Design of high strength concrete as per IRC:44-2008 and IS:10262-2019 with and without steel fibers

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Abstract

High strength concrete is a quasi-brittle material that has low tensile strength and low ductile capacity. These drawbacks may be avoided by adding fibers. Fiber reinforced concrete (FRC) is primarily made of cement, fine and coarse aggregate and discontinuous discrete reinforcing fibers. Fibers are generally used to improve resistance to cracking and strength of concrete. In this study HSC mixes for grades ranging from M70 to M100 are designed based on the provisions of IRC:44-2008 and IS:10262-2019 in Excel platform. From these mixes, two grades of concrete namely M70 and M80 are considered for the laboratory investigation keeping in mind the importance of trial mixes. The experimental study consists of compression, flexural and abrasion behavior of concrete as obtained from load controlled testing. Two volume fractions of fibers namely 0.5% and 1% are considered as a part of fiber reinforced concrete and the results are compared with plain concrete counterparts. Based on the observation and discussion of results few important conclusions are drawn.

1 Introduction

Plain concrete mainly consists of cement, fine and coarse aggregates and water. But now a day apart from these four ingredients few more ingredients are added such as fly ash, metakaolin, silica fume, super plasticizer and steel fibers as the situation demands. The objective of proportioning concrete mixes is to arrive at the most economical and practical combinations of different ingredients to produce concrete that will meet the performance requirements under specified conditions of use. High strength concrete is a quasi-brittle material that has low tensile strength and low strain capacity [1]. These drawbacks may be avoided by adding fibers. When steel fibers are added to concrete the flexural strength of the composite is increased from 25% to 100% depending on the proportion of fibers added in the mix design. Steel fibers actually transform a brittle material into a more ductile one [2]. High strength concrete (HSC) is characterized by high amount of cement and pozzolanic materials, low to very low water-to-cementitious materials (w/cm) ratio and smaller sized coarse aggregates. These characteristics increase the strength and impermeability of the concrete matrix, but also its brittleness and shrinkage strain [2]. Addition of fibers to the concrete mix increases the energy absorbing capability, ductility, and toughness of plain concrete. The randomly oriented fibers not only arrest cracking and its propagation, but also reduce spalling of concrete, which is an important consideration for HSC performance. In this study mix design for HSC from M70 and M100 is generated as per IRC:44-2008 and IS:10262-2019 guidelines using excel programme. Importance of various parameters of mix design is studied to explore the code provisions. From the design mixes so generated, two grades of HSCs namely M70 and M80 are considered for laboratory studies from the point of mix design requirements.

Keywords: Steel fiber reinforced high strength concrete, Volume fraction, Compressive strength, load deflection under flexure, IS:10262-2019 and IRC:44-2008.

2 Literature Review

Use of HSC and fiber reinforced HSC is increasing day by day in India. Now the design of HSC is not difficult as the BIS released the new version of IS:10262-2019 last year addressing the proportioning for HSC, which is not available in the earlier version of the code IS:10262-2009 [3, 4]. Design of HSC already exists in IRC:44-2008 code and this code also recommended the use of steel fibers for the pavement concrete [5, 6]. Keeping this in mind the present study is considered and few literatures are also studied to focus on the important aspects of HSCs with and without fibers.

It is known that concrete is a quasi-brittle material that has low tensile strength, low strain and toughness capacity. HSC is still more brittle and its failure is very sudden and catastrophic though it exhibits many desirable properties. As a result, its application in seismic area has been limited and its performance in rigid pavement is not very effective. These drawbacks of plain concrete can be avoided by adding steel fibers. Many researchers have reported that the addition of fibers increases the energy absorbing capability, ductility, and toughness of plain concrete [7-9]. Though increase in compressive strength is marginal, the increase in tensile strength is considerable [10]. Earlier studies have reported on materials requirement for producing high strength concrete (HSC). Use of quality materials, low water-binder ratio, larger ratio of coarse aggregate (CA) to fine aggregate (FA), smaller size of coarse aggregate, and suitable admixtures are found necessary to produce HSC [11, 12]

In this work cement, silica fume, ground granulated blast furnace slag (GGBFS), coarse aggregate, fine aggregate, water, high range water reducing (SP) chemical admixture, and high strength steel fibers are used for the mix proportioning of HSC. Various properties of these ingredients are determined in the laboratory and used as input in the programme. The designed mixes are tested in the laboratory for their fresh and hardened properties. In addition, the necessary trial mixes are also designed and tested to explore the complete potential of the code.

A. Objective of the work

Based on the literature work, following objectives are identified in the present work;

1. Understand the mix design as per IS:10262-2019 and IRC 44-2008 for HSC which can be extended to SFRC.
2. To study the compressive behavior of high strength steel fiber reinforced concrete for M70 and M80 grades and for two volume fractions of fibers.
3. To study the flexural behavior of high strength steel fiber reinforced concrete beams under two point loading for M70 and M80 grades and for two volume fractions of fibers.
4. To reduce the environment hazards by minimizing the cement content using supplementary materials namely GGBFS and silica fume as part replacement to cement.
5. To study the abrasion behavior of plain and fiber reinforced concrete for M70 grade for the two fiber volume fractions of fibers.

3 Steel Fiber Reinforced HSC Mix Design as Per IRC: 44-2008[5]

Mix proportioning approach consists of following steps;

1. Target compressive and flexural strengths for mix proportioning
2. Selection of maximum size of aggregate.
3. Estimation of air content.
4. Selection of water content and admixture content.
5. Selection of water -cement ratio (w/c).
6. Calculation of cementitious material content.
7. Estimation of coarse aggregate proportion.
8. Estimation of fine and coarse aggregate contents.
9. Percentage of steel fibers by total density of concrete.
10. Design of trial mixes.

Similar steps are found in IS:10262-2019 as well for HSC and the same is implemented in the programme.

4 Experimental Validation

A Materials

Ordinary Portland cement of 53 grade conforming to IS: 269: 2015 [13], Silica fume having a specific gravity of 2.09 [14] and Ground granulated blast furnace slag having a specific gravity of 2.83 are used as cementing materials. Coarse aggregate having two fractions namely 10-20 mm and 4.75-10 mm and crushed stone sand conforming to Zone II are used which satisfied the requirements of IS 383:2016 [15]. The specific gravity of coarse and fine aggregates is found to be 2.64 and 2.65 respectively. High range water reducing admixture belonging to polycarboxylate ether group having specific gravity of 1.1 is used to get the desired workability [16]. High strength crimped steel fibers are considered whose properties are reported in Table 1.

Table 1. Specification of steel fibers

Sl. No.	Fiber type	Low carbon cold drawn wire(rounded crimped type)
1	Fiber length	35mm
2	Diameter	0.6mm
3	Aspect ratio	53
4	Tensile strength	>1100MPa
5	Fiber shape	Undulated along its length

B Mix design for HSC

As stipulated in IS:456-2000, fibers may be added to concrete for special applications to enhance concrete properties for which special literature may be consulted [17]. HSC is generally employed in road applications as mentioned in IRC: 44-2008. Mix design of HSC is covered in IRC: 44-2008 and recently IS:10262-2019 has proposed the design method for several concretes including HSC. IS:10262-2019 is salient about the use of steel fibers but its inclusion is recommended in IRC 44-2008. The mix design method of both codes is more or less similar. Building structural concrete is designed based on its characteristic compressive strength and pavement structural concrete is designed based on its characteristic flexural strength at specified ages. As observed in literature, sufficient mortar is required to ensure workability and cohesiveness of SFRC. HSC consists of relatively high cement and rich mortar and its workability is generally achieved from chemical admixtures. For such HSC about 0.5% to 1% volume fraction of fibers can be simply added and the resulting mix performance can be studied. If needed, mix proportions can be adjusted to satisfy the additional requirements of SFRC.

In this study, detailed mix design based on IS:10262-2019 and IRC:44-2008 has been carried out for concrete grades M70 to M100. M65 to M100 grades are recommended in IS code as HSCs [18]. For design water-cement ratio is obtained from Table 8 of IS: 10262-2019 to start with which is based on the 28days compressive strength. Excel programme is developed to consider several mixes involved in the project and the varying properties of different ingredients used in the study. One typical mix design for M70 is presented for understanding the design procedure as illustrated in the next section. Mix design results are presented in Table 2 and graphically in Fig. 1

Mix design illustration

Grade designation	M70
Type of cement	OPC 53 grade
Specific gravity of	
1. Cement	3.15
2. Silicafume	2.20
3. Coarse aggregate	2.64
4. Fine aggregate	2.65
5. GGBFS	2.85
Maximum size of aggregate	20mm
Zone of fine aggregate	II
Workability	50mm (slump)
Maximum cement content, assumed	425 kg/m^3
Minimum cement content, assumed	325 kg/m^3

Characteristic strength for mix proportioning at 28 days

Compressive strength f_{ck}	70 MPa
Flexure strength, f_{cf}	6 MPa

Target strength for mix proportioning at 28 days

Compressive strength $f_{ck'}$	79.90 MPa
Flexure strength	6.26 MPa
w/cm ratio	0.29

Selection of water content

Water for 20 mm aggregate = 186 kg/m^3

(for 25mm slump without using superplasticizer)

For rigid pavement purpose, workability suggested with vibration is 25-50mm slump

as superplasticizer is used, the water content can be reduced by 30% = 0.3

hence reduced water content	= 130.2 kg/m^3
Cementitious material (cm) content	= 448.96 kg/m^3

GGBFS @17% by weight of cm	76.32 kg/m^3
Silica fume @10% by weight of cm	44.90 kg/m^3
Cement content	327.74 kg/m^3
w/cm	0.29
Minimum cement	325 kg/m^3
Maximum cement content	425 kg/m^3
Check for minimum cm	TRUE
Check for maximum cement	TRUE

Proportion of vol. of C.A & F.A

Form table 10, volume of CA for 20mm size aggregate & FA of zone II =0.66 per unit vol. of total aggregate.(at rate of -/+0.01 for every 0.05 change of w/cm) = 0.66

This is valid for cm ratio = 0.3 and as w/cm ratio 0.29, it is taken as 0.66

Vol. of Fine aggregate 0.34 per unit vol. of total aggregate

Mix calculation

Total volume	1 m^3
Vol. of entrapped air	0.005 m^3
Vol. of cement	0.104 m^3
Vol. of water	0.130 m^3
Vol. of GGBFS	0.0267 m^3
Vol. of silica fume	0.0204 m^3
Vol. of admixture	
@0.5% by wt. of cm	0.00207 m^3
Vol. of all aggregate	0.711 m^3
Mass of CA	1290.553 kg
Mass of FA	637.279 kg

Table 2. Mix proportions for trail mix 1

Designation	Cement kg/m³	Silica fume (10%) kg/m³	GGBFS (17%) kg/m³ 17%	Water kg/m³	Fine Agg. kg/m³	Coarse Agg. kg/m³	w/cm	SP (0.5% of cm) kg/m³	Yield kg/m³
M70	327.74	44.90	76.32	130.20	637.28	1290.55	0.29	2.24	2509.2
M80	325.50	50.08	125.19	130.20	609.23	1267.42	0.26	2.50	2510.1
M90	352.63	54.25	135.63	130.20	589.40	1248.57	0.24	2.71	2513.4
M100	402.74	61.96	154.90	130.20	556.03	1210.37	0.21	3.10	2519.3

Mix proportions

Cement	327.74 kg/m^3
Ggbfs 17%	76.32 kg/m^3
Silica fume 10%	44.90 kg/m^3
Water content	130.20 kg/m^3
Fine aggregate	637.28 kg/m^3
Coarse aggregate	1290.55 kg/m^3
W/cm	0.29
Super plasticizer	2.24 kg/m^3
Total density, yield	2509.24 kg/m^3

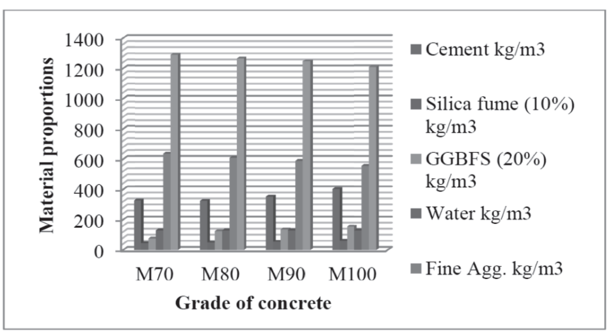

Fig. 1 Variations of materials per m^3 for the mix proportion

5 Results And Discussion

For performance studies two mixes for grades M70 and M80 are considered. The proportions as illustrated in Table 2 is taken and for these concrete steel fibers are added at 0.5% and 1% volume fraction separately for further studies.

A Workability

The slump of M70 and M80 grade of HS-SFRC obtained is in the range of 25-50mm which is in the low workability range as assumed in the mix design. This is achieved by using 0.5% to 1% SP. The dosage can be varied to get the desired value of workability. The workability test results for different volume fractions of steel fibers are presented in Table 3 and graphically in Fig. 2. The typical slump test is shown in Fig. 3.

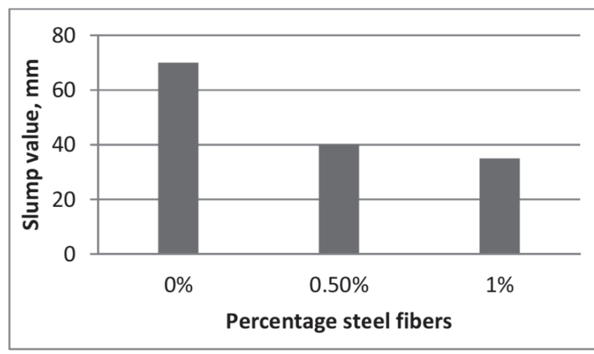

Fig. 2 Slump for different steel fibers percentage for M70 grade

B Flexure strength

For this test 100mm x 100mm x 500mm prisms are cast and tested at 28 days using UTM in two-point loading arrangements. Mechanical dial gauge reading gives the central deflection at an interval of 100kg loading. A graph of load v/s deflection is plotted for both M70 and M80 grades of concrete and for 0.5% and 1% steel fibers. The maximum load causing the failure is noted down to determine flexural strength of the respective grades.

Table 3 Workability results for different volume fractions

Sl. No.	Steel fiber Volume fraction, %	Quantity of steel fiber per m³ of concrete, Kg/m³	Slump for M70 with 0.5% SP	Slump for M80 with 1 % SP	Nature of concrete
1	0%	0	70	80	All mixes are cohesive and balling of fiber is not noticed
2	0.5%	39	40	45	
3	1%	78	35	25	

The theoretical flexural strength as per IS:456-2000 is given by $F = 0.7\sqrt{f_{ck}}$ and is compared with the practical value from (3WX/a^3) where X=133.3mm, a=100mm and W= Maximum or failure load. From this it is clear that the theoretical strength


Fig. 3 Slump value of HSSFRC is 35mm

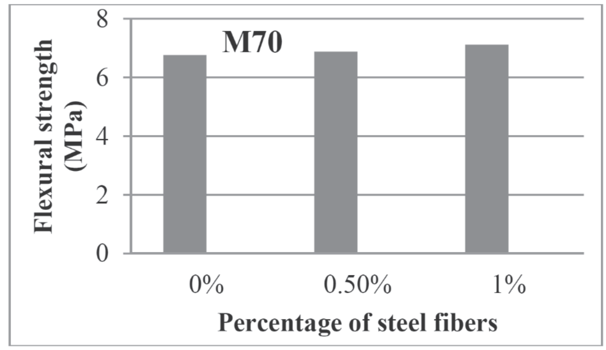

Fig. 4 Flexural strength of M70 grade HSC steel fibers

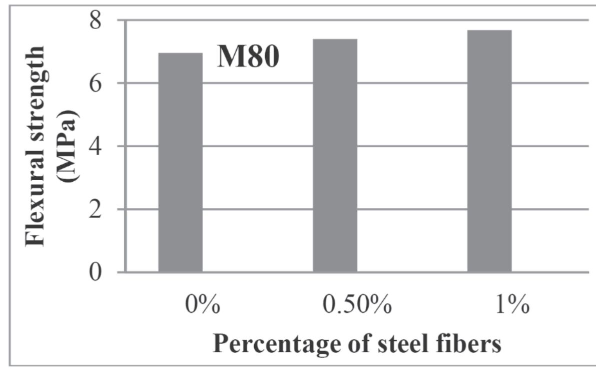

Fig. 5 Flexural strength of M80 grade HSC steel fibers

values are less than the practical strength values. The calculated flexural strength at 28 days based on the failure load is more than required target flexural strength of 6.26MPa required as per design. The results of flexural strength are presented in Tables 4 and 5 and graphically in Figs. 4 and 5 respectively.

It is observed from Tables 4 and 5 that the flexural strength increases with the addition of fibers and as the fiber volume fraction increases the flexural strength also increases. Similar variations are observed by the other investigators as well. The increase in flexural strength is up to about 10%.

Table 4 Flexural strength at 28 days of M70 grade concrete

Sl. No.	Theoretical value	Practical value			Percentage of increase compared to theoretical value
	IS:456-2000 $F = 0.7\sqrt{f_{ck}}$ MPa	Volume fraction of Steel fibers, %	Maximum applied load, W (N)	Flexural strength, (3WX/a^3), (MPa)	
1	5.86	0%	1690	6.76	0
2		0.5%	1720	6.88	1.77
3		1%	1780	7.12	5.32

Table 5 Flexural strength at 28 days of M80 grade concrete

Sl. No.	Theoretical value	Practical value			Percentage of increase compared to theoretical value
	IS:456-2000 $F = 0.7\sqrt{f_{ck}}$ MPa	Volume fraction of Steel fibers, %	Maximum applied load, W (N)	Flexural strength, (3WX/a^3), (MPa)	
1	6.26	0%	1740	6.96	0
2		0.5%	1850	7.40	6.32
3		1%	1920	7.68	10.34

i) Load deflection

The prisms are tested in UTM by two-point loading method and dial gauge attached to the UTM gives the central deflection at an interval of a 100 kg load. Graphs are plotted between load and deflection for both grades and for two volume fractions of fibers namely 0.5% and 1%. The maximum load is noted which caused sudden cracking of beam. The beam did not break in to pieces and sustained reduced load with increased deflection. Few readings of load and deflection are taken for generating the descending part of the curve. Here an attempt is made to get the descending nature with the load controlling method. Use of servo controlling method is beyond the scope of this study which is discussed in the literature[8]. The load deflection curves can be seen in Figs.6 and 7. The two-point loading test setup in UTM is as shown in Fig. 8 and the typical failure of sample is shown in Fig. 9. The area under the load-deflection for 1% volume fraction of fiber is substantially higher compared to 0.5% volume fraction of fiber corresponding to certain deflection level (say 1mm or 2 mm) indicating its enhanced ductility.

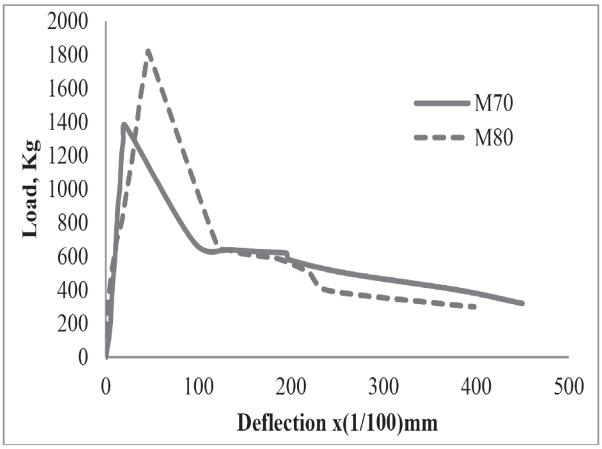

Fig. 6 Load deflection curve for M70 and M80 grade for 0.5% fibers

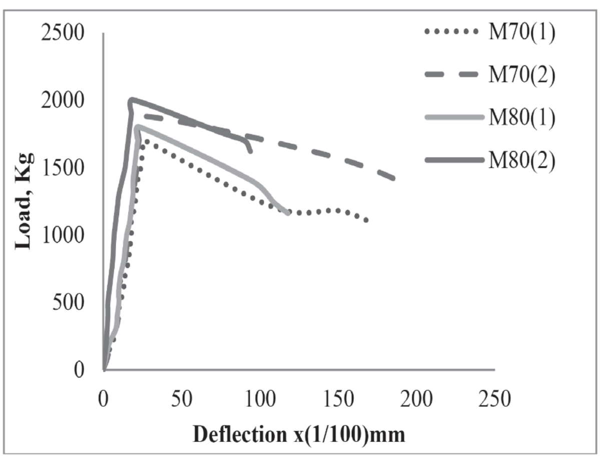

Fig. 7 Load deflection curve for M70 and M80 grade for 1% fibers

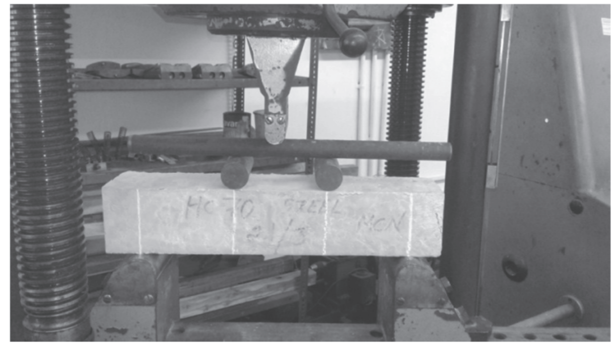

Fig. 8 Two point loading test setup in UTM

Fig. 9 Failure of sample under two point loading test

C Compressive strength

Compression test is conducted at 7 and 28 days as per 1S:516 using cubes of size 100 x 100 x 100mm and the average results of three samples obtained are shown in Table 9 and graphically in Fig. 10.

The target compressive strengths for M70 and M80 concrete are 79.9 MPa and 89.9MPa respectively. Both grades of plain concretes gave the desired strength at 28 days which is somewhat higher as seen in Table 9. When fibers are added, compressive strength has marginally affected (±5%) due to random distribution of fibers. It is reported in the literature that the compressive strength generally increases with fiber addition and in some cases it can decreases as well. Increase in compressive strength is marginal in case off HSC due to fiber addition. What is important in compression is the increase in toughness which is quite enormous than the increase in strength for which stress-strain diagram from servo controlled testing is essential [10]. Such a study

Table 9. Compressive strength at 28 days of M70 M80 grade concrete

Sl. No.	Volume fraction of steel fiber, %	Target compressive strength at 28 days, MPa		Remarks
		M70	M80	
1	0%	79.92	91.22	Satisfied the workability and the target compressive strength. Mix is cohesive.
2	0.5%	74.54	86.32	Satisfied the workability and NOT the target compressive strength at 28 days. Mix is cohesive and free from balling
3	1%	80.20	91.43	Satisfied the workability and the target compressive strength. Mix is cohesive and free from balling

is not done in this investigation as it is beyond the scope of the present work. Since 0.5% volume fraction of fiber has not resulted in the desired target strength, additional mixes are to be considered to finalyse the mix design. In order to economize the mix design, trial mix design is necessary as discussed in the code. It is done for both M70 and M80 plain concrete and not attempted for fiber reinforced concrete.

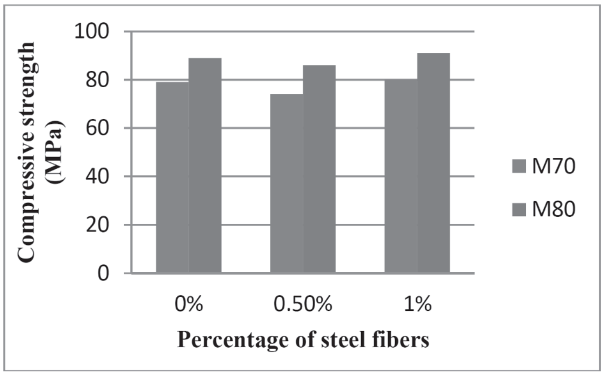

Fig. 10 Compressive strength of M70 and M80 grade with steel fibers

i) Trail mix test results

In order to perform the complete mix design in the laboratory, two additional trail mixes namely Trail 3 and 4 are designed for the assumed water content and by varying water-cement ratio by ±10% as discussed in IS:10262 [3]. Trail 2 is not considered as the workability is satisfied with SP. All mixes are initially tested for workability and the necessary cubes are cast for determining the compressive strength at 7 and 28 days. The strength results of trial mixtures obtained for both concrete are shown in Table 10 and graphically in Figs. 11 and 12. Extrapolation of the graphical results (based on the power curves fitted) provides additional information regarding the w/c ratios to be adopted for any other grades of concrete to be designed for the given set of ingredients. This will reduce the number of trails needed for other grades if the mix design is required. Similar trials are needed for fiber concrete mix design as well.

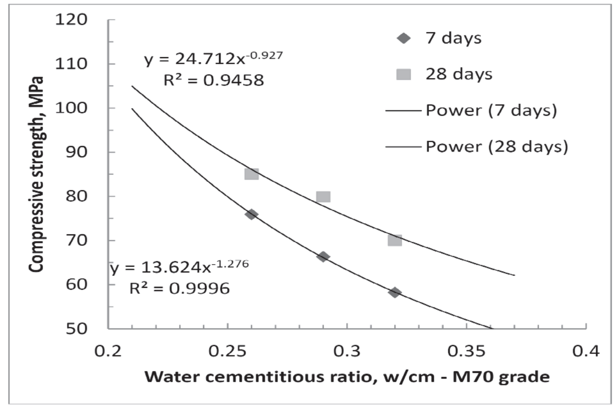

Fig.11 Compressive strength vs. Water/cementitious ratio for M70

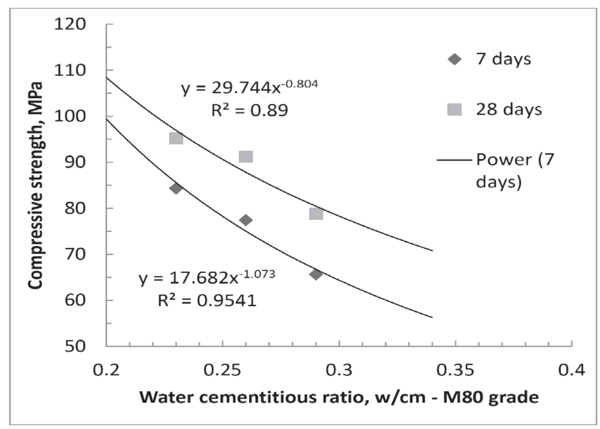

Fig.12 Compressive strength vs. Water/cementitious ratio for M80

D Abrasion test as per IS:13801-1993[19]

Abrasion wear occurs due to rubbing, scraping, skidding or sliding of objects on concrete surface and is commonly observed in pavements. Numerous studies on the abrasion resistance of concrete have been carried out to show that the abrasion resistance of concrete is strongly influenced by compressive strength, surface finishing techniques, curing types, aggregate properties, testing conditions and presence of steel fibers [20]. Here M70 grade only is considered with 0.5% and 1% volume fraction.

Table 10.Compressive strength of plain concrete trail mixes

Age, Days	Compressive strength, MPa					
	M70			M80		
	Trial mix 3 w/c=0.26 10% decrease	Trial mix 1 w/c=0.29	Trial mix 2 w/c=0.32 10% increase	Trial mix 3 w/c=0.23 10% decrease	Trial mix 1 w/c=0.26	Trial mix 2 w/c=0.29 10% increase
7	75.91	66.33	58.23	84.33	77.44	65.64
28	85.03	79.92	70.05	95.22	91.22	78.86

Abrasion resistance is carried out at 28day according to IS:13801[19]. Abrasion test apparatus is shown in Fig.13. While testing 20 ± 0.5 g of wear dust (corundum crystalline Al_2O_3) is spread on the disc, the specimens are

Table 11 Comparative abrasive test results of M70 with and without fibers		
Grade of concrete	Average loss in mm (by formula)	Average loss in mm(by difference of initial and final thickness)
M70-plain concrete	0.37	0.41
M70-Fiber concrete (0.5%)	0.36	0.38
M70-Fiber concrete (1%)	0.35	0.42

then placed, the load is applied to the specimen and the disc is rotated for four periods, while a period is equal to 22 revolutions. After that, the surfaces of the disc and the sample is cleaned by the brush, then new 20 ± 0.5 g standard abrasive dust is placed and the specimens are rotated 90° in the horizontal axis. The above-mentioned procedure is repeated for 16 periods (i.e., the specimens are subjected to a 16*22 revolutions) by rotating the specimens 90° in each period. Thickness measurements of the specimens are calculated by formula and difference of initial and final thickness are presented in Table 11 respectively. The abrasion thickness loss can be calculated from:

t = (W1-W2)V/(W1*A); where,

t = average loss in thickness in mm,

WI = initial mass of the specimen in g.

W2 = final mass of the abraded specimen in g,

V = initial volume of the specimen in mm,

A = surface area of the specimen in mm^2

It is observed from Table 11 that the wear results are more or less same in all cases indicating that all concretes behaved more or less same and are equally strong. Concrete with fiber appears to be better compared to plain concrete. Additional tests are to be done to draw concrete conclusions.

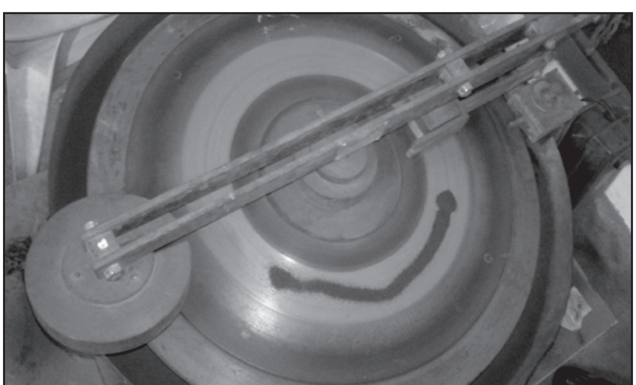

Fig. 13 Abrasion test apparatus

6 Conclusions

Following important conclusions are drawn from the present study;

1. HSC can be designed as per IS:10262-2019 for plain concrete and steel fiber reinforced HSC can be designed as per IRC:44-2008 as the addition of steel fibers are permitted in this code. Mix design procedure is more or less same in both codes.

2. Workability of concrete increases with increase in percentage of SP and about 0.5% to 1% SP is sufficient to get the target workability in terms of slump for 0.5% and 1% of volume fraction of steel fibers.

3. The designed plain concrete for M70 and M80 grades resulted in the desired compressive strength at 28 days. In order to arrive at the economical mix proportion, trial mixes are to be designed and tested. Addition of fiber has varied the strength marginally and the mix is quite cohesive and is free from balling. A marginal reduction in w/c can result in the desired strength for 0.5% which is not considered.

4. Use of silica fume is compulsory in HSC as a pozzolanic material and a microstructure refiner in addition to supplementary cementing material such as GGBFS.

5. In case of HSC, the compressive strength at 7days is substantially higher and is about 85% to 90% of its 28 days compressive strength.

6. The incorporation of steel fibers in the HSC has increased the flexural strength compared to plain HSC. As fiber volume fraction increases, the flexural strength also increases marginally.

7. The ductility of fiber reinforced beams in flexure is quite enormous leading to slow and gradual failure as seen from the load deflection curves. In case of HSC plain beam, the failure is sudden after reaching the maximum load as it is very brittle. The addition steel fiber in HSC prisms gives enough deflection before it fails under two-point loading test. Here M80 grade of concrete with 1% steel fibers gives maximum deflection.

8. Abrasion resistance of fiber reinforced concrete increases marginally as the fiber content increases compared to plain HSC.

9. Both M70 and M80 concretes gave the desired compressive and flexural strengths as a part of mix design requirements satisfying target workability.

10. Trial mixes are necessary to understand the mix design completely from the point of practical requirements and to address material changes that occur in the field from batch to batch.

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