

Bond Strength of Steel Fibre Reinforced Black Marble Stone Aggregate Concrete

N.Venkata Ramana

Department of Civil Engineering, University B.D.T College of Engineering, Davangere, Karnataka (State), India

ABSTRACT: In general granite aggregate is used for construction works. Though IS 383-1970 code specifies the use other aggregate for construction works, but it was rare in reality. In this connection the experimental work was planned to utilize the black marble stone waste as coarse aggregate. In order to know the compressive and pull out bond strengths behaviour of marble stone aggregate concrete, cube specimens were cast with steel crimped fibres and black stone marble aggregate at various replacements. Fifteen mixtures were taken with different percentages of black marble stone aggregates (0, 25, 50, 75 and 100%) and different percentages of crimped steel fibres (0, 1 and 2%). The cubes were tested for compressive and bond strengths. The results provided significant information about the strengths and it is observed that as the percentage of steel fibres increases in the mix the strengths are increased and also noticed that, with increase in the black stone waste aggregate in the concrete mixes the strengths were decreased.

KEYWORDS: Black marble stone aggregate concrete, pull-out strength, compressive strength, crimped steel fibre, failure analysis

I. INTRODUCTION

South India is rich in black marble layered stones and more than two-third of India's production of limestone comes from five states (Madhya Pradesh, Rajasthan, Andhra Pradesh, Gujarat and Chhattisgarh). Specially, Andhra Pradesh, accounting for 15.00 per cent of the total black stone production and it is the third largest producer of black marble stone in India. Commercial grade black stone layered deposits are being exploiting from Bethamcherla, Macherla, Neereducherla, Tandur, (shahabad), Kurnool, Guntur, Anantapur, Rangareddy, and Nalgonda districts of Andhra Pradesh state and these are widely used in our country for panelling, and flooring purposes. The peoples who are living in these locations are not ready to use of next quality material or waste materials, such as black marble stone were quartzite etc. as replacement of natural granite aggregate in construction works. Hence, the need of detailed experimental work on black marble stone aggregate concrete and is become very imperative to encourage the people to use it in construction works. Past few decades, the concrete industry has not utilized black marble stone waste as alternative for natural aggregates. Among the significant developments in concrete technologies during the last decades, fibre reinforced concrete (FRC) has been one of the most relevant fields for research. Hence herein it is planned to know the behaviour of black marble stone waste aggregate as replacement to natural aggregate along with the steel fibres in compressive and bond strengths. In this connection recent past review is presented below to know the status of work has been performed in this area.

HanifiBiniciet.al [1] studied the mechanical properties of concrete containing marble and lime dust. The results showed that abrasion resistance was increased as the rate of marble and lime dust increased and also there was an increase in sodium sulphate resistance. BaharDemir et.al [2] was suggested that the use of waste stone dust as fine aggregate in concrete production is increases the results of compressive strength, ultra pulse velocity and dynamic modulus of elasticity. Shirule et.al [3] studied the replacement of cement with marble dust powder in concrete. The results showed that the 10% replacement by weight of cement increases the compressive strength of cube and also reported that replacement beyond 10% is in effective to compressive strength. Elham Khalizadeh Shirazi et.al [4] suggested that that the substitution of 5% of fine aggregates by stone waste caused higher compressive strength than the control specimens. Ali Ergun [5] studied the granite powder has good effect on the mechanical properties of concrete. Hebhoud et.al [6] conducted the experimental work on concrete. He has chosen the marble aggregate as coarse aggregate. The results showed that use of marble aggregate up to 70% of any formulation is beneficial for the concrete

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Vol. 6, Issue 8, August 2017

resistance. Karaca and EBMSCi[7] were investigated the opportunity and feasibility of using four marbles, two black marble stone, two travertine and two granite types that are being quarried in Turkey as coarse aggregate. The properties such as oven dry density, porosity, water absorption, uniaxial compressive strength, loss angeles abrasion etc were carried on four types of aggregates. The results showed that waste of dolomite marble and limestone are more suitable for concrete works. For green world and the continuous able natural sources the waste stone use in concrete industry is feasible. Raafat El Hacha et.al[8] studied the bond characteristics of high strength steel reinforcement. They have derived few models and compared with ACI codal provisions. Shih Ho Chao et.al [9] investigated the influence of strain softening and strain hardening fibre reinforced cementations composites on the bond strength and the bond slip response of deformed reinforcing bars and the study revealed that bridging effect provided by the fibres in FRC composites. Maria Teresa Gomes Barbosa and Souza Sanchez Filho [10] conducted pull out tests of Brazilians steel with different grades of concretes and for different diameter of bars. They noticed the bond slip and strengths for their test. Few models are developed and compared with CEB provisions. Ismaeel H Musa Albarwary and James H Haido [11] did the experimental work to evaluate the bond strengths on concrete using steel bars of polluted with oil. The results showed as the pollution of steel bars with oil does not affect their bond strength, if the embedded length of the bars is increased and their diameters increased. Sureshbabu and Job Thomas [12] made investigations to evaluate bond characteristics of deformed steel bars in concrete containing manufactured sand as fine aggregate. The results showed as the bond strength is superior for manufactured sand concrete when compared with river sand concrete. Appa Rao [13] studied the influence of embedment length, bar diameter and lateral confinement on the end anchorage bond strength and also studied the bond stress slip response. Vinothini M et.al [14] conducted experimental invitation on geopolymer concrete to study the bond strength behaviour and the study reported that the bond strength of reinforcing bar decreases with increasing the embedment length. Annaduarai and Ravichandran [15] studied the flexural behaviour of high strength concrete using hooked steel fibres, polyolefin straight fibres and the results reviewed that the hybrid fibres shown good results in flexure compared to conventional concrete without fibres and steel fibre reinforced high strength concrete specimens. From the above it came to know that a little work has been taken place on black marble stone waste aggregate. But no work has taken place on bond behaviour of black stone waste aggregate along with the steel fibres. Hence an experimental work was planned to study the behaviour and detailed text programme is presenting below.

II. TEST PROGRAMME

To evaluate the compressive and bond strengths, a total of 90 standard cubes were cast with different percentages of black marble stone aggregates (0, 25, 50, 75 and 100%) and different percentages of crimped steel fibres (0, 1 and 2%). The detailed text program is presented in Table 1. The relative proportions of cement, coarse aggregate, sand and water are obtained by IS - Code method. M30 is considered as the reference mix. The parameters in the present experimental work are percentage of black marble stone aggregate (0, 25, 50, 75 and 100%) and Percentage of Crimped Steel Fibre (0, 1 and 2%).

Table 1: Test Program

S.No	Percentage of black marble stone aggregate	% of Fibres			Type of test conducted
		0%	1%	2%	
1	0	3	3	3	Compression test
2	25	3	3	3	Compression test
3	50	3	3	3	Compression test
4	75	3	3	3	Compression test
5	100	3	3	3	Compression test

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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Vol. 6, Issue 8, August 2017

6	0	3	3	3	Pull out test
7	25	3	3	3	Pull out test
8	50	3	3	3	Pull out test
9	75	3	3	3	Pull out test
10	100	3	3	3	Pull out test

III.MATERIALS USED FOR EXPERIMENTAL WORK

Cement: Ordinary Portland cement of 53 grade confirming to IS 8112-1989 standards was used to cast the specimens. The specific gravity of cement was noticed as 3.05.

Fine aggregate: River sand from local sources was used as fine aggregate and specific gravity of sand was observed as 2.70.

Natural Coarse Aggregate: Crushed natural granite aggregate from local crusher has been used and which has maximum size of 20mm .The specific gravity of coarse aggregate was observed as 2.75.

Black marble stone aggregate: The black marble stone aggregate was obtained from stone polishing industries. To convert the waste as coarse aggregate the waste material was transported to crusher unit and made as 20.00 and 12.5mm aggregate. To obtain a reasonably good grading, 50% of the aggregate passing through 20 mm I.S. sieve and retained on 12.5mm I.S. Sieve and 50% of the aggregate passing through 12.5mm I.S. Sieve and retained on 10 mm I.S. Sieve is used. The specific gravity of the combined aggregate was determined as 2.68.

Water: Clean fresh water was used for mixing and curing of the specimens.

Steel fibers: In the present investigation crimped round steel fibres supplied by “STEWOLS INDIA (P) LTD, an ISO 9001: 2008 Company” at Nagpur were used. The length and the physical properties of fibre are presented Table 2. The used materials of natural aggregate, black marble stone waste aggregate and fibers can be viewed in the figure 1.

Table 2: Physical Properties of fibre

Length of Fibre	50 mm
Aspect ratio	90
Diameter	0.55 mm
Width	2.5 mm
Tensile Strength	450 M pa
Physical form	Clear, bright and undulated along the length
Material Type	Low Carbon Drawn Flat Wire

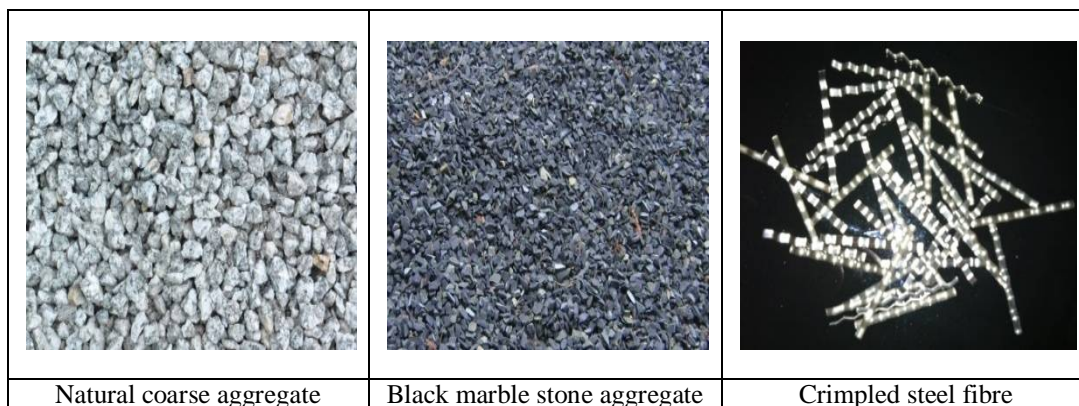


Figure 1: Materials

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Vol. 6, Issue 8, August 2017

IV. PREPARATION AND TESTING OF SPECIMENS

The cubes were cast in steel moulds of inner dimensions of 150 x 150 x 150mm. The cement, sand, coarse aggregate and crimped steel fibres were mixed thoroughly manually. Approximately 25% of water required is added and mixed thoroughly with a view to obtain uniform mix. After that, the balance of 75% of water was added and mixed thoroughly with a view to obtain uniform mix. Care has to be taken in mixing to avoid balling effect. For all test specimens, moulds were kept on table vibrator and the concrete was poured into the moulds in three layers by tamping with a tamping rod and the vibration was effected by table vibrator after filling up moulds. The moulds were removed after twenty four hours and the specimens were kept immersed in water tank. After curing the specimens in water for a period of 28 days the specimens were taken out and allow drying under shade. Later all the specimens were carried to testing.

The compressive strength of the cube was measured at the age of 28 days, by compression testing machine (CTM) having the capacity of 2000KN with a least count of 1kN. The bond strength of the concrete was measured by Universal Testing Machine (UTM) of 60 ton capacity. For each mix six specimens were casted, i.e. three specimens for bond study and three for compressive strength, and tests were conducted according to the relevant IS standards. The HYSD 12 mm bar was embedded vertically along the central axis in each cube specimen for pull out test. The length of embedded in the concrete was provided as 12.5 times of the diameter of bar. This provision was provided for cubes of those are to test for bond stress. Before casting of specimens, the bars were inspected to ensure that they were free from grease, paint or other coating, which could affect their bond. The rust and those scales were removed thoroughly by wire brushing and the proper care was taken to see that the bar was aligned vertically at the time of compaction of concrete.

Among fifteen mixtures, fourteen mixtures we prepared by different percentages of black marble stone aggregate and different percentages of steel fibres and the remaining one was control mixture (NC). To identify the mixtures easily, the each mixture was designated with the names such as NC, BMSC 25, BMSC 50, BMSC 75, BMSC 100. For example BMSC 25 specifies that the concrete mixture made with 25 % replacement of Natural Coarse aggregate by Black marble stone. The results of the samples were noted for individual % of fibre content (i.e. 1% and 2% of fibre).

V. TEST RESULTS AND DISCUSSION

5.1 Workability:

Workability of fresh concrete was measured using compaction factor test and the results are presented (in the form of graph) in the figure.2. The figure 2 explains the effect of black marble stone on the workability of the concrete. It was observed that the compaction factor increase with increase in the % of black marble stone aggregate in the concrete mix. Hankfi Binci et.al(2008) has been also reported same type of result for marble concrete. The increase of workability may be due to lower water absorption and smooth texture surface of Black marble stone aggregate than the granite aggregate.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 8, August 2017

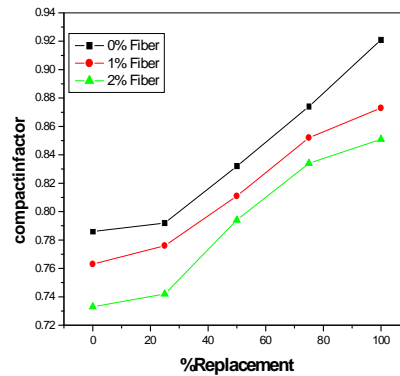


Figure 2: Compaction Factor versus % of replacement of black marble stone aggregate

5.2 Compressive Strength:

The results of the compressive strength tests are presented in Table 3. From this, it can be observed that the 28 days compressive strength decrease with the increase in the percentage of black marble stone up to 100%. For 25% replacement of black marble stone aggregate there is decrease in cube compressive strength by 6.07% over granite aggregate concrete. For 75% replacement level, the compressive strength has decrease by 23.35% when compared with reference concrete. At 100% replacement of black marble stone, the compressive strength has decreased by 29.26% over granite aggregate concrete. This type of observation was observed by Hanfi Binici et.al (2008) for marble concrete. Whereas from present experimental work it was observed that there is continuously decrease in compressive strengths as percentage of black marble stone aggregate increases in concrete mix. This may be due to different surface texture of aggregates. Same pattern observed with incorporation of crimped fibre also. For 1% fibre at 100% replacement of black marble stone, the compressive strength has decreased by 20.17% over granite aggregate concrete. For 2% fibre at 100% replacement of black marble stone, the compressive strength has decreased by 21.90% over granite aggregate concrete. Among the different percentage of steel fibres in the mixes, the 2% fibre dosage shown more strength results compared to other percentage fibres. The compressive strength results are increasing as fibre dosage increases in the concrete mix, this may be due to rule of mixtures and the fibres enhance the energy capacity and also act as Crack Bridge for the matrix.

Table 3: Compressive Strength (MPa)

S.No	Mixture Designation	Average Compressive Strength (N/mm ²)		
		0% Fibre	1% Fibre	2% Fibre
1	NC	45.61 (--)	46.59 (--)	49.4 (--)
2	BMSC 25	42.84 (6.07)	43.2 (7.27)	47.27 (4.31)
3	BMSC 50	38.76 (15.01)	40.67 (12.7)	42.33 (14.31)
4	BMSC 75	34.96 (23.35)	38.99 (16.31)	41.12 (16.76)
5	BMSC 100	32.26 (29.26)	37.19 (20.17)	38.58 (21.9)

Note: The value in () specifies the percentage of strength decreases over that of the plain Concrete.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 8, August 2017

5.3 Bond Strength:

The bond strengths for all mixes were presented in Table 4 and Figure 3. From this, it was observed that the 28 days bond strength decrease with the increase in the percentage of Black marble stone up to 100%. For 25% replacement of Black marble stone aggregate there is decrease in cube bond strength by 15.42% over granite aggregate concrete. For 75% replacement level, the bond strength has decrease by 33.96% when compared with reference concrete. In general the split, bending, shear and bond strengths are correlated to compressive strength results. In the present investigation also this statement holds good, the bond strengths are increasing as the compressive strengths are increasing in the concrete mix (with addition of fibres). Among the 0% of fibre mix, the bond strength is decreasing as the % of black stone waste aggregate is increasing, this may be due to effect of aggregate texture. The black marble stone waste fractured surfaces are not much rough as compared with natural aggregate. As mentioned above the strengths are co-related with compressive strengths hence, herein again the compressive strength discussion placing for better understand to estimate the bond strengths. At 100% replacement of black marble stone, the compressive strength has decreased by 42.00% over granite aggregate concrete. This type of observation was observed by Hanfi Binici et.al (2008) for marble concrete. But Hebhoub et.al (2011) reported in different way for marble concrete. They reported that, at 75% replacement level the strength was enhanced when compared with other replacements and at 100% replacement level there was decrease in compressive strength. Whereas from present experimental work it was observed that there is continuously decrease in compressive strengths as percentage of black marble stone aggregate increases in concrete mix. This may be due to different surface texture of aggregates. Same pattern observed with incorporation of crimped fibre also. For 1% fibre at 100% replacement of black marble stone, the bond strength has decreased by 14.15% over granite aggregate concrete. For 2% fibre at 100% replacement of black marble stone, the compressive strength has decreased by 18.14% over granite aggregate concrete. The bond strengths with 1% of steel fibres at 50%BMS shown a little higher value compared to natural aggregate mix without fibre. Similarly at 2% fibre with 100% BMS the mix has shown more or less same value of natural aggregate mix without fibres. Hence it may conclude that as the % of BMS waste increases in the mix better to use higher dosage of steel fibres to compensate the strength of natural aggregate mix. The bond strengths are increasing as the incorporation fibre dosage increases in the concrete mix. The fibres are keeping the dimensionality stability for the test specimens and the mix with higher percentage of fibres shown lesser crack width.

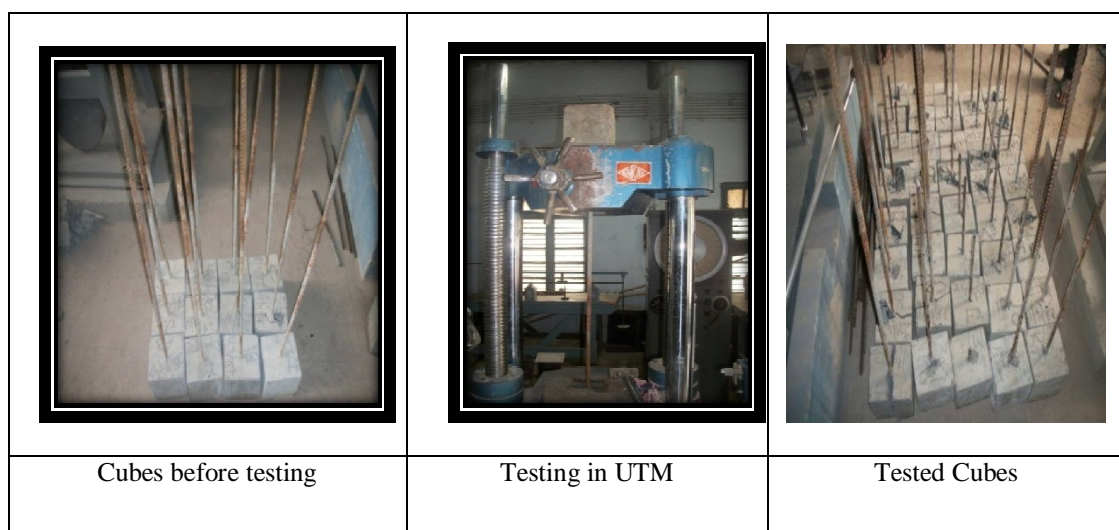


Figure 3: Cubes testing for Bond strength

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

Table 4: Bond Strength of black marble stone aggregate concrete

Sl. No	Nomenclature	0% Fiber		1% Fiber		2% Fiber	
		Ultimate Pullout load (kN)	Average Bond stress (N/mm ²)	ultimate Pullout load (kN)	Average Bond stress (N/mm ²)	Ultimate Pullout load (kN)	Average Bond stress (N/mm ²)
1	NC 1	70.00	12.19	77.50	13.14	87.50	14.11
2	NC 2	72.00		71.50		75.50	
3	NC 3	65.00		74.00		76.50	
4	BMSC 1-25	60.00	10.31	73.50	12.84	73.50	13.56
5	BMSC 2-25	59.50		73.50		78.50	
6	BMSC 3-25	55.50		71.00		78.00	
7	BMSC 1-50	51.00	9.34	67.00	12.30	74.00	12.67
8	BMSC 2-50	58.00		69.50		69.50	
9	BMSC 3-50	49.50		72.00		71.50	
10	BMSC 1-75	40.50	8.05	65.50	12.11	65.00	12.23
11	BMSC 2-75	50.50		72.00		72.00	
12	BMSC 3-75	45.50		68.00		70.50	
13	BMSC 1-100	42.50	7.07	64.00	11.28	65.00	11.55
14	BMSC 2-100	32.50		68.00		63.00	
15	BMSC 3-100	45.00		59.50		68.00	

5.4 Calculation of Average Bond stress:

For calculating average bond stress at the interface, the bond stress variation along the embedment was considered as constant. The bond stress is calculated using the following formula and the obtained results are presented in Table 4.

$$\text{Average bond stress} = \frac{P}{\pi dl}$$

Where,

P = force in the bar (N), d = diameter of the bar (mm), l = embedded length (mm)

In this investigation, the diameter of the steel bar (d) is 12mm, with embedded length (l) being 150mm. The sample calculations for natural aggregate with different percentage of fiber were presented below.

$$\text{Average bond stress} = \frac{70000}{\pi * 12 * 150} = 12.37 \text{ N/mm}^2 \text{ for 0\% fiber}$$

$$\text{Average bond stress} = \frac{77500}{\pi * 12 * 150} = 13.70 \text{ N/mm}^2 \text{ for 1\% fiber}$$

$$\text{Average bond stress} = \frac{87500}{\pi * 12 * 150} = 15.47 \text{ N/mm}^2 \text{ for 2\% fiber}$$

In similar way for each cube specimen the average bond stress calculated and average of three cubes values are depicted in Table 4.

5.5 Failure Mode Analysis:

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 8, August 2017

a) Compression Test: For all cubes compression test was conducted. The 0% fibres concrete cubes were shown lower load when compared with cubes containing with 1 and 2%. Among the 1 and 2% fibre cubes the cubes with 2% showed higher load carrying capacity. In 0% fibre cubes the concrete was peel off at edges this can be viewed in the figure 4, where as the cubes containing fibres showed there is no peel off and as percentage of fibre increases the crack with and less damage was observed during experimentation. It can observe in figure 5 and figure 6.

b) Bond Test: For each mix three cubes were tested for Pullout strength. The pullout test setup can be viewed in Figure 8. From figure 7 to 9 it can observe the modes of bond failures in the Pull out test. Three different types of failures such as the yielding of steel reinforcement, pullout of reinforcing and the splitting of cover concrete were observed in the specimens during experimentation. The cubes with 0% fibre were shown in the, pullout of steel bar from the concrete cube and for steel fibres cubes the failure pattern is splitting failure. (i.e. there is no pullout of bar from the concrete cube). The bond stresses for steel fibre concrete cubes were shown more values than the concrete cubes without steel fibres



Figure 4: Cubes testing for compressive strength (0% fibre)

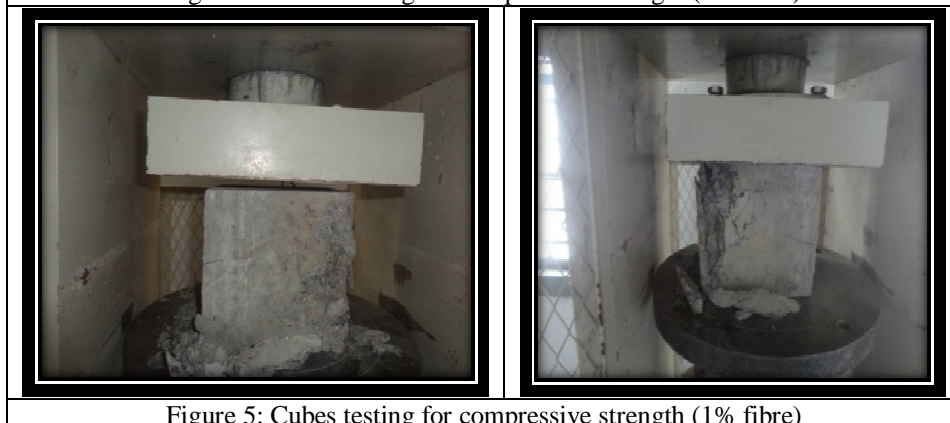


Figure 5: Cubes testing for compressive strength (1% fibre)

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 8, August 2017



Figure 6: Cubes testing for compressive strength (2% fibre)



Figure 7: Failure mode of cube using 0% fibre (Pullout)

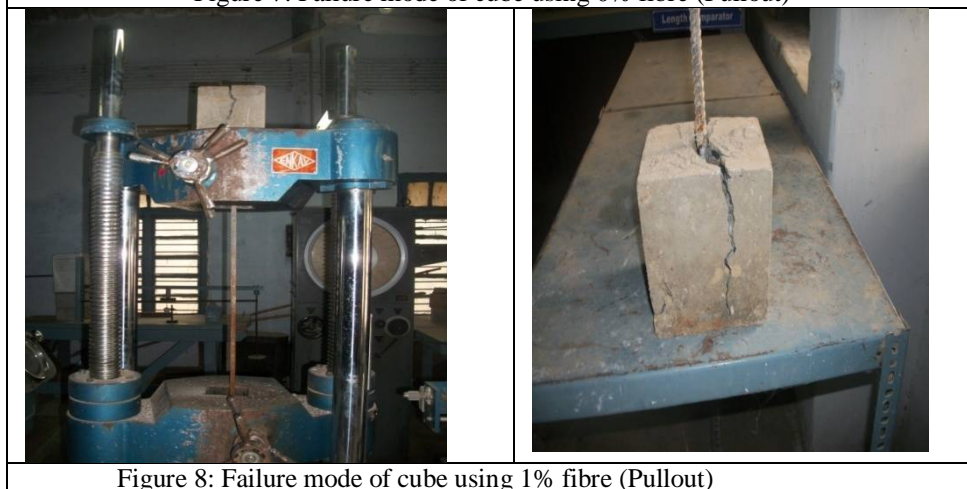


Figure 8: Failure mode of cube using 1% fibre (Pullout)

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 8, August 2017

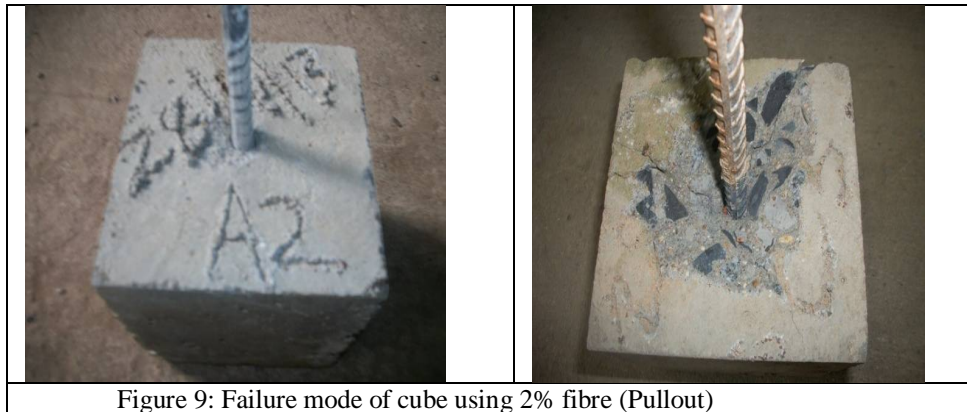


Figure 9: Failure mode of cube using 2% fibre (Pullout)

VI.CONCLUSION

The following conclusions are drawn from the present study.

1. The workability for black marble stone aggregate concrete mix is increases when compared with granite aggregate concrete.
2. The bond strength was decreased with increase the Black marble stone aggregate in the concrete mix.
3. The incorporation of Black marble stone up to 75% is beneficial for the concrete works.
4. The failure modes are similar for both Black marble stone and granite aggregate concrete.
5. The compressive and bond strengths are increasing as % of steel fibre increasing in the concrete mixes
6. The use of Black marble stone aggregate for concrete works is demonstrated in bond strength and compressive strengths
7. The mix with 75% BMS and 1% fibre and also the mix with 100% BMS along with 2% fibres is effective and shown similar results of natural aggregate concrete mix.
8. This study could enlighten the local peoples to use of limestone aggregate for concrete works (minor works at initial stages).

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