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Mechanical and durability characteristics of sustainable coconut fibers reinforced concrete with incorporation of marble powder

Jawad Ahmad¹, Osama Zaid¹, Muhammad Shahid Siddique¹, Fahid Aslam¹, Hisham Alabduljabbar² and Khaled Mohamed Khedher³

¹ Department of Civil Engineering, Military College of Engineering, Risalpur, Branch of National University of Sciences and Technology, Islamabad, Pakistan
² Department of Civil Engineering, Prince Sattam Bin Abdulaziz University, Al-Kharj 11942, Saudi Arabia
³ Department of Civil Engineering, College of Engineering in King Khalid University, Abha, Saudi Arabia

E-mail: osamazaidmarwat@gmail.com

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Abstract

Concrete needs some tensile reinforcement to enhance tensile strength and avoid unacceptable brittle nature. This study is supported out to estimate the characteristics of coconut fibers reinforced concrete with the incorporation of marble slurry. Marble waste used as binding materials in percentage of 0 to 30% in 5.0% increment by weight of cement to enhance compressive capacity while coconut fiber was used in proportion of 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of cement to enhance tensile capacity of concrete. Mechanical performance was evaluated through compressive, flexure, and split tensile strength. To assess durability characteristics of all mix, different parameters such as acid attack resistance, carbonation resistance and water absorption are examined. Experiment findings indicate that marble slurry and coconut fiber decrease the workability of fresh concrete. Furthermore, Concrete specimens’ tests indicate that marble slurry up to 20% and coconut fiber addition 2.0% tend to improve the mechanical performance of hardened Concrete. It also indicates that durability aspects such as water absorption, carbonation resistance and acid attack resistance significantly improved with the substitution of marble waste and coconut fibers. Response surface methodology (statistically models) is used to optimize combine dosage of marble slurry and coconut fiber and verified through experimental tests’.

1. Introduction

The knowledge of sustainable change believes that natural reserves must be considered as reduced imports and the wastes should be reasonably managed. Around all over the world, growing quantities of composed waste is about 2500 million tons per year [1] which inspire the scholar to a built new system of dumping. There are many possibilities to use the waste materials in the concrete production industry. Industrial rubbish or by-products factory can be used as one of the concrete materials.

Fine aggregate for good quality concrete must be hard, strong, neat, and free from any absorb chemicals as well as additional dust particles that affect deuteriation of material. Alas in construction industries, mostly natural river sand is selected for concrete production due to its easily available as well low cost. The properties of sand (chemically as well as physically) affect the durability aspects along with mechanical performance of concrete, therefore sand (fine aggregate) is one of the most important components for good quality concrete.

During manufacturing process in various industries are the main cause of garbage which are delivered as a byproduct. It is recommended that marble waste can be successfully used in the construction industry for preparation of concrete instead of cement [2]. The focus of this article is to utilized waste marble as binding materials which is collected from the marble factory. Real statistics regarding the amount of garbage generated in Pakistan from the marble factory are unavailable meanwhile it is not estimated or supervised by the administration or any other party. Additional quotations approximate that 25 to 30% of the marble delivered
causes dust in the shape of slurry through the slashing procedure [3]. These manufacturing crops which are existing in the environment reason environmental pollution.

Marble has been commonly utilized as a construction raw ingredient. The production’s placing of the marble residue material, which contain of a extremely fine ash, which results currently environmental pollution around the world [4]. It has recommended that environment can be protected from environmental pollution cause by marble waste if it can be used in various industries like paper, agriculture glass as well as in the production of cement concrete [5]. Through the quarrying activity and in the refining of marble stone, marble powder is observed as a trash material [6].

Several advanced nations must place in official rules regarding the improvement of industrials waste seeking to decrease the quantity of garbage and to make sure rubbish reprocessing [7]. We need the case of Japan in visible of us; a nation that positively improved the reprocessing percentage of concrete waste upward to 98% utilizing waste material as aggregate [8]. they identified that the Marble Stone slurry delivered through manufacturing relates to around 40% of the ultimate result from the stone production [9]. They additionally described that workability of concrete reduce with the incorporation of marble slurry. Katuwal et al. (2017) also observed decreased in workability of concrete with incorporation of marble waste as a fine aggregate [10]. They also notice that compressive strength of concrete improved up to 50% substitution marble waste as a fine aggregate which is around 12% more as compare to blank mix [11]. compressive and flexural strength of concrete are improved around 28% and 13% at 50% addition and then slowly decline by the substitution of waste marble powder (WMP) [12]. Opposition to the acid of concrete including waste marble was slightly down in to that of reference mix [13]. It has been recommended that that marble waste can be successfully for the production of cement concrete [2].

All Through large investigation, it has been concluded that the structural properties of concrete such as compressive, tensile, flexure, impact strength as well as ductility and toughness were considerably improved due to the addition of fibers to concrete [14–17]. ACI 544.5R-10 reported that thick fibers are less effective in decreasing the elastic shrinkage cracks width as compare to thin fibers [18]. Most thin diameter microfibers are mostly helpful in decreasing elastic shrinkage cracking of concrete due to large specific fiber surface area [19]. Furthermore, the usage of fibers in concrete improves permeability and bleeding of concrete [20–23].

Different types of fibers are used to reinforce cement-based matrixes. The choice of fibers varies from synthetic organic materials such as nylon, synthetic inorganics such as steel or glass, and natural organic materials such as cellulose or sisal to natural inorganic asbestos [24]. The selection of the type of fibers is guided by the properties of the fibers such as diameter, specific volume, Young’s modulus, tensile strength, etc, and the extent to which these fibers affect the properties of the cement matrix [25]. Mainly the fibers are divided into two types, that is, metallic and nonmetallic. Steel and carbon fibers are termed metallic fibers and fibers like polymeric, coconut, glass and naturally occurring fibers are clubbed under the umbrella of nonmetallic fibers [26].

2. Significance of research

The present research mostly focuses on the use of waste materials such as waste marble (WM) to make eco-friendly concrete, have a good mechanical performance, and also sustainable as per of author in a study [27]. The initial aim of this research is to determine the impact of cement substitution with waste marble (WM) and coconut fibers (CFs) on concrete mechanical properties. The second objective of this study is to evaluate the sustainability performance of adding waste products like Waste Marble (WM) in concrete, how waste material (Waste Marble) in concrete helps the environment and bring a low carbon concrete to the construction industry.

The study on addition of Waste Marble (WM) concrete as a substitute for cement plus coconut fibers has not been performed in the past research studies according to the author’s best information. Assessment of sustainable development of concrete using Waste Marble (WM) and coconut fibers (CFs) has not been reported previously according to the author’s best information. Ahmad et al. [28] reported that fiber enhances the tensile capacity of concrete much more effectively than compressive strength. Further research was recommended [28] to use the combination of a fiber of mineral additives to enhance the compressive capacity of fibers reinforced concrete. Adding Waste Marble (WM) in a combination of coconut fibers (CFs) can offer a significant improvement in mechanical performance and can reduce environmental issues and waste discarding problems, thus forming a clean and sustainable environment.

Consequently, the current study is carried out to utilized waste marble as binding materials in percentage of 5%, 10%, 15%, 20%, 25% and 30% by weight and coconut fiber addition 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of cement to evaluate its mechanical as well durability aspects. Furthermore, the application of statistical analysis (response surface methodology) was used for the optimization of marble and fibers in concrete to obtained high strength as well as durable concrete.
2.1. Materials and methodology

2.1.1. Cement

According to ASTM C150 \[29\], type-1 cement was used in this study. Table 1 shows the chemical composition and physical properties of OPC used in this study.

| Chemical property | Percentage (%) | Physical property | Results          |
|------------------|----------------|------------------|------------------|
| CaO              | 64.7           | Size             | \(\leq 75\mu\)   |
| SiO₂             | 23.9           | Fineness         | 92%              |
| Al₂O₃            | 5.4            | Normal Consistency | 31%               |
| Fe₂O₃            | 3.6            | Initial Setting Time | 33 min           |
| MgO              | 3.5            | Final Setting Time | 410 min          |
| SO₃              | 2.9            | Specific Surface | 322 m² kg⁻¹      |
| K₂O              | 2.4            | Soundness        | 1.70%            |
| Na₂O             | 1.3            | '28-days compressive Strength' | 42MPa |

2.1.2. Coconut fibers

Coconut fibers with 8 to 10 mm long length and diameter of 0.5 to 1.0 mm were used throughout the experimental work. Table 2 shows the physical aspects of coconut fibers used in this study.

| Physical properties | Results          |
|---------------------|------------------|
| Length              | 8 to 10 mm       |
| Diameter            | 0.5 to 1.0 mm    |
| Breaking Elongation | 25%              |
| Density             | 1.4 g/c.c.       |
| Young’s Modulus     | 4.5GPa           |

2.1.3. Aggregate

Sand which is locally available was utilized as a fine aggregate for mixes in saturated surface dry conditions (SSD). Similarly crush stone which is easily available in market was utilized as coarse aggregate. Various experiments were done on aggregate to assess its properties. Figure 1 display size grain curves (gradation curve) of both fine and coarse aggregates while table 3 displays the physical characteristics of both fine and coarse aggregates.

2.1.4. Waste marble (WM)

Waste marble was obtained from the marble factory industrial zone Risalpur Pakistan and grinded at PCSIR lab Peshawar to the required particle of size (less than 75 microns). Different tests were executed on aggregate to find properties of waste marble (physical and chemical) which were presented in table 4.

To assess the mineralogical composition, crystallography, and pozzolanic reactivity of marble waste (MW), x-ray Diffraction test is performed at the 'Material Research Laboratory of Physics department, University of Peshawar'. The amount of different minerals like quartz, mullite, hematite, and magnetite present in the material were assessed. To analyze mineralogy of the sample, hardened parts of marble waste (MW) was ground finely and then subjected to XRD analysis after passing through sieve \#200. The test was performed on the grounded powdered form of crushed sample by using the diffractometer equipment available in the MRL lab of Peshawar university. The test arrangements were organized in such a way that copper (Cu) and Kα radiations were used as source for the operation by applying 30mA and 40KV conditions. An interval of 2θ is kept constant in the range of 15° and 75° with angular step of 0.02°. A step time 0.5 seconds is set down and 0.5° diversion slit is used \[30\]. The mineralogy of the tested specimens was analyzed by using the obtained results from the diffracted radiations as shown in figure 2. From figure 2 it can be observed that, wide range of diffusive amorphous peaks of quartz in the XRD analysis of marble waste (MW) at 30°, 35°, and 50° can be observed apparently which
indicates the dominant amorphous nature of marble waste (MW). Additionally, the peaks of other minerals like mullite, hematite, and magnetite can also be observed clearly.

2.1.5. Superplasticizer
Chemrite-530 was utilized as a superplasticizer. From safety point of view, this admixture is non-harmful in relevant. Additionally it is according to the requirements define by codes of ASTM [31] and EN [32] and ASTM. Table 5 shows different physical properties superplasticizer applied in this research.

2.2. Size and tests of specimen
The workability of concrete was evaluated based on the Slump flow cone as per ASTM [33]. For compressive strength, according to ASTM [34] cylinder of size 150 (mm) in diameter with 300 (mm) length were casted and tested at specified curing days (7, 14 and 28 days). According to ASTM [35] cylinders of size (150 mm diameter and 300 mm length) were cast and tested to evaluate the tensile strength of the concrete mix. A beam of size

![Figure 1](image-url)
(150 × 150 × 500 mm) was cast and tested to evaluate their flexure strength according to ASTM [27, 36]. At 7, 14- and 28-days curing, three samples of each test were tested, and their average value was taken as a strength for that particular test. For durability assessment, as per ASTM C642 [37], 50 mm thick and 100 mm diameter discs are cast for water absorption test. For acid-resistant, a 100 mm cubical specimen of varying percentages of marble slurry and coconut fibers was cured in 4% acid (H2SO4) solution for 7, 14, and 28 days. The acid solution was changing every week to maintain 4% concentration. The acid attacks were measured in terms of mass loss (%) due to sulfuric acid (H2SO4) attacks. The casting of test sample and compaction was done with tamper rod at three different levels manually giving twenty five blows each level according to the method defined by ASTM C-31. To examine the influence of marble waste (MW) as well as coconut fibers on the performances of concrete, six batches were casted. Aspects of each batch with different dosages of marble waste and coconut fiber were provided in Table 6.
Table 6. Quantification of materials per m.

| Mix ID  | Cement (kg) | Sand (kg) | Coarse Aggregate (kg) | Water (kg) | Super-plasticizer (kg) | Marble Waste (kg) | Coconut Fibers (kg) |
|---------|-------------|-----------|-----------------------|------------|-----------------------|-------------------|--------------------|
| Control | 425         | 625       | 1275                  | 180        | 2.12                  | 21                | —                  |
| MW-5%   | 403         | 625       | 1275                  | 180        | 2.12                  | 42                | —                  |
| MW-10%  | 382         | 625       | 1275                  | 180        | 2.12                  | 63                | —                  |
| MW-15%  | 362         | 625       | 1275                  | 180        | 2.12                  | 85                | —                  |
| MW-20%  | 340         | 625       | 1275                  | 180        | 2.12                  | 85                | —                  |
| MW-25%  | 319         | 625       | 1275                  | 180        | 2.12                  | 106               | —                  |
| MW-30%  | 298         | 625       | 1275                  | 180        | 2.12                  | 127               | —                  |
| CFs-0.5%| 425         | 625       | 1275                  | 180        | 2.12                  | —                 | 2.12               |
| CFs-1.0%| 425         | 625       | 1275                  | 180        | 2.12                  | —                 | 4.25               |
| CFs-1.5%| 425         | 625       | 1275                  | 180        | 2.12                  | —                 | 6.37               |
| CFs-2.0%| 425         | 625       | 1275                  | 180        | 2.12                  | —                 | 8.5                |
| CFs-2.5%| 425         | 625       | 1275                  | 180        | 2.12                  | —                 | 10.6               |
| CFs-3.0%| 425         | 625       | 1275                  | 180        | 2.12                  | —                 | 12.75              |
Concrete ingredients are a mix, transport, place as well as compact, and then mind while designing a concrete mix. Workability, is defined by ACI 116, is the extent of how smoothly the concrete ingredients are a mix, transport, place as well as compact, and then finish [38].

Results of Slump flow and fresh density of varying dosage of marble waste and coconut fibers are display in figures 3 and 4. slump flow value reduced as the proportion of marble waste improved. Maximum slump flow value was achieved at 0% (control) replacement of marble waste whereas minimum slump flow value obtains at 30% substitution of marble waste. The decrease in workability due to the incorporation of marble waste can be attributed because, particle shape (flat and elongated) surface texture (rough), which increase the internal friction between the concrete ingredients as well as the larger surface area of marble waste results in more water needed for lubrication and as results less workable concrete [5].

As for coconut fibers concern, the Slump flow value decrease as the dosage of coconut fibers increased. The highest slump flow was achieved at 0% addition of coconut fibers while minimum slump flow was observed at 3.0% substitution of coconut fibers as shown in figure 3. The decrease of slump flow of concrete when coconut fibers are increased is expected to the greater surface area of coconut fibers which need more water to cover them and thus less free water is present for oiling. Moreover, coconut fibers enhanced the internal friction among the concrete ingredients which required additional cement paste to cut such friction [28].

Figure 4 demonstrates the fresh density by varying dosages of marble waste and coconut fibers. It can be observed that fresh density increases as the content of waste marble increase up to 20% replacement and then decrease progressively. The highest fresh density was achieved at 20 percent addition of marble waste as compared to the control mix (0% of waste marble). However, fresh density was reduced at a higher dosage (beyond 20%). The positive impact on fresh density is attributed to the pozzolanic reaction of SiO₂ in marble waste with Calcium hydrate (CH) of cement producing additional cementitious compounds leading to more dense concrete [39]. However, at a higher dosage, the compaction process becomes more difficult due to less flowability which cause more voids in harden concrete, resulting lower strength [40].

As for Coconut fiber concerns, fresh density increased as the percentage of Coconut fiber increase up to 2.0% and then reduced as compared to reference concrete which was shown in figure 4. Coconut fiber with a 2.0 percent dosage shows the maximum fresh density as compared to the reference concrete (0% addition of coconut fibers). However, fresh density was reduced for further addition of coconut fibers having a minimum fresh density at 3.0% addition of coconut fibers as compared to other coconut fibers reinforced concrete. The decrease in fresh density of concrete blend with coconut fibers is due to crack prevention as coconut fiber reinforced concrete has less and gives more dense concrete as a result fresh density concrete improves. However, at higher dosages, at 4.0% substitution of coconut fibers, the compaction process becomes more difficult which results in porous concrete, leading to a less fresh density of concrete. Fresh density is about 15% increased if the 1.5% fibers by volume are added to concrete [41].

Figure 5 demonstrate the relationship among density of fresh concrete and workability with varying percentage polypropylene fibers is shown in figure 5. It is observed that a strong relationship occurs between workability and concrete density of fibers reinforced concrete having an R² value greater than 90%. It is due to
fact that density is the function of workability. Low workability leads to more voids in occupied space which results in ultimate less density.

3.2. Hardened concrete

3.2.1. Compressive strength

The ability of materials to resist the force when it is subject to compressive force is termed as the compressive strength of that material. According to the standard procedure defined by ASTM as ASTM C39/C39M [34] was used for the compressive strength test for standard size (300 mm length and 150 mm diameter) cylindrical specimens.

Figure 6 demonstrates the compressive strength of different dosages of marble waste. It can be observed that compressive strength increases as the percentage of marble waste increase up to 20% substitution by weight of cement and then decrease gradually. As reported by the previous research that concrete strength increased with the incorporation of marble waste [42]. Maximum compressive strength was achieved at 20% substitution of marble waste as in comparison reference mix (0% replacement). Though, compressive strength was decreased due to more addition of waste marble (beyond 20%). The positive impact on compressive capacity is due to pozzolanic activity of SiO₂ in marble waste by CH of cement producing additional cementitious compounds [39]. The extra binder generated due to marble waste reaction with accessible lime allocates marble waste to maintain gain of strength with the passage of time. But, at a greater quantity of marble waste (beyond 20%) concrete strength decreases owing to the dilution because of which cause alkali-silica reaction owing to a greater amount of unreactive silica accessible due excessive quantity of marble waste. Also, at a higher dosage, the compaction process becomes more difficult due to absence of flowability which cause voids in harden concrete, resulting less compressive strength [40]. Therefore, it is recommended that marble waste should be used up to 20% substitution by weight of cement.

As for Coconut fiber concerns, compressive strength enhanced as the dosage of Coconut fiber increase up to 2.0% and then reduced as compared to control which were shown in figure 6. According to past literature, Compressive strength improved up to 2.0% addition of fiber in concrete [43]. At 2.0% addition of coconut, fibers show maximum compressive strength after 28 days curing as compared to the control mix (0% fibers). It can be also noticed that compressive strength due to the further addition of coconut fibers (beyond 2.0%). The positive impact of coconut fibers on compressive strength because of confinement of coconut fibers around the cylindrical specimens. Laterally expansion produces under the application of compressive for which resist it due to confinement which results to enhance compressive strength. However, at higher dosage (beyond 2.0%) this confinement resistance reduces due to lack of workability. The compaction process becomes more difficult particularly at higher dosage (3.0% coconut fibers), leading to porous concrete, and hence the compressive strength is reduced. According to past literature fresh density is about 15% increased if the 1.5% fibers by volume are added to concrete [41] which gives more dense harden concrete leading to more compressive strength. Also reported that fibers at 1.0% fibers by volume cause a significant increase at the beginning along with prolonged concrete compressive strength. The highest improvement in compressive strength was seen at 29.15 percent as compared to reference concrete [44]. Therefore, it is essential to use an optimum dosage of coconut fibers in fiber-reinforced concrete. Experimental work shows that the best possible substitution of Coconut fiber which produces better compressive strength is 2.0% by weight of cement.
A relative is also carried out in which 28 days compressive strength of control mix is considered as reference mix, from which different mix of varying percentages of marble waste and Coconut fiber is compared as shown in figure 7. After 7 days curing, compressive strength is about 13% and 20% less than as compared to control (28 days) at 20% and 2.0% substitution of marble waste Coconut fiber respectively. At 14 days curing, concrete compressive strength is only 2.0% less than reference concrete / control (28 days) at 2.0% substitution of coconut fibers while 18% higher than reference concrete / control (28 days) at 20% substitution marble waste. At 28 days curing, concrete compressive strength is 33% and 15% higher than reference concrete at 20% and 2.0% substitution of marble waste and Coconut fiber respectively. It can be concluded that marble waste not much improves compressive strength at an early age (7 and 14) while later age strength improves considerably. It is because of pozzolanic activity which results gain in strength with time. It has been also reported that, strength gain due to pozzolanic reaction lower than early days [45]. It can also indicate that coco fibers improve less compressive strength as compare to marble waste which was also reported by an earlier researcher that fiber not much improves compressive strength considerably [28].

Response surface methodology is a statistical tool, and its main purpose is to optimize a response which can be affected by numerous factors. Whenever there is more than one response, so it is essential to evaluate the combined best possible dosage of both materials that do not optimize only one response [46]. In this research,
Minitab software was used to develop a 3D response surface and contour plot for combine effects of marble waste (MW) and coconut fibers (CFs) verse strength. To evaluate optimum dosage MW and CFs in concrete, 3D response surface was converted into contour plot in which 18% marble waste (MW) and 2.0% coconut fibers (CFs) are selected from contour plot giving compressive strength 29 Mpa as shown in figures 8 and 9. It can also indicate that strength increase as the percentage of coconut fiber and marble increase giving maximum strength (29 Mpa) at 2.0% coconut fibers and 18% of marble waste. To validate the calculated value of statistical models for compressive strength of concrete, the similar dosage of 18% marble waste (MW) and 2.0% coconut fibers (CFs) are cast and experimentally tested in the laboratory. It has been concluded that the predicted value from the contour map (29 Mpa) and laboratory experimental value (28.6 Mpa) was approximately equal which validates the response surface model.

3.2.2. Split tensile strength
Splitting Tensile strength is the stresses produce owing to employing load in compressive nature with the help of compressive testing machine in such a way that concrete cylindrical specimen split in vertical diameter. It is called the indirect technique to find the strength of concrete against tensile load. The direct method is not possible because of grip cylindrical sample satisfactory as well as eccentric load. Therefore, the direct tensile test
is not the standardized method. At specified period of curing, concrete tensile was find according to ASTM C496-71 [35] of a standard cylindrical sample of size 150 (mm) in diameter with 300 (mm) length.

Concrete tensile capacity by differing quantities of marble waste was shown in figure 10. Similar concrete strength against compressive load, tensile strength of concrete is also improved as a proportion of marble waste improved up to 20% replacement but then reduced slowly. Corresponding to experimental work highest tensile strength was attained at 20% substitution of waste marble with cement, and minimum tensile of concrete strength was observed at 0% addition of marble waste. The marble slurry has greater carbonate content which enhances the aggregate cement paste bond which is the main cause for the rise of concrete compressive strength at various curing periods [13]. The positive impact of marble waste on split tensile strength is due to the pozzolanic reaction of marble waste, producing additional cementitious compounds [45]. It has been also reported that marble waste shows pozzolanic properties if the particle size is less than cement particles i-e 75 microns [4]. The extra binder generated by marble waste reaction with accessible lime allows marble waste concrete to gain strength with passage of time. However, at a higher dosage (30%), the compaction process becomes more difficult due to less of flowability which results in more voids, leading to lower strength. Similarly, due to its fineness, marble waste behave as a filler material in binder aggregate matrix which fill micro voids resulting more dense concrete [47].

As for coconut fibers (CFs) concern, as compared to control concrete, split tensile was enhanced up to 2.0% addition of coconut fiber similar to compressive strength which is shown in figure 10. Maximum concrete
tensile capacity is achieved at 2.0% substitution of CFs as compared to control (0% of fibers) after specified days curing. Previous research suggests that split tensile strength is 40% as compared to reference mix at 2.0% substitution of fibers. It can also indicate that fibers improve compressive strength more effectively than compressive strength [48]. However, split tensile strength decrease gradually after the further substitution of coconut fiber (beyond the 2.0 percent) due to lack of workability. The flexibility of concrete increases due to the addition of coconut fibers by means of stopping the formation of cracks or stopping the creation of cracks which results the tensile strength capacity of fibers reinforced concrete is much better than conventional concrete mix. CFs act as crack stoppers and not as crack prevention. It worth mentioning here that CFs enhance tensile strength more effectively as compared to compressive strength. It has been reported that fibers are well known to increase the post cracking behavior of concrete [49]. Also, fibers with 0.5 to 2.0% by volume show a much more effective influence on the tensile capacity of concrete [50].

As previously reported, that tensile capacity of concrete shows the similar behaviors as compressive strength. Hence, a strong relationship was existed among compressive and split strength having $R^2$ value in regression graph is more than 90% as shown in figure 11.

![Figure 13. 3D response surface for split tensile strength.](image-url)  

![Figure 14. Contour plot for split tensile strength.](image-url)
A relative analysis was also performed in which twenty eight days curing tensile strength of reference concrete is considered as reference mix, from which different mix of varying percentages of marble waste and Coconut fiber is compared as display in Figure 12. After seven days curing, tensile strength is about 16% lower as compared to control (28 days) at 20% substitution of marble waste while approximately equal to control (28 days) at 2.0% of Coconut fiber. At 14 days curing, concrete split tensile strength is only 9.0% and 29% higher than reference concrete/ control (28 days) at 20% and 2.0% substitution of marble waste Coconut fiber respectively. At 28 days curing, concrete split tensile strength is 23% and 47% higher than reference concrete at 20% and 2.0% substitution of marble waste Coconut fiber respectively. It is worth mentioning here that, the fiber improves split tensile strength much more effectively than compressive strength which is already reported by the earlier researcher that fiber improves split tensile strength much more efficiently than compressive strength [28].

To evaluate optimum dosage marble waste (MW) and coconut fibers (CFs) for split tensile strength for concrete, 18% marble waste (MW) and 2.0% coconut fibers (CFs) are selected from the contour plot giving split tensile strength 5.0 Mpa as shown in Figure 13 and 14. To validate the calculated value of statistical models for split tensile strength of concrete, a similar dosage of 18% (MW) and 2.0% (CFs) are cast and experimentally tested in the laboratory on the same days. It can be observed that the predicted value from the contour map and laboratory test value (4.7 Mpa) for split tensile were comparable to each other’s, which validates the statistical models (response surface methodology).

3.2.3. Flexure strength
It can be defined as, the ability of materials to resist deformation just before it fails [51]. It is also known as bending strength of modulus of rupture. Flexural strength test was evaluated on beam sample of size 150 × 150 × 500 mm at specified curing of concrete.

Flexure strength by differing quantities of marble waste coconut fibers was given in Figure 15. Like compressive capacity of concrete, Flexure strength was also enhanced as the substitution rate of marble waste enhanced up to 20% addition and afterward reduced steadily. Based on experimental work, highest flexure strength was obtained with 20% addition of marble waste, and minimum flexure strength was achieved at 0% addition of marble waste (reference concrete). It has been also reported that flexure strength in with incorporation of waste marble [4]. The highest flexure strength was obtained at 20% of marble waste as compared to control (0% substitution). Flexure strength was reduced gradually for further addition of marble waste (beyond 20%). The positive influence of marble waste on flexure strength is due to the pozzolanic reaction of SiO2 in marble waste with CH of cement producing additional cementitious compounds [39]. But, at a maximum substitution of marble waste (after 20%) flexure capacity reduces owing to dilution impact which result to alkali-silica reaction due to greater amount of unreactive silica accessible due to large quantity of marble waste. Also, at a higher dosage, the compaction process becomes more difficult due to absence of flowability of fresh concrete which results more voids in harden concrete, leading to lower strength [40].
Figure 15 shows flexure strength with a varying dosage of coconut fibers starting from 0% up to 3.0% by weight of cement for specified days of curing. Like the compressive capacity, Flexure strength improved as the proportion of Coconut fiber increase up to 2.0% by the weight of cement and then decreased as compared to a reference or conventional concrete (0% substitution of coconut fibers). According to past research, up to 2.0% addition of fibers shows better flexure strength as in comparison to control [43]. Maximum flexure strength was obtained at 2.0% substitution of coconut fibers as a comparison to control after specified days curing. Flexure strength was reduced gradually beyond 2.0% substitution of coconut fibers. All the coconut fibers reinforced concrete mixes show better flexure strength as compared to conventional mix. The positive influence of CFs on flexure strength is due to crack prevention. When coconut fibers are present in a concrete mix, the exterior load can be easily shifted to CFs via interfacial among concrete ingredients and coconut fibers. Coconut fibers inhibit the crack transmission and transverse around crack to transmit inner load, coconut fibers along with concrete matrix resist load as a whole [44] and hence flexure strength is improved. The compaction process becomes more difficult as the percentage of fiber increased. At higher dosage i-e 3.0%, workability decreased which led to porous concrete, and hence the flexure strength is reduced.

Figure 16. Co-relation between compressive and flexure strength.

Figure 17. Relative analysis of flexure strength.
Co-relation between compressive strength and flexure with the incorporation of waste marble and coconut fibers is shown in figure 16. From figure 16, it can be notice that a strong relationship is exist the between compressive and flexure capacity having $R^2$ more than 90 percent.

A relative is also carried out in which 28 days flexure strength of control mix is considered is reference mix, from which different mix of varying percentages of marble waste and Coconut fiber is compared as displayed in figure 17. After seven days curing, flexure capacity is around 16% lower than as compared to control (28 days) at 20% substitution of marble waste which equals to control at 2.0% coconut fiber. At 14 days curing, concrete flexure strength is only 10% and 26% higher than reference concrete / control (28 days) at 20% and 2.0%. At 28 days curing, concrete flexure strength is 27% and 45% higher than reference concrete / control (28 days) at 20% and 2.0%. It can be concluded that fibers improve flexure strength more effectively than compressive strength.

To evaluate optimum dosage marble waste and Coconut fiber for flexure strength for concrete, 18% marble waste and 2.0% Coconut fiber are selected from the contour plot giving flexure strength 9.0 Mpa (at 28 days) as shown in figures 18 and 19. To validate the calculated value of statistical models for flexure strength of concrete, the similar dosage of 18% (MW) and 2.0% (CFs) are cast and experimentally tested in the laboratory on the same days. It can be observed that the predicted value and laboratory test value were comparable, which validates
the calculated response surface models. It can be concluded that a combination of fiber and marble waste improve mechanical properties much more effectively, flexure capacity of reference concrete at twenty eight days of curing is about 3.7Mpa while optimization with help of response surface methodology, flexure strength is about 9.0 Mpa at 18% of marble waste and 2.0% coconut fibers. which were almost 150 times more than as compared to blank mix/control.

4. Durability

4.1. Water absorption

It is an indirect method to evaluate durability of concrete. Generally toxic chemicals are available in water. Such elements react with cement constituents, which cause variations in the concrete performance. Additional water available in the pore of cement concrete cause freeze and thaw effect due to the temperature change, which cause crack the concrete structure due to expansion and contraction. Because this reason water absorption test was performed on different days of curing with varying proportions of marble waste (MW) and coconut Fibers CFs.
Figure 20 shows water absorption test outcome of different dosages. Water absorptions decrease as the amount of marble waste increase up to 20% replacement of marble waste and the decrease progressively having maximum water absorption at 0% addition whereas minimum water absorption is 20% substitution of marble waste. It is due to the pozzolanic activity of SiO₂ in marble waste with CH of cement producing additional cementitious compounds leading to more dense concrete with low voids content. It has been also reported that density is directly related to water absorption. Higher density results in low water absorption and vice versa [40].

However, at a higher dosage, the compaction process becomes more difficult due to a less of flowability which results in voids in hardened concrete, leading to more water absorption.

Table 3. Acid resistance.

Figure 22. Contour plot for water absorption.

As for coconut fibers (CFs) concern, Water absorptions decrease as the percentage of coconut fibers increases up to 2.0% substitution of coconut fibers and the decrease gradually having maximum water absorption at 0% substitution whereas minimum water absorption is 2.0% substitution of marble waste. It has been also reported that minimum water absorption was obtained at 2.0% substitution of steel fibers [28]. It is due to fact that Elastic modules of normal concrete are lower than fibers reinforced concrete. So, the addition of CFs would lead to increased tensile properties of concrete, and as a result, it would restrict the formation and development of initial cracks [52]. In other words, the density of concrete is increased which would lead to water absorption of concrete decreased. However, at higher dosage (beyond 2.0%) water absorption increased due to lack of workability leading to less dense concrete.
To evaluate the optimum dosage of marble waste and Coconut fiber for water absorption of concrete, 18% marble waste and 1.8% Coconut fiber are selected from the contour plot giving water absorption 7.5 in percentage (at 28 days) as shown in figures 21 and 22. To validate the calculated value of statistical models for water absorption of concrete, a similar dosage of 18% (MW) and 1.8% (CFs) are cast and experimentally tested in the laboratory on the same days. It has been concluded that the predicted value from the contour map (7.5%) and experimental value for water absorption (8.1%) are approximately equal which validates the response surface model.

4.2. Acid resistance

Although there are several aggressive acids, such as hydrochloric acids, nitric acids, sulfuric acids (H₂SO₄), and acetic acids. In this analysis, H₂SO₄ was taken as an acid attack, on the concrete sample with various percentages of marble waste and coconut fibers CFs. The test results of acid resistance are shown in terms of loss of mass due to sulfuric acid strike of the specimens after 7, 14 and 28 days for each mix as shown in figure 23 show mass loss owing to sulfuric acid significantly declines with the addition of marble waste up to 20% addition. Minimum weight loss was obtained at 20% substitution of marble waste while maximum weight loss was obtained at 0% (control/reference mix) of marble waste. It due to the pozzolanic activity of marble waste which results in more tightness (dense concrete). Fast penetration of sulfuric acid decreases due to more dense concrete which results
in decrease weight loss of concrete specimens due to sulfuric acid attacks. It has been also reported that weight loss due to acid attacks depend on concrete porosity [40]. More porous concrete, fast penetration of acid into the concrete body which aggressively damages the concrete structure due to reaction with cement constituents.

As for coconut fiber (CFs) concern, mass loss owing to sulfuric acid decrease up to 2.0% substitution of coconut fibers. Maximum weight loss was observed at 0% substitution of CFs while minimum weight loss due to sulfuric acid was observed at 2.0% substitution of CFs. It is due to fact that the addition of CFs efficiently controls the development and creation of initial cracks which cause to decrease porosity of the concrete [52] which prevents fast penetration of sulfuric acid. Concrete attrition is due the solution of calcium aluminate as well as calcium hydroxide due to sulfuric acid [53–55]. Attrition rate will mostly depend on sulfuric acid infiltration percentage into the concrete mass as well as to reach calcium hydroxide and calcium aluminate. So, decrease in the porosity of concrete results more compact concrete due to the adding of CFs. The decreased in porosity of concrete result low diffusion ratio of sulfuric acid.

To evaluate optimum dosage of marble waste and Coconut fiber for acid resistance of concrete, 18% marble waste and 1.8% Coconut fiber are selected from the contour plot giving weight loss due to sulfuric acid attack 0.8 in percentage (at 28 days) as shown in figures 24 and 25.

To validate the calculated value of statistical models for sulfuric acid resistance of concrete, a similar dosage of 18% (MW) and 1.8% (CFs) are cast and experimentally tested in the laboratory on the same days. It can be observed that the laboratory work (1.2%) almost equal to value obtain from contour graph (0.8%), which supports the estimated RSM.

4.3. Carbonation resistance
Carbonation of concrete is one of the critical parameters associated with the corrosion of steel reinforcements. Figure 26 demonstrates the carbonation depth of specimens with varying dosages of MW and CFs dosage. Carbonation depths decrease as the proportion of MW increase up to 20% addition of marble waste and then decrease steadily having maximum Carbonation’s depth at 0% substitution whereas minimum Carbonation’s depth is 20% substitution of marble waste. This can be attributed the pozzolanic reaction of SiO₂ in marble waste with CH of cement producing additional cementitious compounds leading to more dense concrete with low voids content which results to decrease the diffusion of CO₂. However, at a higher dosage, the compaction process becomes more difficult due to a less of flowability of fresh concrete which results more voids in harden concrete, resulting to more Carbonations depth.

As for CFs, it can be noticed that the carbonation depth of concrete decreases as the percentage of CFs increase from 0% to 2.0% and decreased steadily as the percentage of CFs increase beyond 2.0% by weight of cement. All CFs reinforced mix shows lower carbonation as compared to the conventional concrete without fiber. The minimum depth was observed at 2.0% of CFs which is almost 48% (at fourteen days curing) lower as compared to the conventional concrete. Many holes are formed in concrete which facilitate the diffusion of CO₂ in concrete due to loss of available water and shrinkage. Addition of coconut fibers (CFs) blocks the diffusion channel of CO₂ which results to improve the resistance for CO₂ penetration. This results in a decrease of carbonation speed [56]. However, at a higher dosage of CFs (3.0%), the fiber prevents the cement paste to fill the
voids in microstructure which increased internal porosity and can provide a new channel for CO$_2$ to penetrate in a concrete structure which results in increased speed of carbonation [57].

To evaluate optimum dosage of marble waste and Coconut fiber for carbonation depth resistance of concrete, 18% marble waste and 1.8% Coconut fiber are selected from the contour plot giving carbonation depth 0.8 in percentage (at 14 days) as shown in figure 27 and 28. To validate the calculated value of statistical models for carbonation depth of concrete, a similar dosage of 18% (MW) and 1.8% (CFs) are cast and experimentally tested in the laboratory on the same days. It can be observed that that the laboratory work (1.10%) almost equal to value obtain from contour graph (0.92%), which supports the estimated RSM (response surface model).

5. Conclusion

In this research, marble waste (0%, 5.0%, 10%, 15% and 20%, 25% and 30% by weight of cement) and coconut fibers (0%, 0.5%, 1.0%, 1.5% and 2.0%, 2.5% and 3.0% by weight of cement) is being used in concrete production. It has been concluded that the optimum dosage for combine substitution of waste marble and
coconut fiber 18% and 1.8% by weight of cement. The subsequent conclusions were obtained on the present study.

- Strength (Compressive, tensile, flexure, as well as bond strength) enhanced as the content of marble waste (MW) was increase to 20% replacement and then decrease compared to the control mix. It is due to microfilling voids in aggregate as well as pozzolanic activity of marble waste (MW).

- In the case of coconut fibers (CFs), strength (Compressive, tensile, flexure, as well as bond strength) increases up to 2.0% substitution and then decreases as compared to conventional concrete. The positive impact on strength is due to the restriction of concrete with addition of coconut fibers. At higher dosage (beyond 2.0% substitution), the compaction will be become more difficult due to less flowability, leading to porous concrete which results in decreased strength.

- Based on work results, the predicted value from statistical analysis and the experimental value were comparable.

- The highest strength was obtained at the ratio of 18% marble waste (MW) and 1.8% coconut fibers (CFs) respectively had a maximum compressive strength of 23 Mpa were almost 37% higher than from reference concrete. Therefore 18% marble waste (MW) and 1.8% coconut fibers (CFs) were optimum dosages for combined substitution.

- Durability aspects such as water absorption carbonation depth considerable improved with incorporation of waste marble and coconut fibers.

Ultimately, the current study concludes that marble waste and coconut fibers (CFs) are suitable, accessible in large quantity, local eco-material, economical, that can be used for concrete construction, in a point of view between financially and the environmentally friendly.

Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

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All writers have no conflict among them.

ORCID iDs

Osama Zaid https://orcid.org/0000-0002-8071-1341

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