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Comparative Study on Shear Strength of Steel Fibre reinforced Self-Compacting and Normal Cement Concrete of Grades M30 and M60

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Abstract*— Today, self-compacting concrete (SCC) is the most popular form of concrete that is being delivered by ready-mix-plants (RMC) in India. The construction industry, at present, is using SCC for all major works. There are some areas of construction where normal cement concrete (NCC) is also being used. The main purpose of the present work is to have a comparative idea of the shear strength (using push-off specimen) of SCC and NCC of grade M30 (representative of normal strength concrete) and M60 (representative of high strength concrete). In the present work, the cube compressive strength and the shear strength (using push-off specimen) are determined for M30 and M60 grades of self-compacting concrete and 0.0, 0.5, 1.0 and 1.5 percentages of crimped steel fibres with an aspect ratio of 60. It is observed that the increase in 14 and 28 days compressive strength with fibre percentage is each maximum at 1% of steel fibres for SCC of M30 and M60 grades. The increase in 14 and 28 days shear strength with fibre percentage in the case of SCC of M30 and M60 grades is each observed to be maximum at 1% of steel fibres also. Existing literature reveals that the 14 and 28 days shear strengths increase monotonically as the fibre percentage increases up to 1.5% for both M30 and M60 grades of NCC. For SCC of M30 grade and a given percentage of steel fibres, the shear strength at 14 and 28 days is smaller than that of the corresponding NCC. For SCC of M60 grade and a given percentage of steel fibres, the shear strength at 14 days is greater than that of the corresponding NCC for fibre % up to 0.5. For SCC of M60 grade and a given percentage of steel fibres, the shear strength at 28 days is greater than that of the corresponding NCC for fibre % up to 1.0. Equations for the 28 days shear strength of self-compacting concrete of grades M30 and M60 as a function of fibre percentage have been developed.

Keywords: Self-compacting concrete (SCC), Normal cement concrete (NCC), Crimped type steel fibres, Compressive strength, Push-off specimen, Shear strength.

1.0 INTRODUCTION

Self-compacting concrete (SCC) was introduced in 1986 in Japan by Hajime Okamura. At present it is the most widely used form of concrete in civil engineering structures. Shear strength of concrete is defined as the ability of concrete to resist forces tangential to the internal planes which are subjected to shear forces or sliding. Many structural members in practice are subjected to shearing forces (direct and indirect). The shear strength of fibre-reinforced concrete in flexural members depends on grade of concrete, percentage of steel fibres and percentage of tension steel provided. In the present experimental work crimped steel fibres are used in the SCC. Shear strength of SCC is determined by using push-off specimen. The loading on the specimen consists of axial compressive forces (P) applied to the specimen as shown in Fig.1.

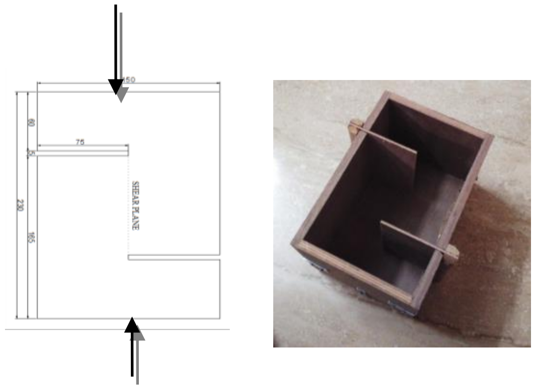

Fig.1: Push-off Specimen and Loading

Vast literature exists on fibre reinforced normal cement concrete as well as on self-compacting concrete and a very brief review is presented here. Dr.Muhaned A, Shallaland Sallal R, Alowaisy(2008)[1] studied the influence of steel fibres on shear transfer strength of concrete by performing push-off tests. Steel fibres were included along with stirrups crossing the shear plane. 0.0%, 0.5%, 1.0% of steel fibres were used. The results indicated that the use of 1.0% of steel fibres can replace part of stirrups without compromising on shear strength and ductility. J. Jayaprakash et al (2009)[2]conducted experimental investigation on shear capacity of reinforced concrete precracked push-off specimens with externally bonded bi-directional carbon fibre reinforced polymer fabrics. In this study the precracked reinforced concrete was externally bonded with carbon fibres. It was observed that the increase in strength varies from 7% to 56% over the unstrengthened reinforced concrete. Rahele Naserianet al (2011)[3]investigated the interaction of internal steel reinforcement and external fibre reinforced polymer (FRP) composites on the behaviour of shear transfer. 16 non-cracked push-off specimens were tested. It was observed that the effectiveness of FRP strips in unreinforced specimens is significant compared to steel reinforced ones. The shear transfer capacity in strengthened specimens increased from

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3% to 38% compared to plain specimens. Constantinescu Horia and Magureanu Cornmelia (2011)[4] have used the push-off tests to determine the influence of transverse reinforcement on the shear behaviour of high performance concrete with a compressive strength of 100MPa. It was noticed that the contribution of high performance concrete in resisting shear forces is significantly greater than what is currently being considered in structural design. K.C. Denesh (2014)[5]determined the workability and strength of self-compacting concrete of M30 and M40 grades. Crimped steel fibres having an aspect ratio of 80 were used. 0.25%, 0.5%, 0.75% and 1% steel fibres were used. It was found from the results that 1% of fibre gives maximum compressive strength. It was also observed that the flexural strength of concrete increases with the addition of steel fibres to self-compacting concrete. Javier Echegaray Oviedo et al (2015)[6] conducted upgraded PUSH-OFF tests to study the mechanism of shear transfer in FRC elements. Push-off test has been upgraded to control the pre-cracking and in the push-off stages. Harish Kumar N.R et al (2015)[7]evaluated in-plane shear strength of SCC using inclined plane push-off specimen. The shear plane inclination was varied (0^0, 11^0, 22^0, and 31^0). Both plain SCC and reinforced SCC specimens were tested at all the aforesaid inclinations. It was observed that the shear strength increased with the inclination both in plain and reinforced SCC.

The construction industry in India, at present, is using self-compacting concrete for all major works. There are some areas of construction where the normal conventional concrete is also being used. In the present work two grades of concrete have been selected viz., M30 (*representative of normal strength concrete*) and M60 (*representative of high strength concrete*). The compressive strength (using standard cube specimens) and the shear strength (using push-off specimens) are determined for M30 and M60 grades of SCC and 0.0, 0.5, 1.0 and 1.5 percentages of crimped steel fibres in the present work. Chandrashekaramurthy et al [8] have determined the compressive and shear strengths in a similar manner for normal cement concrete (NCC) of M30 and M60 grades. The main objective of this work is to get a comparative idea of compressive strength and shear strength (using push-off specimens) when NCC is replaced by SCC. A comparison is made between the results of the present work and the results obtained by Chandrashekaramurthy et al [8].

2.0 PRESENT EXPERIMENTAL WORK

2.1 Scope

- To study the variation of 14 and 28 days compressive strength and shear strength (using push-off specimen) of M30 and M60 grades of SCC as the percentage of steel fibres increases from 0.0 to 1.5 % in steps of 0.5%.
- To develop equations using regression analysis for the 28 days shear strength of M30 and M60 grades of SCC.
- To compare the results of the present work with that of Chandrashekaramurthy et al[8].

2.2 Materials used

The properties of the 53 grade ordinary Portland cement used in the present work as determined by conducting relevant tests in accordance with the Bureau of Indian Standards are given in Table 1.

Table 1: Properties of cement used

Sl. No.	Physical property	Value
1	Specific gravity	3.13
2	Fineness (%)	1.2
3	Standard consistency (%)	28
4	Initial setting time in minutes	40
5	Final setting time in minutes	193

Locally available river sand was used as fine aggregate in the present work. Tests were conducted in accordance with BIS on the river sand used in the present work and the results are furnished in Table 2. Specific gravity and fineness modulus were determined as per IS: 2386-1968[9] (Part I) and (Part II). The results of sieve analysis obtained are plotted in Fig.2. Clearly, the fine aggregate used in the present work conforms to Zone-II of IS: 383-1970[10].

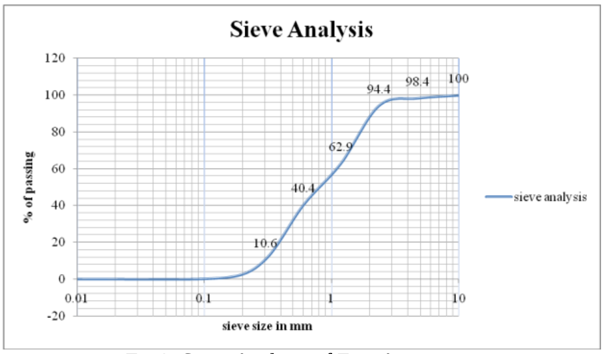

Fig.2: Sieve Analysis of Fine Aggregates

Table2: Properties of fine aggregate used

Sl. No.	Physical property	Value
1	Fineness modulus	3.95
2	Specific gravity	2.67
3	Bulk density (kg/m^3) (compacted)	1603.33
4	Bulk density (kg/m^3) loose	1473.32
5	Water absorption	2%

Locally available 20mm down size crushed stone aggregates were used in the present work. The properties determined by laboratory testing in accordance with IS: 2386-1968[9] are given in Table 3.

Table 3: Properties of coarse aggregate used

Sl No.	Property	Result
1	Fineness modulus	4.47
2	Specific gravity	2.79
3	Water absorption (%)	0.44
4	Bulk density (kg/m^3) Compacted	1631.65
5	Bulk density (kg/m^3) Loose	1425.50

Master Glenium SKY 8233 superplasticizer was used in the present work to improve the flow-ability of concrete. First, the aggregates and cement were mixed with water and later the superplasticizer was added. It is not advisable to add the superplasticizer to dry mix. The new generation Master Glenium is based on modified chains of polycarboxlic ether and it is primarily developed in concrete industry. Potable drinking water supplied by Bengaluru Water Supply and Sewerage Board is used and it meets all the requirements of IS: 3025[11]. The crimped steel fibres used are shown in Fig.3.

Fig.3: Crimped steel fibres

Its properties as furnished by the manufacturer are given in Table 4.

Table 4: Properties of crimped steel fibres

Sl. No.	Property	Value
1	Fibre type	Crimped type fiber
2	Length	30mm
3	Diameter	0.5mm
4	Density	7850 kg/m^3
5	Tensile strength	940MPa
6	Aspect ratio	60

2.3 Mix design

Nan Su method[12] is used for the mix design of M30 and M60 grades of SCC in the present work. The mix proportion arrived at for M30 grade of SCC is given in Table 5.

Table 5: Mix proportion for M30 grade of SCC

Cement	400 kg/m^3
Fine aggregate	891.35 kg/m^3
Coarse aggregate	705.625 kg/m^3
Water	168 kg/m^3

The mix proportion arrived at for M60 grade of SCC is given in Table 6.

Table 6: Mix proportion for M60 grade of SCC

cement	545.45 kg/m^3
fine aggregate	972.395 kg/m^3
coarse aggregate	769.97 kg/m^3
water	163.63 kg/m^3

To enhance the workability and make it self-compacting, superplasticizer, namely, Master Glennium is used in the present work. The dosages of superplasticizer used for M30 and M60 grades of concrete for various percentages of steel fibres are given in Table 7.

Table 7: Dosage of superplasticizer

% of fibre	M30	M60
0%	0.60%	0.80%
0.50%	0.60%	0.85%
1.00%	0.70%	1.00%
1.50%	0.85%	1.25%

2.4 Workability Tests for SCC

The results of the workability tests conducted on M30 and M60 grades of SCC are given in Tables 8 and 9 respectively. Perusal of these tables clearly reveals that the said M30 and M60 concretes have passed all the required tests for being considered as self-compacting.

Table 8: Properties of M30 self-compacting concrete

% of fibre	0	0.5	1	1.5
Slump Flow Test (mm)	690	660	670	650
T50cm Slump Flow (seconds)	3	4	4	4
V-Funnel Test (seconds)	10	10	9	9
V-Funnel at T_5 (seconds)	11	12	12	11
L-Box Test (h_2/h_1)	0.95	0.95	0.92	0.93

Table 9: Properties of M60 self-compacting concrete

% of fibre	0	0.5	1	1.5
Slump Flow Test (mm)	683	665	650	650
T_{50}cm Slump Flow (seconds)	3	4	4	4
V-Funnel Test (seconds)	9	8	9	9
V-Funnel at T_5 (seconds)	12	12	12	13
L-Box Test (h_2/h_1)	0.95	0.95	0.9	0.93

2.5 Methodology

Compressive and shear strength tests (using push-off specimens) were conducted at 14 days and 28 days of curing. Two identical specimens for each percentage of steel fibres and each concrete grade were cast and tested at 14 days. The average of the two values was adopted at 14 days. Three identical specimens for each percentage of steel fibres and each concrete grade were cast and tested at 28 days. The average of the three values was adopted at 28 days. The cubes and push-off shear strength specimens cast in the present investigation are shown in Fig.4. These specimens were cast following the standard procedure. In the case of push-off shear strength specimens the wooden piece provided in the groove was removed as shown in Fig.4.

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Fig.4: Cubes and push-off shear strength specimens

2000 kN compression testing machine was used for the experiments. 150 mm x 150 mm x 150 mm size cubes were used for determining the compressive strength. The cube test was conducted as per IS 516: 1959[13]. The compressive load was applied at a rate of 140 kg/cm^2/minute. The load at failure for each specimen was noted and the compressive strength computed as usual. The size of push-off shear strength specimen used was 230 mm x 150 mm x 150 mm. Two wooden planks each of size 160 x 160 x 25 mm were placed at top and bottom to ensure uniform distribution of load over the surface. The load was applied at a rate of 140 kg/cm^2/minute. The load at which the specimen fails for each specimen was noted. The shear strength of each specimen was computed using

$$\text{Shear strength} = \frac{ultimateload}{\text{shear area}}$$

where shear area = 150 mm x 100 mm

The failed push-off specimen is shown in Fig.5.

Fig.5: Failed push-off specimen

2.6 Compressive strength test results and discussion

2.6.1 Compressive strength of M30 grade SCC

The results of the compression tests conducted on SCC cubes made of M30 grade concrete at 14 and 28 days are presented in Table 10.

Table 10: Compressive strength results of SCC of M30 grade

% of steel fibres	Compressive Strength in N/mm^2		% Increase in Compressive Strength over that of the Control Specimen	
	14 days	28 days	14 days	28 days
0.0 (control specimen)	34.6	36.72	-	-
0.5	36.48	41.59	5.43	13.26
1.0	40.5	45.6	17.05	24.18
1.5	38.47	41.85	11.18	13.97

From Table 10, the following are observed:

- The strength developed at 14 days is more than 85% of the 28 day strength for all percentages of steel fibres.
- The percentage of increase in the compressive strength of fibre-reinforced SCC (both at 14 days and 28 days) over that of unreinforced SCC increases as the fibre percentage increases up to 1% and later decreases.
- The increase in 14 and 28 days compressive strength is maximum at 1% of steel fibres.

2.6.2 Compressive strength of M60 grade of SCC

The results of the compression tests conducted on SCC cubes made of M60 grade concrete at 14 and 28 days are presented in Table 11.

Table 11: Compressive strength results of SCC of grade M60

% of steel fibres	Compressive Strength in N/mm^2		% Change in Compressive Strength over that of the Control Specimen	
	14 days	28 days	14 days	28 days
0 .0 (control specimen)	57.26	64.63	-	-
0.5	59.48	67.4	3.88 (increase)	4.29 (increase)
1.0	59.8	69.4	4.44 (increase)	7.38 (increase)
1.5	42.6	55.36	25.60 (decrease)	14.34 (decrease)

From Table 11, the following are observed:

- The strength developed at 14 days is more than 85% of the 28 day strength for all percentages of steel fibres up to 1.0.
- The percentage of increase in the compressive strength of fibre-reinforced SCC (both at 14 days and 28 days) over that of unreinforced SCC increases as the fibre percentage increases up to 1% and later decreases.
- The increase in 14 and 28 days compressive strength is maximum at 1% of steel fibres.

2.7 Shear strength test (using push-off specimen) results and discussion

2.7.1 Shear strength of M30 grade of SCC

The results of the shear strength tests conducted using push-off specimens made of SCC M30 grade concrete at 14 and 28 days are presented in Table 12.

Table 12: Shear strength results of SCC of grade M30

% of steel fibres	Shear strength in N/mm^2		% Increase in shear strength over that of the control specimen	
	14 days	28 days	14 days	28 days
0.0 (control specimen)	5.24	6.47	0.00	0.00
0.5	7.12	8.173	35.88	26.32
1.0	7.82	8.38	49.24	29.52
1.5	6.863	7.102	30.97	9.77

From Table 12, the following are observed:

- The strength developed at 14 days is about 80 to 95 % of the 28 days strength.
- The percentage of increase in the shear strength of fibre-reinforced SCC (both at 14 days and 28 days) over that of unreinforced SCC increases as the fibre percentage increases up to 1% and later decreases.
- The increase in 14 and 28 days shear strength is maximum at 1% of steel fibres.

2.7.2 Shear strength of M60 grade of SCC

The results of the shear strength tests conducted using push-off specimens on SCC cubes made of M60 grade concrete at 14 and 28 days are presented in Table 13.

Table 13: Shear strength results of SCC of grade M60

% of steel fibres	Shear strength in N/mm^2		% Increase in shear strength over that of the control specimen	
	14 days	28 days	14 days	28 days
0.0 (control specimen)	6.49	6.98	0.00	0.00
0.5	6.76	7.95	4.16	13.90
1.0	7.19	9.75	10.79	39.68
1.5	7.14	8.28	10.02	18.62

From Table 13, the following are observed:

- The strength developed at 14 days is about 75 to 90 % of the 28 days strength.
- The percentage of increase in the shear strength of fibre-reinforced SCC (both at 14 days and 28 days) over that of unreinforced SCC increases as the fibre percentage increases up to 1% and later decreases.
- The increase in 14 and 28 days shear strength is maximum at 1% of steel fibres.

2.7.3 Change of 14 days shear strength of SCC with grade for different % of fibres

The changes in 14 days shear strength of SCC of grades M30 and M60 for different percentages fibers are given in Table 14.

Table 14: 14 days shear strength of M30 and M60 grade SCC for different % fibers

% of steel fibres	M30 (N/mm^2)	M60 (N/mm^2)	% of change in shear strength
0.00	5.24	6.49	19.26 (increase)
0.50	7.12	6.76	5.33 (decrease)
1.00	7.82	7.19	8.76 (decrease)
1.50	6.86	7.14	3.88 (increase)

From Table 14, it is noticed that the 14 days shear strength decreases as the grade of concrete changes from M30 to M60 for 0.5 and 1.0% of steel fibres, the decrease being not much. Beyond 1.0% there is an increase which is also insignificant. Thus we can say that the increase or decrease in the 14 days shear strength is negligible when the grade of concrete is changed from M30 to M60.

2.7.4 Change of 28 days shear strength of SCC with grade for different % of fibres

The changes in 28 days shear strength of SCC of grades M30 and M60 for different percentages of fibers are given in Table 15.

Table 15: 28 days of shear strength of M30 and M60 grades of SCC for different % of fibers

% of steel fibres	M30 (N/mm^2)	M60 (N/mm^2)	% of change in shear strength
0.00	6.47	6.98	7.31 (increase)
0.50	8.173	7.95	2.81 (decrease)
1.00	8.38	9.75	14.05 (increase)
1.50	7.102	8.28	14.23 (increase)

From Table 15, we can conclude that the increase or decrease in the 28 days shear strength is not very significant when the grade of concrete is changed from M30 to M60.

2.8 Equations for 28 days shear strength of SCC of grades M30 and M60

Equations for the 28 days shear strength of self-compacting concrete of grades M30 and M60 have been developed at by fitting the best quadratic curve to the points obtained in this experimental work. They are given in Table 16:

Table 16: Equations for the 28 days shear strength (using push-off specimen)

Grade of SCC	Equation for 28 days shear strength
M30	$\tau = -2.981\ p^2 + 4.8921\ p + 6.4705$
M60	$\tau = -2.44\ p^2 + 4.8\ p + 6.775$

Where τ = shear strength at 28 days in MPa and
p = percentage of crimped steel fibres

3.0 COMPARISON OF TEST RESULTS ON SCC AND NCC OF GRADES M30 AND M60

3.1 General

Chandrashekaramurthy et al have carried out similar experimental studies on NCC (normal cement concrete) of grades M30 (*representative of normal strength concrete*) and M60 (*representative of high strength concrete*). A comparison is made between the results of Chandrashekaramurthy et al and that of the present work.

3.2 Compressive strength of NCC & SCC of M30 and M60 grades

3.2.1 14 days compressive strength of NCC and SCC of M30 grade

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The 14 days compressive strength of NCC and SCC of M30 grade for different percentages of fibres are given in Table 17.

Table 17: 14 days compressive strength of M30 grades of SCC and NCC (MPa)

(%) of steel Fibres	For M30 SCC	For M30 NCC	% difference in 14 days compressive strength
0.0	34.6	33.37	3.55 (decrease)
0.5	36.48	34.87	4.41 (decrease)
1.0	40.50	35.25	12.96 (decrease)
1.5	38.47	33.26	13.54 (decrease)

From Table 17, the following are observed:

- For the same fibre percentage, the compressive strength at 14 days of SCC is greater than that of NCC, the magnitude depending upon on the fibre percentage.
- The 14 days compressive strength of SCC and NCC increases as the fibre percentage increases up to 1.0% and later decreases.

3.2.2 14 days compressive strength of NCC and SCC of M60 grade

The 14 days compressive strength of NCC and SCC of M60 grade for different percentages of fibres are given in Table 18.

Table 18: 14 days compressive strength of M60 grades of SCC and NCC (MPa)

% of steel fibres	For M60 SCC	For M60 NCC	% difference in 14 days compressive strength
0.0	57.26	60.22	5.17 (increase)
0.5	59.48	60.78	2.19 (increase)
1.0	59.8	60.78	1.64 (increase)
1.5	42.6	49.32	15.77 (increase)

From Table 18, the following are observed:

- For the same fibre percentage, the compressive strength at 14 days of SCC is smaller than that of NCC, the magnitude depending upon on the fibre percentage.
- The 14 days compressive strength of SCC and NCC increases as the fibre percentage increases up to 1.0% and later decreases.

3.2.3 28 days compressive strength of NCC and SCC of M30 grade

The 28 days compressive strength of NCC and SCC of M30 grade for different percentages of fibres are given in Table 19.

Table 19: 28 days compressive strength of M30 grades of SCC and NCC (MPa)

% of steel fibres	For M30 SCC	For M30 NCC	% difference in 28 days compressive strength
0.0	36.72	35.25	4.00 (decrease)
0.5	41.59	38.10	8.39 (decrease)
1.0	45.60	38.78	14.96 (decrease)
1.5	41.85	34.00	18.76 (decrease)

From Table 19, the following are observed:

- For the same grade of concrete and fibre percentage, the compressive strength at 28days of SCC is greater than that of NCC, the magnitude depending upon on the fibre percentage.
- The 28 days compressive strength of SCC and NCC increases as the fibre percentage increases up to 1.0% and later decreases.

3.2.4 28 days compressive strength of NCC and SCC of M60 grade

The 28 days compressive strength of NCC and SCC of M60 grade for different percentages of fibres are given in Table 20.

Table 20: 28 days compressive strength of M60 grades of SCC and NCC (MPa)

% of steel fibres	For M60 SCC	For M60 NCC	% difference in 28 days compressive strength
0.0	64.63	67.12	3.85(increase)
0.5	67.4	68.40	1.48(increase)
1.0	69.4	68.20	1.73(decrease)
1.5	55.36	50.85	8.15(decrease)

From Table 20, the following are observed:

- For the same fibre percentage, the compressive strength at 28 days of SCC is smaller than that of NCC up to 0.5% fibre percentage.
- The 28 days compressive strength of SCC increases as the fibre percentage increases up to 1.0% and later decreases.
- The 28 days compressive strength of NCC increases as the fibre percentage increases up to 0.5% and later decreases.

3.3 Shear strength of NCC & SCC of M30 and M60 grades

3.3.1 14 days shear strength of NCC and SCC of M30 grade

The 14 days shear strength of NCC and SCC of M30 grade for different percentages of fibres are given in Table 21.

Table 21: 14 days shear strength of M30 grades of SCC and NCC (MPa)

% of steel fibres	For M30 SCC	For M30 NCC	% difference in 14 days shear strength
0.0	5.24	7.66	31.59 (increase)
0.5	7.12	7.83	9.07 (increase)
1.0	7.82	9.17	14.72 (increase)
1.5	6.86	10.67	35.68 (increase)

From Table 21, the following are observed:

- For the same fibre percentage, the shear strength at 14 days of SCC is smaller than that of NCC, the magnitude depending upon on the fibre percentage.
- The 14 days shear strength of SCC increases as the fibre percentage increases up to 1.0% and later decreases.
- The 14 days shear strength of NCC increases monotonically as the fibre percentage increases.

3.3.2 14 days shear strength of NCC and SCC of M60 grade

The 14 days shear strength of NCC and SCC of M60 grade for different percentages of fibres are given in Table 22.

Table 22: 14 days shear strength of M60 grade NCC & SCC (MPa)

% of steel fibres	For M60 SCC	For M60 NCC	% difference 14 days shear strength
0.00	6.49	3.33	94.89 (decrease)
0.50	6.76	6.00	12.67 (decrease)
1.00	7.19	8.50	15.41 (increase)
1.50	7.14	9.33	23.47 (increase)

From Table 22, the following are observed:

- For the same fibre percentage, the shear strength at 14 days of M60 grade SCC is greater than that of NCC, upto0.5%.
- The 14 days shear strength of SCC increases as the fibre percentage increases up to 1.0% and later decreases.
- The 14 days shear strength of NCC increases monotonically as the fibre percentage increases.

3.3.3 28 days shear strength of NCC and SCC of M30 grade

The 28 days shear strength of NCC and SCC of M30 grade for different percentages of fibres are given in Table 23.

Table 23:28 days shear strength of M30 grade NCC & SCC (MPa)

(%) of steel Fibres	For M30 SCC	For M30 NCC	% difference in 28 days shear strength
0.00	6.47	8.17	20.81 (increase)
0.50	8.17	9.33	12.40 (increase)
1.00	8.38	10	16.20 (increase)
1.50	7.10	11.17	36.42 (increase)

From Table 23, the following are observed:

- For the fibre percentage, the shear strength at 28 days of SCC is smaller than that of NCC, the magnitude depending upon on the fibre percentage.
- The 28 days shear strength of SCC increases as the fibre percentage increases up to 1.0% and later decreases.
- The 28 days shear strength of NCC increases monotonically as the fibre percentage increases.

3.3.4 28 days shear strength of NCC and SCC of M60 grade

The 28 days shear strength of NCC and SCC of M60 grade for different percentages of fibres are given in Table 24.

Table 24: 28 days shear strength of M60 grade NCC &SCC (MPa)

Fibre (%)	For M60 SCC	For M60 NCC	% difference in 28 days shear strength
0.00	6.98	5.50	26.91 (decrease)
0.50	7.95	6.50	22.31 (decrease)
1.00	9.75	8.50	14.71 (decrease)
1.50	8.28	10.33	19.85 (increase)

From Table 24, the following are observed:

- For the same fibre percentage, the shear strength at 28 days of M60 grade SCC is greater than that of NCC up to 1.0%, the magnitude depending upon on the fibre percentage.
- The 28 days shear strength of SCC increases as the fibre percentage increases up to 1.0% and later decreases.
- The 28 days shear strength of NCC increases monotonically as the fibre percentage increases.

4.0 CONCLUSIONS

The following are the important conclusions made from the present work.

(a) *Compressive strength of SCC*
The 14 days compressive strength of SCC of M30 and M60 grades is, in general, greater than 85% of the 28 days strength. In the case of SCC of M30 and M60 grades, the increase in 28 days compressive strength with fibre percentage is maximum at 1% of steel fibres.

(b) *Shear strength of SCC*
The 14 days shear strength of SCC of M30 and M60 grades is, in general, greater than about 80% of the 28 days strength. In the case of SCC of grades M30 and M60, the increase in 28 days shear strength is maximum at 1% of steel fibres.

(c) *Change in shear strength with increase in the grade of SCC*
As the grade of SCC changes from M30 to M60, the change in the 14 days and 28 days shear strengths is small.

(d) *Comparison of SCC with NCC*

(i) *In respect of compressive strength*
For M30 grade and a given fibre percentage, the compressive strength at 14 and 28 days of SCC is

greater than that of NCC, the magnitude depending upon on the fibre percentage. For M60 grade and a given fibre percentage, the compressive strength at 14 days of SCC is smaller than that of NCC, the magnitude depending upon on the fibre percentage. For M60 grade, the compressive strength at 28 days of SCC is smaller than that of NCC up to 0.5% of steel fibres.

(ii) In respect of shear strength

In case of SCC of M30 grade and a given fibre percentage, the shear strength at 14 and 28 days is smaller than that of NCC, the magnitude depending upon on the fibre percentage. In case of SCC of M60 grade, the shear strength at 14 days is greater than that of NCC, fibre percentage up to 0.5%. In case of SCC of M60 grade, the shear strength at 28days is greater than that of NCC, fibre percentage up to 1.0%. In case of SCC of M30 and M60 grades, the 14 and 28 days shear strengths are maximum at 1% of steel fibres. In case of NCC of M30 and M60 grades, the 14 and 28 days shear strengths increase monotonically as the fibre percentage increases.

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