Study of Effectiveness of Range of Polypropylene Fibers in Self Compacting Concrete

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Abstract— **In this paper, Nominal Mix Self Compacting Concrete (NMSCC) and Fiber Reinforced Self Compacting Concrete (FRSCC) are compared in terms of its fresh and hardened properties. For this purpose, M20 SCC mix design has been done using BIS 10262:2009 and ACI 211.1-91 guidelines. To achieve NMSCC, mineral admixture i.e. Fly ash 10% of weight of cement and chemical admixture i.e. Super Plasticizer (SP) CONPLAST SP430SRV 0.25, 0.30 and 0.35% of cement is used with different w/c ratios. To obtain FRSCC, three different types of varying length Polypropylene (PP) fibers are mixed with proportion of 0.9, 1.35 and 1.8 kg/m^3 of concrete volume in addition to NMSCC.**

This research investigates, the fresh characteristics of both mixes which are evaluated based on its filling ability, segregation resistance and passing ability using V-funnel and L-box test apparatus. The hardened properties of above mixes viz. unit weight, compressive strength, split tensile strength and flexural strength are also examined. For this, standard 30 cubes, 4 cylinders and 4 beams are casted and tested after 7 and 28 days using Compression and Universal Testing Machine in standard laboratory setup. The performance of NOKRACK fibers in SCC mortar is observed by testing 12 standard mortar cubes after 28 days curing.

Keywords— ***Chemical Admixture, Compressive strength, Polypropylene fibers, Filling ability, Passing ability, Self compacting concrete, Split tensile strength***

I. INTRODUCTION

The constructions are using Self Compacting Concrete i.e. SCC. Moreover fibers added to it so called Fiber Reinforced Self Compacting Concrete are very popular due to its finishing and strength properties. Since 1997 till date structural synthetic fibers are used in Self Compacting Concrete by various Japanese construction companies. The finer aggregate gives flowability but limits the strength of SCC [1]. The past researchers have been underscored the use of mineral and chemical admixtures in SCC to gain good self compaction ability with marginal reduction in unit weight and slight increase in compressive strength [2]. Polypropylene (PP) fibers tend to reduce the flowability and passing ability but will increase viscosity and segregation resistance of SCC [7]. The slump reduction is noticed beyond 1.5% dosage; as the mix becomes fibrous and difficult in handle [4]. Chemical admixture found effective in attaining self compactability with regular ingredients [14]. The addition of 2-4 kg/m3 of PP fibers influenced little bit flowability, while 6 kg/m3 of fibers significantly deteriorate this property [12]. Since the specific gravity of PP fibers is low, higher fiber content also reduces the unit weight of concrete [11]. Increase of fiber content in SCC enhances harden composite properties and reduces bulk density. [12].

One of the investigations for M20 mix, there was about 18.5% increase in the ultimate load carrying capacity of the beams containing fibers [3]. An economical SCC of M20 and M25 grade can be successfully developed by incorporating high volumes of Class F fly ash [5]. Using the PP fibers of same volume fraction of three different cut length fibers shows nearly same results with minor increase in compressive strength[6][9]. The addition of PP fibers at low values actually increases the 28 days compressive strength but decreases at more fibers from original by 3 to 5%[13]. The split tensile strength of fiber reinforced increased in case of longer fibers [9].The split tensile strength of fiber reinforced concrete was dependent on length of fiber used. By addition of longer length fiber, the split tensile strength increases [8]. No significant change is found for compressive strength but flexural, split tensile and shear strength improves greatly, when compared to the plain concrete [10]. A notable increase in flexural, tensile and shear strength was found. However, no change in compression strength was noted. The addition of PP fibers at low values, the tensile strength increases about 65%~70% [13]. The SCC tensile strengths after 7 days were almost as high as those obtained after 28 days for normal concrete. [14]. PP fibers does not disperse properly in the mixing water. Addition of fibers to dry mix was found to be more practical. The presence of fibers in concrete alerts the failure mode of material which is by spalling in plain and bulging in fiber concrete [10]. The PP fibers enhance the strength of SCC significantly, without causing well known problems associated with steel fibers [11].

This paper represents behavioral response study of NMSCC and FRSCC incorporating synthetic PP fibers. The general objective of this paper is to evaluate the effectiveness of different length and increased proportion of synthetic fibers in SCC and mortar mix. It gives an approach for use of wide range of fibrillated polypropylene fibers in SCC. This is prior study for normal grades which can be applied to check the same properties of higher grade concrete mixes. This work may extend up to use of steel and hybrid fibers.

II. MATERIALS USED

It was a step to select materials to obtain self compacting concrete by keeping in mind the acceptance criteria.

Therefore following materials were selected to produce both nominal mix and fiber reinforced self compacting concrete

A. Cement

An Ordinary Portland Cement (OPC) confirming IS12269-1987 is used to obtain SCC. The locally available market brand Birla Super Cement is purchased in order to enforce binding properties.

B. Fine Aggregate and Coarse Aggregate

Sieved ordinary river sand (S<5mm) is used. . The 10 and 20 mm size stone aggregates are used in 8:2 proportions. It is recommended to reduce coarse aggregate content in concrete mix for avoiding harshness and attaining easiness in mixing. The Yashganga Stone Co. supplied fine and coarse aggregate throughout work..

C. Water

A potable drinking water supplied by corporation and availed readily in laboratory. It is free from solid impurities and preferred for purpose of mixing all ingredients.

D. Mineral Admixture

The best suitable mineral admixture i.e. fly ash is used as important filler in mix proportion. It is made availed locally, confirming class F. Another mineral additive i.e. PP fibers decided to add and check the variation in properties of FRSCC as compared to NMSCC. It was sponsored by Dolphin Floats Pvt. Ltd. in a bag of 1 kg each. There are three types of fibers used in this work viz. Nokrack Fibers- 12 mm length, Strongplast Fibers- 20 mm length and Strongcrete Fibers- 25 mm length.

E. Chemical Admixture

Several chemical admixture i.e. super plasticizers play a major role in making better quality SCC for different site conditions. Therefore it is decided to use a poly-carboxylate based Conplast SP430SRV as a Viscosity Modifying Agents (VMA). It complies with the requirement of ASTM C 494-80, Type-G (High range water reducing admixture).

III. Concrete Mix Design And Proportion

The trial mix design made using both BIS and ACI codes, which suggest decreased sand content for increased strength requirement. The M20 grade SCC is made including constant percentage of fly ash with varying proportions of super plasticizers and PP fibers. The calculated proportion of quantities of materials used for M20 grade SCC is tabulated as given in Table I below. The cubes without fibers are designated as N1, N2 and N3 whereas fiber added cubes are noted as F1, F2 and F3 in increasing order. The beams and cylinders are abbreviated as B0, B1, B2, B3 and C0, C1, C2, C3 respectively for with and without fibers. The following mix proportion is used throughout testing all strength characteristics i.e. flexural strength of beams, split tensile strength of cylinders. The unit weight of hardened cube, beam and cylinder is also observed after 7 and 28 days curing.

TABLE I

Mix proportion of M20 Grade SCC for various trial mixes

Sr. No.	Cement	Fine Aggregate	Coarse Aggregate	Water	Fly ash	Conplast SP 430 SRV	PP Fibers
Prop.	1	1.78	3.85	0.6	0.1	0.0027	0.9
Qty.	313.2	558	1207	208.8	34.8	0.87	0.04252
Prop.	1	1.78	3.85	0.6	0.1	0.0033	1.35
Qty.	313.2	558	1207	208.8	34.8	1.04	0.06378
Prop.	1	1.78	3.85	0.6	0.1	0.0038	1.8
Qty.	313.2	558	1207	208.8	34.8	1.22	0.08505

The above mix proportion is used throughout testing all strength characteristics i.e. flexural strength of beams, split tensile strength of cylinders. The unit weight of hardened cube, beam and cylinder is also observed after 7 and 28 days curing.

IV. Experimental Results and Discussions

The following fresh and hardened properties of NMSCC and FRSCC are tested in working laboratory set up systematically as per IS and EFNARC procedures.

A. Slump Cone and Flow Table Test: The slump height and slump diameter of prepared concrete tested using Abraham's slump cone. The collapse slump found satisfactory i.e. more than 190 mm height and 650 mm diameter slump flow in this test. It is observed the required flowability with some indication of segregation at 0.6 w/c ratio even after using higher super plasticizer. The same concrete mix is tested on flow table test apparatus which gives better average spread diameter after 15 successive blows. It is found with flow percentage more than 100%. The concrete % flow calculated and found to be improved at higher w/c ratio again with partially non-uniform flow round the flow table.

B. V- Funnel and V-Funnel @ $T_{5\ min}$ Test: Now it is necessary to achieve SCC which has required filling ability even at thinner and highly reinforced sections. Therefore it is checked by filling fresh mixture in V-Funnel test apparatus as shown in Fig. 1 below. The time is measured to empty the funnel on stopwatch. Further same mix is filled after 5 minutes in V-Funnel without cleaning to check increased viscous flow. The time of V-Funnel at T_{5min} is also measured accurately. Every time it found to be in increasing order proportionally to fiber content. The summary of observations is given in Table II below.

Fig. 1. Conductance of V-funnel and L-box test

TABLE II

V-FUNNEL, V-FUNNEL AT $T_{5\ Min}$ TIME FOR NMSCC AND FRSCC

Type of SCC Mix	V-Funnel Time	V- Funnel at $T_{5\ min}$ Time
NMSCC	7.10 sec	8.72 sec
FRSCC 1 (0.9)	8. 11 sec	10.80 sec
FRSCC 2 (1.35)	11.74 sec	13.22 sec
FRSCC 3 (1.8)	14.49 sec	16.36 sec

It has been observed that fibers tend to reduce the flowability and passing ability of SCC. But it will increase viscosity i.e. cohesiveness of concrete and segregation resistance as well even at increased fiber proportion.

C. L-Box Test: SCC is also examined to know its passing ability using L-Box test apparatus as shown in Fig. 1 above. It found that concrete mixture without fibers was passed through bars easily. But it gets affected when fibers were added in it. The height H2 is measured at the far end of horizontal section of L-Box. The blocking ratio (H2/H1) is then calculated, where H1 was constant height of horizontal section of this apparatus. It was a crucial time for us to check effect of fibers on passing ability of prepared SCC mix. The results shown above in Table III are all about calculated H2/H1 as blocking ratios.

TABLE III

BLOCKING RATIO FOR NMSCC AND FRSCC

Type of SCC Mix	**T_{20} time**	**T_{40} time**	**Height (H1)**	**Height (H2)**	**Blocking ratio (H2/H1)**
NMSCC (NIL)	2.15	3.30	150 mm	123 mm	0.820
FRSCC 1 (0.9)	2.30	3.51	150 mm	121 mm	0.806
FRSCC 2 (1.35)	2.45	4.56	150 mm	115 mm	0.766
FRSCC 3 (1.8)	3.55	5.18	150 mm	103 mm	0.686

The above values show that fibers greatly affect the flow by reducing flowabilty in addition to increased T_{20} and T_{40} flow time in horizontal section.

D. Unit Weight and Compressive Strength Test: The compressive strength is tested by testing 30 cubes of standard size, casted using three types of fibers. All are tested under Compression Testing Machine after 7 and 28 days curing as shown in Fig. 2. Before each testing, the density of concrete hence calculated found to be lesser; which implicates light weight concrete even after 28 days curing also. The following Fig. 3 and Fig. 4 shows calculated unit weights and compressive strengths after said curing.

TABLE IV

UNIT WEIGHT AND COMPRESSIVE STRENGTH FOR NMSCC AND FRSCC

Range Of Fibers	Specimen Designation	Proportion of Fibers kg/m^3	Avg. Unit weight (gm/cm^3)		Avg. Unit weight (gm/cm^3)	
			7 Days	*28 Days*	*7 Days*	*28 Days*
Nokrack Fibers (12mm L)	N1	NIL	2.548	2.530	21.55	33.44
	F1	0.9	2.524	2.554	23.77	33.44
	F2	1.35	2.518	2.497	24	31.77
	F3	1.8	2.488	2.435	23.55	26.77
Strongplast Fibers (20mm L)	N1	NIL	2.548	2.530	21.55	33.44
	F1	0.9	2.542	2.577	23.11	31.77
	F2	1.35	2.518	2.325	22.66	31.55
	F3	1.8	2.459	2.358	22.44	30.77
Strongcrete Fibers (12mm L)	N1	NIL	2.548	2.530	21.55	33.44
	F1	0.9	2.554	2.568	20	28.51
	F2	1.35	2.536	2.515	19.11	25.71
	F3	1.8	2.465	2.459	17.77	22.53

Fig. 2. Cubes before and during testing under CTM

Most of the fiber added cubes failed showing bulging surfaces except nominal mix. The strength is calculated in MPa by $\sigma_c = P/A$; where P is failure load (N) and A is surface area (mm^2). The important aspect of concrete strength resulted drastic gain at early stage.

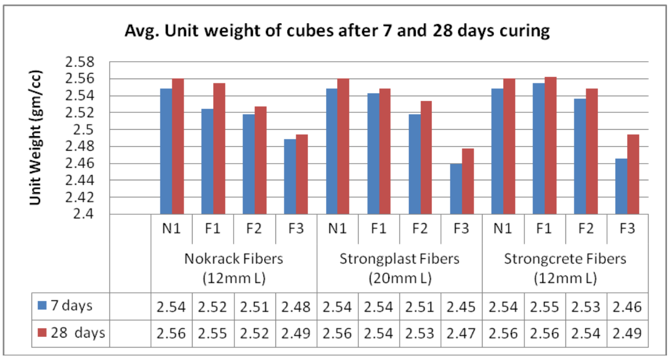

Fig. 3 Variation of Unit Weight in NMSCC and FRSCC Cubes after 7 and 28 days curing

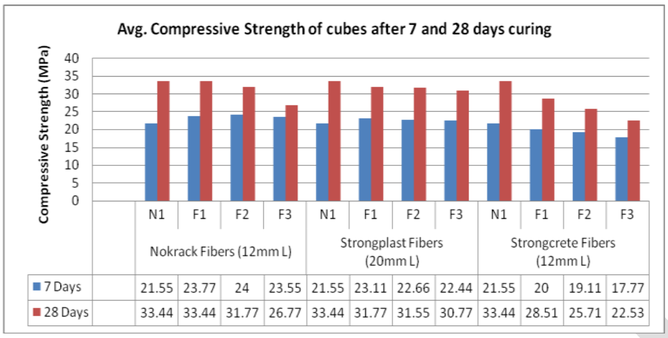

Fig. 4 Variation of Comp. Strength in NMSCC and FRSCC Cubes after 7 and 28 days curing

The values obtained indicate fibers are responsible only for gaining faster development of strength within 7 days. But it becomes slower in all cases after 28 days curing. The compressive strength increased when length and proportion of fibers was lesser. But it is decreased at increased fibers dosage and longer length fibers.

E. Unit weight and Split Tensile Strength Test: The four cylinders of 150 mm diameter and 300 mm length are casted with and without fibers adding three lengths of fibers in it. The cured cylinders were tested under Digital Universal Testing Machine (DUTM). The loading given to cylinder surface through loading device and split was observed as shown in Fig. 7 below. The following Fig. 5 and Fig. 6 shows variation in unit weight and tensile strength respectively after 28 days fresh water curing.

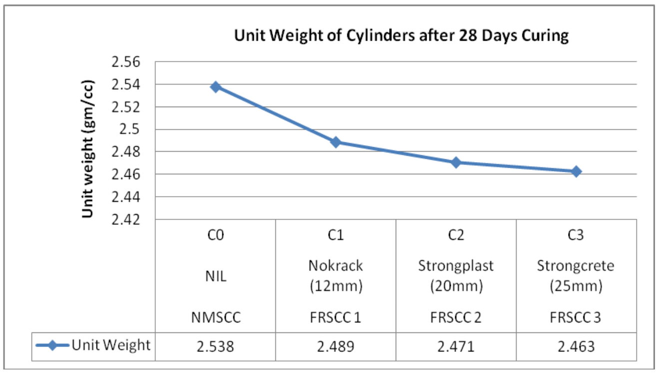

Fig. 5 Variation of Unit weight in NMSCC and FRSCC Cylinders after 28 days curing

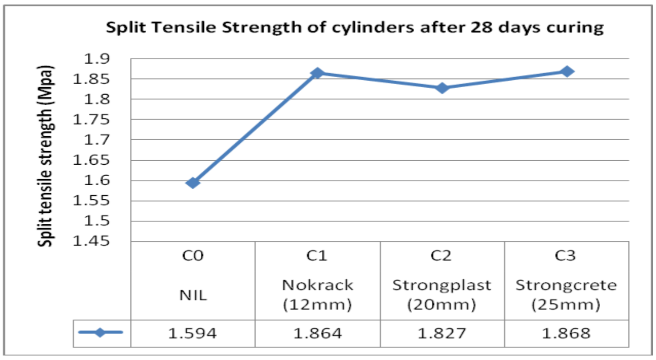

Fig. 6 Variation of Split Tensile Strength in NMSCC and FRSCC Cylinders after 28 days curing

The unit weight observed to be decreasing with increase in fiber length at constant dosage (1.8 kg per cum.) of three fibers. It is almost 2.96 % maximum decrement in weight than SCC without fibers. The failure of cylinders was in the form of several parallel cracks without crushing. It is calculated in MPa by $\tau_s = 2P/\pi DL$; where P is failure load in N, D is diameter of cylinder and L is length of cylinder in mm. The flexural strength increases due to addition of fibers. The figures above shows tensile strength goes on increasing with increase in length of fibers. But it is optimum at 20 mm medium length fibers.

Fig. 7. Cylinders and Beams during testing

F. Unit Weight and Flexural Strength Test: To test bending behaviour of both mixes, four beams of size 500x100x100 mm are casted. During test an effective span was adjusted to 300 mm and central point load applied under same DUTM as shown in Fig. 7 above. The observed failure loads were used in simplified flexural formula $\sigma_b = 1.5\ wL/bd^2$; where w is failure load in Newton, L, b and d are length, breadth and depth of test beam respectively in mm each. The following observations are noted as given in Fig. 5 below.

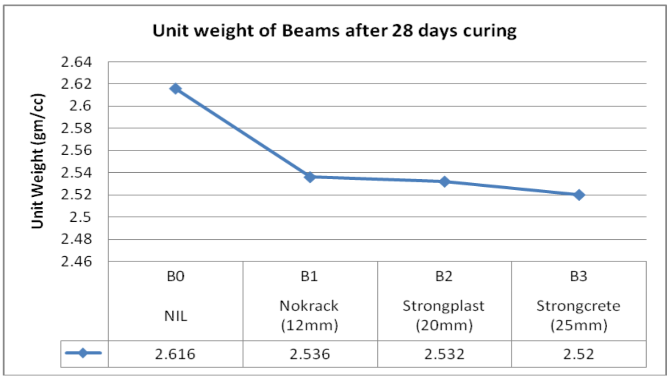

Fig. 5 Variation of Unit weight in NMSCC and FRSCC Beams after 28 days curing

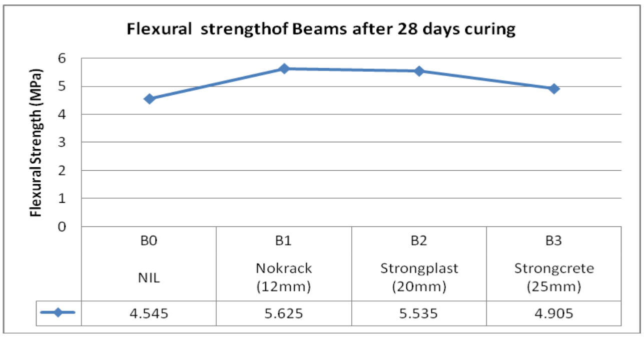

Fig. 6 Variation of Flexural Strength in NMSCC and FRSCC Beams after 28 days curing

Here also the unit weight of each beam found to be in decreasing order indicating lightness in concrete. From Fig. 6, it is clear that bending strength of FRSCC is more than at short fibers whereas is reduces at longest fibers. In short both tensile and flexural properties improved at optimum length propylene fibers.

G. Mortar Cube Test: A separate study was conducted to check the effectiveness of PP fibers in SCC mortar of proportion 1:3 for all 12 cubicles. The mortar cube moulds of 75 mm side was casted and tested after 28 days complete curing under DUTM. The effectiveness of Strongplast Fibers in SCC mortar was tested as supplier* recommended it for plastering. The observations are given in Table V.

TABLE V

AVG. UNIT WEIGHT AND AVG. COMPRESSIVE STRENGTH OF SCC MORTAR CUBES AFTER 28 DAYS CURING

Type of SCC	Fibers Content	Avg. Density (gm/cc)	Avg. Compressive Strength (MPa)
NMSCC	NIL	1.99	17.67
FRSCC 1	0.9 kg/m3	2.002	17.14
FRSCC 2	1.35 kg/m3	2.001	21.18
FRSCC 3	1.8 kg/m3	2.03	19.9

The Strongplast fiber inclusion gives almost increasing density with minor variation. But the compressive strength increased with more fibers in mortar mix. At moderate density, it found 18.49 % more at 1.35 kg/m^3 proportion than reference mortar mix. The advantage of this type of fibers give extra smooth finishing to surface of cubes.

V. CONCLUSIONS

SCC is a highly innovative concrete to be used widely in most part of the world. The effectiveness of varying range of fibers helps to modify fresh characteristics of SCC up to certain extent. But these fibers become a key tool to improve almost all strength characteristics in a better way.

A. General Remarks: Self Compacting Concrete is a highly innovative concrete to be used widely in most part of the world. The effectiveness of varying range of fibers helps to modify fresh characteristics of SCC up to certain extent. But these fibers become a key tool to improve all strength characteristics in a better way. During experimental work, some of the general observations are noted down, which we found more important. Such observations are enlisted as follows.

1. Fly ash helps to reduce cement requirement and improves workability.
2. Chemical admixture gives flowable concrete and increases segregation and bleeding if exceeds.
3. Fibers decreases workability but can be maintain using mineral and chemical admixtures
4. The fiber added concrete may not have smooth finish than nominal mixes.
5. Mixing of fibers in dry state gives uniform distribution and homogeneous mix.
6. The flowability of nominal mixture of SCC gets reduced. Therefore addition of fibers should be at optimum level to avoid more viscous flow.
7. The filling ability of SCC remains unaffected showing better segregation resistance at lesser length and proportion of fibers in it. Hence it is recommended to uses polypropylene fibers.
8. It is found that passing ability decreases proportionally with incremental fibers dosage. It may require partial surface vibration energy.
9. The compressive strength is achievable for short fibers. However longer fibers of lesser proportion may also help to achieve target strength at its earliest.
10. Fiber addition proved on its performance analysis in split tensile strength. No structural failure can occur in the form of crushing; but it takes certain tensional forces showing bulging. It will be more beneficial in strut and tie members as well.
11. Various ranges of synthetic fibers gives better flexural resistance showing its suitability in RCC, PC and PSC beams.
12. The use of fly ash in SCC is not only beneficial in reducing cement content but it helps to maintain workable concrete.
13. The increased dosage of chemical admixture i.e. SP found to get flowable concrete. But extra addition of SP leads to segregation and bleeding.
14. The special Strongplast® fibers give better smooth finish to surface under treatment. But it holds good compressive strength if cured properly.

B. Experimental Remarks: This experimental research forced to draw following concluder statements as an outcome.

1. The V-Funnel and V-Funnel at $T_{5\ Min}$ time for 12mm Nokrack fiber give 14.49 sec and 13.22 at 1.8Kg/m^3 and 0.9 Kg/m^3 content respectively; which was more than other types of fibers. It clearly indicates that short length of fiber gives better flow even with more fiber content. But FRSCC mix was less flowable than NMSCC.
2. The calculated blocking ratios for Nokrack and Strongplast fibers are about 0.806 and 0.8 at 0.9

Kg/m^3; which found to be in prescribed EFNARC limits. But it reduced when proportion is increased.

3. The Blocking ratios for longer length fiber i.e. Strongcrete are lesser even at all proportions. It indicates that SCC flow affects at more content of longer length fibers compared to NMSCC.
4. The unit weight i.e. density of cubes was decreased max. by 3.03% and 2.79% after 7 and 28 days respectively. One can say that density is inversely proportional to fiber content and fiber length.
5. For 7 days strength, in case of all fiber types, the compressive strength found slight improved. It was maximum by 10.30% using short length fibers only i.e. for NOKRACK® fibers. It was somewhat different experience for 28 days ultimate compressive strength. It increased only maximum 2.81% for shorter fibers.
6. Fiber addition proved the decrement by 1.93%, 2.63% and 2.95% in unit weight of cylinders proportionally with length of fibers.
7. The split tensile strength of FRSCC was improved by max. 14.66 % and min. by 14.61% as compared to NMSCC with increase in length of fibers.
8. The fibers have shown the reduction by min. 3.05% and max. 3.66% in unit weight of FRSCC beams compared to nominal mix SCC beams.
9. Various ranges of polypropylene fibers give better flexural resistance about 19.2% maximum and minimum of about 7.92%. It slightly increased at shorter length fibers and decreased with addition of longer length fibers.
10. At moderate density, it found 18.49 % more at 1.35 kg/m^3 proportion than reference mortar mix.
11. It is suggested to use polypropylene fibers at 1.35 kg/m^3 in Self Compacting Concrete. It is also recommended to use short fibrillated fibers to produce enhanced FRSCC. But mixing of fibers should be done in dry state only to get more homogeneous and workable concrete.

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