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Study of The Effect of Fiber Type and Volume Variation on High Performance Concrete

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Abstract: *High-performance concrete (HPC) is an innovative material characterized by its exceptional strength, durability, and ductility in comparison to traditional concrete. It finds application in various high-stakes scenarios, including the construction of tall buildings, the fabrication of long-span precast/pre stressed bridge girders, as well as in marine, aviation, and defense construction projects. The study focuses on the comparison of effect of different percentage of fibers (0%, 1%, 1.5%, 2%, 2.5%, 3%) and different type of fibers (Steel Fibers, Polypropylene Fibers, and a mix of both) on addition to high performance concrete. The investigation employs a comprehensive experimental approach to assess the fresh and hardened properties, through laboratory testing and analysis, such as slump flow ability and compressive strength test on the prepared mix. The results indicated that the compressive strength of the HPC exhibited a direct relationship with the fibre content, showing higher values with increased fibre content. Furthermore, with an increase in the percentage of fibres, the flow ability of the concrete reduced, necessitating higher dosage of superplasticizer. Notably, the study highlighted the substantial contribution of steel fibres to the compressive strength, as even a minor replacement with polypropylene fibres resulted in a significant reduction in strength.*

Key Word: *High Performance Concrete, Polypropylene, Superplasticizer.*

I.INTRODUCTION

Concrete is one of the most widely used materials in the world today, yet it has several drawbacks, including susceptibility to extreme loads, high permeability, and significant carbon dioxide emissions. To address these issues, extensive research over the past few decades has focused on developing concrete with greater strength, improved durability, enhanced impermeability, and reduced CO2 emissions. High Performance Concrete (HPC) represents one of the latest advancements in concrete technology, achieving exceptional strength through the optimization of particle packing density within the cementitious matrix [1]. This matrix also gives very high durability properties which results in long lasting structures which helps to reduce the maintenance cost and give more sustainable structure [2]. Bache [3] and Birchall [4] tried to make some improvements in ordinary conventional concrete by using some superplasticizers and admixtures, for that small particles and macro defect free concretes having high strength and low porosity. The mechanical characteristics such as tensile strength, flexural strength, toughness, ductility, and the impact resistance was enhanced by providing fiber reinforcement [5].

The incorporation of high-strength steel fibers has contributed to the toughness, that is it converts the brittle concrete behavior to ductile [6]. It also suggests that fibers play a crucial role in influencing crack behavior, managing the brittle fracture process, and enhancing post-cracking strength and toughness. The characteristics of fiber reinforcement encompass differences in material composition (steel, mineral, or synthetic fibers), geometry, aspect ratio (length of fiber divided by its diameter), and mechanical properties. In conventional Fiber-Reinforced Concrete (FRC), the fiber volume fraction typically falls between 0.25 to 3 vol-%, whereas commercially available High Performance Concrete (HPC) mixes reportedly contain 2 to 6 vol-% of fibers [6].

In this research, fiber volume fraction is taken as the main parameter, and its effect on the compressive strength of hardened HPC and flow ability of fresh HPC were studied.

II.EXPERIMENTAL STUDY

2.1 Materials

- **Ordinary Portland Cement.** Cement going with the Egyptian standard was used as shown in Table 1. The specific gravity and fineness are 3.15 and 5% respectively.
- **Alccofine and GGBS.** Supplementary cementitious materials like alccofine and Ground Granulated Blast Furnace Slag is used with specific gravity 2.8 and 2.9 respectively as in Table 1.

- **Fine aggregates.** Here different sands like manufactured sand which was sieved through 4.75-micron sieve and retained on 1.18-micron sieve with specific gravity 2, and water absorption 2.24% as shown in Table 1.
- **Superplasticizer.** SP with relative density 1.108, dry material content 42.89%.
- **Steel Fibers.** Straight steel fibers are used with length 20mm, diameter 200 micron, aspect ratio 100, and tensile strength 3000MPa.

Table 1. Material properties for the study

Properties	Cement	Alccofine	GGBS	M-Sand
Specific Gravity	3.15	2.8	2.9	2
Water Absorption	-	-	-	2.24
Fineness	5%	-	-	-

2.2 Mixture Proportions

A single mix was designed and tested to study the effect of different volume fraction of fiber, and with different type of fiber of high-performance concrete materials on the compressive strength and flow ability of the mix. All the concrete mixtures were made with ordinary Portland cement with 600kg/m^3, 280kg/m^3 of GGBS, and 300kg/m^3 of alccofine with different fiber content of 0%, 1%, 1.5%, 2%, 2.5%, and 3% as shown in Table 2 and different fiber type (steel and polypropylene) as shown in Table 3.

Table 2. Proportion of mixture for effect of fiber content on HPC

Designation	0F	1F	1.5F	2F	2.5F	3F
Cement kg/m^3	600	600	600	600	600	600
GGBS kg/m^3	280	280	280	280	280	280
Alccofine kg/m^3	300	300	300	300	300	300
Fiber (%)	0	1	1.5	2	2.5	3
SP (% of binder)	1.1	1.35	1.4	1.45	1.5	1.9
Aggregate	1000	1000	1000	1000	1000	1000
w/b	0.17	0.17	0.17	0.17	0.17	0.17

Table 3. Proportion of mixture for effect of fiber type on HPC

Designation	2% SF	2% PF	1.6%SF0.4%PF
Cement kg/m^3	600	600	600
GGBS kg/m^3	280	280	280
Alccofine kg/m^3	300	300	300
Steel Fiber (%)	2	0	1.6
Polypropylene Fiber (%)	0	2	0.4
Total Fiber (%)	2	2	2
SP (% of binder)	1.45	1.55	1.45
Aggregate	1000	1000	1000
w/b	0.17	0.17	0.17

2.3 Mixing, Casting and Curing Procedure

The process of material selection begins by considering the availability of materials in the local area, as well as consulting relevant literature on the subject. Once materials are selected, their properties are determined in accordance with standard codes. This ensures that the properties of the materials used in the construction process are consistent and reliable.

Next, the control mix is developed by testing different base mixes obtained from literature Base mixes are casted and tested for suitability until a satisfactory mix is selected.

The mixing procedure for the study was carried out in a mixer with capacity of 15L to produce HPC with different dosages of fiber and different fiber type. The following was the procedure carried out for the mixing. Firstly, cement, alccofine, GGBS, and fine aggregates were mixed at low speed for about 3 minutes. Then to this 80% of water is added to the mixer while it is rotating in about 1 minute. Then to this add superplasticizer mixed with the rest 20% of water, and rotate in high speed for about another 3 minutes. When a flow able mix is obtained, reduce the speed and add the fibers. Here each mix is mixed with different dosages of fiber for first study, then for the second study, first mix is with 2% of steel fibers, second mix with 2% polypropylene fibers, and third mix with 1.6% of steel fibers and 0.4% of polypropylene fibers. In about a total of 14 to 16 minutes take the mix and check for slump using cone (as per ASTM C230/C230M [7]).

Finally, they were casted in molds of size 70.6mm×70.6mm×70.6mm, and vibrated for about 10 seconds. The specimens were then covered using plastic sheets. After that all specimens were demolded after 24 hours and then kept in water for normal curing for another 24 hours and then kept in accelerated curing tank for heat curing for about another 48 hours.

2.4 Testing Process

Compressive strength testing is done at 3, 7, 28 days, cubes of size 70.6mm×70.6mm×70.6mm were used to measure the compressive strength according to IS: 516-2021 (part 1) [8]. Three cubes are tested at each age and averages of three samples are reported as test results in the form of bar graphs.

III.RESULTS AND DISCUSSION

3.1 Test Results of Effect of Fiber Content

With the help of the slump cone the flow results are obtained for the mixtures having different fiber volume as shown in Fig. 1. And compressive strength results as in Fig. 2.

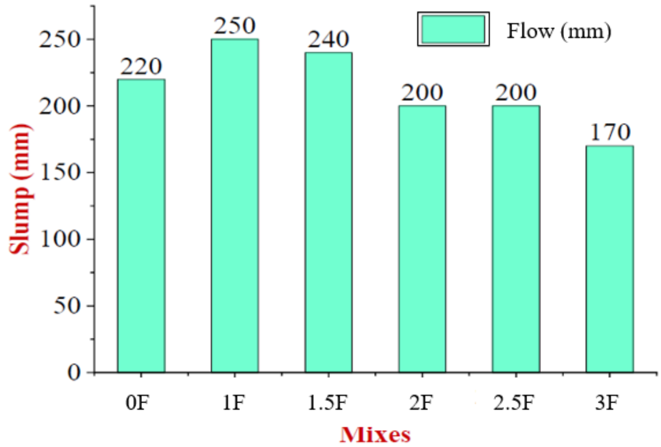

Fig. 1. Flow of Trial Mixes to Determine the Effect of Fiber Content

As the percentage of fiber in a composite material increase, the flow ability of the material decreases as shown in Fig. 1, and it requires an increased dosage of superplasticizers to maintain proper workability as shown in Table 2. This relationship between fiber content and flow ability can be attributed to the fact that as the quantity of fiber in the composite material increases, the interlocking between the fibers reduces the mobility of the mix, thus increasing the resistance to flow.

Therefore, it becomes more challenging to work with the material, and to address this issue, additional superplasticizers need to be added to maintain the desired flow ability.

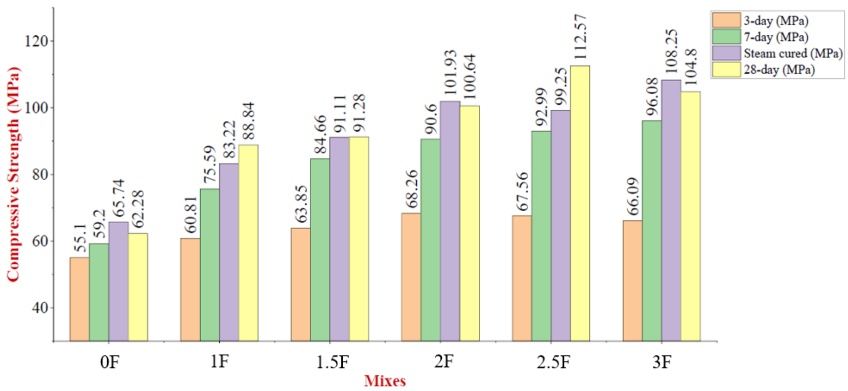

Fig. 2. Compressive Strength to Determine the Effect of Fiber Volume

As shown in Fig. 2, based on the 28-day compressive test results, it is evident that the addition of 1% fiber to the mix resulted in a significant increase of 42.6% in the compressive strength. This can be attributed to the fact that the fibers act as reinforcement and help to distribute the stresses more evenly, thereby enhancing the overall strength of the concrete. Additionally, the fibers also prevent the development of micro cracks that can lead to failure under load. However, further addition of fiber beyond 1% resulted in a small increase in the compressive strength. As the fiber content increases, the fibers tend to clump together, leading to an interlocking effect that can actually reduce the compressive strength. This is because the inter-locking effect creates voids in the mix that can act as weak points and reduce the overall strength of the concrete.

In the present case, the compressive strength increased by 2.74%, 10.25% and 11.85% for 1.5%, 2% and 2.5% fiber contents, respectively. However, when the fiber content was increased to 3%, there was a decrease in the compressive strength by 6.9%. This can be attributed to the excessive interlocking effect of the fibers in the mix, which created voids and weakened the concrete. Therefore, it is important to carefully balance the fiber content with the workability of the mix to achieve the optimal compressive strength. Since, 2% of fiber content gave the best required result, this mix was accepted and taken for the type of fiber test.

The compressive strength of a composite material increases with an increase in the percentage of fibers used as shown in Fig. 2. This relationship between fiber content and compressive strength can be attributed to the reinforcing effect of the fibers. The fibers, especially long fibers, act as load-bearing elements, increasing the overall load-bearing capacity of the composite material. Therefore, as the percentage of fibers increases, the compressive strength of the composite material also increases. When HPC is subjected to compression testing, it can still develop cracks due to the applied load. However, when fibers are added to HPC, they can help to prevent the formation and propagation of cracks. As the volume of fibers in UHPC is in-creased, the fibers begin to form a network throughout the concrete, creating a reinforcement system that can help to arrest the formation of cracks. The fibers act as small bridges that span across the cracks, distributing the load and preventing the cracks from opening further.

3.2 Test Results of Different Fiber Type

The compressive strength results as obtained from 3, 7, 28 days, and heat curing are as shown in Fig. 3 for the effect of different fiber type with the obtained 2% fiber results and that shown by Fig.4 depicts the flow ability results of the effect of fiber type on HPC Mixes.

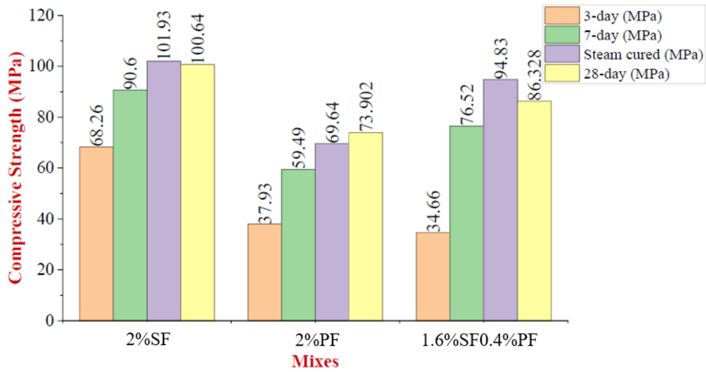

Fig. 3. Compressive Strength to Determine the Effect of Fiber Type

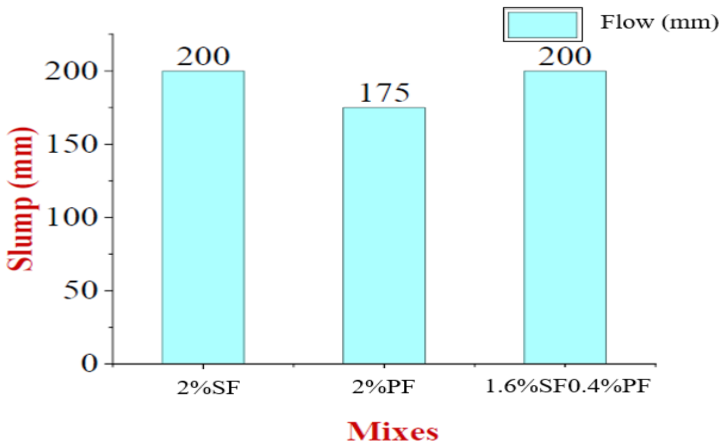

Fig. 4. Flow of Trial Mixes to Determine the Effect of Fiber Type

Fig.3. which illustrates the compressive strength of the three mixes, it is observed that mix 2%SF, comprising 2% steel fiber alone, attains a 28-day compressive strength of 100.64 MPa. Conversely, the mix containing 2% polypropylene fiber alone exhibits a 28-day strength of only 73.902 MPa, representing a reduction of 26.57% in com-pressive strength when steel fibers are entirely replaced.

In the case of mix 1.6%SF0.4%PF, where a small fraction of steel fibers (around 20%) is replaced with polypropylene fibers, the 28-day compressive strength is measured at 86.328 MPa, indicating a reduction of 14.22% in strength. This demon-strates that even a slight replacement of steel fibers significantly affects the com-pressive strength of HPC.

Based on the analysis of Fig. 4, which depicts the workability of the three different mixes, it becomes evident that all the mixes exhibit satisfactory workability, except for mix 2%PF, which solely contains polypropylene fiber. This could be attributed to the water absorbing property of polypropylene fibers when compared to steel fibers. However, in mix 1.6%SF0.4%PF, where only 20% of the steel fibers are replaced with polypropylene fibers, the impact on workability is relatively minimal.

These findings strongly indicate that steel fibers play a vital role in enhancing the compressive properties of HPC, and even minor substitutions have a noticeable impact on strength. Further research on alternative synthetic fibers is necessary to confirm these observations and evaluate their influence on HPC performance.

IV.CONCLUSIONS

An experimental procedure was carried out to determine the effect of fiber volume on a certain mix of HPC and also by replacing the steel fibers with polypropylene fibers to have an analysis on the fresh and hardened properties of High-Performance Concrete. The following were concluded from the experimental study:

- As the percentage of fiber increases, the flow ability reduces, and the SP dosage increases.
- The matrix is not strong enough to grip on to the fibers during the initial period (inferred from 3-day strength)
- At later stages the matrix become stronger and hence the strength also increases with age for matrix with more fiber content.
- 2% fiber content was selected as the best mix for HPC, anything lesser or more than that had significant decrease in strength or flow.
- It also showed the importance of steel fibers, as even a minor replacement with polypropylene fibers resulted in significant reduction in strength.

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