and the findings are illustrated in Table 3.

Table 3. Properties of coarse natural stone aggregates.

Physical properties	Values
Specific gravity	2.63
Water absorption	1.11%
Free surface moisture	1.976
Water content	1.4%

Polypropylene fibre: Polypropylene fibre was taken from Indiamart. The length of the fibres was 2-12 mm; diameter was 0.01-0.1 mm and was having an aspect ratio of 200. Other specifications of these fibres are presented as under. The digital photograph of polypropylene fibre used in this work and its properties are recorded in Table 4.

Table 4. Properties of polypropylene fibre

Properties	Value
Unit weight	0.91 g/cc
Length	2-12 mm
Diameter	0.01-0.1 mm
Colour	White
Moisture absorption	Nil
Modulus of elasticity	3500 MPa
Tensile strength	40,000 psi
Dispensability	Excellent

Sodium sulfate: The sodium sulfate which was used in the work was procured from ROYAL CHEM in Delhi. The properties are shown in Table 5.

Table 5. Properties of sodium sulfate.

Properties	Value
Chemical formula	Na_2SO_4
Appearance	White crystalline solid
Odor	Odorless
Density	2.664 g/cm^3
Melting point	884
Boiling point	1429

Figure 1. Digital photograph of polypropylene fibre used in this work

2.2. Mix Proportioning

The mix proportion followed in this study was 1:1.479:3.19 according to IS-10262 [13] with water-cement ratio of 0.5 for M20 grade of concrete. The calculated proportion for 1 m^3 is illustrated in Table 6.

Table 6. Mix proportions per cubic meter

Material	Quantity
Cement	383.33
Fine aggregate	567.102
Coarse aggregate	1224.9
Water	191.61
Water/cement ratio	0.5

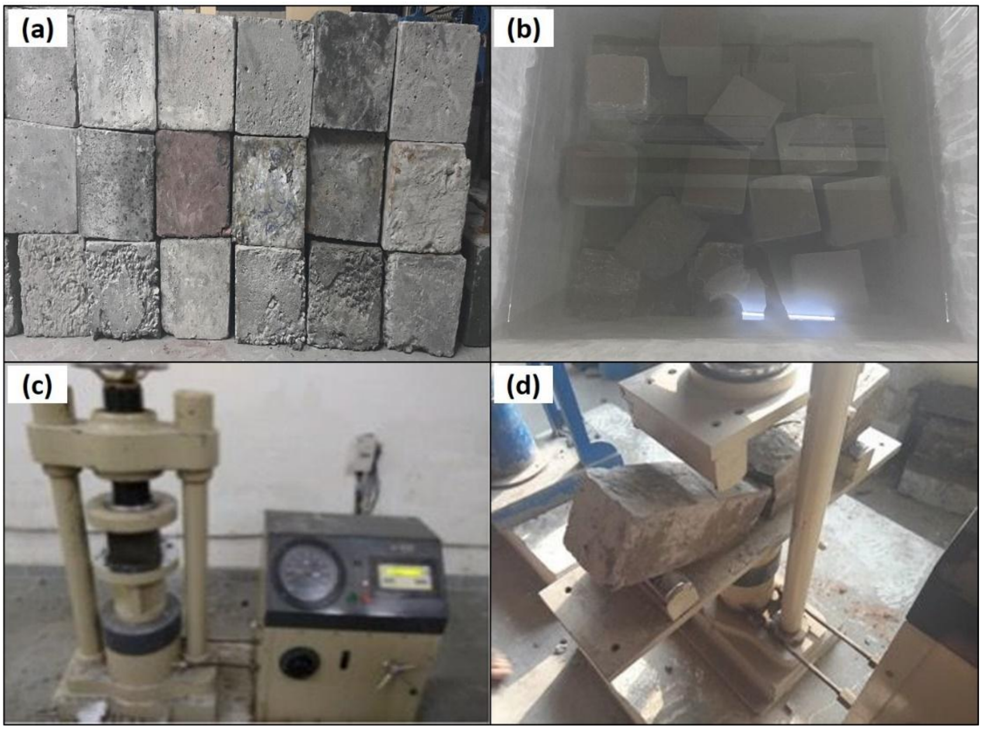

Figure 2. Digital photograph of (a) cast samples, (b) curing process, (c) compressive test and (d) flexural test being carried out on the samples

2.3. Mixing of Concrete

Mixing was carried out manually. First, the dry mix components, cement and both types of aggregates, were mixed for 2 minutes, then water was added and mixing was carried out for additional 2 minutes. The cumulative time of mixing was maintained at 4 min in all experiments until a homogeneous mixture was produced. Compaction was first done manually using a standard tamping rod, with appropriate blows to ensure layered filling of the mold, and finally compaction was performed using a vibrator. All samples were taken out from the mold after 24 h and placed in water until the testing was performed.

2.4. Casting and Curing of Test Specimens

For compressive strength, total 72 cubes of size 150 x 150 x 150 mm were casted using M20 mix of concrete. Demoulding of the casted cubes was done after 24 hours from the time of casting of cubes. Water curing of the respective cubes was done for 7, 28 and 56 days in normal water and acidic water. These cubes were removed from the curing tank and tested while still wet, immediately after removal from the water. The support surface of the cube was wiped clean to remove all the loose particles adhered on to the surface. For permeability, 3 cubes were casted which includes one cube of normal concrete, one cube by adding 0.25% of fibre by weight of cement in concrete and one cube by adding 0.75% of fibres to the concrete.

For flexural strength, total 72 beams were prepared using M20 mix of concrete having size of 100 x 100 x 500 mm. Demoulding of the casted beams was done after 24 hours from the time of casting of beams. Water curing of the respective beams of normal concrete and fibre reinforced concrete was done for 7, 28 and 56 days in normal and acidic water. These beams were removed from the curing tank and tested while still wet, immediately after removal from the water.

2.5. Testing of Specimens

Test methods include workability testing of fresh concrete mixtures and compressive and flexural strength testing of hardened concrete samples. To estimate the workability, slump test was conducted as per IS-1199 [13]. Compressive strength tests were conducted as per IS-516 [13].72 cubes of size 150 x 150 x 150 mm were prepared for each mix which includes 36 cubes for normal water curing and 36 cubes for acidic water curing. After 24 hours, the samples were taken out from the molds and allowed to cure in water for 7, 28, and 56 days. Flexural strength was measured according to IS-516. Tests were conducted on beam samples with dimensions of 100 x 100 x 500 mm after 7, 28 and 56 days of curing. The reported values of both types of strengths is the average of the results obtained from three identical test samples for each configuration. Digital photograph of cast samples, curing process, compressive test and flexural test being carried out on the samples is shown in Fig. 2.

3. RESULTS AND DISCUSSION

3.1. Slump values

The slump values obtained for the fabricated specimens is shown in Fig. 3. Results reveal that concrete without fibre exhibited the highest slump value (72 mm). Continuous increase in the quantity of fibres resulted in a decline in the slump value from 64 mm for concrete containing 0.25% fibres to 39 mm for concrete containing 0.75% fibres. The slump decreased with the incorporation of polypropylene fibre due to the high absorption characteristics of the fibers. The results of the slump test conclude that as the fiber content in the concrete mixture increases, the workability of the mixture continues to decrease. The workability of the concrete mix decreased by 11.11%, 19.44% and 45.83% upon addition of 0.25 %, 0.5%, and 0.75% of fibres respectively to the concrete.

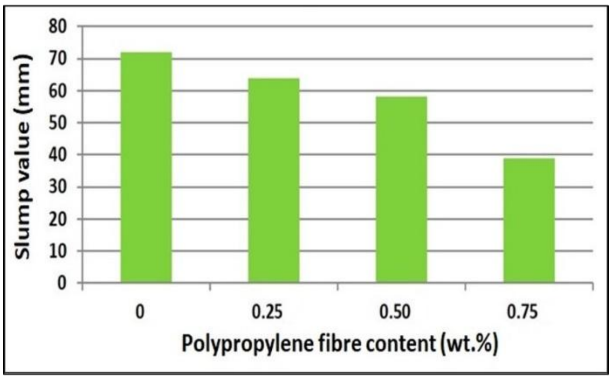

Figure 3. Slump values of concrete mixtures containing different proportions of polypropylene fibers

3.2. Compressive Strength

The results of compressive strength test performed over the fabricated samples is displayed in Table 7 (normal water curing) and Table 8 (acid water curing). It is evident that the compressive strength of the concrete increases monotonously with increase in the fibre loading irrespective of the curing medium. In case of water curing, with increase in concentration of polypropylene fibre from 0.25% to 0.75%, the average compressive strength got enhanced from 28.11 MPa to 30.76 MPa showing an increase of 8.7%. Similarly, for acid curing the compressive strength enhanced by 19.8% upon increasing the fibre content from 0.25% to 0.75%. This behavior may be attributed to the fact that the polypropylene fibres hold the micro-cracks and delay their propagation when the concrete is subjected to compressive load [14]. Furthermore, the table indicates that increasing the curing time led to an upsurge in the compressive strength for both type of curing medium. In case of normal water curing, for the sample containing 0.75% fibre, the compressive strength increased from 22.96 MPa to 29 MPa upon increasing the curing time from 7 days to 28 days. Further increasing the curing time to 56 days led to a further increase in compressive strength to 40.35 MPa. In case of acidic water curing, the compressive strength of 0.75% fibre reinforced concrete was found to be 15.23 MPa, 20.32 MPa and 32.99 MPa for 7, 28 and 56 days of curing, respectively. Among all tested configurations, highest compressive strength of 40.35 MPa was reported for the specimen having 0.75% polypropylene fibers cured for 56 days in normal water. The compressive strength of the specimens cured in normal water was found to be greater than the samples cured in acidic water. Consequently, the loss in compressive strength for the considered concrete mixes as a result of change in the curing medium from normal water to acidic water post 28 and 56 days of curing.is displayed in Fig. 4.

Table 7. Influence of polypropylene fibres on the compressive strength of concrete mix post normal water curing

S. No.	Polypropylene fibre (%)	Compressive strength (MPa)			Avg. compressive strength (MPa)
		7 days	28 days	56 days	
1	0	18.40	24.93	35.86	26.394
2	0.25	19.87	26.88	37.58	28.11
3	0.5	20.32	28.06	38.57	28.98
4	0.75	22.96	29.00	40.35	30.76

Table 8. Influence of polypropylene fibres on the compressive strength of concrete mix post acidic water curing

S. No.	Polypropylene fibre (%)	Compressive strength (MPa)			Avg. compressive strength (MPa)
		7 days	28 days	56 days	
1	0	11.06	16.94	22.94	16.98
2	0.25	13.74	18.33	25.19	19.08
3	0.5	14.70	19.61	28.05	20.78
4	0.75	15.23	20.32	32.99	22.85

It is apparent that the loss in compressive strength is much more substantial in case of unreinforced concrete than the reinforced concrete specimens. Additionally, the loss in compressive strength diminished with upsurge in the fibre loading. For instance, the loss in compressive strength for 0.25% fibre reinforced concrete post 56 days of curing is 32.9%, which reduces significantly to 18.2% upon 0.75% fibre reinforcement.

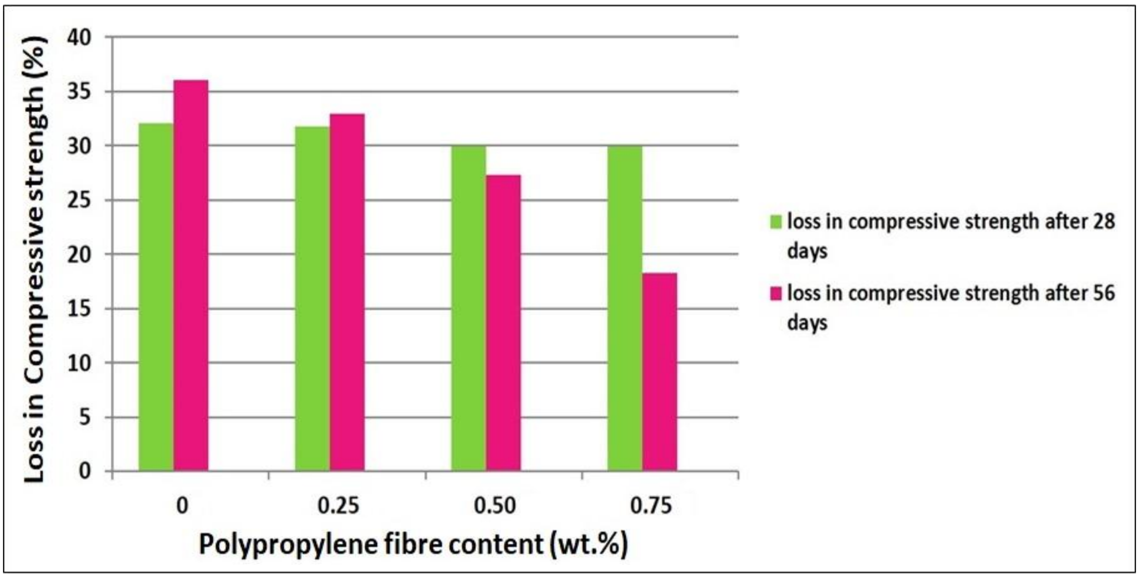

Figure 4. Loss in compressive strength for the considered concrete mixes as a result of change in the curing medium from normal water to acidic water post 28 and 56 days of curing

3.3. Flexural Strength

Flexural strength of concrete mix comprising of varied loadings of polypropylene fibre after 7, 28 and 56 days of curing in normal water and acidic water is illustrated in Fig. 5a and 5b, respectively. Remarkable improvement in the flexural strength was obtained on addition of polypropylene fibres into the concrete. Adding 0.25% polypropylene fibres caused an increase in the flexural strength of conventional concrete mix by 15.78% and 10.29% when cured in normal water for 28 days and 56 days, respectively.

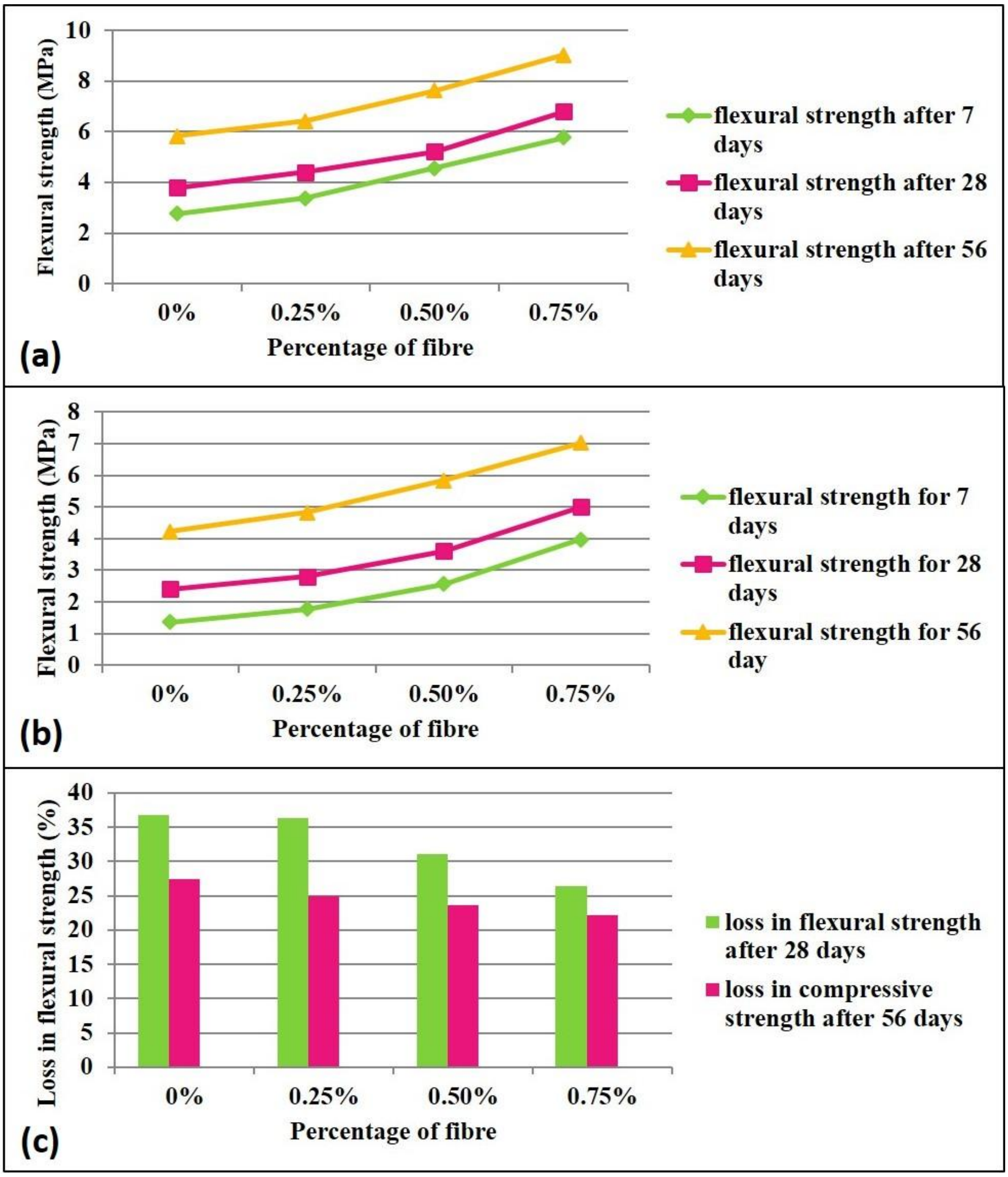

Figure 5. Influence of polypropylene fibres on the flexural strength of concrete mix post (a) normal water curing and (b) acidic water curing; and (c) loss in flexural strength for the considered concrete mixes as a result of change in the curing medium post 28 and 56 days of curing

Increase in the loading of polypropylene fibre to 0.75% led to a further improvement in the flexural strength of the concrete mix by 78.94% for 28 days and 54.88% for 56 days of normal water curing. Similar behavior was found for the samples cured in acidic water. The flexural strength of the specimens cured in normal water was found to be greater than the samples cured in acidic water. Fig.

5c depicts the reduction in the flexural strength for the considered concrete mixes as a result of change in the curing medium from normal water to acidic water post 28 and 56 days of curing. It is clear that the fibre reinforced concretes are more resistant to acids than the normal concrete. The loss in flexural strength in case of normal unreinforced concrete was found to be 27.61% for 28 days and 22.06% for 56 days of curing. However, the addition of 0.75% of fibre in concrete reduced the loss in strength to 16.13% for 28 days and 11.97% for 56 days of curing. The loss in flexural strength decreased upon increasing the percentage of polypropylene fibres in the concrete. It is worth mentioning that the findings of the flexural test were in line with the observations found in case of compressive test.

4. CONCLUSION

In this investigation, polypropylene fibres were added by weight of cement (0.25%, 0.5% and 0.75%) in M20 grade of concrete and their effect on workability, compressive strength and flexural strength was assessed and analyzed. Additionally, the specimens were cured in normal and acidic water for 7, 28 and 56 days to understand the effect of curing medium and curing time. The findings of the study are summarized in the following observations and conclusions.

- The slump test revealed that as the polypropylene fiber loading in the concrete mix was increased, the workability of the mixture continued to decrease. The workability decreased by 11.11%, 19.44% and 45.83% upon addition of 0.25 %, 0.5%, and 0.75% of fibres respectively to the concrete.
- The compressive strength as well as the flexural strength of the concrete increased monotonously with increase in the curing time and fibre loading. For instance, in case of acidic water curing, the compressive strength enhanced from 19.08 MPa to 22.85 MPa upon increasing the fibre content from 0.25% to 0.75%. Adding 0.25% polypropylene fibre resulted in an increase in the flexural strength of conventional concrete mix by 15.78% and 10.29% when cured in normal water for 28 days and 56 days, respectively.
- Both compressive and flexural strength of the samples cured in normal water was found to be higher than the samples cured in acidic water and it was observed that the fibre reinforced concretes were more resistant to acids than the normal unreinforced concrete.

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IZVOD

ISPITIVANJE UTICAJA POLIPROPILENSKIH VLAKANA I PARAMETARA OČVRŠĆAVANJA NA OBRADIVOST I MEHANIČKA SVOJSTVA BETONA

Polipropilenska vlakna poseduju određene karakteristike koje ih čine idealnim parom za postizanje eksplicitnih prednosti kada se koriste za građevinske radove, tačnije kada se dodaju betonu. U ovom istraživanju dodata su polipropilenska vlakna po masi cementa (0,25%, 0,5% i 0,75%) u betonu marke M20 i procenjen je i analiziran njihov uticaj na obradivost, čvrstoću na pritisak i čvrstoću na savijanje. Test sleganja je otkrio da kako je opterećenje polipropilenskim vlaknima u betonskoj mešavini bilo povećano, obradivost smeše je nastavila da opada; obradivost je smanjena za 11,11%, 19,44% i 45,83% nakon dodavanja 0,25%, 0,5% i 0,75% vlakana u beton respektivno. Čvrstoća na pritisak kao i čvrstoća betona na savijanje monotono su se povećavala sa povećanjem vremena očvršćavanja i opterećenja vlaknima. Na primer, u slučaju kiselog očvršćavanja u vodi, čvrstoća na pritisak se povećava sa 19,08 MPa na 22,85 MPa povećanjem sadržaja vlakana sa 0,25% na 0,75%. Dodavanje 0,25% polipropilenskih vlakana rezultiralo je povećanjem čvrstoće na savijanje konvencionalne betonske mešavine za 15,78% i 10,29% kada se osuši u normalnoj vodi tokom 28 dana i 56 dana, respektivno. Utvrđeno je da su i tlačna i savojna čvrstoća uzoraka očvršćanih u normalnoj vodi veća od uzoraka očvrsnutih u kiseloj vodi i uočeno je da su betoni ojačani vlaknima otporniji na kiseline od normalnog nearmiranog betona.

Ključne reči: *Cement, vreme očvršćavanja, ponašanje pri slijeganju, čvrstoća na pritisak, čvrstoća na savijanje*

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