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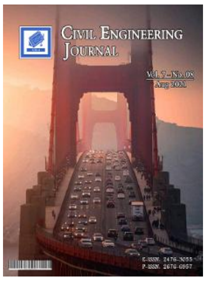

Effect of using Nylon Fibers in Self Compacting Concrete (SCC)

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Abstract

The self-compacted concrete (SCC) is a special type of concrete which settles down in the formwork and fills its every corner without any use of compaction or vibration. As SCC has higher flow-ability that causes brittle behaviour resulting in poor performance under tension and bending. The inclusion of randomly distributed short and discrete fibers is one of the most effective way to improve the tensile as well as flexural performance of SCC. In this regard this experimental study is undertaken to investigate the effect of nylon fibers (NF) on fresh and hardened properties of SCC. Two different lengths; 20 mm and 12 mm and five different volumetric percentages; 0.1, 0.2, 0.3, 0.4 and 0.5% of NF were used. The results revealed that addition of NF slightly affects the fresh properties of SCC. However, the extent of the effect is not of that order to be considered as major factor. The fresh properties for entire mixes lie within the required range according to EFNARC guidelines. The strength properties increases with addition of NF, the extent of increment is greater for the longer length of NF. The optimum volumetric fraction of NF for producing high strength SCC was found as 0.5%.

Keywords: Self-Compacting Concrete; SCC; Nylon Fibers; NF; Fresh Properties; Filling ability; Passing ability; Hardened Properties; Compressive Strength; Spilt Tensile Strength.

1. Introduction

The concrete is most widely used man made construction material all around the world. Due to its extreme durability and high compressive strength, the concrete proves itself as global construction material. Inconvenience is faced during poring the fresh concrete in slabs, beams, beam-column joints, deep and narrow sections means the congested areas with heavy reinforcement without segregation it needs an appropriate compaction also. Improper compaction/vibration affects the durability and strength characteristics of concrete structures. To avoid such issues of strength and durability the self-compacting concrete (SCC) may be the better solution [1].

The self-compacting concrete is a special type of concrete that flows under its own-weight and fills the every corner of formwork without any need of compaction or vibration efforts [2]. SCC has been most widely used all around the world due its high flowing ability and extreme durability [3-6]. SCC offers various advantages to the normally vibrated concrete, such as improved quality of construction with brilliant finishing, reduces construction time by faster construction, reduces all over cost of construction etc. [7].

Although, SCC has excellent flow ability, but its brittle behaviour reduces the performance under tension. The inclusion of fibers is proved to be an effective to improve the performance of concrete particularly in tension and

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bending [8]. The SCC with fiber reinforcement has various advantages like crack resistance, impermeable surfaces improves the flexural and fractures toughness of concrete at hardened state. However, the workability of SCC is affected with addition of fibers, but the degree of decrease is dependent on the type, size and shape of the fibers used. A balanced distribution of fibers is however necessary for achieving the optimum benefits of fibers [9].

Different types of fibers i.e. steel, polypropylene, glass etc. have been used for evaluating the fresh, hardened and durability characteristics of SCC. Recently, several investigations have been carried to determine ability of incorporating various types of fibers into SCC [10-13]. El-Dieb and Taha [9] used the steel and polypropylene fibers in SCC to show the flow behaviour of fiber reinforced SCC. Three mixes with different binder content and w/b ratio were designed. Steel and polypropylene fibers with different length, aspects ratios and volumetric fraction were used to assess the flow properties (slump flow, V-funnel and filling box). It was found that acceptable results of flow characteristics can be achieved by using fiber reinforcement in SCC. However, the mix composition, fibers types and dosage significantly affect the flow performance of FRSCC. Frazao et al. [14] through their research presented the durability properties of fiber reinforced SCC. Hooked steel fibers (L= 3mm, dia= 0.5mm, aspect ratio L/d =70) were used in developing the (FR-SCC). One controlled SCC mix and other FRSCC mixes with same w/b ratio equal to 0.31 were designed in order to evaluate the corrosion resistance, fresh, mechanical and other durability parameters of FRSCC. The results revealed that addition of steel fibers to SCC were very effective in terms of increasing the post-cracking flexural resistance and the energy absorption, and did not have significant effect on fresh and durability indicators of SCC.

Yehia et al. [15] evaluated the mechanical and durability properties of FRSCC with steel and synthetic fibers individually and hybrid. Synthetic and steel fibers with 0.92 and 7.77 specific gravity and 0.025-0.05% and 0.5% volumetric fraction respectively were used. In this study tests were conducted in two phases. In phase-1 workability and strength properties were determined and in phase-II FRSCC were exposed to wet/dry cycles. It was observed that all mixture of FRSCC have cube compressive strength more than 70 MPa. Furthermore, it was noticed that exposure of FRSCC to early wet/dry cycles improves the mechanical properties of all mixtures. The Nylon is a synthetic polymer based material with silky surface. The nylon is tough material possessing excellent abrasion and tearing resistance [16, 17]. The nylon net is mostly used for fish hunting. And lot of waste nylon net is dumped in the sea that pollute marine environment. To address the environmental issue these waste can be utilized as fiber reinforcement as an additive in production of concrete. Afriandini et al. [18] investigated the effect of nylon fibers and zeolite ash on the fresh and hardened properties of SCC. They used volumetric fraction of NF as 1% with 50 mm length, while the percentage of ash was varied from 5, 10 and 15% as partial replacement of cement. The reported results showed that by adding both the nylon fibers and zeolite ash the strength properties remarkably increased. Also it may be concluded that mix with 1% NF and 5% of zeolite ash gives optimum results.

Hanoora et al. [19] used pineapple leaf fibers and polypropylene fibers in production of SCC. The fibers were used with 12 mm length and 0.2, 0.3 and 0.4 by weight of cement. The results revealed that the fresh properties were slightly decreased with increasing the fibers content. While the strength properties increased. The maximum compressive strength was obtained at 0.3% of fibers content of 56.28 MPa and 58.04 MPa for pineapple leaf fiber and polypropylene fiber at the age of 28 days. Furthermore, the maximum flexural strength was observed at 0.4% of both the fibers content. A research work conducted by Zoe et al. [20] on SCC with metakaolin and nylon fiber. The reported that the nylon fibers and metakaolin together gives excellent strength properties of SCC instead of individual used in concrete. Habib et al. [21] used nylon fiber in cement based mortar. They reported that the nylon fibers increases the compressive strength of mortar. The maximum increment of 42.8% was observed with 2% of NF compared to the normal cement based mortar. It was also observed that the length of fibers significantly affects the compressive strength of mortar. The fibers with shorter length cases the decreases in compressive strength. The performance of mortar was improved with addition of higher percentage of longer length of NF [22].

The above discussion of available literature indicates very limited investigations conducted by researchers in the area of SCC with fiber reinforcement particularly for nylon fibers. However, the scope of these studies has very limited and wide variation in the results. Thus, a systematic and broad based study is essential to arrive at the logical conclusions. Hence, this experimental study is carried out to investigate the effect of nylon fibers on the fresh and hardened properties of SCC.

2. Research Methodology

Figure 1 presents the systematic structure of article to show the sequence of different parts of the research work to achieve the objectives of the study.

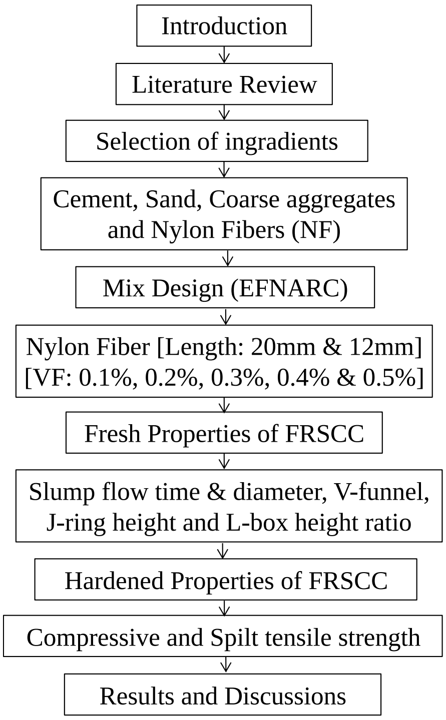

Figure 1. Flowchart of methodology and plan of work

In this study total 11 mixes were produced with fixed w/b ratio 0.34 and binder content 550 kg/m^3 [8]. Out of which one plain SCC mix and ten FRSCC mixes were designed according to EFNARC guidelines [5] with different length (12 & 20mm) and volumetric percentage (0.1, 0.2, 0.3, 0.4 and 0.5%) of Nylon fibers. Table 1 shows the details of mixes and quantities of ingredients for one cubic meter of concrete.

Table 1. Composition of SCC and FRSCC mixes for 1 m^3

Mixes	Cement Kg/m^3	FA Kg/m^3	CA Kg/m^3	W/B (%)	Water Kg/m^3	Nylon Fibers (%) by volume	SP (%)	SP Kg/m^3
SCC	550	870	890	0.34	187	--	2	11
FRSCC	550	870	890	0.34	187	0.1, 0.2, 0.3, 0.4, 0.5	2	11

3. Materials and Their Sources

3.1. Cement

Ordinary Portland cement (OPC) of LUCKY brand conforming according to ASTM C150M-18 [23]. Figure 2 shows the gradation curve of cement.

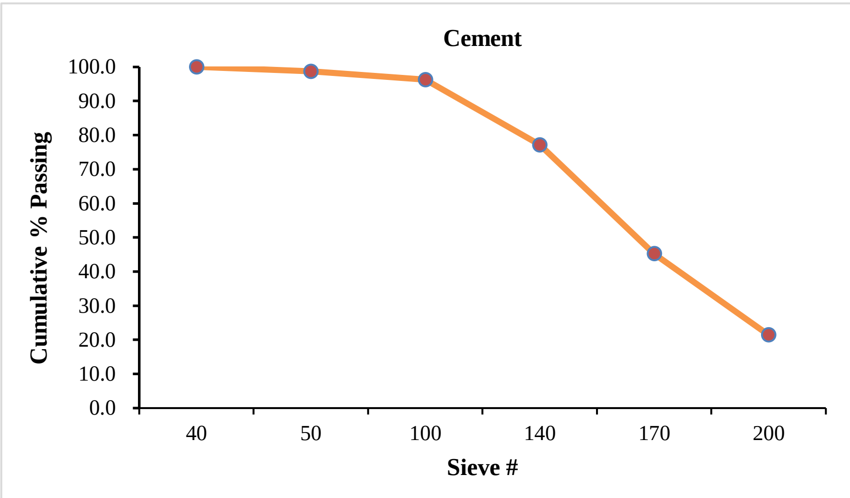

Figure 2. Gradation curve of cement

3.2. Fine Aggregates (FA)

Locally available hill sand passing from # 4 sieve as per the specifications according ASTM C 778-02 [24]. The gradation curve for fine aggregates is given in Figure 3.

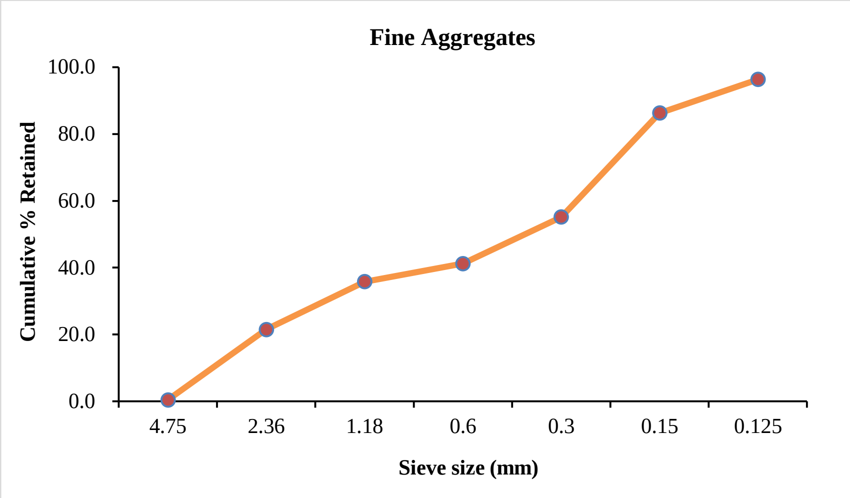

Figure 3. Gradation curve of fine aggregates

3.3. Coarse Aggregates (CA)

Coarse aggregates crushed in nature with maximum size 12.5 mm with gradations as shown in figure 4 were used according to EFNARC standard (EN:12620). The aggregates are washed before using in concrete as per SSD.

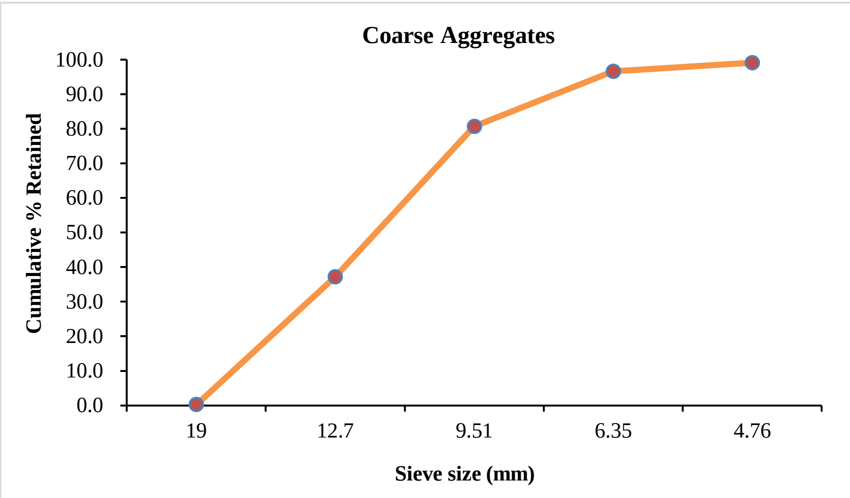

Figure 4. Gradation curve of coarse aggregates

3.4. Superplasticzer (SP)

Locally available SP with brand name "Master Poly heed 996", a polycarboxylic ether based liquid superplasticzer was used throughout the study.

3.5. Water

Potable water for drinking purpose free from organic and inorganic impurities was used in production as well as for curing of concrete specimens.

3.6. Nylon Fibers (NF)

Nylon fibers with two different length; 20 and 12 mm and percentage volumetric fraction; 0.1, 0.2, 0.3, 0.4, and 0.5% were used for production of nylon fiber reinforced self-compacting concrete (NFRSCC). Figure 5 and Table 2 present pictorial view and the physical properties of used nylon fibers.

Figure 5. Pictorial view of Nylon Fibers

Table 2. Physical properties of Nylon fibers

Physical properties	Description
Colour	Transparent white
Fiber length (mm)	20 & 12
Fiber diameter (mm)	0.75
Specific gravity	0.9

4. Results and Discussions

4.1. Fresh Properties

The fresh properties of SCC and NFRSCC were evaluated by two major tests flow ability and passing ability. The flow ability was determined by slump flow time T_{50cm}, slump flow diameter and V-funnel tests. While the passing ability was recorded by J-ring and L-box tests. Figure 6 shows the pictorial view of few tests for fresh properties of concrete.

Figure 6. Fresh properties of SCC

For each mix several trials were carried for optimizing the suitable dosage of superplasticizer to obtain the required values of slump flow time (T_{50cm}) according to the EFNARC guidelines [9]. Table. 1 shows the optimized value of SP for both the controlled mix and FRSCC mixes.

Table 3. Fresh properties of SCC and FRSCC

S. No.	Mixes	Slump flow time T_{50} (sec) limits 2-5 sec		Slump flow diameter (cm) limits 65-80 cm		V-funnel time (sec) limits 8-25 sec		J-ring height (mm) limits 0-10 mm		L-box height ratio limits 0.8-1.0	
		NF Length (20mm)	NF Length (12mm)	NF Length (20mm)	NF Length (12mm)	NF Length (20mm)	NF Length (12mm)	NF Length (20mm)	NF Length (12mm)	NF Length (20mm)	NF Length (12mm)
1	SCC	2.2		76		8.2		7.8		0.94	
2	0.1% FRSCC	3	2.8	74.12	75.5	11	10.6	8.1	8.2	0.9	0.91
3	0.2% FRSCC	3.4	3.1	73.55	74.3	12.5	11.7	8.34	8.45	0.87	0.89
4	0.3% FRSCC	4.2	3.8	72.04	73.11	13.6	12.3	9.2	8.98	0.84	0.85
5	0.4% FRSCC	4.9	4.4	71.39	72.5	15.6	13.9	9.48	9.3	0.82	0.83
6	0.5% FRSCC	5.1	4.8	70.35	71.17	16.3	15.6	9.8	9.61	0.8	0.81

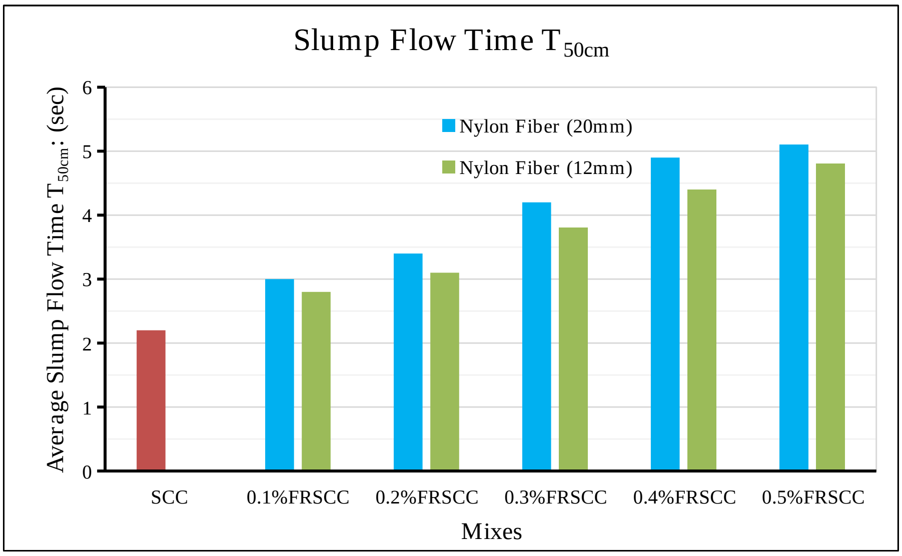

Figure 7. Effect of Nylon fiber on Slump Flow Time of FRSCC

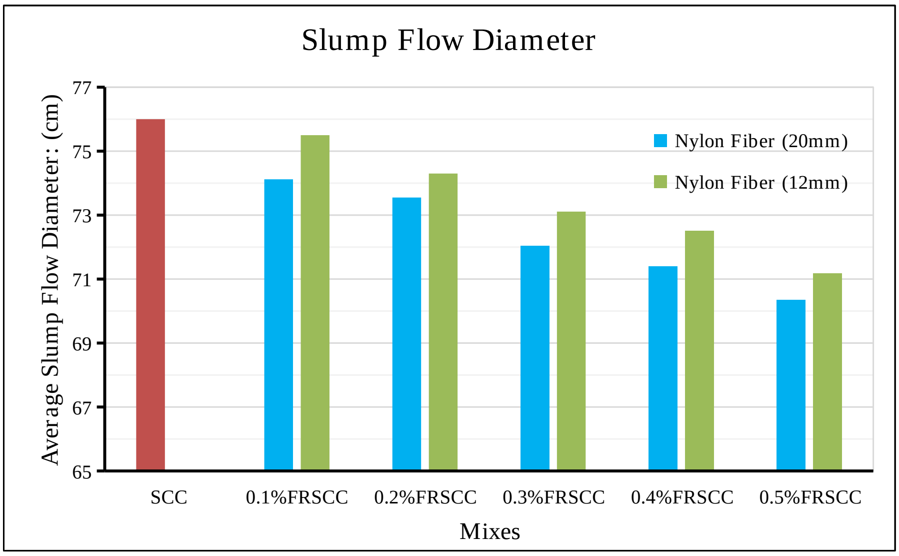

Figure 8. Effect of Nylon fiber on Slump Flow Diameter of SCC and FRSCC

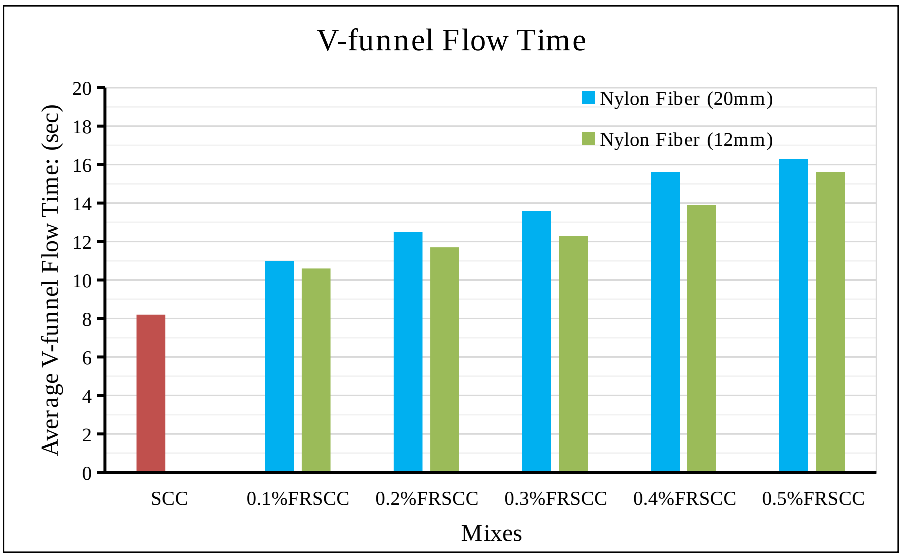

Figure 9. Effect of Nylon fiber on V-funnel flow time of FRSCC

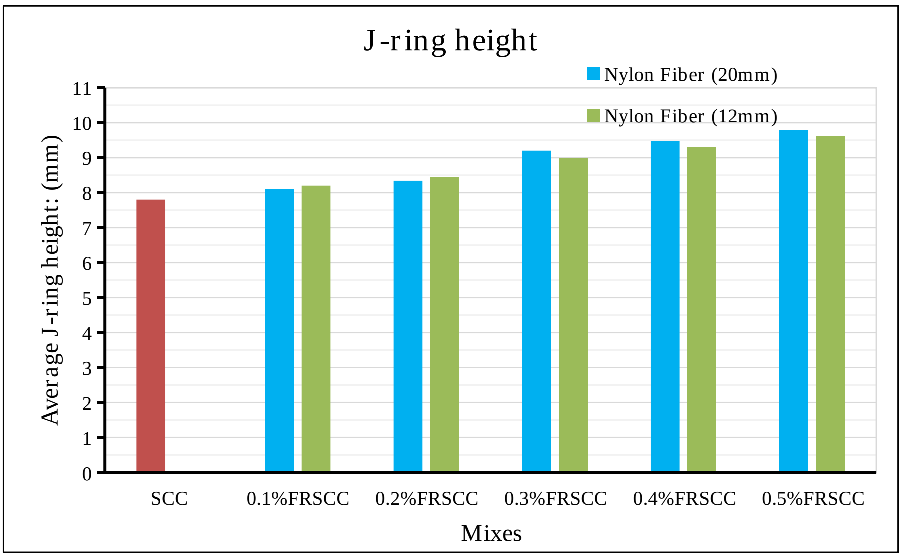

Figure 10. Effect of Nylon fiber on J-ring height of FRSCC

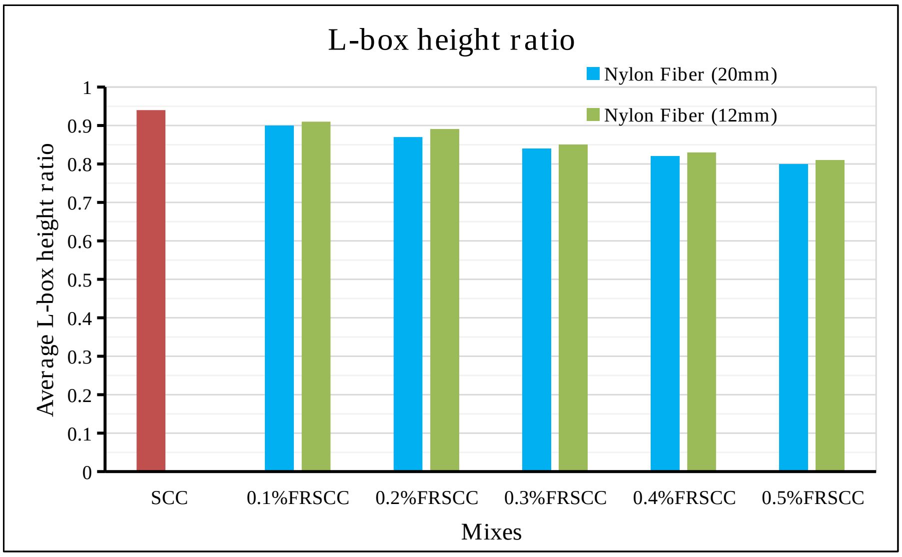

Figure 11. Effect of Nylon fiber on L-box height ratio of FRSCC

Table. 3 shows the results of fresh properties of both SCC and FRSCC with nylon fibers. The Figures 7 to 11 represent the graphical views of slump flow time T_{50cm}, slump flow diameter, V-funnel time, J-ring height and L-box height ratio respectively of controlled mix and mixes with nylon fibers. The results are also compared with the controlled mix without nylon fibers. It may be observed from bar charts that all the fresh properties were slightly affected by the inclusion nylon fibers. Also the length of fiber has greater effect on workability values of SCCs. Figures 7 to 9 symbolize the flow ability of FRSCC. From figures it can be seen that flow ability of concretes decreases with the increase in length and volumetric percentage of NF. The maximum decrease in workability values was observed for the mix with 0.5% and 20mm length of NF. Figures 10 and 11 show the passing ability of FRSCC. The similar trend was observed for passing ability of concretes. Moreover, the results revealed that all the fresh properties of all the mixes with different lengths and dosages of NF lie within the required range according to EFNARC guidelines.

4.2. Hardened Properties

The hardened properties of SCC were determined through compressive strength and spilt tensile strength. Five cube and cylindrical specimens of standard size for each mix were cast and tested for evaluating the compressive and tensile strength of FRSCC with nylon fibers. All the specimens were kept at room temperature and demoulded after 24 hours of casting. The specimens were dipped into the water tank for wet curing. The testing of specimens was done at the age of 28 days. To determine the compressive and spilt tensile strength the cube and cylinder specimens were tested in universal testing machine (UTM). The ultimate strength at crushing of both the cube and cylindrical specimen was recorded. Figure 12 shows the pictorial view of specimen under testing.

Figure 12. Pictorial view of cube and cylinder specimen at ultimate failure

Table 4. Strength properties of SCC and FRSCC

S. No.	Mixes	Compressive Strength (MPa)		Spilt Tensile Strength (MPa)	
		NF Length (20 mm)	NF Length (12 mm)	NF Length (20 mm)	NF Length (12 mm)
1	SCC	43.4		3.91	
2	0.1% FRSCC	45.63	44.9	4.3	3.98
3	0.2% FRSCC	47.7	45.8	4.51	4.12
4	0.3% FRSCC	48.3	46.36	4.76	4.35
5	0.4% FRSCC	49.72	48.1	4.82	4.67
6	0.5% FRSCC	50.8	49.21	5.02	4.92

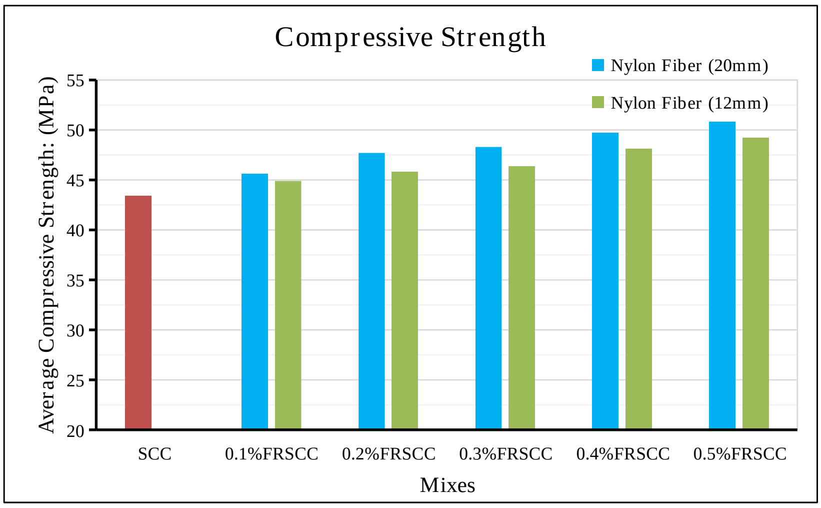

Figure 13. Effect of Nylon fiber on Compressive strength of FRSCC

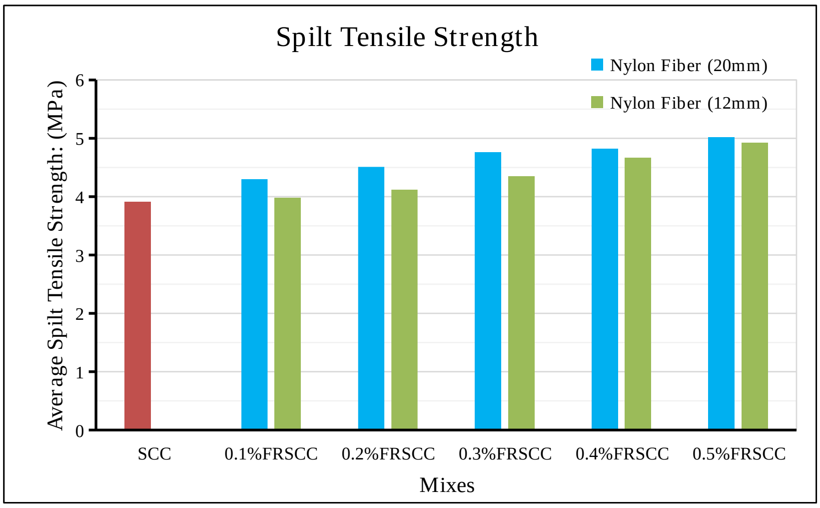

Figure 14. Effect of Nylon fiber on Spilt tensile strength of FRSCC

The values of average compressive and spilt tensile strength of nylon fiber reinforced SCC are given in Table 4. Figures 13 and 14 represent the graphical views of average compressive and spilt tensile strength respectively. The compressive and spilt tensile strength of controlled mix at 28 days curing were measured as 43.4 and 3.91 MPa respectively. The use of NF in SCC increases both the compressive and spilt tensile strength as volumetric fraction and length of fibers increased. This is because by adding NF in concrete the plasticity increases thus delaying the formation of cracks in concrete when load is applied. The similar trend results were also discussed by Hanif et al. (2017) [25]. The maximum compressive strength of 50.8 MPa and spilt tensile strength of 5.02 MPa were obtained at 20 mm length and 0.5% of NF. The maximum increment in compressive and tensile strength was observed 17% and 28% respectively. Furthermore, it is also noted that the cube and cylinder specimens with nylon fibers did not collapse completely into pieces during crushing. It is due to the reason that parts of specimens were attached with each other with fibers. It is worth noting that the specimens with nylon fiber shows the warning sign before the complete failure.

5. Conclusions

From the obtained results following are the conclusions.

- The fresh properties of SCC and FRSCC depend upon the mix proportions and can be adjusted by varying the dosage of SP.
- T_{50} test is considered as key test for fresh properties of SCC and FRSCC with NF and T_{50} time between 2-5 sec is considered as substitute values according to EFNARC.
- Addition of NF slightly affects the fresh properties of SCC. However, the extent of the effect is not of that order to be considered as major factor.
- Also the length of NF has adverse effects on passing ability of SCC. The appropriate choice of length and percentage of NF should be necessarily kept in consideration while designing the FRSCC mixes with nylon fibers.
- It is noted that all the values of fresh properties for all the mixes lie within the required range according to EFNARC guidelines.
- Likewise, fresh properties the strength properties of SCC and FRSCC with NF depends on the length and percentage of NF.
- The compressive strength of FRSCC increases with addition of NF.
- The maximum compressive strength was recorded at 20 mm length and 0.5% of NF.
- The maximum increment in compressive strength is approximately 17% of controlled concrete without NF.
- The similar trend was also observed by the spilt tensile strength.
- The maximum increment in spilt tensile strength is about 28% of CM.
- It is worth noting that the specimens with nylon fibers did not collapse completely into pieces during testing at ultimate load. Thus by giving the warning time before complete failure.

6. Declarations

6.1. Author Contributions

Conceptualization, M.H.L., N.A.M. and M.A.M.; methodology, M.H.L., N.A.M. and M.A.M.; formal analysis, M.A.M.; resources, M.H.L. and M.A.M.; writing—original draft preparation, M.H.L. and M.A.M.; writing—review and editing, M.H.L. and M.A.M.; supervision, N.A.M. and M.A.M. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

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6.4. Acknowledgements

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6.5. Conflicts of Interest

The authors declare no conflict of interest.

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