

FLEXURAL STRENGTH OF CONCRETE BLENDED WITH RECYCLED AGGREGATES, MARBLE DUST, AND BAMBOO FIBERS

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Abstract

In this research article combined effect of marble dust and bamboo fiber on flexural strength of recycled aggregate concrete is presented. The recycled aggregate concrete is an effort towards achievement of sustainable development. But its lesser strength is a key issue which can be improved by using additives. Marble dust has good cementous properties, hence is used as partial replacement of cement whereas, bamboo fibers are used as fibrous material in concrete matrix. 1:2:4 mix with water cement ratio equal to 0.5 was used in preparation of the proposed concrete. Marble dust is first optimized using dosage from 2.5% to 15% with increment of 2.5%. total of six batches with three prisms (914.4mm x 152.4mm x 304.8 mm) in each batch were prepared. In all mixes recycled coarse aggregates from demolished concrete and conventional coarse aggregates were used in equal proportion. Comparison of the test result with conventional concrete prisms of same size revealed 10% marble dust as optimum as at this dosage 25% increase in the strength is recorded. In second phase of the work bamboo fibers from 0.25% to 2% with increment of 0.25% along with optimized dosage of marble dust were used in preparing of concrete prisms of same size. Total of eight mixes were prepared. In each mix three prisms were prepared and cured for 28-days. Comparison of the test results showed 1.25% of the bamboo fibers as optimum with 51.5% and 21.2% higher flexural strength than conventional concrete and concrete with marble dust. In both phases the central deflection of the proposed concrete prisms were recorded higher compared to conventional concrete but within allowable limits of ACI. This shows the positive performance of both additives.

INTRODUCTION

In this era of increased urbanization and high-rise construction, the need for long-lasting and eco-friendly building supplies has never been higher than it is now. The composite blend of cement, sand, and aggregates serves as the backbone of structures. But the progress of modern

civilization, however, makes it impossible to ignore the mounting environmental concerns associated with the extraction of natural resources, production of cement and the increased production of garbage. Demolished and construction waste has become a serious

issue around the globe from management and environmental point of views. A possible solution of it is to use it in new construction. Thus, researchers throughout the world are interested in recycled aggregates because of their potential to reduce environmental degradation. It also reduces the waste management burden also. Additionally, it also decreases the load on natural resources. Among the aggregates, coarse aggregates occupy more volume of concrete thus the waste has got more attentions of the research community to be used as coarse aggregates. Various proportions from minimum to total has been attempted by the scholars but the quality of the aggregates and the scatter in the results show clearly that more work is needed in the field of study.

The use of the marble in the infrastructure for beautification has also increased with time. It in turn also generates huge quantum of the waste in quarrying, cutting and shaping. The landfills are often the final resting place for marble waste (dust). The shortage of the landfills poses serious problem of the management of this waste also. The pozzolanic properties of the waste makes it promising sustainable material for cement replacement. Thus, the mechanical characteristics of concrete may be improved and industrial waste reduced if this byproduct were used as a supplemental material in concrete preparation. The research community has also devoted good enough time and effort to study the effect of cement replacement with marble dust. However, the scatter in the results is also evident.

The shortcoming of recycled aggregate concrete particularly with reference to strength may be improved by using additives specially fibers. Various fibers are available for the purpose. Among them bamboo fiber is a naturally fast-growing plant and is locally available everywhere. The growing rate of this fiber is nearly 20 million tons with more than 1000 species. It is light weight and strong. Non-structural use of bamboo can even be seen in scaffolding these days. This fiber has been attempted in concrete by various researchers to enhance the mechanical properties. However, it has a negative of being suspect of termite, fungus and water absorption which

produce decay in it or destroy its bond with concrete. Therefore, normally it is treated against these effects before using in concrete.

This research work therefore, proposes the use of marble dust as cement replacement and bamboo fiber as fibrous reinforcement in recycled aggregate concrete to check their effect on the flexural strength. It is hoped that the finding of the proposed work will help architects, engineers, contractors, and legislators to define the future of the building sector.

1. Literature review

The review of state-of-art relevant to topic of the research not only provides the efforts already made by the research community but also highlights the areas which need more work. In the following the review of the literature relevant to the proposed topic of research is presented.

The recycled aggregates produced from demolished waste has been attempted by several scholars [1]-[5]. The published work with reference to benefits, restrictions and issues has been review by Memon [6] among many others. It is well established that the quality of the aggregates obtained from demolished waste is less compared to the conventional aggregates due to the old mortar attached with the aggregates, age of the demolished building and exposure during service life. Also, the type and dosage of the aggregates has great influence on the final strength of the concrete [7]. Processing techniques of recycled aggregates, basic properties of aggregates, fresh and hardened properties of concrete have been checked by research community [8][9]. Among strength properties flexural strength is the key property which not only controls the deflection of structural members but also ensures proper serviceability of flexural members. The same for concrete using recycled aggregates has been studied by different scholars around the globe [10]-[12]. Except few studies which report flexural strength of recycled aggregate concrete nearly equal to the conventional concrete, rest of the outcome shows reduction. Flexural

behavior of recycled aggregate concrete reported in [13] along with shear and bond slip also report reduced flexural strength. Other than conventional scenario, flexural strength of recycled aggregate concrete under fire has also been studied by Buller et al. for 6-hour [14], 18-hour [15], and 24-hours [16]. In all the research studies authors reported reduced flexural strength due to recycled aggregates and further aggravation due to fire. But demonstrates the effect of both parameters and highlights the remedial measures particularly for rehabilitation. Flexural strength under 12-month long term loading has been studied by Oad et al. [17]. Flexural strength of high strength concrete [18] and no-fines recycled aggregate concrete [19] has also been studied. Despite of good quantum of work in the area of study, the scatter in the results is evident and require more work for better confidence in the use of the material.

Marble dust is by product of marble quarrying, cutting and shaping industry. Its high calcium content and pozzolanic makes it fit for cement replacement [20][21], however total replacement is not feasible. Careful selection of the dosage of marble dust in concrete is key aspect to ensure strength increase. Different studies report different dosage i.e., 25% [22], 15% [23], 10% [25] and 17.5% [26], 7.5% [27], of marble powder as optimum. Ofuyatan et. al. [28] in their research program attempted to optimize the dosage of marble dust based on the compressive and tensile strength of conventional concrete. The authors used 15%, 25% and 35% replacement of sand instead of cement. Using normal mix with 0.5 water cement ratio samples were prepared and cured for 56 days. The laboratory investigation showed the authors that at 25% dosage of marble dust as sand replacement compressive strength increased by 11% and tensile strength by 25%. From this study, it may be observed that the sand replacement by marble waste give better results but other studies on the topic show a different set of results. Faizyab et al. [29] used marble dust as cement

replacement to study the flexural strength and modulus of elasticity. Cement was replaced up to 10% with increment of 2.5%. With equal proportion of conventional and recycled aggregates sample were prepared using normal mix and cured for 28-days. From the laboratory investigations authors observed 12% loss of strength and 5% more deflection at 5% replacement of cement with marble dust. However, the obtained results were better compared to the recycled aggregate concrete. The authors also observed that ACI empirical equation for predicting modulus of elasticity can comfortable be used for recycled aggregate concrete with 5% marble dust. Although, above discussion pertains to selected reference from long list yet the scatter in results for both conventional and recycled aggregate concrete may clearly be observed. Not only the dosage of recycled aggregates and marble dust but also the loss of strength require more work and use of additives to improve the strength at least in line with that of conventional concrete.

Fibers among many other additives are very useful for concrete strength improvement. Fibers act as fibrous reinforcement and provide good bonding between concrete ingredients and help in crack arrest phenomenon. Among, many type of fibers bamboo fibers are one. As stated earlier it is abundant around the world. Thus, has got considerable attention of the research community [30][31]. Authors in [32, 33] reviewed the use of bamboo fibers in concrete highlighting it uses, problems and benefits. The study revealed that the use of bamboo fibers improves the tensile strength and torsional toughness of the concrete. Authors in [34] used bamboo fibers in the dosage of 0.5%, 1%, 1.5%, 2%, and 2.5% to check its influence on compressive and tensile strength. The laboratory investigations on cubes, cylinders, and prism specimens showed 2%, 3% and 19% increase in the compressive, tensile and flexural strengths at the optimum dosage of 2%. Kavitha and Kala [35] used bamboo fibers up to 1.25% with increment of

0.25%. Due to induction of the fiber authors observed 14% loss in workability of normal concrete mix. But 25%, 79.1% and 57.6% increase was recorded in compressive, tensile and flexural strength respectively at optimum dosage of 1%. Kumar et al. [36] in another study also observed 1% as optimum dosage while studying the compressive strength of hollow concrete blocks. To avoid organic degradation of the fiber authors used 10% alcofine to treat the fiber before using in concrete. The study revealed 11.3% increase in compressive strength of the blocks. Bamboo fiber also have been attempted in self-compacting concrete. In this regard Kavitha and Kala [37] used bamboo fibers of 40 mm length up to 1.25% to test the specimens for compressive, tensile and flexural strength of self-compacting concrete and observed 25.21%, 68.3% and 59.2% increase respectively. The optimum dosage was recorded equal to 1%. Asamoah and Osei [38] have also used bamboo fiber in self-compacting concrete but in place of shear reinforcement. The dosage of fiber was 1.5% and 3%. Test results revealed satisfactory shear performance of the concrete beams but with 2.5 times higher deflection than conventional concrete specimens. Bamboo fibers with fly ash [39], polypropylene fiber [40], and e-glass [41] have also been used.

It may be observed from above discussion of relevant state-of-art that many efforts have been made in using recycled aggregates, marble dust and bamboo fibers alone and in conjunction with other materials. Yet not only the dosage of the materials is varying but the scatter in the outcome of strength parameters even at same dosage require more work in the field of study. Therefore, this research work proposes the use of bamboo fibers along with marble dust and recycled coarse aggregates from demolished waste in concrete and to check their effect on the flexural strength.

2. Material and testing

This section describes the details of material and methods used to carry out the proposed

research. Among the ingredients of concrete, ordinary Portland cement sold under brand name Lucky Cement was used. Basic properties of cement, i.e., fineness, consistency, initial and final setting time were evaluated as per ASTM C150[42] and were found within specified limits of the code. Hill sand obtained from approved quarries was used as fine aggregates. To confirm the adequacy of the material water absorption and specific gravity were evaluated and recorded equal to 1.44% and 2.34 respectively. The values fall within the specified range of the relevant code. Further gradation of the material was done following the instructions specified by ASTM C136 [43]. The fineness modulus of the material from sieve analysis results was evaluated equal to 3.84 which specified the material as coarse sand. Following the similar pattern as of fine aggregates, coarse aggregates were also tested for water absorption and specific gravity. The results of the parameters were recorded equal to 1.03% and 2.61 respectively. The water used in concrete should be potable water. To meet the requirement water obtained from city water supply line was checked. The pH value was noted equal to 6.7 confirming the water as potable water. The conventional ingredients of concrete are shown in Figure 1. As the proposed research aims at using the recycled material. Therefore, the recycled coarse aggregates were processed from the large blocks of demolished waste by manual hammering (Figure 2). The maximum size of the aggregates was kept approximately equal to 25 mm. The processed material was washed and sorted for impurities. Followed by sieve analysis of both recycled and conventional coarse aggregates as per ASTM C136 [43]. The water absorption, specific gravity and fineness modulus of recycled aggregates was recorded equal to 2.23%, 1.72 and 5.84 respectively. The fineness modulus of the recycled aggregates was noted 13.1% lower than the fineness modulus of conventional coarse aggregates. The optimized dosage of the recycled aggregates (50%) was used in this

work following the recommendations of Oad et al. [2]. Thus, the equal proportion of conventional and recycled aggregates was used in this research work for all batches of concrete.

Marble dust used in this research work (Figure 3) was obtained from local marble cutting shops. The obtained material was sieved using



Figure 1: Conventional ingredients



Figure 3: Marble dust

Bamboo fibers (Figure 4) used in this work were shredded from locally available bamboo. The moisture content of the bamboo ranged from 38.2% to 13.1% (Bottom to top) with average of 23.6%. Therefore, it was dried under sun for 15-days. The process reduced the average water content to 4.3%. Specific gravity and tensile strength of the fiber was recorded equal to 0.62 and 203.7 MPa. The dosage of the fiber in this work was used from 0.25% to 2% with increment of 0.25% by weight of cement.

2.1 Mix details

As stated above the recycled coarse aggregates from demolished waste and conventional coarse aggregates were used in 50% each. The dosage of marble dust (5%) was used in all the concrete mixes. The bamboo fiber was used from 0.25% to 2% with increment of 0.25%.

#200 sieve to ensure its adequacy for cement replacement [44]. The specific gravity and moisture content of the material were recorded equal to 3.02 and 4.13% respectively. The dosage of the material was adopted equal to 2.5% to 15% with increment of 2.5%.



Figure 2: Recycled aggregates



Figure 4: Bamboo fibers

In all batches 1:2:4 mix was adopted as is commonly used concrete mix in the construction industry. 0.5 water cement ratio was adopted for all batches due to higher water absorption rate of recycled aggregates.

In first phase of the work marble dust was used in concrete containing 50% of each conventional and recycled aggregates. The dosage was introduced from 2.5% to 15% with increment of 2.5% thus, total of six mixes were prepared. In second phase optimized dosage of marble dust along with bamboo fibers was used. The bamboo fibers were used from 0.25% to 2% with increment of 0.25%. Thus, total of eight mixes were prepared. Additionally, one mix without any additive but 50% recycled aggregates was prepared to check and compare the results of proposed concrete mixes.

Table 1 gives the details of the mixes and quantities of the ingredients used in phase 1 for optimization of marble dust. Whereas, Table 2 gives the quantities of ingredients of concrete containing optimized dosage of marble dust and varying dosage of bamboo

fibers. The slump cone test was conducted on each mix following the standard procedure defined in ASTM C143 [45]. The obtained results are tabulated in last column of respective table.

Table 1: Concrete quantities with marble dust

Batch	MD (g)	Cement (Kg)	Sand (Kg)	CA (kg)	RCA (Kg)	Water (kg)	Slump (mm)
CC	0.0	14.870	29.73	29.73	29.73	7.43	74
MD1	371.75	14.495	29.73	29.73	29.73	7.43	74
MD2	743.50	14.126	29.73	29.73	29.73	7.43	71
MD3	1115.25	13.755	29.73	29.73	29.73	7.43	70
MD4	1487.00	13.383	29.73	29.73	29.73	7.43	65
MD5	1858.75	13.011	29.73	29.73	29.73	7.43	62
MD6	2230.50	12.639	29.73	29.73	29.73	7.43	61

Table 2: Concrete quantities with optimized dosage of marble dust and bamboo fibers

Batch	BF (g)	Cement (Kg)	Sand (Kg)	CA (kg)	RCA (Kg)	Water (kg)	Slump (mm)
BF1	37.175	14.870	29.73	29.73	29.73	7.43	64
BF2	74.35	14.870	29.73	29.73	29.73	7.43	60
BF3	111.525	14.870	29.73	29.73	29.73	7.43	60
BF4	148.7	14.870	29.73	29.73	29.73	7.43	58
BF5	185.875	14.870	29.73	29.73	29.73	7.43	56
BF6	223.05	14.870	29.73	29.73	29.73	7.43	51
BF7	260.225	14.870	29.73	29.73	29.73	7.43	46
BF8	297.4	14.870	29.73	29.73	29.73	7.43	41

2.2 Casting and curing

Three prism specimens of size 914.4mm x 152.4mm x 304.8 mm were prepared in each batch. In preparation of the specimen instruction specified in ASTM C943-17[46] are followed. The inner surface of the molds was oiled. Ingredients were thoroughly mixed followed by mixing in concrete mixer till uniform paste is achieved. The molds were

filled in three layers with compaction by table vibrator. After one day time, the samples were de-molded and allowed to air dry in laboratory for a day. Few specimens are shown in Figure 5. Thereafter, the samples were fully immersed in potable water for curing for 28-days (Figure 6).



Figure 5: Prism specimens



Figure 6: Curing

2.3 Strength evaluation

After curing the specimens were tested in universal testing machine under central point load as per the specification mentioned in ASTM C293 [47] to optimize the dosage of marble dust. All specimens of six batches of first phase were tested in turn. The load was applied gradually till failure of the prism specimen (Figure 7). During the testing load and deflection were monitored carefully. After failure the failure mode was recorded. Using the failure load flexural strength was evaluated using standard formula given by the code batches is given in Table 4.

($f_r = \frac{3PL}{2BD}$). The average of the obtained results of the specimens in batch along with average deflection at failure load are given in Table 3. As mentioned earlier the specimens containing optimized dosage of marble dust and varying dosages of bamboo fibers (eight mixes) were then tested in similar fashion as earlier specimens in universal load testing machine under gradually increasing load. Similar parameters were recorded. The average flexural strength and central deflection of all



Figure 7: Specimen testing



Figure 14: Failure mode

3. Results and discussion

The basic properties of the concrete ingredients and additives presented and discussed earlier shows clearly that the water absorption of recycled aggregates is higher compared to those of conventional aggregates whereas, specific gravity is less. Also, the fineness modulus of the material is higher.

These deviation are mainly attributed to the age and strength of parent concrete and exposure conditions faced by it during service life in the structure. These factors alarm the user to take proper care of them in mix design. Particularly the water cement ratio otherwise may result in stiffer concrete hard to place and compact. The same has been taken care of in present study by increasing it to 0.5.

The basic properties of the additives were observed good enough to be used in concrete. pH value of water also fall in the range of potable water thus ensures the purity and cleanness of it.

For all proposed concrete mixes along with control mix, slump test was conducted. The

results of it were presented earlier in tabular form. The same are plotted as bar chart for clarity and comparison in Figure 8 for concrete containing only marble dust and Figure 9 for concrete mixes containing optimized dosage of marble dust and varying dosage of bamboo fibers.

Table 3: Average flexural strength of concrete with marble dust

Batch	MD (%)	Average Flexural Strength		Deflection (mm)
		(psi)	(MPa)	
CC	0.0	399.95	2.76	0.72
MD1	2.5	440.25	3.03	0.80
MD2	5.0	478.97	3.31	0.60
MD3	7.5	482.55	3.32	0.85
MD4	10.0	499.92	3.34	0.88
MD5	12.5	479.11	3.31	0.85
MD6	15.0	445.89	3.07	0.80

Table 4: Average flexural strength of concrete with bamboo fibers

Batch	MD (%)	BF (%)	Average Flexural Strength		Deflection (mm)
			(psi)	(MPa)	
BF1	10	0.25	501.43	3.45	0.97
BF2	10	0.5	517.20	3.56	1.00
BF3	10	0.75	548.83	3.78	1.12
BF4	10	1.00	551.93	3.81	1.12
BF5	10	1.25	605.30	4.17	1.25
BF6	10	1.50	597.13	4.12	1.23
BF7	10	1.75	590.96	4.07	1.23
BF8	10	2.00	560.81	3.86	1.00

It may be observed that induction of marble dust alone and with bamboo fibers affected the concrete slump adversely. Reduction in slump of proposed concrete with marble dust alone was less compared to that of control concrete. Maximum reduction in slump was recorded at the maximum dosage of marble dust (17%). Indeed, it is attributed to the marble dust that fills the pores thereby increasing the surface area. Which in turn need more water to lubricate. Water absorption of marble dust, increased cohesion due to finer particles and slow pozzolanic

reaction. The reduction in slump was recorded more when bamboo fibers were introduced in concrete. A reduction of 44.5% was observed while comparing the reduction with that of control concrete and 37% with concrete containing marble dust. This also reveals that concrete becomes more cohesive due to interlocking nature of fibers and reduces the slump. Therefore, careful consideration of the water cement ratio is highly necessary to maintain the required workability.

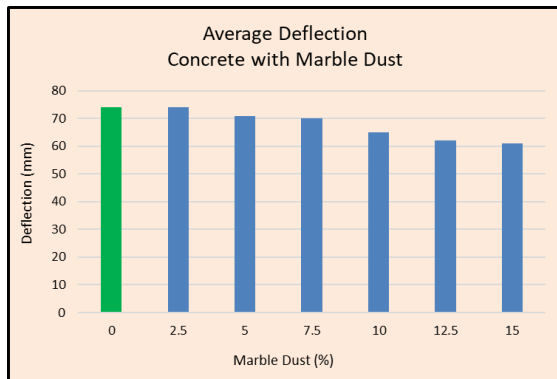


Figure 8: Deflection (Concrete with MD)

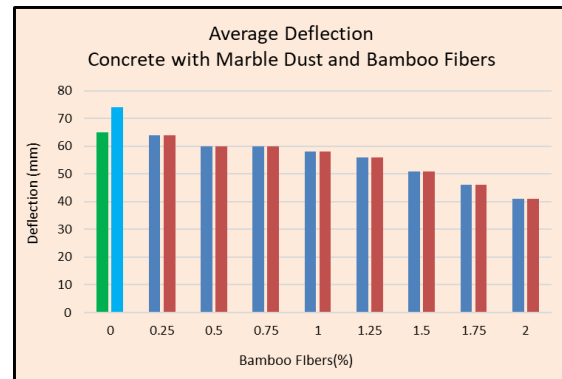


Figure 9: Deflection (Concrete with BF)

The results of the samples containing marble dust and recycled aggregates are also plotted in Figure 10. It may be observed that the induction of the marble dust improved the flexural strength of concrete in comparison to the flexural strength of concrete with only recycled aggregates. It is indeed due to same reasons pertaining to marble dust as highlighted earlier which improves the strength properties of concrete. However, beyond a certain limit the flexural strength

reduces instead of increasing. Based on the results of this study this dosage of marble dust is 10%. The reduction is contributed to the thicker surface coat of marble and slow pozzolanic reaction. This optimum dosage of marble dust was then kept constant in all specimens of phase 2 of the work and the bamboo fibers were introduced as mentioned earlier. The average flexural strength results of the concrete specimens containing the bamboo fibers is shown in Figure 11.

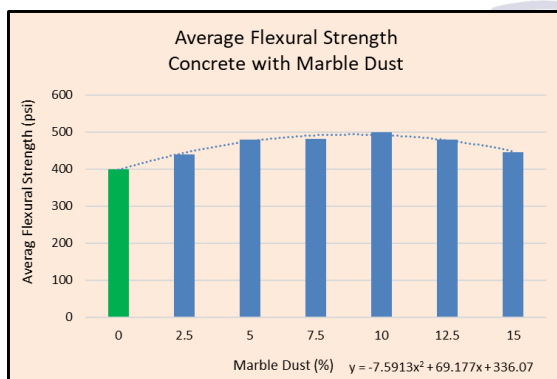


Figure 10: Average FS of concrete with MD

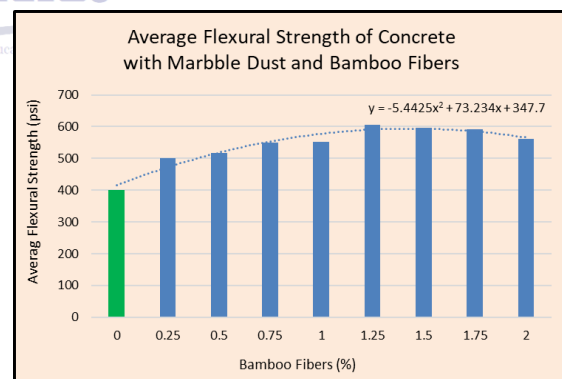


Figure 11: Average FS of concrete with BF

It may be observed that the induction of the fibers improved the flexural strength at all dosages than the average flexural strength of recycled aggregate concrete. The maximum increase was recorded equal to 73% where as comparing the same with concrete containing optimized dosage of marble dust the increase was found equal to 21%. Both increases were recorded at the optimum dosage of 1.25% of

the fibers. Beyond this dosage the strength reduced yet was observed higher than the recycled aggregate concrete and recycled aggregate concrete containing marble dust only. Hence 1.25% of fibers is recorded as optimum. Indeed, it is due to the interlocking nature of the fibers but beyond the optimum dosage fibrous material occupies more space in body of concrete resulting in weaker bond of the matrix. The percentile error of average

flexural strength of concrete containing marble dust and concrete containing both

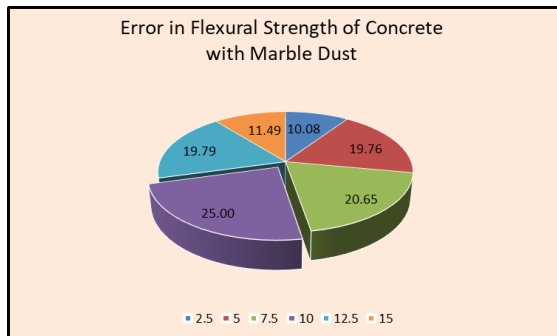


Figure 12: Deviation of FS of concrete (MD)

The failure mode of the specimens was observed during the testing. A selected specimen is shown in Figure 14. The failure in all specimen was observed flexural failure with minor cracks offside the center. It complies with the failure requirement of the concrete. Additionally, the trend line analysis between the dosage of marble dust and flexural strength and between flexural strength and dosage of bamboo fibers. The developed equations are illustrated in Figure 10 and 11. The variable “y” in both figures represent flexural strength whereas the variable “x” in Figure 10 represent dosage of marble dust and in Figure 11 dosage of bamboo fibers. Both of the equations are observed estimating results in good agreement with experimental results.

4. Conclusion

In this research article combine effect of recycled aggregates from demolished waste, marble dust and bamboo fibers are presented. Recycled aggregates are proportioned at 50% with conventional aggregates, marble dust is used as partial replacement of cement from 2.5% to 15% with increment of 2.5%. Flexural strength results using concrete prisms revealed 10% dosage of the material as optimum with 22% increase than the same of the recycled aggregate concrete. Thereby, this optimum dosage is utilized with varying percentage of bamboo fibers from 0.25% to 2% with increment of 0.25%. Test results of fibrous

marble dust and bamboo fibers is illustrated in Figures 12 and 13.

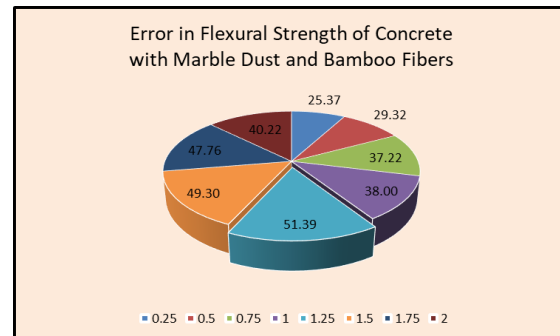


Figure 13: Deviation of FS of concrete (BF)

recycled aggregate concrete showed 51.4% increase in the strength parameter.

Central deflection of prisms recorded at optimum dosage of marble dust was 22% higher, whereas, the same for fibrous concrete was 73% higher than recycled aggregate concrete. Yet both of the values were within the prescribed limit of ACI-318. The mode of all prisms was observed as flexural failure which confirms with theoretical failure requirement for concrete. Equations developed using trend line analysis also showed good agreement with experimental results. Hence, it seen that the proposed additives with optimum dosage mentioned earlier has positive effect of the flexural strength of concrete, thus can be used in structural concrete but with care to control water cement ratio and deflection.

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