Scientific Journal of Impact Factor (SJIF): 4.72

e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 8, August -2017

Utilization of Black Marble Stone Waste for Concrete Works

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Abstract- *This paper presents the value creation opportunity of black marble stone waste as fine aggregate in the concrete mix. Five concrete mixes are prepared by replacing the natural sand with stone waste as fine aggregate in the ratio of 0%, 25%, 50%, 75% and 100% by weight. The experimental study is focused to evaluate the properties of compressive and split tensile strengths. The strengths were compared with ACI 318-M-11 and GB50010-2002 codes. From the results it is noticed that, the codes are underestimates the real strengths. Hence a regression model was developed to estimate the results and also microscopic analysis was carried out to using SEM analysis. SAP-2000 analysis was performed to obtain the stress variation in the concrete cube. From the results is observed that, the black marble stone waste can be used up to 75% replacement of fine aggregate (natural sand) without affecting the desirable strength.*

Keywords- *Black Marble Stone Waste (BMS), Compressive Strength, Split Tensile Strength, SEM analysis, Regression Model, SAP analysis.*

1. INTRODUCTION

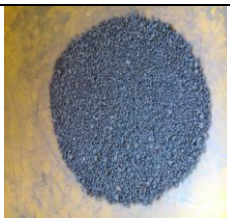
The Conventional concrete is a combination of cement, coarse aggregate and sand. Aggregates play an extremely critical role in the concrete mix. Durability and also the performance of concrete primarily rely on the characteristics of aggregates and the fine aggregate is an indispensable component of concrete mix. River sand is normally utilized as fine aggregate in the concrete mix for construction works. In general aggregates (course and fine) occupy 75-80% of volume of concrete mix. Hence, it is significant to acquire right and good quality type of aggregates at location. The usage of natural sand is quite high demand in India due to the fast infrastructural growth. From this, at present the public facing deficiency to procure good quality of fine aggregate. Now a day's due to lack rain fed, the regular sand layer deposits are being exhausting and inflicting severe hazard to surroundings as well as the public. Increasing exploitation of ordinary sand from stream beds causing serious issues like losing water holding sand layers, extending of the stream ways and inflicting bank slides, damage to plant life on the sides of waterways, disruption to the marine life. In the past decade variable expense of natural sand used as fine aggregate in concrete has expanded the cost of construction many folds.

Due to demand in the building industry the price of sand is also increasing. In this situation scrutiny as started for inexpensive and easily accessible alternate material to sand. Certain materials have previously been utilized as a part of natural sand. Fly-ash, slag, manufactured sand; stone powder waste and siliceous stone powder were used in concrete mix as a full and partial replacement of ordinary sand. However, insufficiency in required characteristic feature is the major restriction in the above mentioned materials. At present sustainable infrastructural development demands the alternate material that ought to fulfil the technical requisites of fine aggregate and at the same time it should be available abundantly. In the regard the recent past literature is presenting here in. Nagabhushana et.al, [1] conducted the experimental work on utilization of crushed rock powder as replacement of fine aggregate in mortar and concrete. From their investigation they found that up to 40% replacement of sand by crushed rock powder is more effective without reduction in strength. Lohani et.al, [2] carried an experimental investigation on optimum utilization of quarry dust as partial replacement of sand in concrete From their study it is observed that the optimum utilization of quarry powder that can be replaced is up to 30% is more effective. Omar et.al, [3] studied on the impact of limestone waste as partial replacement material for sand and marble powder in concrete properties. From the results they observed that up to 50% replacement the compressive strength is increasing. Divakar et.al,[4] conducted investigation on performance of concrete with use of granite fines. From the entire test data's it was found that the overall increase in strength was achieved by replacing the fine aggregate with the granite fines up to 35%. Seeni et.al,[5] conducted an experimental work on partial replacement of sand with waste material from china clay. The outcomes showed that replacing sand by the industrial waste up to 30% induced greater compressive, flexural and split tensile strength. Sakthivel et.al, [6] conducted a research work on innovative method of replacing river sand by quarry dust waste in concrete for sustainability. On investigation, they observed that the partial substitute for fine with 10% of quarry dust has shown the optimal results. Chandana Sukesh et.al,[7] concentrated on the research work on partial replacement of sand with quarry dust in concrete. The concrete workability decreases as the quarry dust content increases because of more concentration of water. In their work they suggested that up to 55 to 75 % of quarry dust can be replaced in case of compressive strength. Furthermore increasing the proportion of replacement can be made helpful by addition of fly ash along with the stone dust to achieve 100% replacement for sand. Nataraja et.al, [8] concentrated on use of granulated blast furnace slag as fine aggregate in mortar. The test data's obtained showed that, the mortar compressive strength increases with increase in the level of GBFS content. They recommend that GBFS can be utilized as an alternate material to sand up to 75% from the fact of strength. Sohail et.al, [9] reported the concrete properties by replacing sand with waste foundry sand.From their interpretations they suggested that foundry sand can be utilized in concrete up to 70% replacement is suitable in the building works. Rachana et.al, [10] conducted an experimental investigation on robo-sand as replacement material of fine aggregate in normal concrete. From the investigational results 50% of fine aggregate can be replaced with robo-sand. For economical constructions 100% of robo-sand can be adopted for flexure strength. For 75% of robo-sand replacement better compressive strength is obtained than that of normal concrete. Sandeep Kumar Singh et.al, [11] conducted an experimental investigation on stone dust as partial replacement of fine aggregate in concrete. From the test results they confirmed that use of stone dust as an alternative material for the fine aggregate does not affect the compressive strength up to replacement level of 40%. Adanagouda et.al,[12] carried out an experimental study on properties of concrete for replacement of sand by stone waste for different types of cement with chemical admixture. They suggested that up to 30% replacement level is effective in concrete. Roshan Lal et.al, [13] attempted to make an experimental investigation on mechanical properties of waste marble powder concrete. From their study, they suggested that the partial replacement up to 20% is more effective for fine aggregate. From the recent past literature is noticed that the black marble stone waste is not used as fine aggregate in the concrete mix. Hence an attempt made here to evaluate the compressive and split tensile strength properties.

II. RESEARCH SIGNIFICANCE

The purpose of this work is to make use of black marble stone waste as an alternate material to replace the fine aggregate and to assess the performance of the concrete in terms of strengths for construction purpose. The utilization of alternative material as a source of replacement for fine aggregate in the preparation of new concrete has become more common in recent past. The expanding cost of landfill and the shortage of natural resources for aggregate, urges for the utilization of other materials as a replacement for fine aggregate. In this inspiration, a ray was focused on the utilization of black marble stone as a fine aggregate for the concrete. It might be an alternative material to replace the fine aggregate in construction. In the present study the stone waste produced from polishing industries and mines was taken for the present experimental work. Geographically, this stone is available in Kurnool, Kadapa and Anantapur districts of Andhra Pradesh (A.P) state. For present experimental work the stone waste is collected from polishing industries, which were located at Tadipatri (town) in Anantapur (Dist). The black stone is extracted as layers from quarries to make them in to finished products. Mainly the black layered stone is used for flooring purpose and also for some other usages like sink, sitting chairs etc. During the process of finished product, waste is generating. The local people this waste is using for land filling and construction purpose of pavements. For the present experimental work the stone waste is crushed up to size of fine aggregate and this is used as replacement of natural sand in the concrete. The process of getting the material is shown in Table 1.

Table 1: Conversion of waste marble stone in to fine aggregate

			
Marblae Mine	**Waste genration during polishing**	**Crusher**	**Fine aggregate**

III.OBJECTIVES AND METHODOLOGY

The purpose of this research study is to replace the fine aggregate with black marble stone waste in different percentage for the concrete works. To know the performance of concrete, the sand is replaced with the black marble stone waste in the proportion of 0, 25, 50, 75 and 100%. For all the replacement mixes, M20 grade mix design is adopted. During the process of mix design the following data was considered and this data obtained from the tests conducted in the laboratory.

Data for mix design.

- Specific gravity of Cement (G_c) = 3.12
- Normal Consistency of Cement (%) = 32%
- Initial Setting time of Cement (min) = 45 min
- Final Setting time of Cement (min) = 372 min

- Specific gravity of FA (G_{fa}) = 2.58
- Specific gravity of CA (G_{ca}) = 2.69
- Specific gravity of BMS Waste (G_{bms}) = 2.67
- Specific gravity of water (G_w) = 1.0
- Bulk density of FA (W_{fa}) = 1705 Kg / m^3
- Bulk density of CA (W_{ca}) = 1688 Kg / m^3

The design mix of concrete is carried out as per IS: 10262-2009 provisions. The mix proportion for M20 grade concrete was arrived as 1:1.47:2.57 with water cement ratio of 0.45. After getting the mix proportion, the sand was replaced with black marble stone waste in the above specified proportions. For each mix 9 cubes of size 150 x 150 x 150 mm and 18 cylinders of size 150 mm diameter and 300mm in height were casted for conducting compressive strength test of cube and cylinder and split tensile strength of cylinders. Total 45 cubes and 90 cylinders are cast and tested in the laboratory. The mixing of concrete and testing of cube, cylinder can be observed in Table 2.

Table 2: Concrete mix and testing of cube and cylinder specimens

			
Mixing of concrete	Cube Compression test	Cylinder compression test	Split tensile test

IV. DISCUSSION OF TEST RESULTS

4.1 Cube Compressive Strength

The compressive strength results for all mixes are presented in Table 3 and Fig 1. From those it is observed that as the % of black marble stone waste increases, the compressive strength is decreasing. For Natural aggregate concrete (it may refer as control specimens or reference mix), the compressive strengths (average of three cubes) at 3, 7 and 28 days are 21.91, 25.69 and 30.04MPa respectively. The target mean compressive strength for M20 grade concrete is 26.6MPa. The control specimen shows higher compressive strength at 28 days than the target mean compressive strength. At 3 days, the compressive strength is decreased from 14 to 41% for 25 to 100% replacement of black marble stone waste when compared with the normal or control concrete specimen. At 7 days, the compressive strength is decreased from 8 to 35% for 25 to 100% replacement when compared with the normal concrete specimen. The trend is continued for 28 days strength also. The decrease in compressive strength is about 6 to 40% for 25 to 100% replacement of black marble stone waste.

Initially the mix was designed for M20 grade concrete and it is to be implicit that, the mix should possess a minimum strength of 20MPa. From Fig 1 it is observed that, the design strength line (20MPa) touches the 28 days curve at 75% of replacement of black marble stone waste. From this it is observed that the black marble waste can be used as replacement for the fine aggregate up to 75%.

Table 3: Cube compressive strength

Sl. No	Nomenclature	Average cube compressive strength (MPa)		
		3 Days	7 Days	28 Days
1	NC 0	21.91	25.69	30.04
2	BMC 25	18.67	23.6	27.96
3	BMC 50	16.44	21.29	24.22
4	BMC 75	14.62	18.84	20.31
5	BMC100	12.84	16.53	17.96

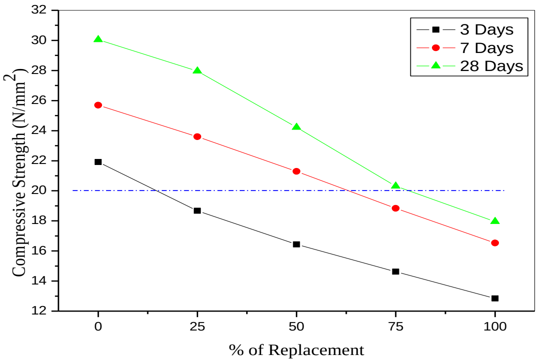


Figure 1: % of Replacement v/s Compressive strength (MPa)

4.2 Cylinder Compressive Strength

The cylinder compressive strength results for all mixes are presented in Table 4 and Fig 2. From them it is observed that, as the % of black marble stone waste increases, the cylinder compressive strength is decreasing. For control specimen, the compressive strengths at 3, 7 and 28 days are 11.99, 17.09 and 22.86MPa respectively. The control specimen show higher compressive strength at 28 days than the minimum compressive strength (i.e.,20 MPa, this value was shown in the figure 2 as dotted lines). At 3 days, the compressive strength is decreased from 11 to 40% for 25 to 100% replacement of black marble stone waste when compared with the normal or control concrete specimen. At 7 days, the compressive strength is decreased from 13 to 36% for 25 to 100% replacement when compared with the normal concrete specimen. The trend is continued for 28 days strength also. The decrease in compressive strength is about 5 to 36% for 25 to 100% replacement of black marble stone waste. To find the cylinder compressive strength of concrete, mixes were prepared with M20 grade. It means that, the mix should possess a minimum cube compressive strength of 20MPa. In general the cylindrical compressive strength is about 70-75% of cube compressive strength, it is due to geometric effect. From the experimental work the cylinder compressive strength for NC 0 (Reference mix) is 22.86 MPa. The average cube compressive strength at 28 days is 30.04 MPa (Table 3), if it is considered to obtain the cylindrical compressive strength, as per the general value it should be in the range of 21.02 (0.70×30.04) to 22.53MPa (0.75×30.04). The experimental cylinder compressive strength is nearly matches at higher end ratio i.e 0.75 times of cube compressive strength.

Table 4: Cylinder compressive strength

Sl. No	Nomenclature	Average cylindrical compressive strength (MPa)		
		3 Days	7 Days	28 Days
1	NC 0	11.99	17.09	22.86
2	BMC 25	10.64	14.83	21.50
3	BMC 50	9.39	13.29	18.67
4	BMC 75	8.38	11.99	15.33
5	BMC100	7.13	10.86	14.59

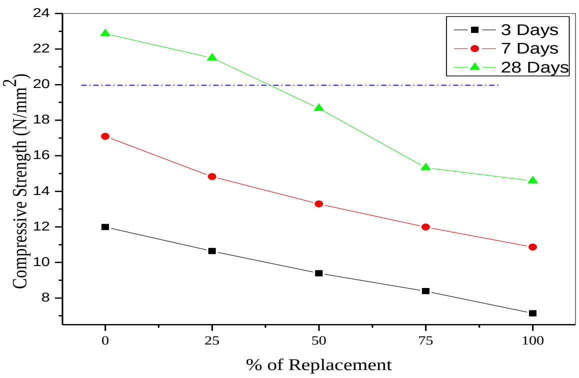


Figure 2: % of Replacement v/s Cylinder compressive strength (MPa)

The ACI-318 M-11 code suggests that the compressive strength of cylinder is 0.76 times of cube compressive strength. The obtained experimental results of cylinder compressive strengths are compared with the ACI code and presented in

Table 5. From this table it is observed that ratio of EXP/ACI is about 0.9 to 1.06. From this it noticed that the ACI result has good compatibility with the experimental results. This statement is also evident with Fig 3. From this it is noticed that, the experimental compressive strength values scattering from 45^0 lines is almost less. This indicates, the ACI code suggested statement holds close agreement with present experimental work.

Table 5: Comparison of experimental cylinder compressive strength with ACI code

Sl. No	Nomenclature	Exp Compressive Strength (MPa)	ACI Value (MPa)	EXP/ACI
1	NC 0	22.86	22.83	1.00
2	BMC 25	21.50	21.24	1.01
3	BMC 50	18.67	18.40	1.01
4	BMC 75	15.33	15.43	0.99
5	BMC100	14.59	13.64	1.06

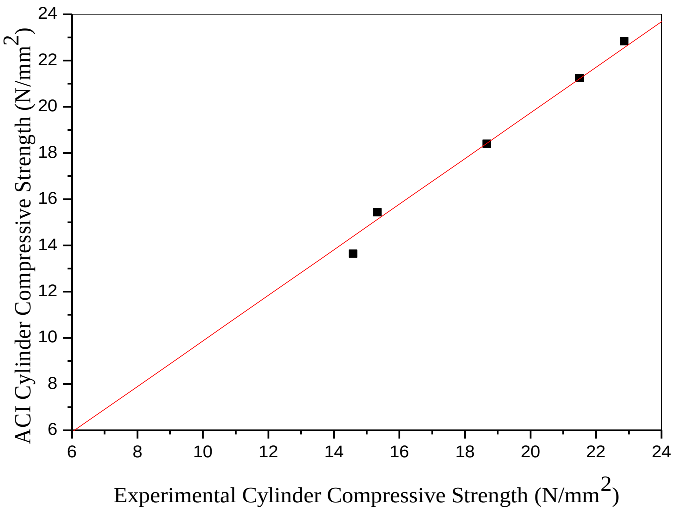


Figure 3: Comparison of Cylinder compressive strength

4.3 Split Tensile Strength of Cylinder

The split tensile strength results are presented in Table 6 and Fig 4. From these results it is observed that as the % of black marble stone waste content increases the tensile strength decreased. For control or reference concrete specimen at 3, 7 and 28 days, the tensile strength is observed as 2.77, 2.99 and 3.44MPa respectively. At 3 days, the tensile strength is decreased from 3 to 27% for 25 to 100% replacement of black marble stone waste content compared to control specimen. At 7 days, the % of decrease in tensile strength is about 4 to 26% for 25 to 100% replacement levels. The % of decrease at 28 days is about 9 to 31% for 25 to 100% replacement of black marble stone waste, when compared with the reference concrete. In over view, the compressive and split tensile strengths were decreased in all the mixes, it may be due to poor bond between the mortar and aggregates. This bond characteristic is studied using SEM analysis.

Table 6: Cylinder split tensile strength

Sl. No	Nomenclature	Average Split Tensile Strength (MPa)		
		3 Days	7 Days	28 Days
1	NC 0	2.77	2.99	3.44
2	BMC 25	2.66	2.87	3.11
3	BMC 50	2.49	2.72	3.04
4	BMC 75	2.21	2.29	2.57
5	BMC100	2.00	2.21	2.35

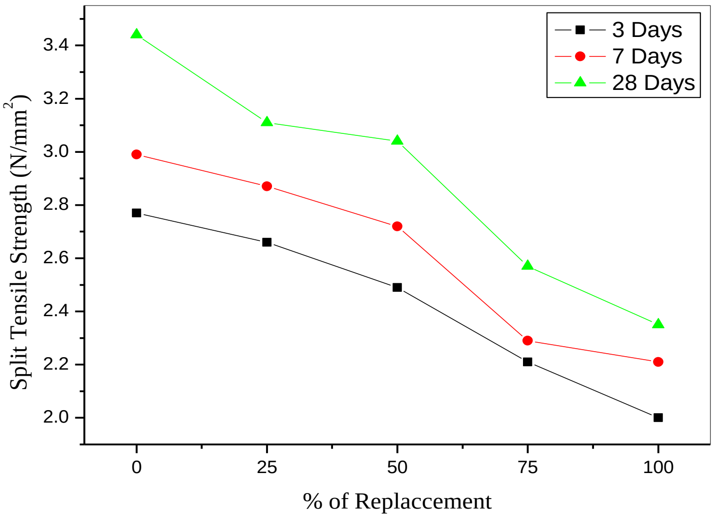


Figure 4: % of Replacement v/s Split Tensile strength of cylinder (MPa)

4.4 Scanning Electron Microscope (SEM) Analysis

A scanning electron microscope (SEM) is used to generate surface images of a specimen on a microscopic level. It does this, by scanning a specimen with a beam of high energy electrons in an optical column. The electrons emitted by the beam then interact with the atomic structure of the specimen and generate topographic images. In our study samples of specimens were exposed to SEM after 28 days of curing. The micro structure of 0, 25, 50, 75 and 100% BMC specimens were studied using SEM images [Fig 5 to 9]. The reference mix SEM image is depicted in Fig 5. It clearly shows that the control mix possesses lower porosity, voids and more packing structure. It illustrates the development of proper and clear C-S-H paste in many phases. The important point to be noted in the micrograph is that the C-S-H pastes i.e. the bright mass with chalky gel portions are spread over the whole aggregates (both coarse and fine) thus acting as binder paste. Fig 6 is micrograph of BMC 25 mix. It shows that the C-S-H paste is not as broadly spread as it was in the control mix, showing little aversion to the binder paste but more significantly the effect of black marble stone waste on the strength because of porosity and voids in the BMC mix compared to control mix. The microstructure also shows the occurrence of black marble stone waste particles of different sizes at different locations. The decrease in strength of BMC 25 specimen is 6.92% compared to control mix. The decrease in strength may be due to the non-formation of proper C-S-H paste as compared to control mix, although, at few places the creation of C-S-H paste could be noticed. The densification of the mixes of BMC 25 is less compared to control mix.

The SEM images for BMC 50 and BMC 75 depicted in Fig 7 & 8. These micrographs show presence of some pores at various places. The reaction or development of C-S-H gel is not good, there by indicating less densification of mixes as related to control mix and BMC 25 mix. The strength of BMC 50 and BMC 75 mixes is decreasing compared to control and BMC 25 mix. The percentage of decrease in strength is about 19.37% and 32.39% respectively.

The SEM image of BMC 100 mix (Fig 8) shows that, the mix has crumbled with coming out of black marble stone waste from the mix. The C-S-H gel could not be seen at many places in the SEM image. The most important implication from the image is that the paste is crumbling, as the equilibrium falls and leads to lower strength.

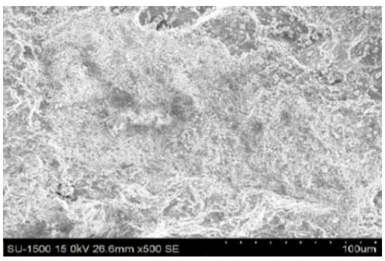


Figure 5: Micrograph of Control mix

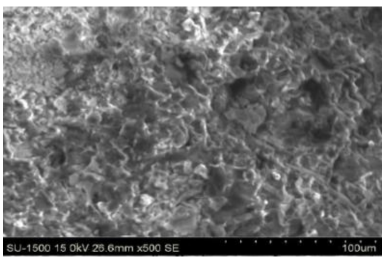


Figure 6: Micrograph of BMC 25% mix

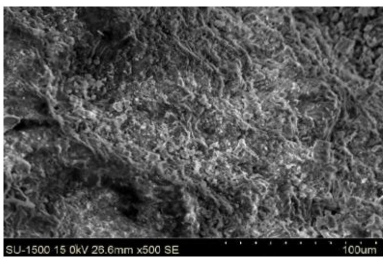


Figure 7: Micrograph of BMC 50% mix

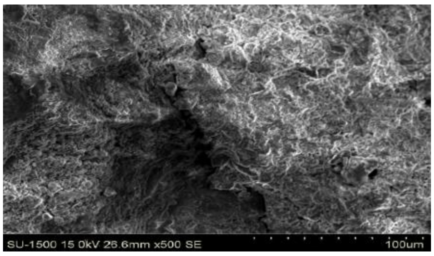


Figure 8: Micrograph of BMC 75%

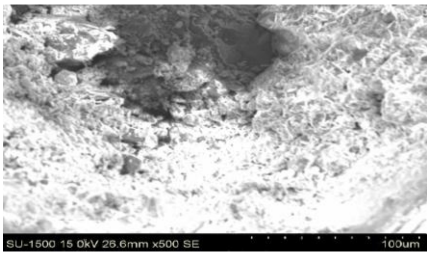


Figure 9: Micrograph of BMC 100%

4.5 Relation between Split Tensile Strength and Cube Compressive Strength

The split tensile strength is often used to obtain the tensile strength of concrete, rather than by a direct tensile strength test, because the former is easier to perform. As per CEB-FIB code it is observed that the direct tensile strength is 0.9 times the split tensile strength of cylinder. In practical applications, the tensile strength of concrete is often estimated from the compressive strength. In the ACI 318-M-11 and Chinese code (GB 50010-2002), the relationship between split and compressive strength for normal concrete, expressed as

$f_{sp} = 0.49\sqrt{f_{ck}}$ As per ACI code

(Note: cylinder compressive strength=0.76 Cube compressive strength)

$f_{sp} = 0.19\,(f_{ck})^{0.75}$ As per GB code

Where

f_{ck} - Cube Compressive Strength (MPa)

f_{sp} - Tensile Strength of concrete (MPa)

By using the above equations the results are given in Table 7. From this table it is observed that the results under estimates for BMC concrete. The ratio of EXP to ACI and GB is varying about 13% to 47%. To improve the above equations, a regression analysis was performed for the obtained test results and the following regression equation is deduced with correlation coefficient R^2 is 0.97964 and Standard Deviation (SD) is 0.14911.

$$\mathbf{f_{sp} = 0.596\sqrt{f_{ck}}}$$

Where

f_{ck} - Cube Compressive Strength (MPa)

f_{sp} - Tensile Strength of concrete (MPa

Comparison between the test results and that predicted by proposed equation is presented in Table 8 and Fig 10. From those it is observed that, the ratio between EXP/RM is about 0.9 to 1.05. From this it noticed that the proposed equation has good agreement with the experimental results.

Table 7: Comparison of experimental split tensile strength with ACI and GB codes

S.No	Nomenclature	Exp Split Tensile Strength (MPa)	ACI (MPa)	GB (MPa)	EXP/ACI	EXP/GB
1	NC 0	3.44	2.69	2.44	1.28	1.41
2	BMC 25	3.11	2.59	2.31	1.20	1.35
3	BMC 50	3.04	2.41	2.07	1.26	1.47
4	BMC 75	2.57	2.21	1.82	1.16	1.41
5	BMC100	2.35	2.08	1.66	1.13	1.42

Table 8: Regression model performance for split tensile strength

S.No	Nomenclature	Exp Tensile Strength (MPa)	Regression Model (MPa)	Exp Split Tensile Strength / Regression Model
1	NC 0	3.44	3.27	1.05
2	BMC 25	3.11	3.15	0.99
3	BMC 50	3.04	2.93	1.04
4	BMC 75	2.57	2.69	0.96
5	BMC100	2.35	2.53	0.93

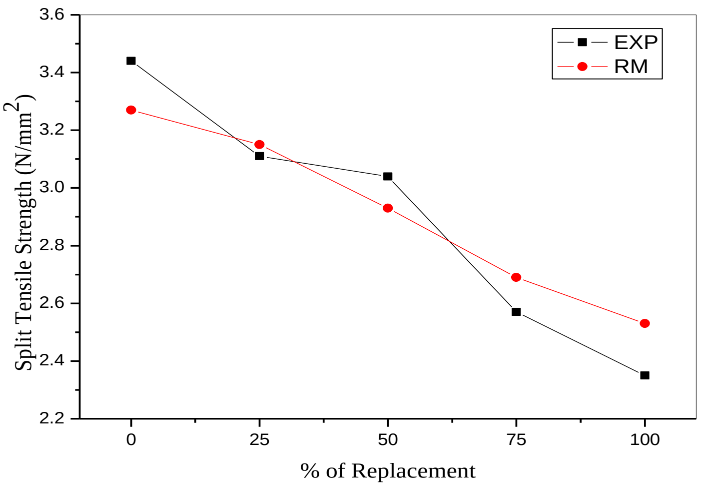


Figure 10: Performance of regression model

4.6 Integral Absolute Error (IAE):

In the above discussion the regression model was deduced to predict the split tensile strength with respect to compressive strengh of cube. The performance of regression model is checked with realiability based Intergral Absolute Error (IAE). The IAE equation is given below and this Index was used by Gardner[14],Oluokun[15] and Anoglu[16].

$$IAE = \sum \{[(E_i-P_i)^2]^{1/2}\} \times 100 / \sum E_i$$

Where E_i is the experimental value and P_i is the predicted value obtained from the regression equation. The IAE measures the relative deviations of results from the regression model equation. When the IAE is zero, the predicted values are equivalent to the experimental values; this circumstance rarely occurs. When comparing different equations, the regression equation having least value of the IAE can be judged as the most reliable. A range of the IAE from 0 to 10% may be considered as the limits for an acceptable regression equation. The value of IAE computed for the developed regression equation and is found as 4.27% (Table 9).This value reveals that, is in good agreement with the suggested range value of 0 to 10%.

Table 9 : IAE value for proposed regression model

Nomenclature	**Exp Tensile Strength (E_i)**	**RM (P_i)**	**$[(E_i-P_i)^2]^{1/2}$**
NC 0	3.44	3.27	0.17
BMC 25	3.11	3.15	0.04
BMC 50	3.04	2.93	0.11
BMC 75	2.57	2.69	0.12
BMC100	2.35	2.53	0.18
	$\sum$ **E_i**= 14.51		$\sum$ **$[(E_i-P_i)^2]^{1/2}$** = 0.62

$$IAE = \sum \{[(E_i-P_i)^2]^{1/2}\} \times 100 / \sum E_i = (0.62/14.51)100 = 4.27\%$$

4.7 SAP Analysis

FEA involves of a computer model of design i.e. stressed and analyzed for detailed results. For analysis of cubes SAP 2000 software is used and results are obtained for each specimen (For 28 days cubes only) which are presented in the Table 10. SAP2000 is complete finite-element based structural database for the analysis & design of civil structures. It offers a natural, however effective program with user interface with several tools to support in the quick and precise model constructions, along with the sophisticated logical methods desirable to do the difficult projects.The direct stress and shear stresses are obtained for all the cube specimens i.e. for NC 0, BMC 25, 50, 75 and 100 mixes. Herein as per representation of different stresses, the S33 values are considered as compressive stresses. From the experimental work, it was concluded that, the black stone marble waste can be used up to 75% as replacement to fine aggregate. Hence here the direct stress (compressive) value for BMC 75 mix is the average direct stress value obtained is 18.28MPa. The IS: 456-2000 code has correlated the various strengths of concrete (flexure, shear, and torsion) with cube compressive strength. Hence the SAP-2000 analysis is carried here in for concrete cube only. After performing the analysis for each cube specimen the results are presented in Table 10. From this it is noticed that the experimental and SAP analysis results are varied about 11%. The compressive stress and deformation shape pattern for NC 0 can be viewed from Fig 11. But during experimentation the displacements are not noticed due to limitations of technical instruments. However this was done in SAP analysis. During experimentation the cube and cylinder are failed by peel off the concrete mass at various locations and at some places multiple cracks were noticed.

Table 10: Comparison of experimental cube Compressive strength values with SAP analysis

SL No	Nomenclature	Exp Cube Compressive Strength (MPa)	SAP Values (MPa)	EXP/SAP
1	NC 0	30.04	27.04	1.11
2	BMC 25	27.96	25.17	1.11
3	BMC 50	24.22	21.80	1.11
4	BMC 75	20.31	18.30	1.11
5	BMC100	17.96	16.17	1.11

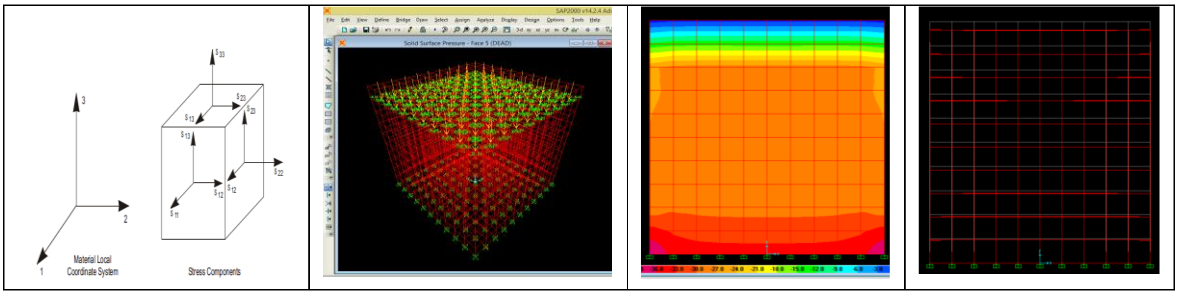


Figure 12: Element stress and deformed shape diagrams for NC 0

V. CONCLUSIONS

From the experimental work the following conclusions are drawn.

1. The studies indicate the viability of using black marble stone waste from the polishing industries as fine aggregates in the preparation of concrete for construction works.
2. As the % of black marble stone waste increases in the concrete mix the compressive and split tensile strengths were decreased.
3. The fraction of fine aggregates can be effectively replaced with a black marble stone waste up to 75% without loss of desirable strengths.
4. The cube compressive strength decreased about 6 to 40% for 25 to 100% black marble stone waste as fine aggregates when compared with normal concrete.
5. The cylinder compressive strength shows that, the strength decreased about 6 to 40% for 25 to 100% black marble stone waste as fine aggregates when compared with normal concrete.
6. The split tensile strength results shows that, as the % of black marble stone waste increases in the concrete mix the strength decreases. The % of decrease is 9 to 31% for 25 to 100% replacement when compared with conventional concrete.
7. The relation between split tensile and compressive strengths given by ACI-318-M11 and GB code are under estimating the experimental results.
8. A regression model is developed between split tensile and compressive strength and it is formulated as $f_{sp}= 0.596\sqrt{f_{ck}}$.
9. Microscope analysis is also carried out using SEM analysis and detailed discussions are presented in the section D.
10. SAP-2000 analysis is carried out on cubes and the results are compared with experimental values. The deviation among them is about 11%.

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