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EFFECT OF NYLON FIBER AND SILICA FUME ON THE PROPERTIES OF CONCRETE

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ABSTRACT

Concrete is the most extensively used building material around the globe. After water, concrete is the second most used material in terms of its usage and production due to its unique characteristics, like its affordability, availability, and adaptability in relation to its Strength and durability. Cement, a binder used in concrete, is the chief responsible for carbon emissions. The cement industry is responsible for around 8-10% of carbon emissions globally. Supplementary cementing materials (SCMs) have been used over the years not only to improve the properties and efficacy of concrete but also to help reduce the carbon emissions due to cement production. These materials are industrial by-products or waste materials with cementitious properties that can partially replace or supplement Portland cement. SCMS includes fly ash, pulverized granulated blast furnace slag, silica fume, rice husk ash, and metakaolin. Etc. This research study involves Silica Fume as SCM to supplement the cement and Nylon Fiber as a reinforcing material. The research conducted on fresh properties (workability), hardening properties (compressive Strength), with and without incorporation of Silica Fume and Nylon Fiber and their effect on the properties of concrete is investigated at 28days of curing ages. The cement content is replaced with 5%, 10%, and 15% with SF by weight. Nylon Fiber, having 20cm length and 0.5mm diameter with dosages of 0.5%, 0.75%, and 1% by volume of concrete, is used as a reinforcing material. Based on the results. It was observed that the workability of concrete decreases as the percentage replacement of cement with silica fume increases. Compressive Strength increases when cement is replaced up to 10% with silica fume. Strength starts to decrease with further replacement. Therefore, maximum compressive strength is achieved at 10% cement replacement with Silica Fume i.e. 29.5 MPA and 2.7 MPA, which is 11.95% and 12.5% more than the control mix. The inclusion of Nylon Fiber also has a negative effect on the workability of concrete as the dosage of Nylon Fiber increases. Compressive Strength has improved significantly with the increase in the dosage of Nylon Fiber. Maximum compressive and splitting tensile Strength was observed at 1% dosage of Nylon Fiber, i.e., 33.4 MPA and 3.28 MPA, which is 26.75% and 36.66% more than the control mix. When each Silica fume proportion was reinforced with each Nylon Fiber dosage, the workability of the concrete was diminished with their combined effect. However, an increase in compressive Strength was observed at 5% cement replacement with Silica Fume reinforced with 0.5% Nylon fiber dosage. Further increase in Silica Fume and Nylon Fiber % decreases the Strength. Maximum compressive strength observed at 5% replacement of cement and 0.5% inclusion of Nylon fiber i,e. 34.6 MPa and 2.75 MPa, which is 31.3% and 14.6% more than the control mix. The research concludes that 5% cement replacement with Silica Fume and 0.5% inclusion of Nylon fiber by volume fraction can certainly enhance the concrete properties.

Keywords: Nylon Fiber (NF), Silica Fume (SF), Compressive Strength, Workability.

I. INTRODUCTION

Concrete is growing in popularity as a building material with great potential for realizing technical solutions that comply with novel standards, resulting in the necessary reduction of environmental impacts and subsequent development of social and economic conditions [1] (Hajek, P. 2018).

The components of concrete are cement, sand, gravel, and water. Concrete is the most extensively used building material in the globe. Concrete is a material that has been utilized for millennia. The specific significance of concrete structures stems from the fact that, after water, concrete is the second most used material in terms of its usage and production due to its unique characteristics, such as its affordability, availability, and adaptability in relation to its strength and durability [2] (Wangler, T et al. 2017). Despite its enormous global production and consumption, it may significantly contribute to emissions of greenhouse gases. An estimated 4.4 billion tons of concrete are produced annually on a global scale, and this figure is projected to reach 5.5 billion by 2050. However, its production, which entails cement, has a substantial environmental impact [3] (Akbar, A., & Liew, K. M. (2020).

When it comes to carbon footprint, the cement used to bond concrete is the real culprit. The cement manufacturing procedure is solely responsible for the concrete industry's 8% contribution to global emissions. It is estimated that 0.90 tonnes of CO2 are emitted per tonne of clinker manufactured [4] (Khongprom, P., & Suwanmanee, U. 2017). In addition to the severe environmental impacts, 1700–1800 MJ per tonne of clinker is the energy required to produce one tonne of cement. There are numerous ways to surmount these obstacles to reduce carbon footprint and save energy required for cement production. The production of blended cement is the most plausible strategy for minimizing carbon dioxide emissions from the cement industry, which involves substituting increasing quantities of cement clinker with SCMs such as Ground granulated blast furnace slag, fly ash, rice husk ash, silica fume Etc. Cementitious mixtures results stronger, more durable, high performance concretes and contribute to reducing global climate impact by decreasing energy consumption and greenhouse gas emissions [5] (Samad, S., & Shah, A. 2017). Using this knowledge, the concrete industry has discovered some sustainable and environmentally favorable alternatives to concrete: green concrete. Green Concrete is an innovative idea in the concrete industry's era. Dr. WG devised it for the first time in 1998 in Denmark. Green concrete is a form of environmentally beneficial concrete made from refuse or residual materials from various sectors, leaving the minimum possible carbon imprint. The three primary goals of the green concrete concept are reducing carbon dioxide emissions, conserving natural resources, and utilizing refuse materials in concrete [6] (Suhendro, B. 2014). Concrete is a brittle material and is more resistant to compression than tension. Generally, 10% of the concrete's compressive strength is considered its tensile strength. Due to this lesser tensile strength, external stresses and agents, such as contraction, dead and live load, and temperature undulation, cannot be implemented precisely upon reaching the tensile limit. This causes the development of fissures within and on the concrete surface. In addition, non-prestressed and ordinary concretes are prone to cracking due to their low tensile strength and straining capacity. Therefore, adding cementitious materials to concrete along with nylon fiber is an innovative method for overcoming tensile splitting and enhancing the concrete's straining capacity. Nylon fiber has an elevated melting point. Excellent impact resistance and flexural strength. Meanwhile, using NF as an additive in plain concrete is promising because it is an alternative way to dispose of fibers and these materials result in more durable and robust concrete as well [7] (Ahmad, J, et al. 2022).

Supplementary Cementing Materials

In conjunction with Portland cement, supplementary cementing materials (SCMs) are used to improve the properties and efficacy of concrete. Typically, these materials are industrial by-products or waste materials with cementitious properties that can partially replace or supplement Portland cement. Typical SCMS include fly ash, pulverized granulated blast furnace slag, silica fume, rice husk ash, and metakaolin. Scientists worldwide have studied different varieties of SCMs, and their use in concrete is beneficial and of vital importance. SCMs enhance the performance of concrete in terms of durability, strength, workability, chemical resistance, etc., resulting in more durable and long-lasting concrete. Adding SCMs to concrete mixtures reduces the heat of hydration, which is produced during the chemical reaction between cement and water [8] (Moon, H. et al. 2018). This reduction in heat helps prevent thermal cracking in large concrete structures and increases their durability. SCMs also contribute to environmental sustainability by reusing by-products and waste materials, reducing consumption of natural resources, and saving costs. Incorporating SCMs can reduce the quantity of cement required in a concrete composition, resulting in environmental benefits such as lower carbon dioxide emissions and lower energy consumption in cement production [9] (Miller, S. A., et al. 2018). Overall, the use of SCMs in concrete offers a variety of advantages, and these materials have become significant in the construction industry as a means to produce high-quality eco-friendly concrete structures.

Mohan et al. (2021) [10] conducted a research where OPC is substituted with GGBS and SF to identify an alternative material that could be used as a cement substitute to benefit the environment by reducing carbon footprint and for more sustainable development. To accelerate the pozzolanic effect, research is conducted on M30-grade concrete with variable proportions of GGBS slag, i.e., adding 40%, 50%, 60%, and 10% SF. Mechanical evaluations such as compressive, split tensile, and flexural are performed to determine the efficacy and quantity of GGBS and silica fume to be substituted for cement to improve the performance of concrete. As a result of this research, the compressive strength of the control mix concrete is greater than that of all replaced proportions of GGBS and SF at 28 days of curing. However, 50% replacement yields superior results to the other proportions and is only marginally inferior to control specimens. The controlled specimen's split tensile strength is greater than that of the other proportions, and the 50% replacement yields are superior to those of the other proportions but still slightly inferior to those of the control specimens. Whereas 50% replacement has the highest flexural strength compared to controlled specimens and other proportions.

Khan & Ali. (2019) [11] carried out research in which fibers (coconut fibers) are incorporated into concrete to modify tensile property of concrete. Adding SF and Fly ash to fiber concrete (coconut fibers) was the subject of an experiment. The mechanical properties of fly ash silica-fume plain concrete (FA-SPC) and fly ash silica-fume coconut fiber reinforced concrete (FA-SCFRC) are examined in this experimental study. The silica-fume content is 15% by cement mass, and 0%, 5%, 10%, and 15% fly ash by cement mass are added. For FA-SCFRC, 50 mm long coconut fibers with a 2% cement mass content are incorporated. The cement, sand, coarse aggregate, and water mix design proportions were 1: 1: 2 and 0.40, respectively. It is revealed that FA-SCFRC has significantly better properties than FA-SPC. In summary, FA-SCFRC, with a 10% fly ash content, exhibits superior mechanical properties than FA-SPC.

Keerio et al. (2020) [12] conducted research on SF as supplementary cementitious material and waste glass as fine aggregate. Utilizing this waste replaced in concrete reduces cement production and co2 emissions and protects the environment. The research was conducted on M15 grade concrete with partial replacement of cement with SF by 5, 10, and 15% and fine aggregate with glass waste powder by 10, 20, 30, and 40%. Workability, water absorption, compressive, and split tensile tests were conducted, and the results of replaced concrete were compared with the standard concrete. As a result of this experimental study, 10% replacement of cement with SF and 30% replacement of fine aggregate with waste glass powder were the best choices for optimum strength. Moreover utilization of glass powder and SF together significantly reduced the workability and water absorption of concrete.

Sasanipour et al. (2019) [13] conducted an experimental work to enhance the properties of SCC made from waste-recycled concrete aggregates, 8% of the weight of SF is substituted with cement. There were three series of mixtures created. With and without SF, recycled coarse aggregates with replacements of 25%, 50%, 75%, and 100% were used. In the third series, 25% of natural fine aggregate was substituted with recycled fine aggregate. Hardened concrete was tested for compressive strength, water absorption, ultrasonic pulse velocity, electrical resistivity, and chloride ion penetration. This experimental investigation demonstrates that SF can reduce water absorption and porosity. The SF demonstrated a notable increase in electrical resistivity. In contrast, replacing 25% recycled aggregates had no significant effect on electrical resistivity, whereas increasing the replacement decreased electrical resistivity.

The aim of this research is to investigate the effect of silica fume and nylon fiber on mechanical properties and workability of concrete.

The Specific Objectives of the Study are:

- To investigate the influence of SF as well as NF on the workability of concrete
- To analyze the mechanical performance of concrete incorporating SF and NF in terms of compressive strength.

II. METHODOLOGY

Cubic specimens measuring 100mm100mm100mm are casted. The dosage of SF was determined to be 5%, 10%, and 15% by weight of cement, while the addition of Nylon fibers ranged from 0.5% to 1%. Based on the problem, research and study proposals have been formulated, and the study's primary purposes have been identified. This study is primarily concerned with the experimental investigation of the workability and compressive strength test of concrete mixes containing SF as partial cement replacement and Nylon fiber as

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reinforcing material to determine the optimal percentages of SF and NF.

2.1 Material used for the research

2.1.1 Cement.

The ordinary Portland cement (ASTM C150 Type-I) was used in this research to prepare the control specimens.

Table 1: Physical Properties of Lucky Cement

Property	Value
Specific Gravity	3.15
Fineness	95
Consistency	32
Initial setting time	155-160
Final setting time	360-365

2.1.2 Fine aggregate

Fine aggregates typically consist of particulates with a diameter of fewer than 4.75 millimeters (0.18 inches). Typically, fine aggregates consist of natural sand, pulverized stones, or gravel screenings. Fine aggregates occupy the spaces between larger particles and aid in binding the concrete. In addition, they contribute to the mix's workability and finish ability. In addition to its use in concrete production, fine aggregate is employed in applications requiring a uniform and cohesive material, such as mortar, plastering, and grouting. Fine aggregate (commonly known as hill sand) free from debris were brought from nearby having 2.6 ofspecific gravity and size below 4.75 mm were used.

Physical properties of fine aggregate are plotted in Table 2.

Table 2: Physical properties of Fine Aggregate

Properties	Fine Aggregate
Bulk specific gravity (OD)	2.582
Bulk specific gravity (SSD)	2.612
Apparent specific gravity	2.664
Water absorption	1.2%
Density	1790 kg/m3

2.1.3 Coarse aggregate

A well-graded mixture of different sizes of coarse aggregates optimizes the packing density, thereby reducing voids and increasing the concrete's overall strength. In addition to their use in concrete production, coarse aggregates are employed in road construction, drainage systems, and foundation bases. They provide these structures with stability, strength, and load-bearing capacity.

Coarse aggregate (crushed stone) passing from 19mm and retained at 4.75mm sieve are used in this research work.

Table 3: Physical Properties of Coarse Aggregate

Properties	Coarse Aggregate
Bulk specific gravity (OD)	2.541
Bulk specific gravity (SSD)	2.595
Water absorption	2.687
Density	1492.4 kg/m^3

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2.1.4 Silica Fume

The byproduct of silicon and ferrosilicon alloy is silica fume, also known as micro silica. SF is gray in color and powder form, resembling Portland or fly ashes. Generally, silica fume is classified as a supplementary cementitious material. SF is composed of extremely thin vitreous particulates almost one hundred times smaller than a standard cement particle. Due to its exceptional fineness and extensive percentage of silica, SF is an extremely pozzolanic substance (Ravitheja, Kumar, & Anjaneyulu, 2021) [14]. SF is utilized in concrete to increase its characteristics, such as excessive early compressive, tensile & flexural strength, enhanced durability, high bond strength, very low permeability to chloride & water intrusion, and excellent durability against chemical attack from acids, chlorides, sulfates, and nitrates, Etc. [15] (Shetti & Das. 2015)

Silica fume used in this research work is obtained from commercial markets of Karachi.

Figure 1: Silica Fume

Table 4: Physical properties of Silica Fume

Properties	Silica fume
Colour	Grey
Density	0.55-0.7g/cm3
Form	Powder
Specific gravity	2.2

Table 5: Chemical Composition of Silica Fume

Chemical composition	Silica fume
SiO_2	89.80
$Al2O_3$	1.40
$Fe2O_3$	1.80
CaO	0.2-0.7
MgO	0.3-0.8
K_2O	0.76
Na_2O	0.4-1.3
LOI	3.0

2.1.5 Nylon Fiber

Nylon is an artificial polymer. Nylon is a thermoplastic silky material that can be melted into filaments, films, & other forms. Numerous products, including carpets, rope, clothing, tires, and other long-lasting materials, are manufactured using nylon filaments. Nylon has a relatively high melting point of 2560 degrees Celsius (4500

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degrees Fahrenheit). The nylon filaments have a negative impact on the environment, but by disposing of them in a usable manner, this impact can be mitigated [16] (Ahmed et al. 2021). Nylon is especially good at providing resistance to impact and flexural durability, in addition to sustaining and elevating the load-carrying capacity of concrete following the initial fracture. Using NF as an additive in cement concrete is favorable as it provides an alternative disposal way for fibers, and these materials will improve the durability and strength of concrete.

- Nylon fiber used in this research work is monofilianment fishing line nylon which obtained from the commercial markets of Karachi. Physical properties of nylon fiber are given below:

Figure 2: Nylon Fiber

Table 6: Physical Properties of Nylon Fiber

Properties	Nylon fiber
Diameter	0.5mm
Length	20mm
l/d ratio	40
Density	1.13g/cm3
Colour	White

2.2 Mix Proportioning of Concrete:

Concrete mix design refers to selecting concrete ingredients and their proportions required to produce concrete. 1:1.5:3 is the concrete proportion (Binding material: fine aggregate: coarse aggregate), and a mix formulation of plain concrete with silica fume was created by replacing cement at varying percentages.5%, 10%, and 15% by weight of cement at a binder-to-water ratio of 0.55. As an additional material in concrete, 0.5%, 0.75 %, and 1% of Nylon Fibre with a diameter of 0.5 mm and a length of 20 mm were added.

Table 7: Mix Proportion Details

Mix ID	Binder		F.A %	C.A%	NF %	NF Length (mm)	w/b ratio
	Partial Replacement						
	Cement %	Silica Fume %					
CM	100	0	100	100	0	0	0.58
SF5	95	5	100	100	0	0	0.58
SF10	90	10	100	100	0	0	0.58
SF15	85	15	100	100	0	0	0.58
NF0.5	0	0	100	100	0.5	20	0.58
NF0.75	0	0	100	100	0.75	20	0.58
NF1	0	0	100	100	1	20	0.58
SF5NF0.5	95	5	100	100	0.5	20	0.58
SF5NF0.75	95	5	100	100	0.75	20	0.58

SF5NF1	95	5	100	100	1	20	0.58
SF10NF0.5	90	10	100	100	0.5	20	0.58
SF10NF0.75	90	10	100	100	0.75	20	0.58
SF10NF1	90	10	100	100	1	20	0.58
SF15NF0.5	85	15	100	100	0.5	20	0.58
SF15NF0.75	85	15	100	100	0.75	20	0.58
SF15NF1	85	15	100	100	1	20	0.58

2.3 Testing of Concrete:

2.3.1 SLUMP CONE TEST:

Conforming to the BS EN 12350-2 standard, a slump test was conducted to evaluate the concrete's workability. A slump test is an on-site evaluation of the workability and consistency of freshly made concrete. This test is crucial for assuring the immediate quality of concrete in a building occupation. It is utilized on nearly all construction sites. This test is uncomplicated and straightforward to conduct.

Additionally, it needs relatively lesser tools and can be completed quickly. These advantages have made the decline test a worldwide phenomenon. The slump test does not immediately measure the workability of concrete. Instead, the concrete's consistency is determined, providing a general indication of the concrete's workability.

2.3.2 COMPRESSIVE STRENGTH TEST:

The compressive strength test is essential for determining the ability of concrete to withstand compressive loads and its resistance to crushing. The compressive strength test on cube-shaped specimens followed BS EN 12390-3. After 28 days of storage, Cubes were utilized in tests. The test may be conducted on a CTM or UTM machine that can apply and measure compressive loads. The average potency was determined by testing four samples. The KN value of the load P where the specimen failed was noted, and the specimen's compressive strength was calculated.

Figure 3: Compressive Test of Concrete Cube

III. RESULTS AND DISCUSSION

3.1 WORKABILITY

Table 8: Results of Workability of Concrete with Different % of SF and NF

Sr. No:	Mix ID	Slump Values (mm)	% increased/decreased
1	CM	90	-
2	5% SF	70	-22.2
3	10% SF	55	-38.9
4	15% SF	45	-50
5	0.5% NF	70	-22.22

6	0.75% NF	55	-38.9
7	1% NF	50	-44.4
8	5% SF 0.5% NF	45	-50
9	5% SF 0.75% NF	40	-55.6
10	5% SF 1% NF	37	-58.9
11	10% SF 0.5% NF	32	-64.44
12	10% SF 0.75% NF	27	-70
13	10% SF 1% NF	25	-72
14	15% SF 0.5% NF	28	-68.9
15	15% SF 0.75% NF	23	-74.4
16	15% SF 1% NF	21	-76.66

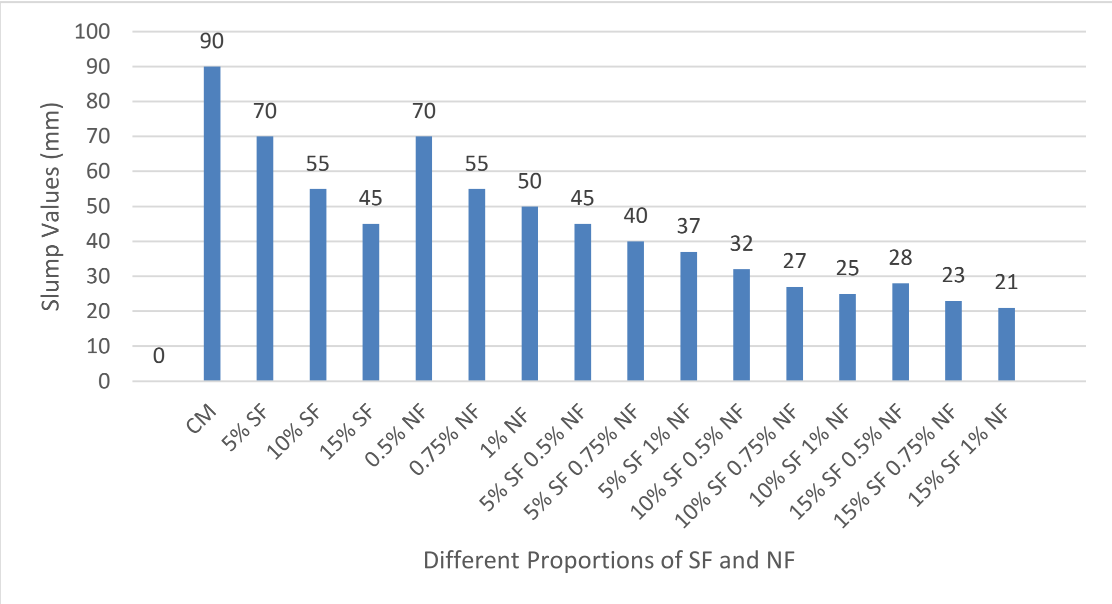

Figure 4: Comparative values of Workability with different SF and NF Percentages w.r.t Control Mix

3.2 COMPRESSIVE STRENGTH TEST

The increase and decrease in the compressive strength can be observed in the figure 5. The results conducted through compressive testing machine with different replacement of cement with silica fume by weight along with the inclusion of different dosage of nylon fiber by volume are plotted in the table 9.

Table 9: Results of Compressive Strength with different % Replacement of Cement with SF along with the Inclusion of various NF Dosages

Sr. No	Mix ID	Compressive Strength (Mpa)	% increase/decrease
1	CM	26.35	-
2	5% SF	27.25	3.4
3	10% SF	29.5	11.9
4	15% SF	27	2.5
5	0.5% NF	26.65	1.2
6	0.75% NF	30.38	15.3
7	1% NF	33.4	26.8

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8	5% SF 0.5% NF	34.6	31.3
9	5% SF 0.75% NF	32.3	22.6
10	5% SF 1% NF	30.26	14.48
11	10% SF 0.5% NF	32.64	23.9
12	10% SF 0.75% NF	32.10	21.82
13	10% SF 1% NF	30	13.86
14	15% SF 0.5% NF	31.7	20.30
15	15% SF 0.75% NF	29.9	13.5
16	15% SF 1% NF	28.44	7.93

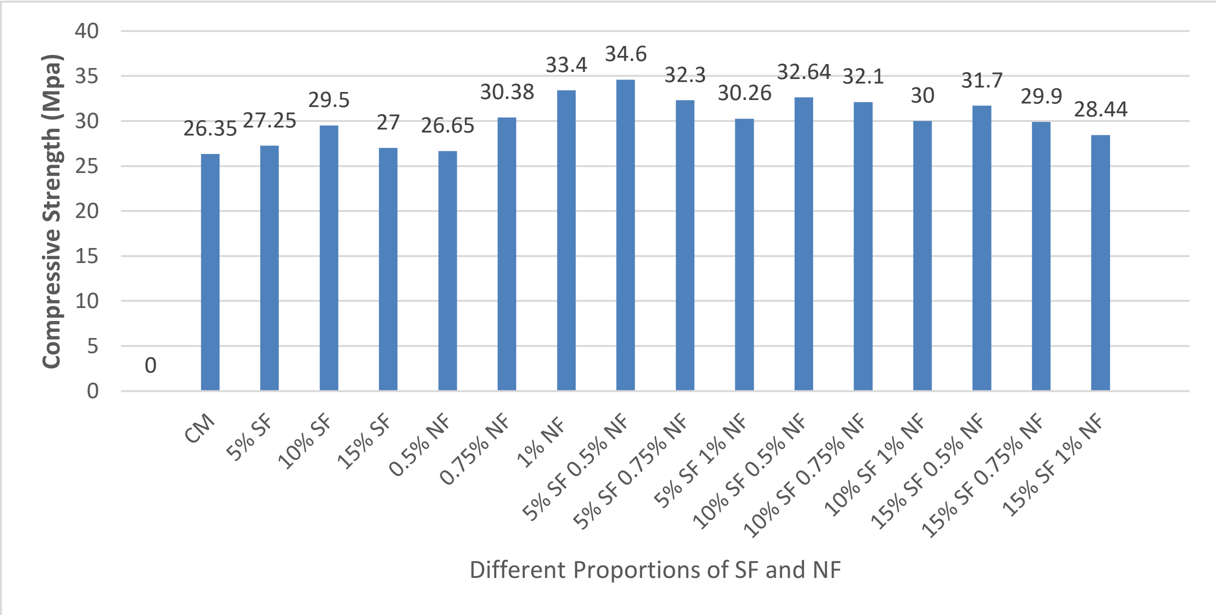

Figure 5: Comparative values of Compressive Strength with different SF and NF Percentages w.r.t Control Mix

IV. CONCLUSION

Following conclusions have been drawn after conducting this research:

- Workability of concrete diminished as the percentage replacement of cement with silica fume along with the inclusion of nylon fiber increased.
- The maximum compressive strength was achieved at 5% cement replacement with silica fume along with 0.5% inclusion of nylon fiber i.e 34.6 MPA which was 31.3% more compared to control mix concrete.
- The maximum split tensile strength was achieved at 5% cement replacement with silica fume along with 0.5% inclusion of nylon fiber i.e 2.75 MPA which was 14.6% more compared to control mix concrete.

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