Steel Fiber Reinforced Shotcrete (SFRS) As Primary Lining In (NATM) Tunneling Method

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ABSTRACT

High strength of steel fiber reinforced shotcrete (SFRS) has been studied in this research project. Hooked-end type of steel fiber has been used with different grades of concrete viz. M25, M30, M40 for the research work. The experimental program includes concrete cubes of above mentioned grades along with cylindrical specimens. From each grade of concrete six specimen cubes are casted on site, three cubes from each grade of concrete consume Steel Fiber as per the specifications, while the other three from each grade of concrete did not have any reinforcement. In addition to the cube specimens, cylindrical specimens were also made from each grade of concrete to determine their toughness and it has been observed SFRS is best to be used in tunnels as primary lining in place of wire mesh reinforced shotcrete.

KEYWORDS: SFRS (Steel Fiber Reinforced Shotcrete. NATM (New Austrian Tunneling Method).

INTRODUCTION

SFRS has been used extensively in construction of industrial floors, bridge deck overlays, airport runways, highway pavements, tunnel linings, spillways, dams, slope stabilizations, and many precast products. An example of recent use of steel fiber in the Construction of Four-Lane Road Tunnel Project at Qazigund (J&K). Steel fibers can improve the characteristics of hardened concrete and can have significant effects on the fresh concrete. Steel fibers significantly reduce the slump of the fresh concrete resulting in an increase in the adhesion and cohesion of the concrete. Steel fibers also reduce the plastic shrinkage cracks. Steel fibers can increase concrete durability against fire, freezing, and chemical attacks. Due to its benefits, Steel fiber reinforced Shotcrete (SFRS) is used in pile foundations, piers, highways, industrial floors, bridge decking and Tunnel Linings.

AIM AND OBJECTIVES

RESEARCH AIM

The Principal aim of this research is to show how SFRS proves to be strong enough as primary lining in tunnels in comparison to wire mesh reinforced Shot Crete.

RESEARCH OBJECTIVES

The main objectives of this research is to investigate the following questions for high concrete strength.

(1) To evaluate the effectiveness of steel fibers on the shear strength of concrete.

(2) To investigate the use of steel fiber reinforced shotcrete as primary lining in tunnels especially in NATM type of tunneling .

(3) To determine how steel fiber reinforced shotcrete with in the proper specifications and the proper mix design make it enough strong to resist the heavy load of the tunnels and how it integrates the rock strata into load bearing ring in comparison of Plain shotcrete and epically its comes more economical than that of plain shotcrete.

The main aim of this paper is to explain how Steel Fiber Reinforced shotcrete has been Used in 4-Lane Road Tunnel Project (Qazigund To Banihal In Jammu & Kashmir) as primary lining & ground strengthening Material and how it proved to be economical than using wire-mesh reinforcement.

MIX DESIGN OF CONCRETE GRADES USED FOR RESEARCH PURPOSE

TABLE 1: Mix design of M25 grade of shotcrete.

Grade Of Shot Crete M25	
Cement	320 Kg/m^3
Water	160 Kg/m^3
Fine Aggregate (crusher dust)	810.64 Kg/m^3
Coarse Aggregate (10mm)	1162.18 Kg/m^3
Chemical Admixture	6.86 Kg/m^3
Water Cement Ratio	0.45
Steel Fiber	45 Kg/m^3

TABLE 2: Mix design of M30 grade of shotcrete.

Grade Of Shot Crete M30	
Cement	360 Kg/m^3
Water	160 Kg/m^3
Fine Aggregate (crusher dust)	792.98 Kg/m^3
Coarse Aggregate (10mm)	1136.88 Kg/m^3
Chemical Admixture	7.82 Kg/m^3
Water Cement Ratio	0.45
Steel Fiber	45 Kg/m^3

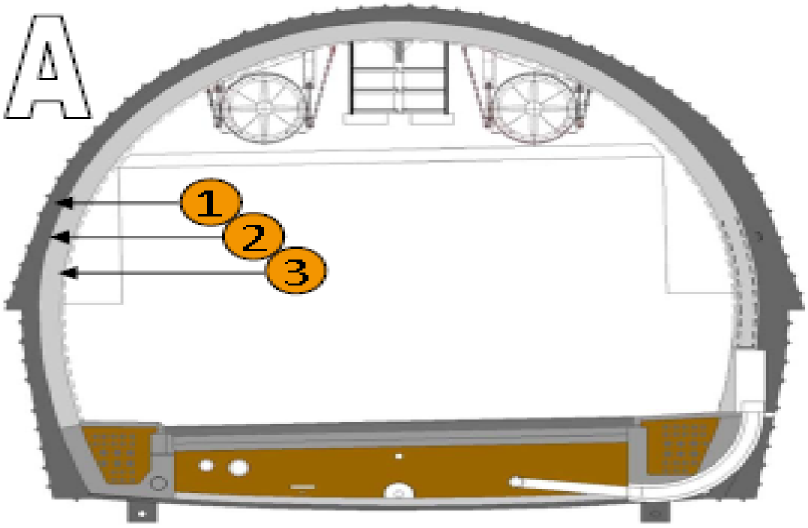
TABLE 3: Mix design of M40 grade of shotcrete.

Grade Of Shot Crete M40	
Cement	438 Kg/m^3
Water	162 Kg/m^3
Fine Aggregate (crusher dust)	727.02 Kg/m^3
Coarse Aggregate (10mm)	1132.92 Kg/m^3
Chemical Admixture	8.42 Kg/m^3
Water Cement Ratio	0.46
Steel Fiber	45 Kg/m^3

CONSTRUCTION METHODOLOGY

All tunnel construction will be carried out in accordance with the principles of the New Austrian Tunneling Method (NATM). The method is based on the concept of a cyclic sequence of excavation with subsequent installation of a primary support (outer lining) followed by the delayed installation of a secondary lining (inner lining)

Fig. 1: Cross section showing different layers of NATM tunnel



The primary support, which consists of shotcrete, generally reinforced shotcrete, lattice girders (where required) and rock bolts, will provide the immediate support and stability of the excavation. The inner lining, which is made with cast-in place concrete, will provide the long-term support and durability of the tunnel.

Tunnel excavation will generally be carried out by means of drilling & blasting with drilling jumbo's or by tunnel excavator. The rock support system for the drill and blast and sections will vary from place to place, depending on rock mass quality.
A subdivision of the tunnel cross-section into top heading and bench will be required. In tunnel sections of unfavorable geotechnical conditions, an invert arch will be installed. Based on the geological-geotechnical model, a rock mass classification and the prediction of rock classes along the tunnel sections have been developed. Specific standard support classes and their respective stabilization measures are designed to cope with all expected conditions.

Different excavation sequences, types and quantities of primary support elements are considered for each support class. The assignment of a tunnel section to a specific support class will be made based on the actual geotechnical conditions encountered during construction. The adjustment and refinement of the primary support, as well as its applicability for different ground conditions identified by regular face mapping, will be carried out with basis on the evaluation of the results of the geotechnical monitoring, which constitutes an essential element of the proposed construction method. Monitoring is carried out at instrumentation sections installed at regular and specific spacing along the tunnel.

TABLE 4: Table shows shotcrete thickness for different rock classes.

Ground Condition [3]	Designed Shotcrete Thickness
Very good rock mass	5 cm
Good rock mass	10 cm
Fair rock mass	15 cm
Poor/ Weak rock mass	20 cm
Very poor rock mass	25 cm
Fault Zones	30 cm

RESULTS OF THE RESEARCH PROGRAM

Tests on fresh shotcrete:

Mixing of ingredients of shotcrete is done for the designed mix proportion M30 and M40 grade of concrete mixes by adding Steel Fibre by weight in terms of Kilograms i.e. 45kg/m^3. Slump cone test for measuring the workability of fresh shotcrete mix. The workability tests are carried out as per IS: 1199-1959, the results of slump are shown below in tables.

Results of slump test values on site for four transit mixers

TABLE 5: Table shows the slump value of M30 grade of shotcrete.

S.No	Grade Of Concrete	Steel Fiber Content (Kg/m^3)	Slump (mm)
1	M30	45	110
2		45	122
3		45	135
4		45	146

TABLE 6: Table shows the slump value of M40 grade of shotcrete.

S.No	Grade Of Concrete	Steel Fiber Content (Kg/m^3)	Slump (mm)
1	M40	45	120
2		45	132
3		45	140
4		45	136

Cube compressive strength:

One of the important properties of concrete is its strength in compression. The strength in compression has a definite relationship with all the other properties of concrete i.e. these properties are improved with the improvement in compressive strength. The size of the mould is 150x150x150 mm. shotcrete cubes are tested for 7, 14 and 28 days strength as per IS: 516-1959 (Part 5) for testing of shotcrete cubes. Rate of application of compressive load is 1.40 KN/Cm^2/Min and is tested in a compression testing machine.

Fig. 2: Compression testing machine

TABLE 7: Compressive Strength OF M25 Concrete Cubes without Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M25	7 Days	480	21.33	21.48
M25	7 Days	500	22.22	
M25	7 Days	470	20.89	

TABLE 8: Compressive Strength OF M25 Concrete Cubes with Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M25	7 Days	730	32.44	32.89
M25	7 Days	750	33.33	
M25	7 Days	740	32.89	

Fig. 3: Bar Chart showing the difference of strength with and without steel fiber for 7 days of M25 grade of concrete:

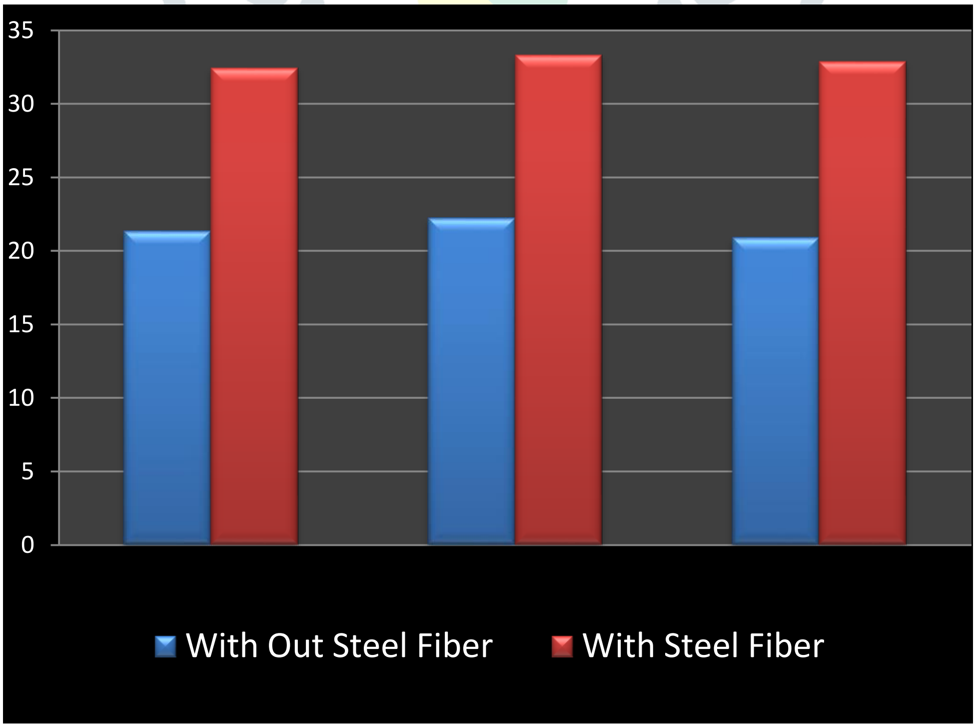


TABLE 9: Compressive Strength OF M25 Concrete Cubes without Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M25	28 Days	680	30.22	
M25	28 Days	700	31.11	
M25	28 Days	720	32.00	31.11

TABLE 10: Compressive Strength OF M25 Concrete Cubes with Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M25	28 Days	950	42.22	
M25	28 Days	960	42.67	
M25	28 Days	940	41.78	42.22

Fig 4: Bar Chart showing the difference of strength with and without steel fiber for 28 days for M25 grade of concrete:

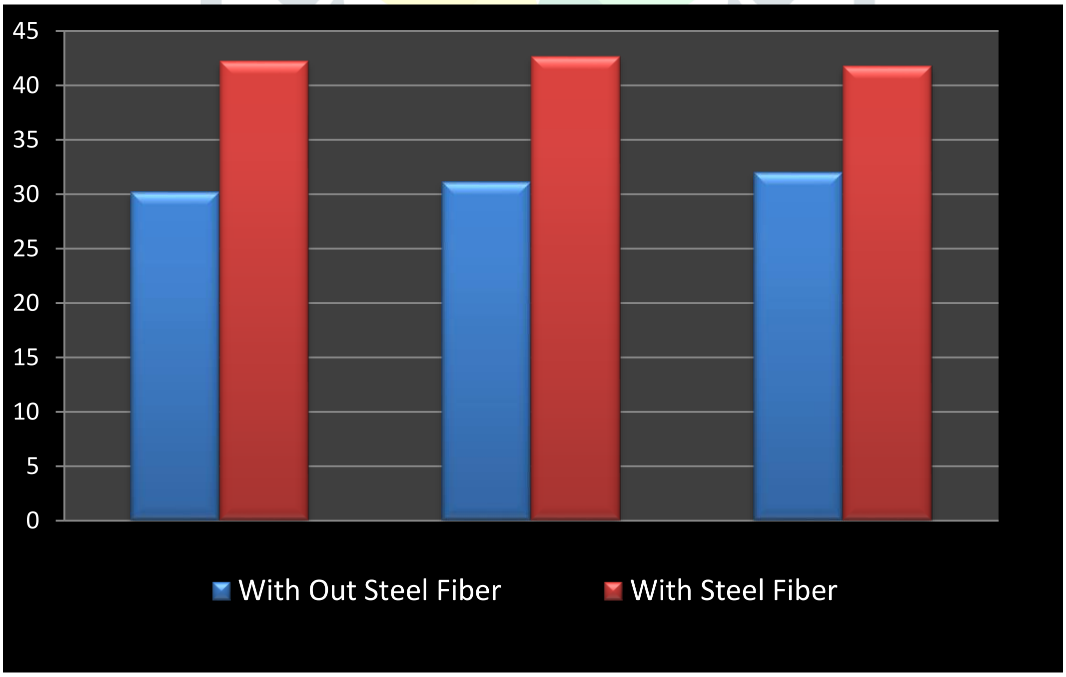


TABLE 11: Compressive Strength OF M30 Concrete Cubes without Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M30	7 Days	600	26.66	26.66
M30	7 Days	610	27.11	
M30	7 Days	590	26.22	

TABLE 12: Compressive Strength OF M30 Concrete Cubes with Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M30	7 Days	810	36.00	35.55
M30	7 Days	790	35.11	
M30	7 Days	800	35.55	

Fig 6: Bar Chart showing the difference of strength with and without steel fiber for 7 days of M30 grade of concrete:

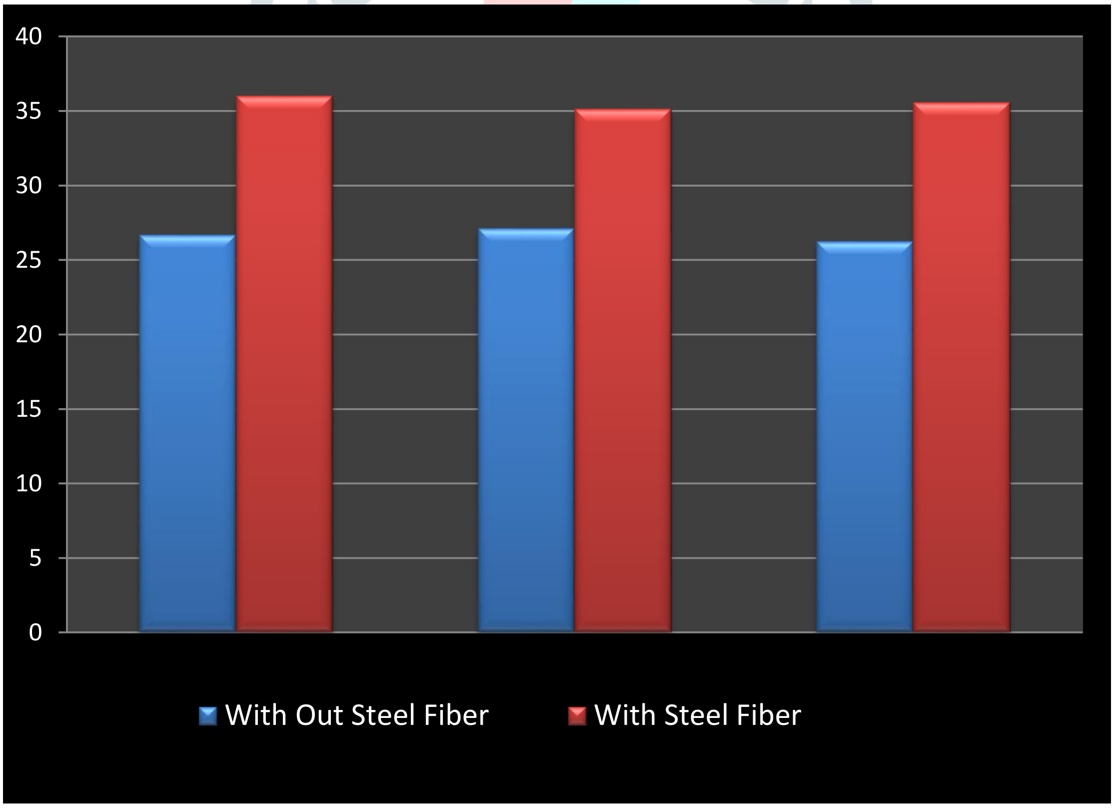


TABLE 13: Compressive Strength OF M30 Concrete Cubes without Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M30	28 Days	810	36	36.74
M30	28 Days	840	37.33	
M30	28 Days	830	36.89	

TABLE 14: Compressive Strength OF M30 Concrete Cubes with Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M30	28 Days	1005	44.66	45.26
M30	28 Days	1020	45.33	
M30	28 Days	1030	45.78	

Fig 7: Bar Chart showing the difference of strength with and without steel fibre for 28 days of M30 grade of concrete:

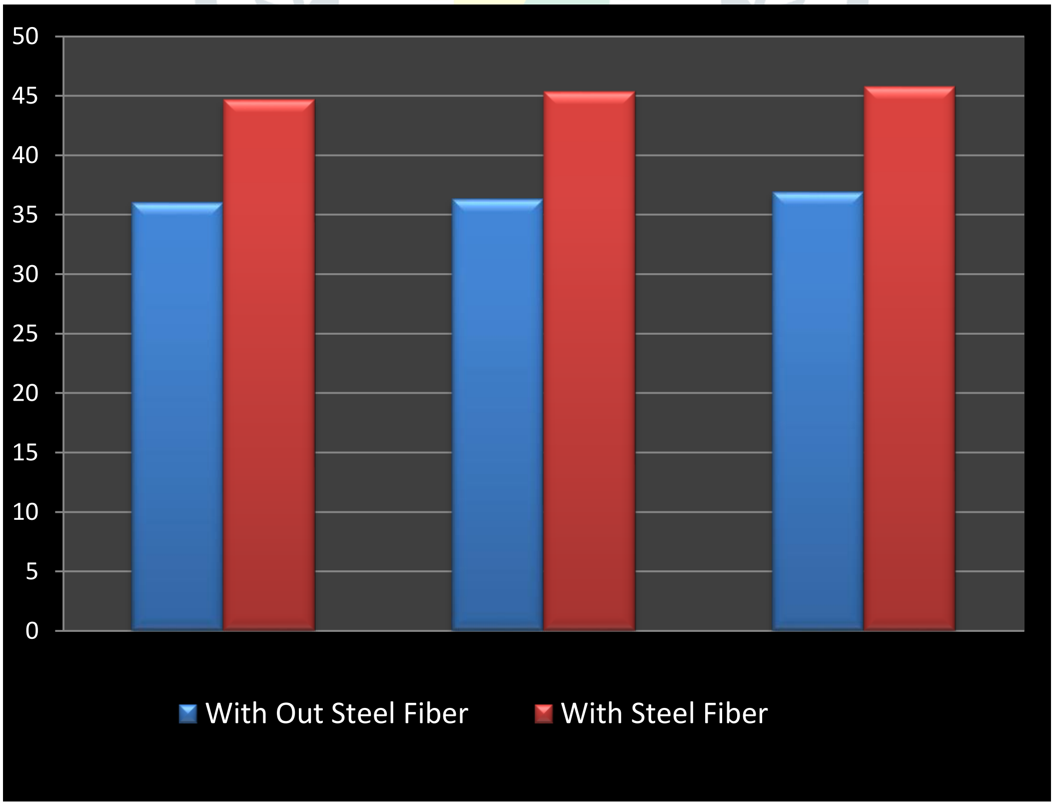


TABLE 15: Compressive Strength OF M40 Concrete Cubes without Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M40	7 Days	630	28.00	28.89
M40	7 Days	670	29.78	
M40	7 Days	650	28.89	

TABLE 16: Compressive Strength Of M40 Concrete Cubes with Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M40	7 Days	810	36.00	36.44
M40		830	36.89	
M40	7 Days	820	36.44	

Fig 8: Bar Chart showing the difference of strength with and without steel fiber for 07 days of M40 grade of concrete:

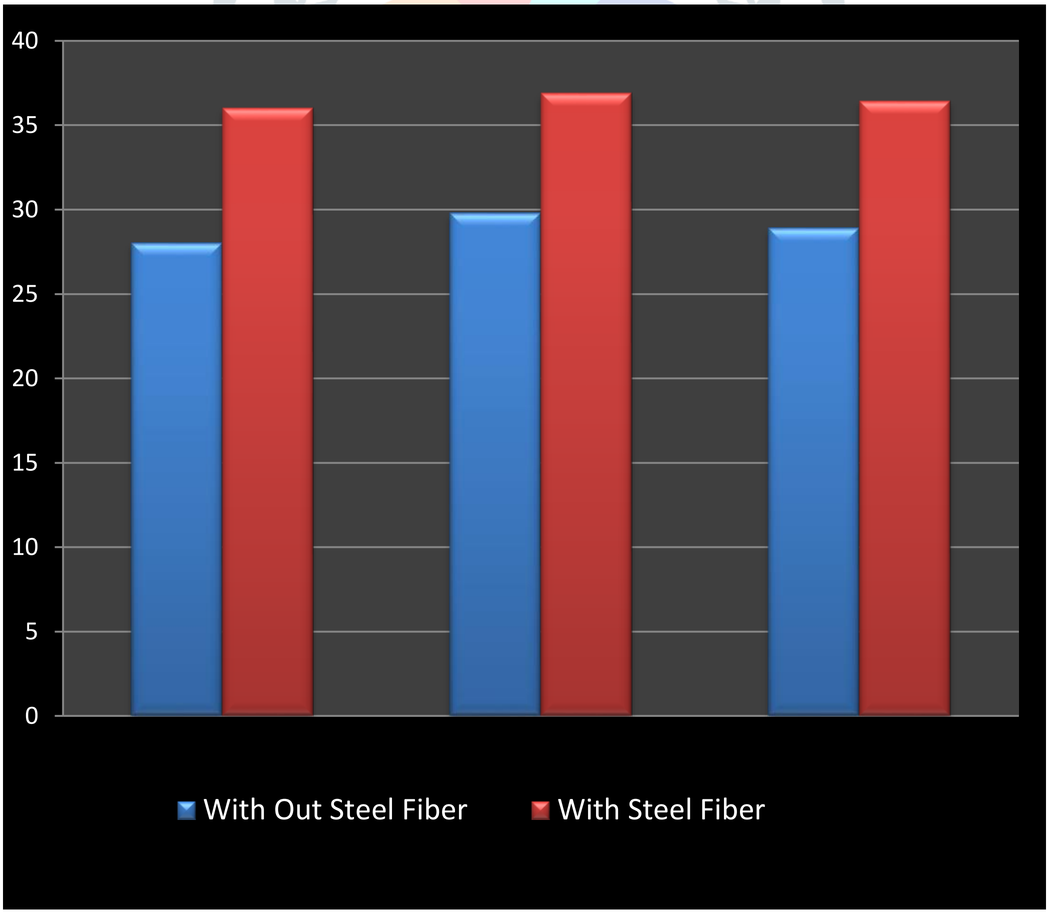


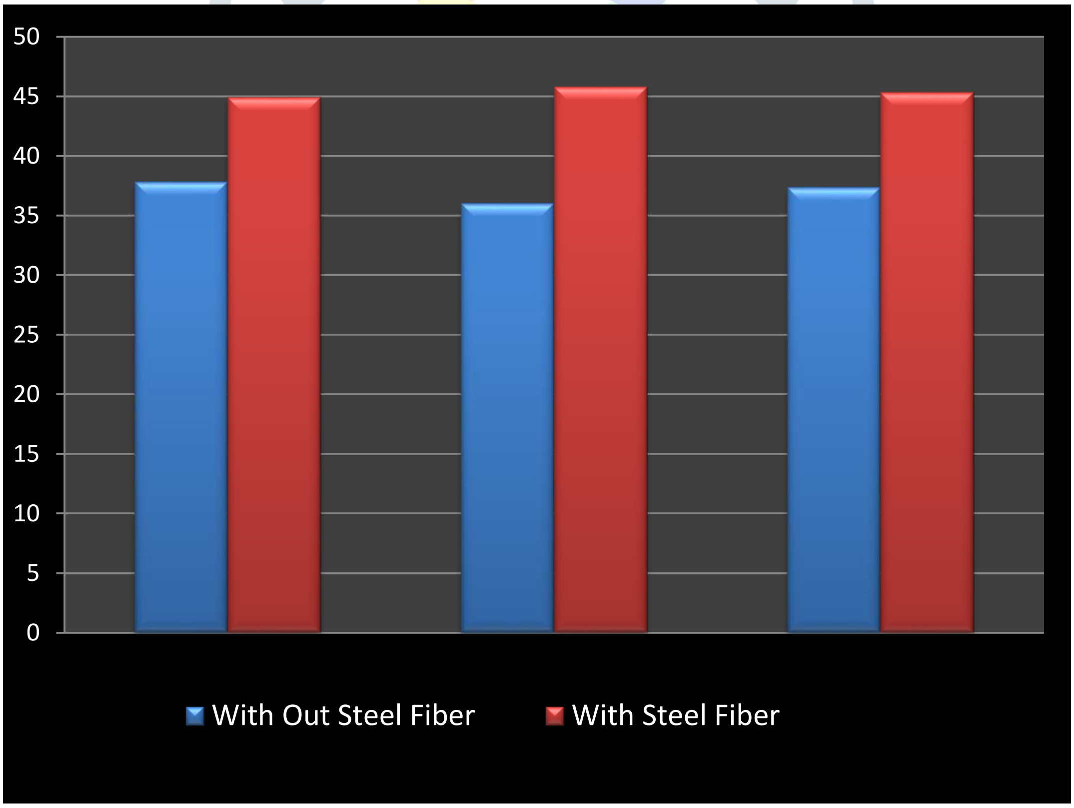
TABLE 17: Compressive Strength OF M40 Concrete Cubes without Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M40	14 Days	850	37.78	37.04
M40	14 Days	810	36.00	
M40	14 Days	840	37.33	

TABLE 18: Compressive Strength OF M40 Concrete Cubes with Steel Fiber:

Grade OF Concrete	Age In Days	Crushing Load(KN)	Strength (N/mm^2)	Avg. Compressive Strength (N/mm^2)
M40	14 Days	1010	44.89	45.33
M40	14 Days	1030	45.78	
M40	14 Days	1020	45.33	

Fig 9: Bar Chart showing the difference of strength with and without steel fiber for 14 days of M40 grade of concrete:



Flexural test:

Flexural strength test was carried out using beam of Steel Fiber Reinforced shotcrete with dimensions of 600mm×150mm ×150mm with three-point loading method at 28 days of curing. The specimens were subjected to bending tests with a concentrated load at the centerline in order to verify their behavior. The bending tests were performed by UTM machine and the results are shown in table below.

Fig 10: UTM machine

TABLE 19: Results obtained from flexural test of SFRS beam.

Description	Symbol	1	2	3
Length Of Beam (mm)	L	600		
Breadth Of Beam (mm)	B	150		
Depth Of Beam (mm)	D	150		
Load (KN)	P	37.50	36	37
Flexural Strength =PL/BD^2 (N/mm^2)	fcr	6.67	6.40	6.58
Average Flexural Strength (N/mm^2)	fcr	6.55		

Shotcrete core test:

Cylindrical Cores are drilled out from the tunnel and the tests conducted on them for different time periods in days like 2, 7, 14, 28 days. The ends of drilled cores are sulphur coated to make the surfaces even for testing.

This test is Conducted for two main reasons one is to determine the shotcrete thickness as per the specifications of particular rock class and another reason is to determine the strength attained by shot Crete under prevailing site conditions . The results obtained from testing are shown in table below.

TABLE 20: Results obtained from core test of SFRS.

Age In Days	Length Of Core (mm)	Diameter Of Core (mm)	Load (KN)	Core Strength (Mpa)	Avg. Core Strength (Mpa)
2	111.35	99.74	88	11.26	11.15
	110.57	99.44	82	10.56	
	122.56	99.87	91	11.62	
7	111.52	99.68	142	18.19	17.91
	110.90	99.87	131	16.72	
	111.54	99.39	146	18.82	
14	111.67	99.98	168	21.40	22.21
	113.52	99.68	178	22.81	
	110.87	99.99	176	22.41	
28	111.69	99.97	248	31.59	31.91
	110.09	99.52	258	33.16	
	112.51	99.74	242	30.97	

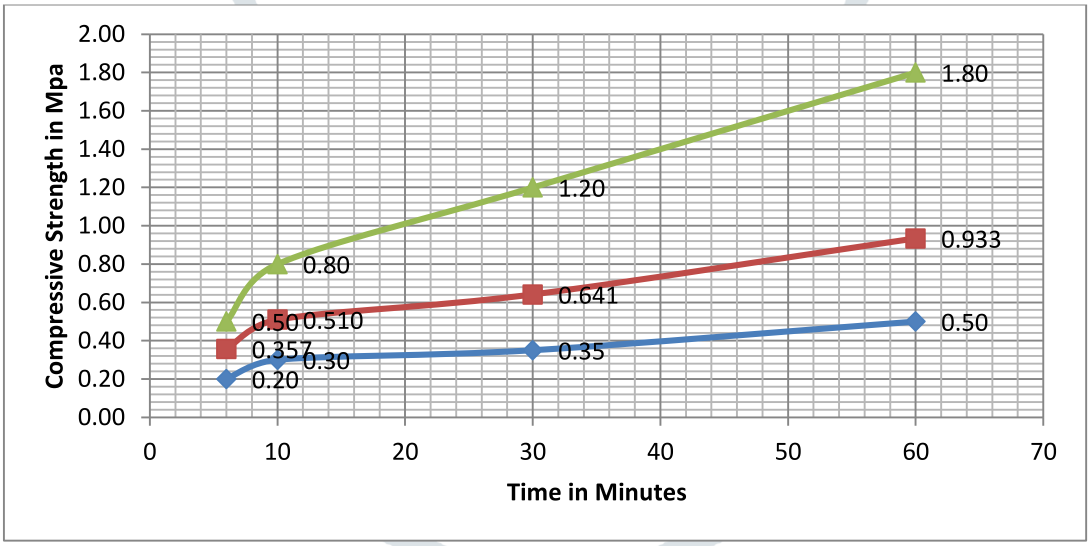
Strength measurement of shotcrete by using needle penetration method:

Results from this method are calculated from the force which is required to penetrate 15 mm of the specimen's surface using a 3 mm needle. The tip of the needle has an angle of 60°. Using this method one can manually determine the strength up to approx. 1.5 MPa.

TABLE 21: Results obtained from needle penetration test of SFRS.

Time in Minutes	Penetrations Force(PN) Reading			Avg. Value	Compressive Strength in (Mpa)		
	1	2	3		Lower Limit	Results	Upper Limit
6	17	22	27	22.00	0.20	0.357	0.50
10	27	32	32	30.33	0.30	0.510	0.80
30	42	37	37	38.67	0.35	0.641	1.20
60	57	62	67	62.00	0.50	0.933	1.80

Fig 11: Graphical representation of above results.



Conclusions:

After conducting all the mentioned tests and different field experiments on SFRS following conclusions can be made:

1) Steel Fiber Reinforced Shotcrete (SFRS) is best to be used as primary lining in tunnels in comparison of Mesh reinforced shotcrete as its compressive strength, tensile strength, crack pattern, flexural strength, and the flexural toughness is more than mesh reinforced shotcrete.
2) It takes less time to finish a layer of SFRS as compared to mesh reinforced shotcrete, hence decreases the usual cycle time in tunnel execution so makes it economical.
3) During spraying of SFRS there is less rebounding because of steel fibers, hence the loose fall comes less in comparison of mesh reinforced shotcrete.
4) SFRS attains quick setting after spraying so makes it easy to go for further tunnel execution within small span of time.
5) After blasting SFRS seals the face strongly to avoid the fall of loose rock strata after blasting hence makes the space beneath safe for working and supporting.
6) SFRS gives proper standup time for supporting especially in loose rock strata of class IV or more.
7) At the time of tunnel cavity SFRS acts as a best, proper and quick remedy to stop the tunnel from collapsing.

Recommendations for further research:

Fiber industry is a developing industry and a variety of types of fibers are being introduced such as arched-hooked end steel fibers. These newer types of fiber should be investigated. Another promising field of study is using hybrid fibers. Hybrid fiber can be obtained by mixing fibers made of different materials such as mixing steel fiber with polypropylene fiber to enhance both fresh and hardened concrete characteristics. Another form of hybrid fiber is mixing fibers of different size or shape and should also be tried in different fields of construction like heavy bridges , mega structure like dams, airport runways etc.

References:

[1] ACI 544, "Design Concsiderations for Steel Fiber Reinforced Concrete," *ACU Jornl Proceedings,* vol. 1, no. 2003, pp. 1-23, 2003.

[2] E. Nawy, Fundmentals of High-performance Concrete 2nd ed., New York: John Wiley& Sons, 2001.

[3] C. Recco , G. Guinea, J. Planas and M. Elices, "Size effect and boundary cocndition in the Brazilian test : Therotical verfication," *Material and Structures* no. 32, pp. 210-217, 1999.

[4] P. S. Song and Hwang , "Mechanicl properties of high-strength steel fiber rienforced cocnrete," *Construction and Building Materials* , vol. 0, no. 18, pp. 669-673, 2004.

[5] J. Thomas and A. Ramaswmy, "Mechanical Properties of Steel Fiber Reinforced Concrete," *ASCE Journal of Materils in Civil Engineering* , vol. 5, no. 19, pp. 385- 392, 2007.

[6] C. D. Johnston, "Properties of Steel Fiber Reinforced Mortar and Concrete," in *Interntional Symposium on Fibrous Concrete* , Lancaster, 1980.

[7] ASTM. C1018, *Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Beam with Third-Point Loading),* West Conshohocken: ASTM International , 2006.