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COMPRESSIVE AND TENSILE STRENGTH OF CONCRETE MADE WITH RECYCLED AGGREGATES, MARBLE DUST, AND BAMBOO FIBERS

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Abstract
The effect of recycled coarse aggregates, marble dust and bamboo fiber on compressive and tensile strength of concrete is presented in this article. Recycled aggregates were developed from demolished waste, marble dust was produced from marble slug of marble cutting shops and bamboo fiber was developed from bamboo root. The concrete mixes were designed using 1:2:4 mix ratio and 0.5 water cement ratio. For checking the results of proposed concrete mixes, a batch was developed only with conventional and recycled aggregates. First the dosage of marble dust was optimized using marble dust from 2.5% to 15% (2.5% increment). Thereafter, the optimized dosage of the marble dust was kept constant and dosage of bamboo fibers was varied from 1% - 1.5% (0.1% increment). In all proposed mixes 50% recycled aggregates were used. In each batch six cylinders of standard size were prepared for compressive and tensile strength testing. Curing of all specimens was done for 28-days. Load recorded from compression testing was recorded and converted in compressive strength of concrete containing marble dust. The results revealed 12.5% dosage as optimum with 41% and 50% increase in compressive and tensile strength respectively. The second group of specimens containing optimized dosage of marble dust and varying percentage of bamboo fibers were tested for compressive strength in similar fashion. The results showed 1.2% of bamboo fibers as optimum with 51% higher values than control concrete and 7% higher than recycled aggregate concrete containing optimized dosage of marble dust only. Analogous to compressive strength, split tensile strength of all specimens in both groups was tested. The highest results of the parameter were observed at same optimized dosage of marble dust and bamboo fibers. This shows that the combined effect of three additives on strength properties of concrete is positive. Hence can be used in structural concrete with due care of water cement ratio.

INTRODUCTION

Migration of peoples from different places to city centers require more living and associated infrastructures. This need construction of more building and associated facilities. But the space problem in city centers made it almost impossible without opting vertical expansion. For it, old, deteriorated and even short height buildings need to be demolished. The action generates demolishing waste to the quantum that is a serious problem from management point of view. On the other hand, the new construction consumes more conventional sources. Concrete is the backbone of modern construction. It is used everywhere from residential homes to massive skyscrapers and highways. The cement is the binding agent in the concrete. In present era with development of modern civilization and urbanization the environmental problems associated with cement production has been identified and cannot be ignore. Thus, the thrust to identify the alternative or partial substitute of cement is more than before.

The management of waste is a serious issue particularly in regions which are short in space even for construction. Usually, a portion of this waste have been used in floor and plinth fills and the residual which is also in large quantum goes to landfills. Failure to it require transportation of the waste to far places but it increase the overburden on the project. On the other hand, it cannot be left unattained. Therefore, its use in fresh concrete as alternative of one or other conventional ingredient not only resolve the issue to some extent but also will help in conserving the conventional resources of that ingredient. As coarse aggregates occupy more space in concrete matrix therefore, use of demolished waste as coarse aggregates is much favorable. Processing of the waste in coarse aggregates, problems associated to it, properties of the aggregates has been studied by different members of research community around the world [1],[9]. But the scatter in the results of the parameters shows clearly that more work is still required in the field.

Beautification of the infrastructures is another key aspect of modern development which is evident at both architecture and material fronts. Marble stone is one among them and is used not only for beautification but also durability of floors and walls. Quarrying, cutting and shaping of marble produce waste in solid and powder form to the extent that it also has become a serious problem from management point of view. To an estimate [2] about 40% of the quarried marble goes in sludge. It can be reused by drying and grinding into powder, but the residual is still to the level of global issue with respect to management and environment. The pozzolanic properties of the material makes it suitable to be used as cement replacement in concrete [3]. To this end it has been attempted in concrete by several scholars of research community around the globe. But the results are showing scatter analogous to recycled aggregates.

Strength of concrete using above two waste materials along or in conjunction have showed the reduction. In turn strength is the parameter which cannot be compromised particularly for load bearing members. To overcome this deficiency different additives, admixtures, and fibers have been used. Fibers have the capability of providing concrete crack arrest mechanism thus improves the overall performance of the concrete. Different types of fibers, i.e., organic, synthetic, steel, glass, carbon, jute etc. have been tested in concrete [4]. Among these fibers bamboo fiber is one. It is fast growing and abundantly available everywhere around the globe. It is light in weight and strong. Although it has a short coming of being suspect of termite in addition to higher water absorption but can be treated to avoid such negative aspects. The fiber has been attempted by scholars in conventional concrete with observation of positive impact on the properties.

Therefore, this research work proposes the use of demolished waste as recycled coarse aggregates, marble dust as cement replacement and bamboo fiber as fibrous reinforcement in preparation of concrete. The effect of these additives will be checked by comparing the compressive and tensile strength of proposed concrete with same parameters of conventional concrete. The outcome of the work will not only improve the confidence in using of such materials but also lessen some burden of waste management and environmental issues. It will also help the concerned personals in further research and use from industrial point of view.

1. Literature review

Although the concrete has proved itself as the best construction material in the industry yet the desire to search the alternative of ingredients of concrete is active since decade. In deed it is to avoid the consequences of achieving the conventional concrete ingredients and develop the indigenous local material as replacement of one or other ingredients of concrete. It may be observed that plethora of work is published on the use of different additives in concrete. This section provides an overview of available state-of-art related to the proposed work.

The use of demolished waste in preparation of new concrete is not new. It has been used in different forms. To this end experimental investigations carried out by Lakshmi and Nivedhitha [5] to gauge the effect of partial replacement of conventional coarse and fine aggregates by recycled coarse and fine aggregates on compressive and tensile strength of concrete. The authors used 10%, 20%, 30% replacement of both type of aggregates. From the experimental observations authors observed up to 20% increase in both compressive and tensile strength of concrete at the dosage of 20%. On the other hand, Al-Azzawi [6] observed no effect on the compressive and tensile strength of concrete for coarse aggregates replacement up to 25%. Whereas, the author observed drastic decrease in almost all properties beyond above mentioned replacement level of conventional coarse aggregates with coarse aggregates from demolished waste. In a separate laboratory program Noshin et al. [7] used 25%, 50%, 75% and 100% replacement of conventional coarse aggregates with recycled coarse aggregates from demolished waste. The comparison of workability and strength properties with conventional concrete showed the authors decrease in all at all replacement levels. Compressive strength was recorded 3.8%, 5.7%, 12.9%, and 15.8% less compared to the same of conventional concrete. Whereas, reduction in the range of 9% - 11% was recorded for compressive strength. Thus, concluding their work, the authors treated 25% replacement as optimum as the reduction in compressive strength was less than 5% at this replacement level. Oad and Memon [8] also studied the effect of recycled aggregates from demolished waste on compressive strength of concrete cylinders. From the comparison of experimental observations authors observed 50% of replacement as optimum with 86% residual strength. Effect of recycled coarse aggregates of flexural performance has been studied [10]-[15]. It is also observed that the processing process of recycled aggregates from demolished waste has also impact on the final properties of concrete. Many scholars in their works discussed several techniques, issues, formulation and hurdles. Also, argued that the age of the structure and the exposure condition during service life of the structure has an impact on the quality of the aggregates thus on the quality of the concrete.

Marble dust obtained directly from cutting and shaping of marble stone or by griding the sludge produce in the process has high calcium content which give it the ability to act as the cement. Only this material used as binding agent has been proved unsuitable therefore cement is partially replaced with it. The use of marble in different concrete mixes has been attempted by different researchers. The published work has also been reviewed by [16]-[18]. Careful selection of the dosage of the marble dust alters concrete properties positively. In a research attempt on use of marble dust in concrete Dhanalakshmi and Hameed [19] used 5%, 10%, 15%, and 20% replacement of cement. The samples were prepared for compressive and tensile strength evaluation in standard fashion and cured for 7- and 28-days. The comparison of the results showed the authors 15% as optimum replacement with increase in both strength parameters up to 10%. Whereas, Handayani et al. [20] based on their work observed 17.7% increase in compressive strength at 10% replacement level of cement with marble dust.

Another attempt on same issue Yunusa et al. [21] observed 20% replacement of cement with marble dust as optimum based on 8%, 12% and 12% increase in compressive, tensile and flexural strength of concrete respectively. Memon et al. [22] attempted marble dust as cement replacement in their research work. Authors used up to 10% replacement with increment of 2.5% and observed 8.3% increase in compressive strength at 5% replacement level. They also observed 2% reduction in weight of the concrete. Marble dust along with silica fume was used by Khodabakhshian et al. [23] to study the durability of the concrete. Comparing the results of 16 mixes with conventional concrete authors observed 10% of marble dust as optimum. Additional parameters like micro-structure, permeation and strength with higher replacement levels have been studied by Vardhan et al. [24]. In the work authors used up to 60% replacement of cement with marble dust. The testing of specimens at the age of 365 days showed the authors remarkable increase in the parameters at replacement level of 40%. Hence the authors concluded their work with 40% marble dust as optimum with elongated curing. Saghir et al. [25] also used up to 15% replacement of cement with marble dust and observed good increase in strength of concrete at 10% replacement level. Marble dust has also been used as sand replacement [26], flexural performance of concrete prisms [27], to study the properties of grout [28], and cement paste [29].

Although careful selection of the marble dust dosage results in considerable increase in the strength properties of conventional concrete but the increase in the strength properties of concrete with recycled aggregates from demolished waste is near to the strength of conventional concrete [22]. Therefore, refinement and addition of more additives or fibers are required to enhance the properties of concrete. To this end several types of fibers have been used in concrete. The bamboo fiber is one among them. The use of bamboo fiber in concrete have been reviewed in articles cited at [30]-[32]. The articles gave details of bamboo fiber, its use in concrete along with its de-merits and method to overcome the shortcomings of the fiber. It may be observed there from that the material has good effect on the strength properties of the concrete. High water absorption and prone to termite and fungus due to organic nature of the fiber may be overcome by using timber protector's ant termite solution [33]. The fiber has high tensile strength and it provide good crack arrest mechanism [34]. Bamboo fibers have also been used in self-compacting concrete as shear reinforcement by Asamoah and Osei [35]. The dosage of fiber used was 1.5% and 3%. From the test results the authors observed satisfactory shear performance of the concrete beams. It was also observed that due to bamboo fiber deflection increased up to 2.5 times than the deflection of similar members made from conventional concrete. In a separate study by Kumar et al. [36], authors used bamboo fibers in preparation of hollow concrete blocks. To avoid the decay of the fiber authors used 10% alcofine to treat it before using. Test results revealed 11.3% increase in compressive strength at the optimum dosage of 1%. On contrary Kumarasamy et al. [37] observed 2% as the optimum dosage based on the 2%, 3% and 19% increase in compressive, tensile and flexural strengths of concrete. Bamboo fibers along with fly ash have also been used in concrete to improve its properties [38].

Above discussion of relevant available literature shows clearly that good many research attempts have been made to improve the performance of sustainable concrete. Although addition of the fibers shows good increase in strength properties yet the dosage of the material has no fixed set of rules. This shows clearly that more trials are still required to reach at certain confidence level. Therefore, this research work proposed the evaluation of compressive and tensile strength of concrete made with recycled aggregates, marble dust and bamboo fiber. First two materials are used as partial replacement of conventional coarse aggregates and cement and the third one is used as fibrous reinforcement in concrete matrix.

2. Material and testing

The materials used in this research work and the testing performed are described in this section.

2.1 Conventional Ingredients

The ordinary Portland cement (Pak Land cement) is used as binding agent. Basic properties of cement evaluated in accordance with ASTM C150[39] were within the specified limits of the code. Water used for washing, mixing and curing was obtained from the main water supply line with pH value equal to 6.8 confirming the water as potable water. For fine aggregates, Hill sand was used. Water absorption and specific gravity of the material was evaluated and is tabulated in Table 1. Thereafter, sieve analysis of the material was performed in accordance with ASTM C136 [40] to ensure well graded material in concrete matrix. From the passing percentage of the material at specified sieves fineness modulus was computed and listed in Table 1. Following the same pattern, coarse aggregates (crush) of maximum size of 25 mm was tested. Water absorption, specific gravity and fineness modulus of the material is listed in Table 1.

Table 1: Basic properties of aggregates

Property	Fine Aggregates	Coarse Aggregates	
		Conventional	Recycled
Water absorption (%)	1.44	1.12	2.7
Specific Gravity	2.34	2.64	2.42
Fineness modulus	3.84	6.70	5.61

2.2 Recycled aggregates

Recycled aggregates used in this research work were produced from large blocks of demolished waste (Figure 1) of a reinforced concrete slab. Manual hammering was adopted to reduce the large blocks to approximately 25 mm size (Figure 2). Obtained stuff was sorted for unwanted objects then washed with potable water and dried for 24-hours. Basic properties of the aggregates were evaluated similar to those of the conventional coarse aggregates and are listed in Table 1. To ensure well grading of the aggregates sieve analysis as prescribed by ASTM C136 [40] was performed and fineness modulus was calculated. The dosage of the recycled aggregates in this work is used following the recommendations of Oad et al. [8]. Equal proportion of both conventional and recycled aggregates (50% each) is used in this work for preparation of all batches.

2.3 Marble dust

The marble dust for this work was obtained from local marble cutting units in the form of sludge. It was ground to powder form (Figure 3). To ensure its fineness it was sieved using #200 sieve. The fineness of the material was 96.1% and was in good agreement with the fineness of the cement [41]. The specific gravity and moisture content of marble dust were found equal to 4.15% and 3.06 respectively. The dosage of the material was adopted from 2.5% to 15% by weight of cement with increment of 2.5%.

2.4 Bamboo fiber

Bamboo is fast growing organic plant available almost everywhere. It's fiber strong and lightweight. But due to its organic nature its water absorption is high and it may be attacked by fungus or termite. This deficiency may be overcome with treatment prior to using in concrete. In this research work bamboo fiber was used without treatment. The average moisture content of bamboo (from bottom to top) was recorded 24.1%. Before using it was dried for 15-days. The process reduced the moisture content of the fiber to 3.8%. The tensile strength of the fiber was found equal to 201.1 MPa. The fiber was used in the dosage of 1% to 1.5% with increment of 0.1% by weight of cement. The length of fiber was maintained approximately equal to 50 mm.


Figure 1: Demolished waste


Figure 2: Recycled aggregates


Figure 3: Marble dust


Figure 4: Bamboo fibers

2.5 Mix details

To achieve the aim of the research, two groups of concrete mixes were designed. Both groups contained equal proportion of the conventional and recycled aggregates. In first group marble dust was introduced from 2.5% to 15% with increment of 2.5%. Total of six concrete mixes were developed to optimize the dosage of the marble dust. The results were compared with control mix (CM) contained 50% of each of conventional and recycled aggregates. In second group of concrete mixes optimized dosage of marble dust was kept constant and percentage of bamboo fiber was varied from 1% to 1.5% with increment of 0.1%. For all batches 1:2:4 mix with water cement ratio of 0.5 was used. Concrete mix ratio is considered based on the fact that most of time it is used in the industry. Slightly higher water cement ratio is adopted considering the water demand of recycled aggregates and bamboo fiber. The workability of the mixes was checked using slump cone test in accordance with the specifications given in ASTM C143 [42The obtained results are tabulated in Table 2.

Table 2: Slump of Concrete

Mix	1	2	3	4	5	6
Control Concrete	79					
Concrete with marble dust only	73	72	70	68	61	58
Concrete with optimized dosage of marble dust and bamboo fibers	53	50	50	47	41	39

2.6 Casting and curing

In each batch, six specimens were prepared; three cubes and three cylinders. Thus, total of 78 cubes (6"x6"x6") and cylinders (6"/12") of standard size were prepared. The concrete cubes were used for compressive strength evaluation and the concrete cylinders were used for evaluation of tensile strength of concrete. The specimens were prepared adhering the specifications given by ASTM C943 [43]. The inner surface of molds was oiled before filling the concrete. Concrete ingredients in specified mix ratio were mixed thoroughly before adding the water. Then the mixer was operated till uniform paste was formed. Each mold was filled in three layers with vibration by table vibrator. On next day of casting, specimens were de-molded and allowed to air dry for 24-hours. Then all the specimens were immersed fully in potable water for curing for 28-days (Figure 6).

Figure 5: Curing

Figure 6: Testing

2.7 Strength evaluation

After completion of curing time, specimens were taken out of water, wiped off with clean cloth, and tested in universal testing machine for failure load under compression (Figure 6). The load was gradually applied till failure. The behavior during testing and failure load was recorded. From the failure load compressive strength was evaluated using standard formula for the purpose. The obtained results of the individual specimens within the batch are shown in Figure 7. The average values of each batch are listed in Table 3.

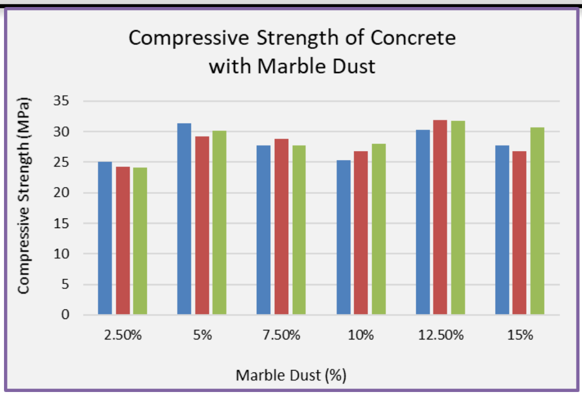
Similar to testing for failure load under compression, split tensile strength of remaining specimen of each batch was performed in universal testing machine (Figure 6). Failure load was recoded and converted to split tensile strength using standard formula given by the code. Obtained values are shown in Figure 8 and averaged values of the splitting tensile strength of the specimens in each batch are listed in Table 4.

Table 3: Average compressive strength

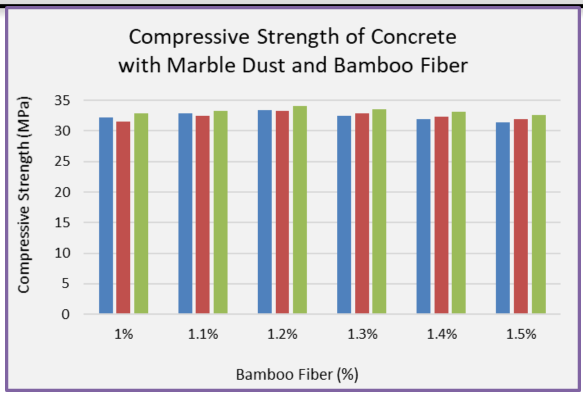
Compressive Strength (MPa)	1	2	3	4	5	6
Control Concrete	22.22					
Concrete with marble dust only	24.48	30.26	28.11	26.73	31.32	28.4
Concrete with optimized dosage of marble dust and bamboo fibers	32.16	32.87	33.59	32.98	32.47	31.98

Table 4: Average tensile strength

Compressive Strength (MPa)	1	2	3	4	5	6
Control Concrete	2.27					
Concrete with marble dust only	2.06	3.15	3.20	3.06	3.40	3.30
Concrete with optimized dosage of marble dust and bamboo fibers	3.58	3.67	3.80	3.74	3.60	3.50

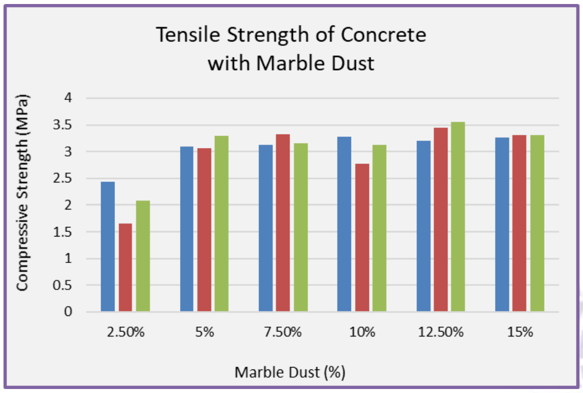


(a) with marble dust

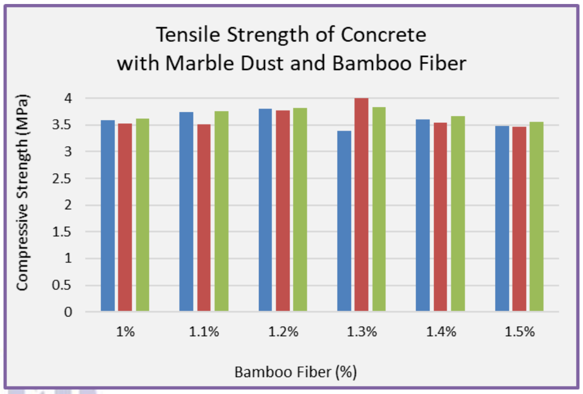


(b) with marble dust and bamboo fiber

Figure 7: Compressive strength



(a) with marble dust



(b) with marble dust and bamboo fiber

Figure 8: Tensile strength

3. Results and discussion

Water absorption and specific gravity of the aggregates presented earlier are compared in Figure 9. It can be observed from the graph that the water absorption of the recycled aggregates is 241% higher than that of conventional aggregates. This shows that the water demand of the mix will higher compare to that of conventional concrete. Therefore, the water cement ratio should be adjusted to meet the conventional aggregates.

demand. Similarly, comparison of specific gravity of recycled aggregates showed 10% reduction in the parameter than the same of the conventional aggregates. This indicates that the material s weaker and the hardened properties of concrete using it will be affected. Hence care must be taken in account to either use additives to improve the strength or limit it use to areas of low load. This is also reflected in comparison of fineness modulus of the aggregates. For recycled aggregates it is 19% lesser than the same of

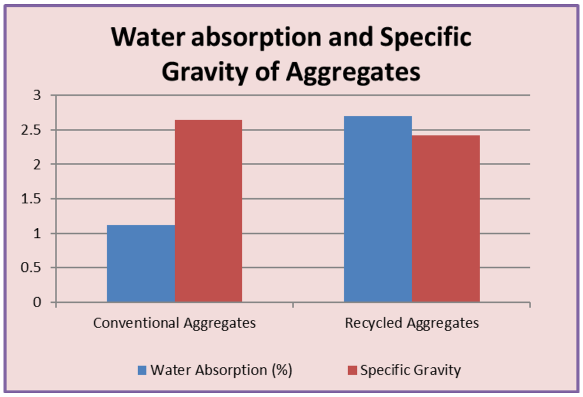


Figure 9: Water absorption and specific gravity

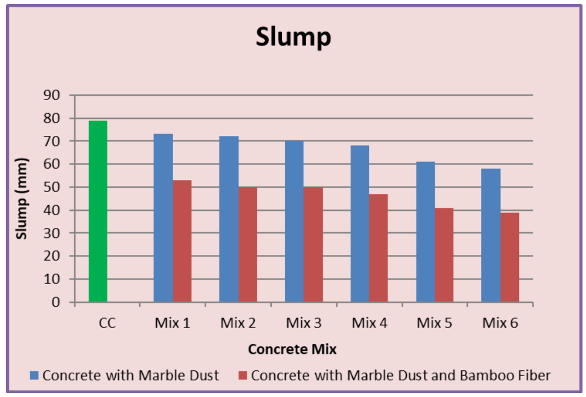


Figure 10: Slump of concrete

The slump of all concrete mixes reported earlier is compared in Figure 10. It can be observed that in comparison to the slump of control concrete, slump of all other mixes is less. Introduction of marble dust affected slump with increase in dosage. Maximum reduction is equal to 26.58% at highest replacement level of marble dust. It was further affected due to addition of bamboo fibers and the reduction reached to 50% at the highest dosage of the fiber. This not only validates the theoretical concept of marble dust and bamboo fibers but also alarm that good care is needed in decision of water cement ratio to avoid stiff concrete at placement level and honeycombing at hardened state. Both of the issues ultimately affect the concrete strength.

3.1 Marble dust optimization

The compressive strength results of the concrete cubes of first group of concrete mixes containing varying dosages of marble dust were presented earlier. The average compressive strength of specimens of each mix is plotted in Figure 11. Due to good cementous properties of marble dust the increase in the parameter can be observed at all replacement levels. But the maximum increase is observed at replacement level of 12.5%. Therefore, this replacement level is considered as optimum. The increase in compressive strength is equal to 41% (Figure 12)

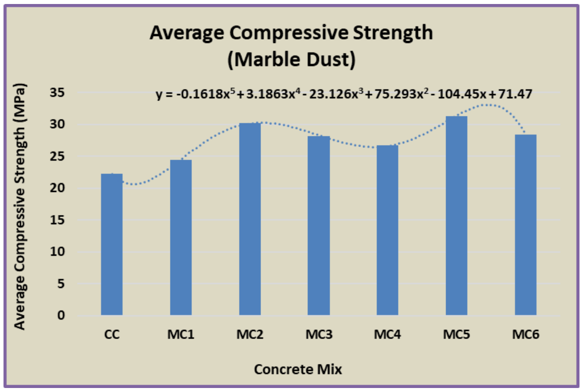


Figure 11: Average CS of Concrete with MD

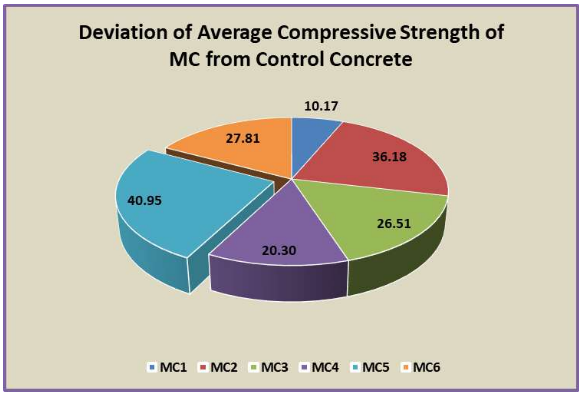


Figure 12: Deviation of CS of MC mixes

Analogous to compressive strength, tensile strength was also averaged and is plotted in Figure 13 and its deviation from control concrete in Figure 14. Observations revealed that the maximum value of the tensile strength is at same optimum dosage as was recorded during compressive strength analysis. At the optimum dosage maximum increase was equal to 50%.

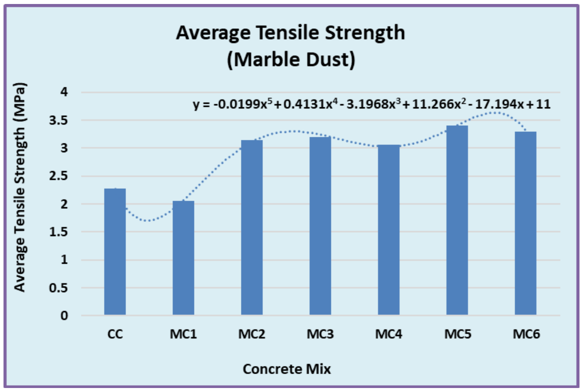


Figure 13: Average TS of Concrete with MD

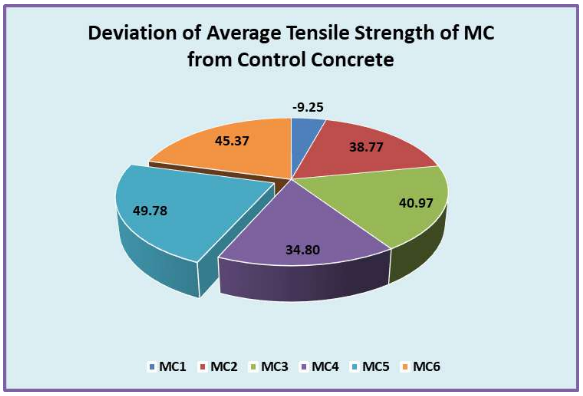


Figure 14: Deviation of TS of MC mixes

3.2 Bamboo fiber optimization

Individual results of compressive strength of second group concrete mixes containing optimized dosage of marble dust and varying dosage of bamboo fiber were averaged and are plotted as bar chart in Figure 15 versus control concrete and in Figure 16 vs concrete containing optimized dosage of the marble dust. The deviation of the parameters with respect to control concrete (Figure 17) and concrete containing optimized dosage of marble dust (Figure 18). All these figure shows increase in the tensile strength with maximum at the dosage of 1.2%. The increase in compressive strength with respect to control concrete is 51% where as it is 7% with respect to the concrete containing optimized dosage of marble dust. It is further observed that the increase in compressive strength than the compressive strength of recycled aggregate concrete containing marble dust is not much (less than 10%) yet it proves the positive impact of bamboo fibers on the compressive strength.

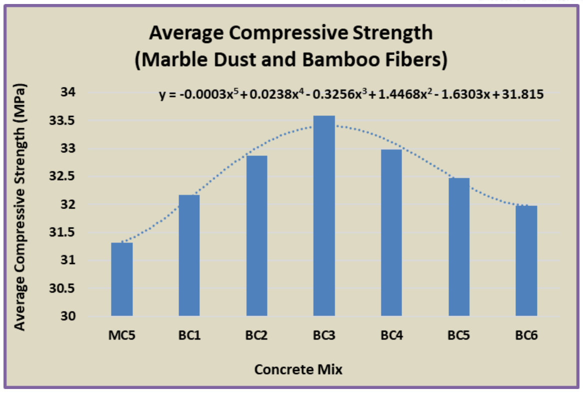


Figure 15: Average CS of BC mixes vs CC

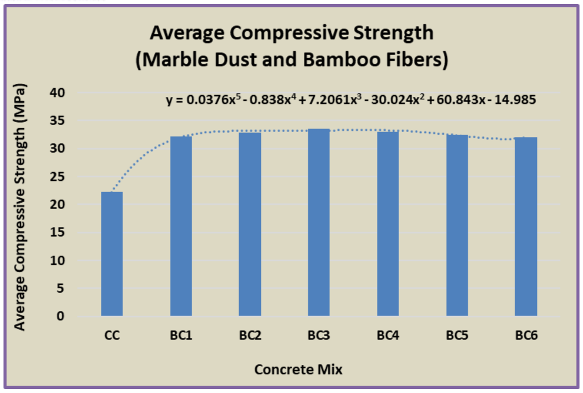


Figure 16: Average CS of MC mixes vs MC5

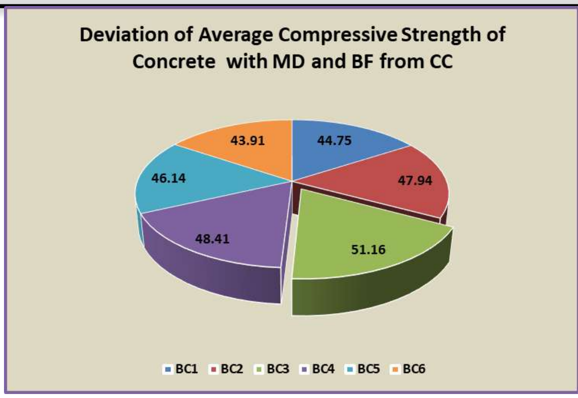


Figure 17: Deviation of CS of BC mixes vs CC

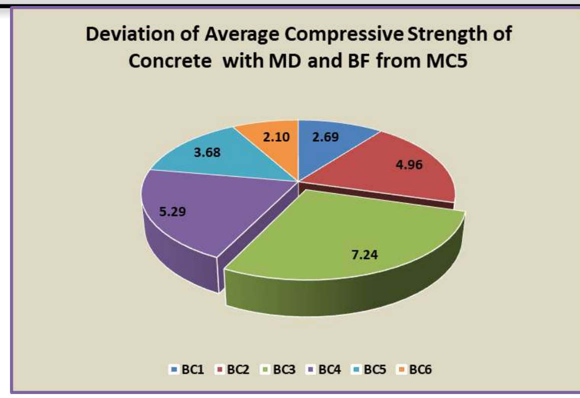


Figure 18: Deviation of CS of BC mixes vs MC5

In similar fashion the tensile strength of concrete mixes of second group is plotted as bar chart in Figure 19 and Figure 20. Trend of tensile strength similar to compressive strength can be observed. The maximum increase versus control concrete equal to 50% (Figure 21) is recorded at the optimum dosage of 1.2%. The same dosage was found optimum while comparing the tensile strength versus the concrete containing optimized dosage of marble dust with maximum value equal to 67%. This show that the impact of bamboo fiber on tensile strength is far better than the effect on compressive strength. It is indeed due to interlocking nature of bamboo fiber.

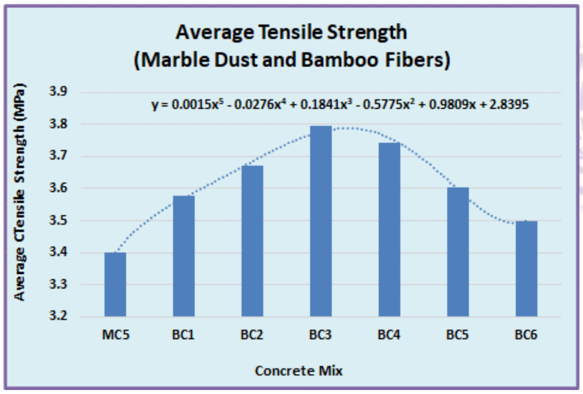


Figure 19: Average TS of BC mixes vs CC

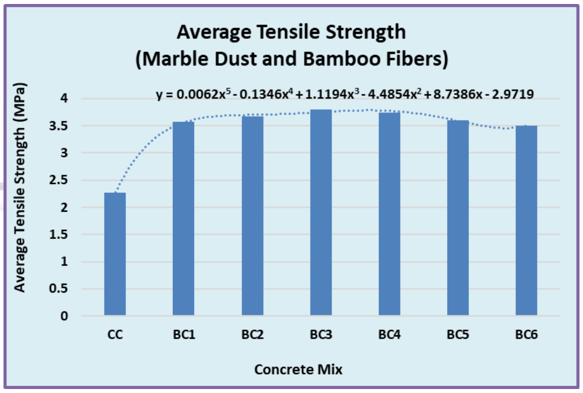


Figure 20: Average TS of MC mixes vs MC5

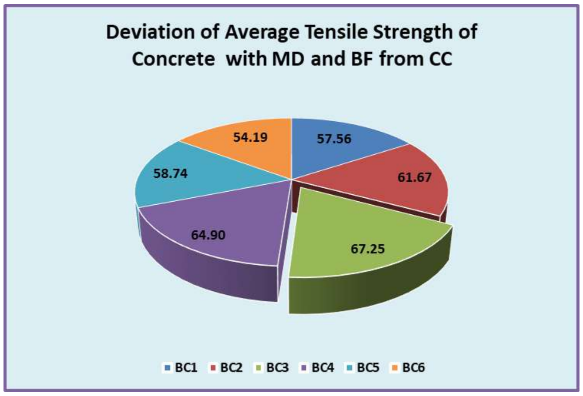


Figure 21: Deviation of TS of BC mixes vs CC

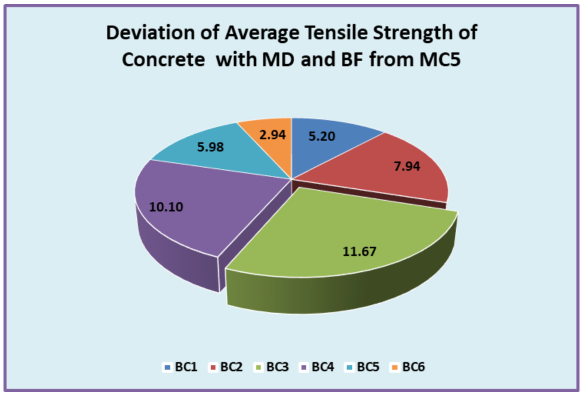


Figure 22: Deviation of TS of BC mixes vs MC5

3.3 Trend line analysis

As the numerical modeling is a good alternative of the experimental work, therefore, trend line analysis for compressive and tensile strength of concrete mixes of both groups is also done. The polynomial developed in the process is shown in the respective graph. In each of the numerical equation "x" represents the dosage of marble dust or bamboo fiber where as the variable "y" represent the respective compressive or tensile strength. It was further observed that the numerical equations predict reasonably good estimate of strength parameter discussed.

4. Conclusion

The article attempted development of sustainable concrete using recycled coarse aggregates, marble dust and bamboo fibers which on other hand are the waste material and need proper attention to dispose of properly. Basic properties, workability, compressive strength, and tensile strength are presented. In all concrete mixes, 50% conventional aggregates were replaced with recycled aggregates from demolished concrete. In first phase marble dust is optimized based on compressive and tensile strength properties. The results showed 12.5% as optimum dosage with respect to both compressive and tensile strength. Then it was kept constant in second phase and bamboo fiber fractions were varied. Again, compressive and tensile strength properties showed similar trend with 1.2% dosage as optimum. Therefore, it is concluded that 50% recycled aggregates from demolished waste, 12.5% marble dust by weight of cement and 1.2% bamboo fibers by weight of cement are optimum to produce sustainable concrete having strength properties higher than the same of recycled concrete alone. Also, the trend line analysis is done to develop numerical equations to predict the strength of proposed concrete based on the dosage of the additives used in this work. The developed equations were found in good agreement with experimental results.

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