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TO OPTIMIZE THE STEEL FIBER CONCRETE PROPERTIES BY THE ADDITION OF FLY ASH AND SUPERPLASTICIZER

By

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Abstract

Workability is an important aspect of concrete; it decides the performance of concrete most critically when it has steel fibers in the case of self-consolidating properties. The optimization of the workability of steel fiber-reinforced concrete (SFRC) was conducted using fly ash and a full range of superplasticizer additives inducing workability improvement to SFRC. Steel fibers are known to improve the strength and durability of concrete; however, they bring along inconveniences where workability is seriously affected. Across the board, varying percentages of steel fibers (1, 2, and 3% by total weight of concrete) were studied. A very well-known supplementary material Fly ash was also varied (3%, 5%, and 8% of the cement weight) on how to improve workability. Different dosages of superplasticizer were added to see the result. The most among all of them is 2% steel fiber, which gives us high strength. The study tries to find the best balance between workability and physical properties through systematic experimentation and analysis. Findings revealed that workability decreased with an increase in steel fiber content, and compensating methods had to be incorporated. Fly ash showed much effect on both workability and other physical properties. On the contrary, superplasticizers had a promising effect on the workability of the concrete mix by improving flow and handling. The information here would receive help from these findings on the synergistic effects of combinations of steel fibers, fly ash, and superplasticizer with respective outputs on the workability and physical properties of SFRC. This complements concrete technology in terms of advancing strategies of improving workability against the application benefits of steel fiber reinforcement and supplementary additives.

KEYWORDS: *Steel Fiber Reinforced Concrete (SFRC), Workability, Superplasticizer, Fly Ash*

1. INTRODUCTION

It all relies on your definition of "concrete" when you try to pin down the exact invention date of concrete. Crushing and burning gypsum or limestone to create crude cement was a frequent practice in ancient times. Crushed, charred limestone is another name for lime. Because sand with the addition of water, these cements transformed into mortar, a plaster-like substance used for stone laying. Concrete evolved from these ingredients after thousands of years of refinement and mixing. Modern concrete recipes call for water, stone, or sand aggregates (both coarse and fine), and Portland cement. Admixtures are chemicals that are added to the concrete mix to influence its setting qualities. They are most often employed when pouring concrete in extremely hot or wintry weather, or when there is a lot of wind.[1]

Metal reinforcing fibers are known as steel fibers. To make steel fiber for reinforcing concrete, the material must be small enough to be mixed into an unhardened concrete mixture in a random fashion using standard mixing techniques. The fibers must also have a cross-sectional shape and a length-to-diameter ratio ranging from 20 to 100. When you add just the right quantity of steel fiber to concrete, its physical characteristics may undergo noticeable changes. Its resistance to cracking, impact, fatigue, bending, tenacity, and durability, among other qualities, can be significantly enhanced. Types of steel fiber include mill cut, changed cold-drawn wire, cut sheet, melt-extracted, and cold-drawn wire, all of which are classified according to the production technique and the form or section of the fiber. The first cement paste with self-sensing characteristics was created in 2003 by Wen and Chung using steel fibers measuring 6 mm in length and 8 µm in diameter. The self-sensing concrete that Hong created made use of 32 mm long and 0.64 mm wide steel fibers.[2]

The findings showed that the normal mix, which does not include fibers, yields the most workable concrete. The results clearly shows that the workability of concrete is significantly affected by the growing proportion of steel fibers. Because of the sharp edges of the steel fibers, the concrete becomes less flowable, and the fibers themselves make the concrete less mobile. Portland cement concrete (PCC) that has fly ash has several advantages and works better in both the wet and dry states. Adding fly ash to concrete makes both plastic and hardened concrete more workable and stronger. The usage of fly ash is also economical. It is possible to lower the quantity of Portland cement used in concrete by adding fly ash. Because it increases the flowability of freshly mixed concrete, fly ash makes the mixture easier to work with. The improved mix flow is a result of the fineness and spherical particle form of the fly ash. Everything affects how well it works. This study followed the guidelines laid forth by ASTM C143 to the letter, recording the workability of concrete mixtures using a slump cone. The findings showed that the normal mix, which does not include fibers, yields the most workable concrete. The results clearly shows that the workability of concrete is significantly affected by the growing proportion of steel fibers. Because of the sharp edges of the steel fibers, the concrete becomes less flowable, and the fibers themselves make the concrete less mobile. Portland cement concrete (PCC) that has fly ash has several advantages and works better in both the wet and dry states. Adding fly ash to concrete makes both plastic and hardened concrete more workable and stronger. The usage of fly ash is also economical. It is possible to lower the quantity of Portland cement used in concrete by adding fly ash. Because it increases the flowability of freshly mixed concrete, fly ash makes the mixture easier to work with. This is because fly ash improves mix flow because of its tiny particle size and spherical shape.[3]

The amount of cementitious paste in the mixture is increased by substituting fly ash for cement on a mass basis. This is because, in comparison to cement, fly ash has a lower specific gravity. Coating the fibers more effectively and lubricating the mix better are both made possible by the increased volume of the paste. The composite material's improved qualities in its hardened form are a result of the improvements in the workability of the fresh mix and the dispersibility of the fibers. So, fly ash not only makes the new mix easier to work with, but it also improves the qualities of the hardened concrete. Fly ash concrete has less air entrained in it because fly ash has carbon. Thus, the carbon content of the fly ash should be considered while adjusting the dose of the air-entraining agent used in fly ash concrete. Concrete with fly ash is more susceptible to temperature changes (26 times slower) and often sets and hardens at slower rates than concrete without fly ash. Consequently, it may need more favorable curing conditions compared to regular concrete. Compared to Portland cement, the chemical and physical qualities of fly ash, a byproduct, are more variable. Consequently, it is important to conduct the necessary quality control procedures based on the needs of the project. Based on the data in the table, steel fiber has a greater impact on the workability of concrete when compared to fly ash.[4]

If you want your dry-pressed concrete to be more workable, have better compaction, increase density, and have a smoother surface, you should add a superplasticizer. To improve the workability and control the setting time of hot weather concrete, superplasticizer (SP) is essential.[5]

3 | Material and Methods

3.1 | Fine Aggregate

Sand, or fine aggregate, is mined at Lakki Marwat (Pizzu). In Table 1 we can see the laboratory-determined physical parameters of fine aggregate, and in chart 1 we can see the gradation curve.

Table 1. Fine aggregate physical characteristics

Property	ASTM Specification	Value
Sieve analysis	C 136 [38]	Well graded
Moisture content	C 566 [39]	1.23%
Specific gravity	C 127 [34]	2.63
Water absorption	C 127 [34]	1.35%

3.2 | Coarse Aggregate.

Coarse aggregate, typically gravel or crushed stone, is sourced from Mir Ali in Waziristan.

The concrete laboratory determined the relevant physical properties according to the standard procedures set up in ASTM [34] and recorded in Table 2 and chart 2, respectively. The nominal maximum size of the aggregate was 19mm.

Table 2. The physical characteristics of pebble-sized rock

Property	ASTM Specification	Value
Sieve analysis	C 136 [38]	Well graded
Moisture content	C 566 [39]	0.33%
Specific gravity	C 127 [34]	2.49
Water absorption	C 127 [34]	0.67%

Chart 1. Gradation curve of fine aggregate

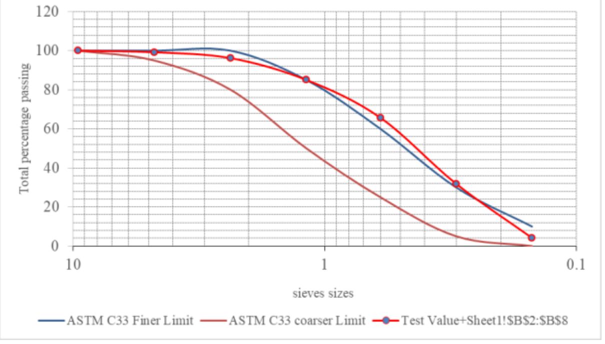

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Chart 2. Gradation curve of coarse aggregate

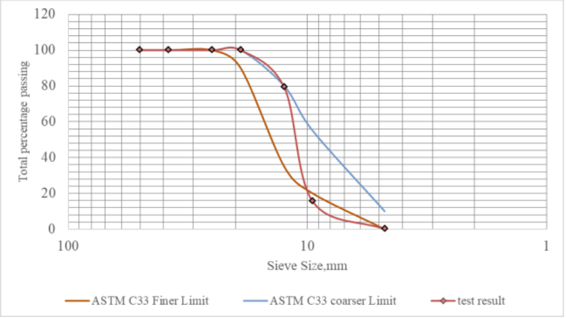

Figure 1. Sample of RSF extracted from scrap tires

3.3 | Steel Fiber.

Steel fibers, used to reinforce concrete, are extracted from scrap tires in Peshawar.

The length and diameter of the steel fiber are 12.3 cm and 0.91 mm, respectively. The dosage of steel fiber varied from 0% to 3% by weight of cement as a variable in all mixes.

3.4 | Fly Ash.

Ordinary type F fly ash was used in our research, collected from Taxila.

3.5 | Superplasticizer.

Peshawar is the source for the chemical ingredient superplasticizer, which makes concrete easier to deal with. Table 3 displays the physical and chemical parameters of the material we employed for our study, Ultra Super Plast 437.

Table 3. Physical and chemical properties of super plast 437

Appearance	Brown Liquid
Specific gravity @20°C±3%	1.155
Chloride Content	Nil
Air Entrainment	Less than 2%

3.6 | Portland Cement

The concrete specimens were prepared using ordinary Portland cement (OPC) with a type-I, 97% fineness, and a specific gravity of 3.12. Bannu, Pakistan-based cement producer supplied the OPC for the present investigation.

4 | Experimental Program

The experimental study aimed to examine the influence of steel fiber, Fly ash, and superplasticizer on the workability and compressive strength of concrete.

Development of Concrete Samples

This study is designed to generate concrete specimens with optimized property results with steel fibers, ash, and a super plasticizer. The "Concrete Mix Design" is based on that of the ASTM and will aim for a compressive strength of about 3000 psi in 28 days for itself, and for workability variation, slump value of 20-80 mm. A mixed ratio of 1:1.9:3.6 (cement: fine aggregate: coarse aggregate) is selected, and a water-to-cement ratio of 0.55. The maximum aggregate size used was 19.05 mm.

Process of Concrete Preparation

Batches of concrete were prepared manually so that proper mixing and uniformity would be achieved. The dry materials, including aggregates and cement, were mixed first on a flat surface for 3 minutes and then water was gradually added while stirring until a homogeneous smooth consistency was reached.

To improve the mixture, coarse aggregates were combined with fine aggregates first before adding them together with cement and water. All admixtures such as superplasticizer and steel fiber were gradually added in the mixing process. The entire preparation time for each batch took 6 minutes.

Incremental changes in superplasticizer dosage assure that the mixture turns out to have greatest workability, resulting in the uniformity of the final concrete.

Assessment of Fresh Concrete Properties

Work-ability Evaluation Using Slump Measurement

Standard slump testing was conducted as per ASTM C143; the fresh concrete sample was assessed for workability through slump tests. All test equipment and devices were washed and dampened before use to prevent concrete sticking.

It was poured into a standard slump cone in three equal layers. Each layer was tamped with a tamping rod through 25 uniformly distributed strokes piercing slightly into the previous layer. After filling the cone, any overage in height was stripped off the top and turned on the cone with vertical lift in controlled manner.

Concrete vertical displacement was defined as the difference between the original height of the cone and the center of the displaced concrete. Results were recorded to the nearest five mm. After each test, the tools were cleaned well to keep consistency for next tests.

Analysis of Hardened Concrete Characteristics

Determination of Compressive Strength

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Based on ASTM C94, the compressive strength was conducted on a 100 x 150mm cylinder specimen. The compressive strength was taken as the average value of three specimens.

Specimen Casting and Curing Protocol

Concrete molds were pre-treated by applying a thin layer of mineral oil to help easy removal. Pouring the concrete into molds was done in three layers of approximately 50 mm thickness each by ASTM C192-88. Each layer was to be compacted by 25 strokes of a tamping rod, followed by the application of a vibrator on the final layer to get rid of air voids.

The specimens were kept under standard laboratory conditions, undisturbed for 24 ± 2 hours. After demolding, they were marked and submerged in curing water until the testing period, which lasted for 28 days. Control tests were conducted at this stage for the evaluation of the mechanical properties of the concrete.

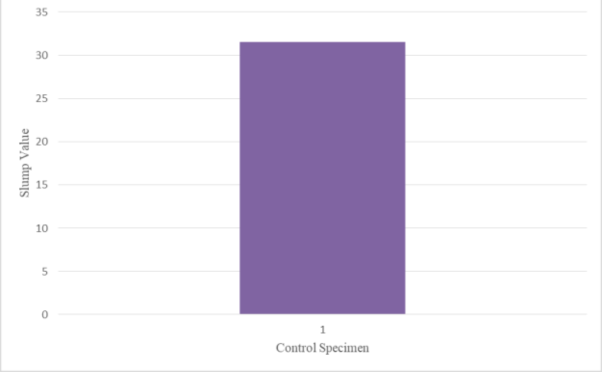
5 | TEST RESULTS AND ANALYSIS

5.1 | Work-ability Test

Slump tests were used as a standardized basis for evaluating the consistency and workability of freshly mixed concrete in this study. This test was performed on the control specimen for the first evaluation and comparison with next trials. As to the control specimen, the recorded workability value was 31.5 mm, showing a degree of moderation in consistency and ease of placement for the mix.

To assure their comparability in all respects, the cement-water ratio was held constant throughout the experiment for both the control mix as well as the mixes having admixtures. This way, all observable changes in workability can solely be attributable to the performance of the admixtures, not because of water or mixing ratios. The workability value recorded for the control specimen gives an important parameter when evaluating the other trials about the inclusion of admixtures.

Chart 3. Slump value of reference specimen



For Trial 1, 1% steel fiber (by total weight of concrete) and 3% fly ash (by total weight of cement) were incorporated into the concrete mix. To keep the same workability as the control specimen, varying dosages of superplasticizer were introduced in different trials. The results proved that a 3% dosage of superplasticizer was best, as it successfully restored the slump value to match that of the control specimen, as shown in chart 4.

Throughout the experiment, the cement-water ratio was held constant to isolate the effects of the added materials—steel fiber, fly ash, and superplasticizer—on the workability and consistency of the concrete mix. This approach ensured that any variations in workability were directly attributable to the admixtures, easing a correct assessment of their influence on the concrete's mechanical properties and overall performance.

In Trial 2, the concrete mix was altered by including 2% steel fiber (by total weight of concrete) with 5% fly ash (by total weight of cement). The differentials jointly act on the workability of the concrete. Steel fibers reduce workability due to their physical nature and interaction with the mix, so the addition of fly ash counteracts this effect because improving the particle packing reduces internal friction and enhances workability.

As shown in chart 5, the increased fly ash content alleviated workability loss caused by the steel fibers to a higher extent. Therefore, a lower dosage of superplasticizer was needed to achieve a target slump value the same as that of the control specimen. For the experiment, the best quantity of superplasticizer was taken as 2%, revealing that even with steel fibers, the synergistic effect of fly ash and superplasticizer could work efficiently in keeping workability.

This implies that the observed variations in workability were due to the combined effects of steel fiber, fly ash, and superplasticizer-emphasizing material optimization in improving fiber-reinforced concrete without compromising placement convenience. This was done by keeping a consistent cement-water ratio throughout all trials.

In Trial 3, the inclusion of 3% steel fiber and 8% fly ash contents (considering the total weight of concrete and the total weight of cement, respectively) was proved to provide a significant interaction between steel fiber and fly ash with regards to workability behavior. The effect of increased steel fiber content from known stiffening and flow inhibition over-workability behavior dominated the workability characteristic since it also increased the aspect of availability of the fly ash part, which does enhance fluidity but proved still to be outdone.

To restore the slump value of the mixed sample to that of the control sample, an amount of superplasticizer dosage was needed, which was 2.5% of the weight of cementitious material. Thus, it is more than that used in Trial 2, and, if at all, highlights the balance between the components—as the steel fiber content stacked up more against fly ash, even more of presenting extra superplasticizer had to counteract the stiffening phenomenon and retain the consistency.

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Chart 4. Slump value with 1% steel fiber.

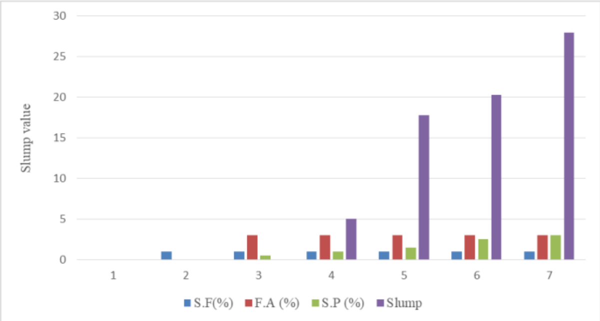


Chart 5. Slump value with 2% steel fiber.

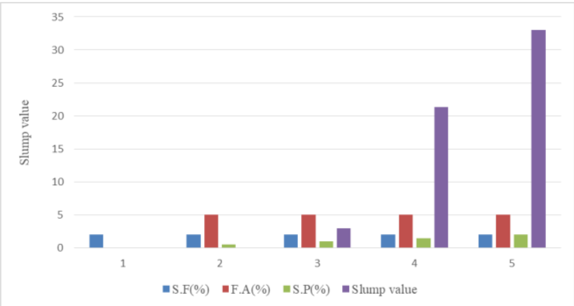


Chart 6. Slump value with 3% steel fiber.

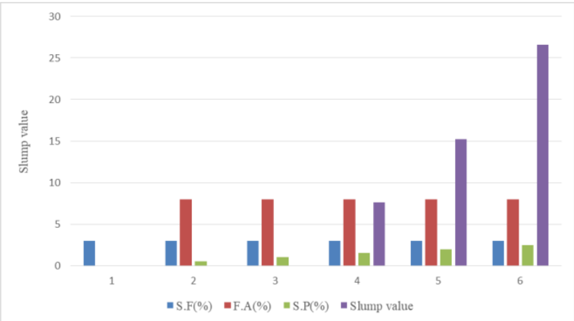


Table 4 shows the percentage of steel fiber, fly ash, and superplasticizer used in each mix, along with the corresponding slump values. This structured presentation highlights the progressive changes in admixture proportions across the trials and their direct impact on keeping the control specimen's workability.

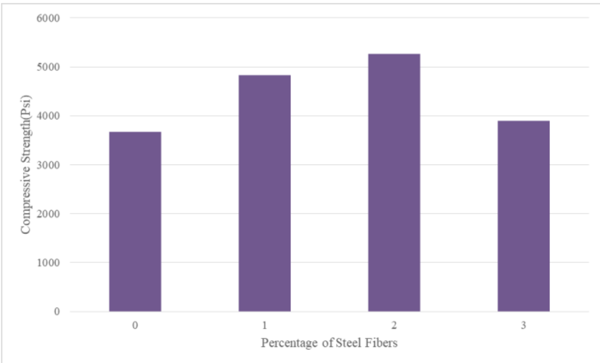
Table 4. Superplasticizer (SP) ratios and their corresponding slump test results

Group No.	Mix No.	SF%	FA%	SP%	Slump value(mm)
	S1	0	0	0	31.55
G1	S2	1	3	0.5	0
	S3	1	3	1	5.08
	S4	1	3	2.5	20.32
	S5	1	3	3	27.96
G2	S6	2	5	1	5
	S7	2	5	1.5	21.3
	S8	2	5	2	33
G3	S9	3	8	1	0
	S10	3	8	2	15.2
	S11	3	8	2.5	26.6

5.2 | Compressive Test Result

The results of the compressive strength tests for both control and steel fiber-reinforced concrete cylinders are given in chart 7 and its corresponding table. The test results show that the compressive strength of the cylinder is affected by the quantity of steel fiber. The compressive strength of concrete is increased due to the inclusion of steel fibers in the mix. At a dose of 2%, the maximum compressive strength was reached, which was over 42% higher than the control specimen. However, the compressive strength began to decrease at a certain point when 3% steel fiber was applied. The chart shows that adding a superplasticizer to concrete makes it more workable, which in turn makes it easier to place and compress. The compressive strength of concrete is enhanced with 1% and 2% steel fiber additions, while it is decreased with 3% steel fiber additions. This decrease in compressive strength is caused by the residual voids after putting and compacting the fibers. Therefore, the compressive strength of fiber concrete is affected by its workability.

Chart 7. Comparison of control and SFRC with different RSF doses in terms of compressive strength



In table 5 only those specimens were evaluated which have same or near slump value to the control specimen due to this the increment in their percentage is more than the general usage of steel fiber

Table 5. Compressive strength test result with different dosage

Group No.	Mix No.	SF %	FA %	SF %	Compressive strength	Increasing
Ref	M1	0	0	0	3.66	

G1	M5	1	3	3	4.82	31.69%
G2	M8	2	5	2	5.2	42.07%
G2	M11	3	8	2.5	3.88	34.01%

6 | Conclusion

This research is on improving workability as well as compressive strength of SFRC through steel fibers, fly ash, and superplasticizers. The experimental results show that although steel fibers are quite effective in increasing concrete strength, they adversely affect workability because of their physical properties. Fly ash counteracts this effect by improving packing between particles and lessening internal friction, thus improving workability. Superplasticizers are found to be more effective in canceling the effects of steel fibers on workability and specific portions restored slump values of concrete to match that of the control specimens.

According to findings, a best combination of 2% steel fiber and 5% fly ash with the addition of a 2 % dosage of superplasticizer was found to be a well-balanced solution in developing both improving workability as well as enhancing the physical properties without loss of strength in concrete.

7 | Declarations

7.1 Contributions of Authors

Concept, S.A., T.U. and A.H.K.; methodology, S.A., T.U., U.W. and T.H.; Data Analysis, S.A., U.W. and T.U.; Research, S.A., N.K. H.M., A.H.K. and M.U.; Material and Data Provision, A.H.K, T.H. and U.W.; Manuscript Drafting, S.A., N.K., A.W., H.M. and T.U.; Manuscript Review and Editing, T.H., U.W., M.U. and A.H.K.; All The final version of the manuscript has been read and approved by all authors.

7.2 Availability of Data

The data that support the findings of this study are available from the corresponding author upon reasonable request.

7.3 Financial Support

No funding was received for this manuscript.

7.4 Declaration of Interests

There are no conflicts of interest declared by the authors.

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