Analytical Study on Steel Fiber Reinforced Concrete Strength Parameters with Stone Dust

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Abstract:
Sustainable development is a need of time as humans excessively use natural materials for a particular use. The study uses stone dust, waste generated from a quarry in the concrete mix, to replace cement. It will help in understanding the change in the engineering property of concrete. The Stone dust steel fiber reinforced concrete (SDSFRC) is then developed for different mix design and every concrete block produced are then tested for strength after curing for 7 days and 28 days. The proportion of various constituents are added with a superplasticizer to improve workability. The results from the study state that the workability of concrete is 30mm for SDM 6, Compressive strength of concrete (SDM6) was 34.671 MPa and 46.012MPa for 7 and 28 days, respectively, and flexural strength of concrete came out to be 5.752 N/mm^2 and 6.211 N/mm^2 for 7 and 28days respectively. The results clearly show that the addition of stone dust to the concrete mix leads to an excellent effect on the strength and durability of concrete. The concrete mix design with stone dust as a constituent will be economical and sustainable as it consumes the waste produced from different industries.
Keywords: Stone dust; Fiber-reinforced concrete; Workability; Compressive strength; Flexural strength; Mix design.

1. Introduction

The main constituent of cement concrete is fine aggregate which is natural sand; due to its limited availability, government officials restrict the use of natural sand in many parts of India. The excessive use of natural sand results in soil erosion, decreased water levels, and decreased supply of sediments (Rajput, 2018). A study suggests after water, sand, and gravel are the most widely utilized raw materials on the planet. Still, scientists have warned that "their consumption far surpasses their natural regeneration rates." (Gavriletea, 2017). The replacement of natural sand is a topic of research for different researchers, different new fine aggregates are discovered, and its properties are analyzed. The fine aggregate increases the internal bond between all the constituents of concrete (Padmanaban et al., 2017). The stone dust or quarry dust replaces fine aggregates, a waste product from the quarry and cheap. The result of sand replacement with stone dust in concrete has shown an increase in compressive strength (Dhanapal & Jeyaprakash, 2019). The stone dust from the quarry is waste utilized in concrete, which will reduce natural sand use from construction work (Gavriletea, 2017). Different studies suggest that if stone dust is used as a substitute for saand in concrete, it shows better results for various tests (Jiang et al., 2020). The Concrete properties vary with their constituents; the proportion of different materials plays a vital role in developing strength in concrete (Gonçalves et al., 2020). In the past decade, various researchers have analyzed materials that can replace natural sand, but those were artificial materials and were costly. The stone dust is available for free because it is a by-product of stone and has less usability (Mehdipour et al., 2020). The use of waste products to improve the mechanical characteristics of concrete has been used for over seven decades. Today's investigators have made commendable efforts to use industrial waste to enhance different qualities of concrete, such as marble dust, tiles dust, stone dust, and so on (Upadhyaya et al., 2020; Wang et al., 2020; Wu et al., 2017; Xu et al., 2020). Sustainable concrete is a need for the future generation. The use of natural resources is having an alarming effect on human beings and the environment. The depletion of the ozone layer and global warming is harming the human. Due to the pollutant from various industrial waste, it is causing mutation in humans' genetic factor and effect on lungs (Babaie et al., 2019; Dawood & Ramli, 2014; Gavriletea, 2017; Kim et al., 2019; Seto, 2015).

The Stone dust steel fiber reinforced concrete (SDSFRC) is the less researched topic, but due to being a waste material, stone dust can be disposed of by using it in the concrete, which will reduce the space required for dumping the dust. (Patel & Pitroda, 2013) states that 250-400 tons of stone dust are generated every year from the quarry. The research by (Abd elaty, 2019; Ammari et al., 2020; Fan et al., 2020) suggests that replacing sand with stone dust increases the compressive strength of concrete, increasing workability and reducing the cost.

The main aim of this study is: (1) To investigate the workability of fresh concrete with the increase of fibers volume content with Stone dust steel fiber concrete (SDSFRC). (2) To investigate the wet and dry density of SDSFRC at 7 days and 28 days with the addition of fibers and stone dust. (3) To investigate maximum percentage increase in mechanical properties of concrete achieved of fiber volume fractions for SDSFRC. (4) To study the deflection on the beam due to applied loading conditions.

2. Experimental Program

Materials Properties

The different materials used for the analysis are OPC cement, Fine aggregate, Coarse Aggregate, Superplasticizers, Water, Stone dust, and Steel fiber reinforcement.

2.1 Ordinary Portland Cement

The cement used in this experimental work is "ordinary Portland Cement." All properties of cement are tested by referring to IS 12269: 2013. Test results are presented in Table 1.

Table 1 Physical properties of cement

Sr. No.	Description of Test	Results
01	Fineness of cement by specific surface area method	3892 cm^2/g
02	Specific gravity	3.15
03	Standard consistency of cement	29%
04	Setting time of cement Initial Final	 38 minutes 180 minutes
05	Soundness test of cement (with Le-Chatelier's mold)	1.5mm
06	Compressive strength of cement 3 days 7 days 28 days	31.3 N/mm^2 42.4 N/mm^2 N/mm^2

2.2 Water

Portable water available in the laboratory is used for mixing and curing the concrete.

2.3 Tests on Aggregates

Natural sand from the river confirming to IS 383-1970 is used. Various tests, such as specific gravity, water absorption, impact strength, crushing strength, sieve analysis, etc., have been conducted on coarse and fine aggregates to know their quality and grading. The results of these tests are shown in tables 2 to 5. Crushed black trap basalt rock of aggregate size 20mm down and 10mm down were used confirming to IS (383-1970, 1970).

Table 2 Physical properties of Fine Aggregate (sand)

Sr. No	Property	Results
1.	Particle Shape, Size	Round, 4.77 mm down
2.	Fineness Modulus	3.17
3.	Silt content	2%
4.	Specific Gravity	2.63
5.	Bulking of sand	4.16%
6.	Bulk density	1793 Kg/m^3
7.	Surface moisture	Nil

Table 3 Physical properties of Coarse Aggregate

Sr. No	Property	Results
1.	Particle Shape, Size	Angular, 20mm,10mm down
2.	Fineness Modulus of 20mm aggregates	7.4
3.	Fineness Modulus of 10mm aggregates	6.87
4.	Specific Gravity	2.77
5.	Water absorption	1.02%
6.	Bulk density of 20mm aggregates	1603 Kg/ mm^3
7.	Bulk density of 10mm aggregates	1585 Kg/mm^3
8	Surface moisture	Nil

Table 4 Sieve analysis of Fine Aggregate

Sr. No.	Sieve size	Weight retained (kg.)	Cumulative wt. Retained
01	4.75mm	0.019	0.019
02	2.36mm	0.123	0.142
03	1.18 mm	0.292	0.434
04	600 µ	0.252	0.686
05	300 µ	0.227	0.913
06	150 µ	0.070	0.983
07	Dust	0.008	0.991

Fineness Modulus=3.17

Table 5 Sieve analysis of coarse aggregates

Sr. No.	Sieve size	Weight retained (kg)	cumulative wt. Retained	%cumulative wt.	% passing
01	40 mm	NIL	NIL	NIL	
02	20 mm	0.065	0.065	1.30	98.7
03	10 mm	4.262	4.327	86.54	13.46
04	4.75 mm	0.673	5.00	100.0	0

05	2.36 mm	-	-	100	-
06	1.18 mm	-	--	100	-
07	600 µ	-	--	100	-
08	300 µ	-	--	100	-
09	150 µ	-	--	100	-
	Total	5.0		687.84	

Fineness Modulus=6.87

The Properties of Superplasticizer are given in Table 6

Table 6 Properties of Super Plasticizer used

Sr. No.	**Properties**	**Description**
1.	Chemical admixture	Masterplast SPL 9-M2
2.	Natural	Single component liquid
3.	Type	Sulphonated naphthalene formaldehyde polymer
4	Specific gravity at 30°C	1.27 $\pm$ 0.02
5.	Chloride content	Nil
6.	Air Entrainment	Nil
7.	Nitrate content	Nil
8.	pH Value	7-9
9.	Viscosity	Medium viscous

2.4 Physical properties of Steel fibers used.

Duramax steel fibers conforming to ASTM A 820 type-I are used for experimental work. Duramax RC - 80/60 - BN is high tensile steel cold drawn wire with hooked ends, glued in bundles & specially engineered for use in concrete. Fibers are made available from Shakti Commodities Pvt. Ltd., New Delhi.

Table 7 Physical Properties of Steel fibers

Sr. No.	**Property**	**Values**
1.	Diameter	0.75 mm
2.	Length of fiber	60 mm
3.	Appearance	Bright in clean wire
4.	Average aspect ratio	80
6.	Deformation	Hooked at both ends
7.	Tensile strength	1050 MPa
8.	Modulus of Elasticity	200 GPA
9.	Specific Gravity	7.8

Dosages used: 0.5% to 5% at the interval of 0.5 by weight of cement

2.5 Mix proportion

2.5.1 Mix Design of Concrete

2.5.2 IS method is used for mix design of M-35 grade of concrete. The quantity of ingredient materials and mix proportions as per design is as given below.

Table 8 Quantity of Materials per Cubic meter of concrete

Material	**Proportion by weight**	**Weight in Kg/m^3**
Cement	1	479
F.A.	1.087	521
CAI (20mm) (60%)	1.419	679.98
CAII (10mm) (40%)	0.947	453.33
Water/cement ratio	0.400	191.61

Table 9 Composition of concrete

Name of composition	**SD**	**SFR**
SDM_0	0	0
SDM_1	2.5	0.5
SDM_2	5	1
SDM_3	7.5	1.5
SDM_4	10	2
SDM_5	12.5	2.5
SDM_6	15	3
SDM_7	17.5	3.5
SDM_8	20	4

3. SYSTEM DESIGN AND IMPLEMENTATION

3.1 Preparations of Specimen

3.1.1 Measurement of ingredients

All materials, i.e., cement, sand, coarse aggregate (20mm), and coarse aggregate (10mm), were measured with digital balance. Water is calculated using a measuring cylinder of 1-liter capacity and a measuring jar of capacity 1000ml, 2000 ml. The plasticizer and Steel fibers were also measured with digital balance.

3.1.2 Mixing of concrete

According to the mix design proportion, the quantity of cement, stone dust, steel fibers, superplasticizers, coarse aggregates are taken on a G.I sheet and mixed properly. Steel fibers reinforced concrete, the necessary quantity of Steel fibers 0.5 % to 5%, at an interval of 0.5, by weight of cement is measured. The required weighted amount of Steel fibers is then uniformly speckled by a hands-on dry concrete mix containing CA, FA, and cement. The dry concrete mix is then thoroughly and uniformly mixed until uniform and homogeneous mixing of fibers in the dry mixture. Care is taken to avoid balling. A selected percentage of superplasticizer is added to the designed water and stirred to mix uniformly in the entire water. The solution is then spread over the concrete mix and remixed thoroughly again for few minutes.

3.1.3 Workability of concrete

The volume fraction of fiber (V_f) and their aspect ratio (*l/d*) lead to a similar effect on the workability. Therefore, their combined effect can be better analyzed using the fiber factor (*Vf.l/d*) as an influencing parameter. The Slump loss, density loss, and fiber factor values are shown in Table 10, and graphs are plotted in Figure 1 and Figure 2.

Here,

$$Slump\ loss = \frac{S_0 - S_f}{S_0} \times 100 \qquad \text{(Eq.1)}$$

where,

S_0=Slump of normal concrete,

S_f = Slump of fiber reinforced concrete.

and

$$Density\ loss = \frac{D_0 - D_f}{D_0} \times 100 \quad \text{(Eq. 2)}$$

where,

D_0 = Density of normal concrete,

D_f = Density of fiber reinforced concrete.

4. EXPERIMENTATION RESULTS

4.1 Workability

The concrete mixer's workability is the ease of transferring concrete from one place to another. The concrete, which is made by mixing different constituents, should be such that it should not be set before reaching the place where it is to be used. The mix design should be proper, which should give better workability, and its strength does not get affected. In the study, the workability is calculated using the slump cone test, and the density of wet and dry concrete is given in Table 10. The workability of fresh concrete is calculated through the slump cone test; the results are as follows.

Table 10 Wet density, dry density, and workability of SFRC.

Sr. no	Mix. designation.	Fibre Volume fraction V_f (%)	Stone Dust SD (%)	Water cement ratio	Wet. Density (Kg/m^3)	Dry Density (Kg/m^3) at 7days	Dry Density (Kg/m^3) at 28 days	Workability by slump(mm)
1	SFSDM00	0	0	0.4	2860	2780	2790	60
2	SFSDM01	0.5	2.5	0.4	2850	2770	2780	50
3	SFSDM02	1	5	0.4	2820	2760	2770	45
4	SFSDM03	1.5	7.5	0.4	2800	2750	2760	42
5	SFSDM04	2	10	0.4	2790	2740	2750	39
6	SFSDM05	2.5	12.5	0.4	2760	2738	2720	36
7	SFSDM06	3	15	0.4	2750	2730	2700	30
8	SFSDM07	3.5	17.5	0.4	2720	2715	2680	25
9	SFSDM08	4	20	0.4	2700	2700	2640	22

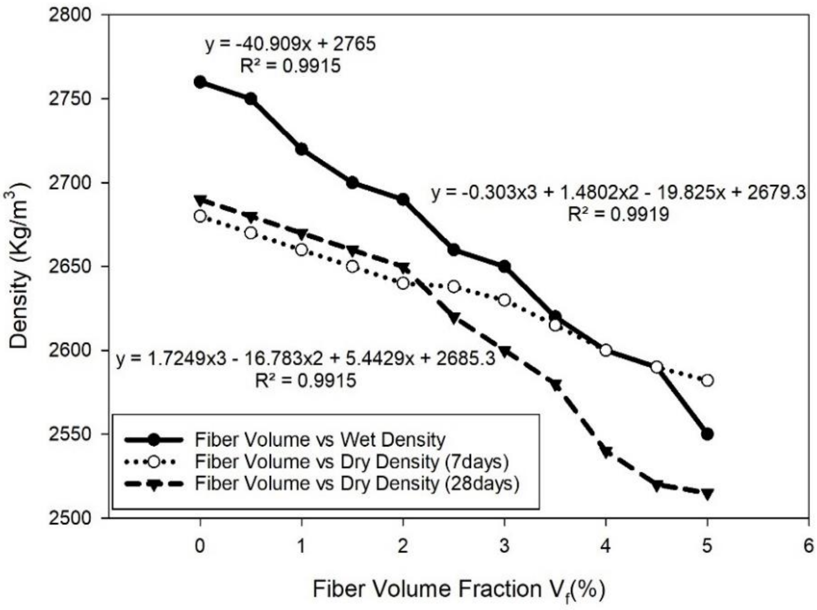

Figure 1 Variation of dry and wet density (7 and 28 days) concerning percentage fiber volume fraction

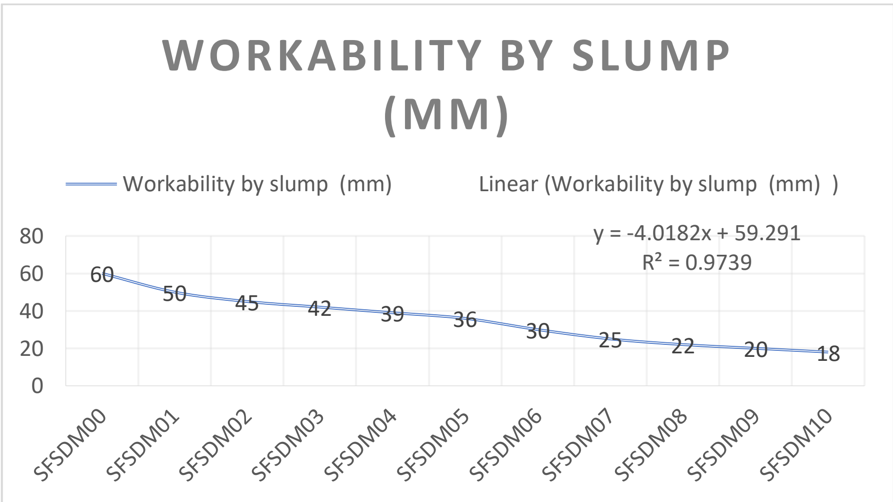

Figure 2 workability by slump cone (in mm)

4.2 Compressive strength test

A cube compression test was performed on standard cubes of plain and SFRC of size 100 x 100 x 100 mm after 7 days and 28 days of immersion in water of curing plain concrete and SFRC specimens. Results are shown in Table 11, and a graphical presentation between compressive strength and percentage fiber volume fraction is shown in

Figure **4**

The eleven different compositions of concrete mix are made using the additional amount of Stone dust and SRF. The Stone dust and SRF are used by replacing cement by its weight. The compressive strength of concrete was observed for 7 days and 28 days of casting and water tank curing. The result obtained after 7 and 28 days are mentioned in Table 11 with percentage variation in compressive strength against standard concrete. The test is conducted using a Compression testing machine (CTM).

The following formula calculated the compressive strength of the specimen:

$$F_{cu} = \frac{P_c}{A} \qquad \text{(Eq. 3)}$$

where

Pc = Failure load in compression, KN

A = Loaded area of cube, mm2

Following are the expressions for cube compressive strength in 3rd degree polynomial in terms of (V_f) Fiber volume fractions are given by the following equations from Figure 01

7 Days: $fcu = -0.0117Vf3 - 0.0581Vf2 + 2.0338Vf + 27.097$ (Eq. 4)

28 Days: $fcu = -0.0318Vf\,3 + 0.4096Vf\,2 - 1.0197Vf + 43.682$ (Eq. 5)

The load-deflection graphs are separately drawn for 7 days and 28 days.

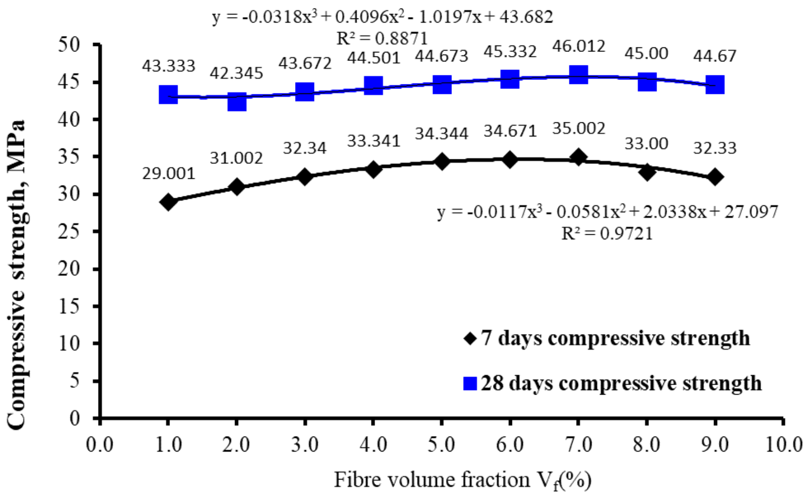

Figure 3 Empirical Variation of compressive strength at 7 and 28 days concerning percentage fiber volume fraction

Table 11 Compressive strength variation over standard concrete

Sr. No.	Mix. Design.	Comp. Strength $f_{cu,}$ MPa		% variation in Comp. Strength over Nominal Concrete	
		7days	28 days	7days	28 days
1	SDM0	29.001	43.333	-	-
2	SDM1	31.002	42.345	6.892	-2.29
3	SDM2	32.34	43.672	11.514	0.772
4	SDM3	33.341	44.501	14.965	2.691
5	SDM4	34.344	44.673	18.416	3.082
6	SDM5	34.671	45.332	19.537	4.621
7	SDM6	35.002	46.012	20.685	6.155
8	SDM7	33.00	45.00	13.79	3.85
9	SDM8	32.33	44.67	11.48	3.08

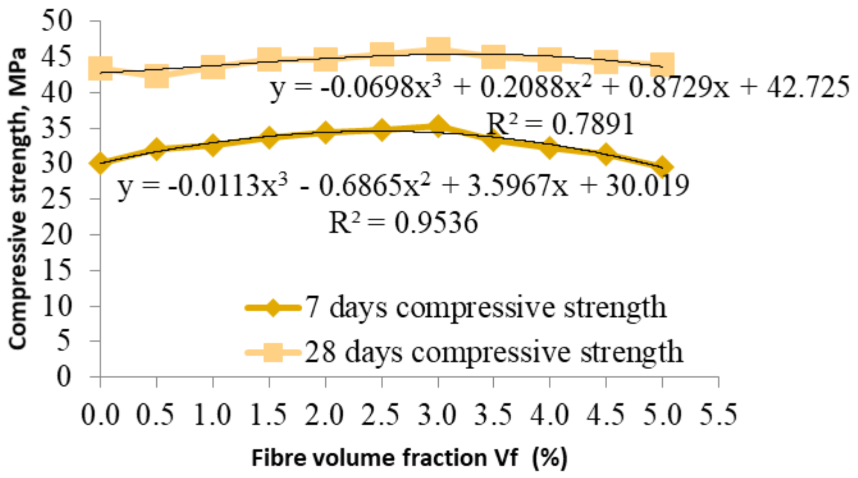

Figure 4 Variation of compressive strength at the age of 7 & 28 days concerning percentage fiber volume fraction

4.3 Flexural Test

Standard beams of size 100 x 100 x 500 mm were supported symmetrically over a span of 400 mm and subjected to two points loading till failure of the specimen. The deflection at the center of the beam is measured with a sensitive dial gauge on UTM. The two broken pieces (prisms) of the flexure test are further used for equivalent compressive strength.

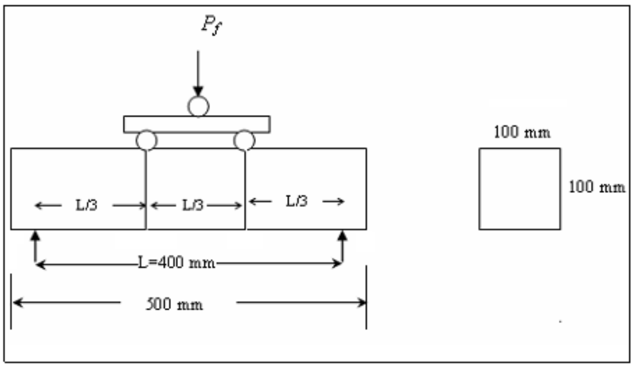

Figure 5 two-point loading setup for flexural test

The flexural strength of beam is computed according to following formula:

$$fcr = \frac{P_f L}{bh^2} \qquad \text{(Eq. 6)}$$

where,

f_{cr}= Cracking or Flexural strength, MPa

P_f = Central point through two-point loading system, N

L = Span of beam, mm

b = Width of beam, mm

h = Depth of beam, mm

Flexural strength test on beam.

Table 12 Flexural Strength of SDSFRC, MPa

Sr. No.	Mix. Designation.	Flex. strength N/mm²		% variation in Flexural Strength	
		7 days	28 days	7 days	28 days
1	SDMO	5.122	6.05	-	-
2	SDM1	5.224	6.032	02.031	-00.440
3	SDM2	5.335	6.013	04.142	-00.660
4	SDM3	5.570	5.954	08.853	-01.761
5	SDM4	5.691	6.110	11.204	00.882
6	SDM5	5.731	6.290	11.981	03.961
7	SDM6	5.752	6.211	12.340	02.643
8	SDM7	5.761	6.532	12.5014	07.941
9	SDM8	5.832	7.013	13.804	15.860

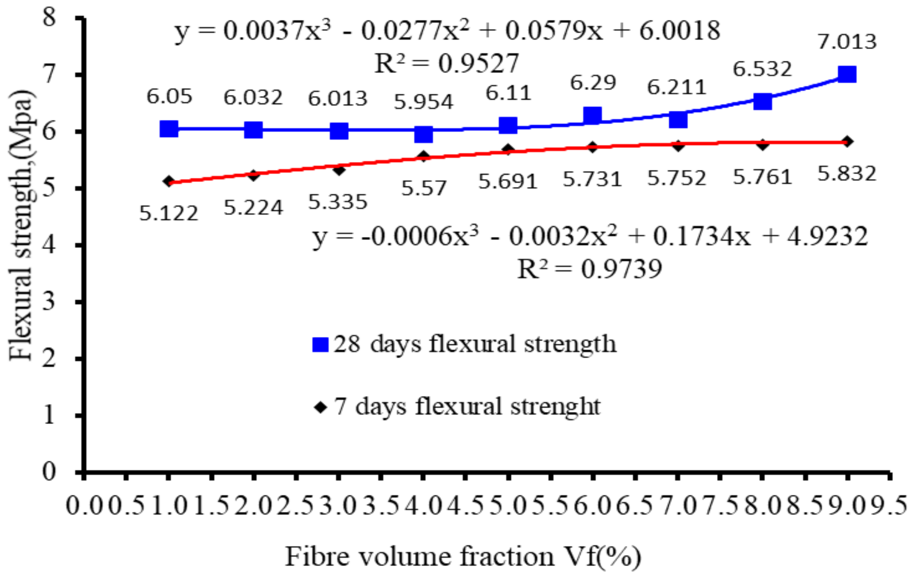

Figure 6 Empirical variation in flexural strength for 7 and 28 days concerning the percentage of fiber volume fraction

Expressions for flexure strength in a 3rd-degree polynomial in terms of V_f are obtained from Figure 6 as

7 Days: $fcr = -0.0006Vf\ 3 - 0.0032Vf\ 2 + 0.1734Vf + 4.9232$ (Eq. 7)

28 Days: $fcr = 0.0037Vf3 - 0.0277Vf2 + 0.0579Vf + 6.0018$ (Eq. 8)

Expression for flexural strength in terms of compressive strength in 2nd degree polynomial is given as below from Figure 7

$$fcr = 0.0184fcu2 - 0.1029fcu + 6.1431 \qquad \text{(Eq. 9)}$$

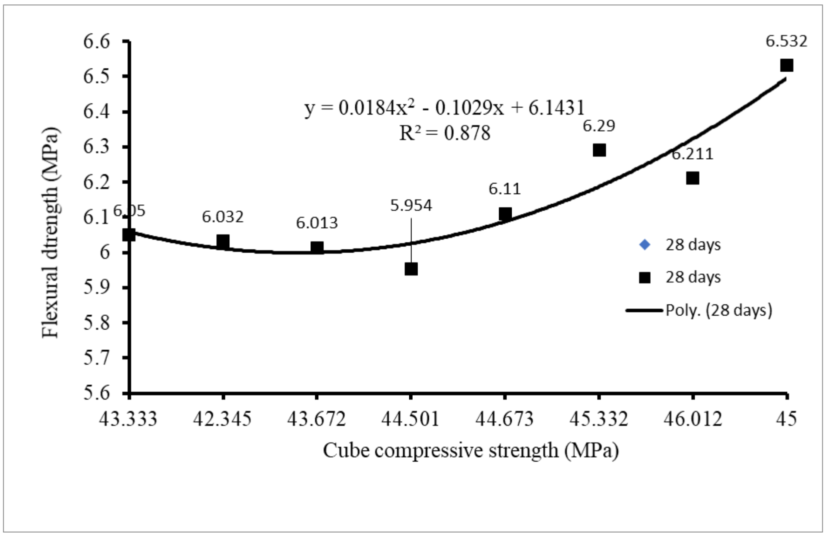

Figure 7 Variation of flexural strength with resp to cube compressive strength for 28 days

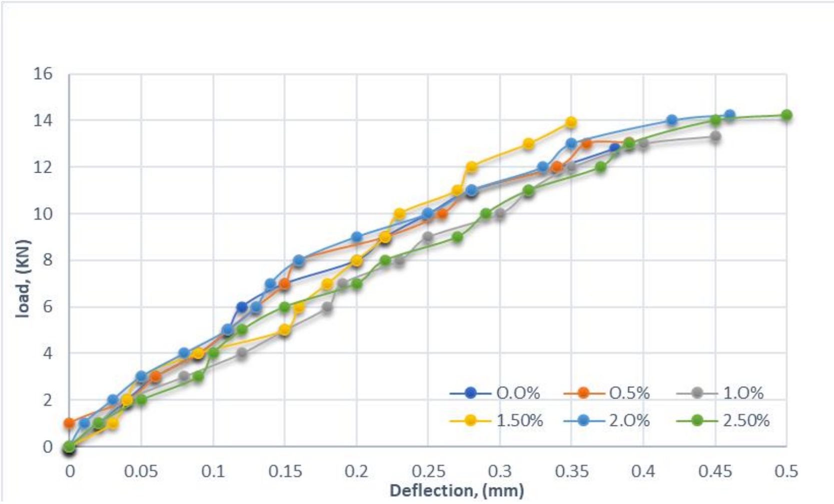

Figure 8 Variation of 7 days central deflection concerning flexural load (0%-2.5%)

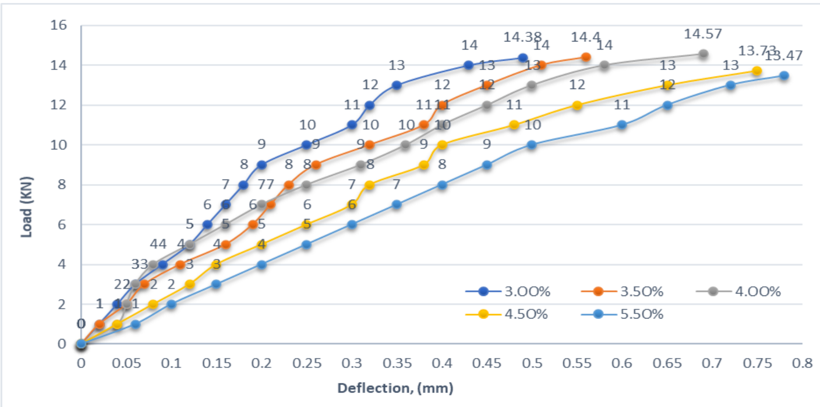

Figure 9 Variation of 7days central deflection concerning flexural load (3%-5%)

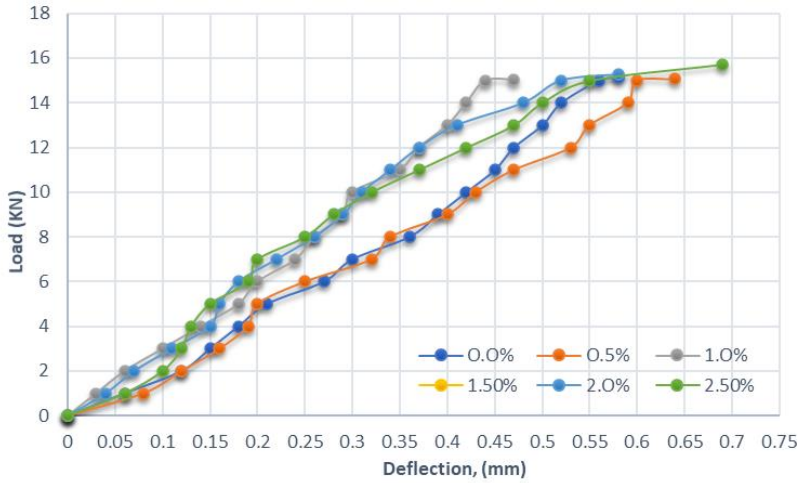

Figure 10 Variation of 28 days central deflection concerning flexural load

5. Discussion

5.1 Workability

The slump cone test is used to analyze the workability of fresh concrete mix. The need to carry out this test is to determine the behavior of concrete. Workability is measured in terms of the slump. Results from Table 10 indicate that for the same mix proportion and Super Plasticizer dose with the same aspect ratio, the workability is reduced up to 58.33 % with the increase in fiber volume fraction and the stone dust. The wet density of concrete is found to decrease with an increase in fiber content. The maximum decrease in wet density is observed at 5 % V_f by 7.67 % over standard concrete. The density of hardened concrete is also reduced by 3.65 % at seven days and 6.50 % at 28 days compared to standard concrete. The decrease in wet and dry densities with increased fiber volume fractions may be attributed to the increase in the entrapped air due to the incorporation of high fiber volume fractions. Table 10 shows that as the fiber factor increases, the workability decreases while slump and density loss increase due to the rise in entrapped air percentage in FRC.

5.2 Compressive strength

Results of compressive strength are shown in Table 11 Compressive strength variation over standard concrete. It indicates the optimum volume fraction of fibers which gives maximum strength at 28 days, is 3.0%. The percentage increase in strength at this volume fraction of fibers over standard concrete at 7 and 28 days is 20.68% and 6.15%, respectively. Cracks occur in the microstructure of concrete, and fibers reduce the crack formation and propagation. After optimum level, there is a drop in compressive strength which indicates air entrapment in the concrete due to the incorporation of high fiber volume fraction.

5.3 Flexural strength

Table 12 shows that the flexural strength increases with increased fiber content up to 4.0%, and then it decreases. The maximum values at 7 and 28 days are 5.83 and 7.01, respectively. Flexural strength increases from 2.03% to 13.80% for 7 days and from 0.88% to 15.86 % at 28 days. The seven days and 28 days variation of flexural strength concerning fiber content is presented in Fibers are usually used in concrete to control cracking due to plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce the bleeding of water. Some types of fibers produce a more significant impact, abrasion, and shatter resistance in concrete.

Conclusion

This study presents a summary of the present study; the significant conclusions and future scope of the investigation are:

The following conclusion is drawn based on the result

1. The study's objective was satisfied; workability decreases with an increase in fiber content due to stone dust.
2. The wet and dry density (7 and 28 Days) decreases as the percentage of fiber volume fraction increases.
3. The maximum percentage increase in compressive strength of concrete is 20.685% and 6.155% for 7 and 28 days, whereas flexural strength increases by 12.340% and 02.643% for 7 and 28 days, respectively.
4. The study shows post cracking behavior of concrete was improved by the use of stone dust.
5. Partly contributed to the enhancement of compressive strength of concrete
6. The study shows that as the beam is subjected to two-point loading, Reduction in sudden failure due to the use of steel fiber, which forms a matrix inside the concrete that prohibits the dispersion of concrete particles.

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