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Research article

Mechanical properties of sustainable concrete modified by adding marble slurry as cement substitution

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Abstract: Industrial waste has been rapidly increased day by day because of the fast-expanding population which inappropriately dumps the waste resulting in environmental pollutions. It has been recommended that the disposal of industrial waste would be greatly reduced if it could be incorporated into concrete production. The basic objective of this investigation is to examine the characteristics of concrete using marble slurry as binding material in proportions 5%, 10%, 15%, 20%, 25%, and 30% by weight of cement. Many properties have been reviewed in the current paper; the results observed from the various studies depict that replacement of marble slurry to a certain extent enhances strength properties of the concrete but simultaneously decreases the slump value with the increase of replacement level of marble slurry.

Keywords: marble waste; slump; split tensile strength; flexure strength; compressive strength

1 Introduction

The idea of sustainable development assumes that natural resources should be treated as limited goods and the wastes should be rationally managed. Increasing amounts of collected waste, up to 2500 million tons per year over the world [1] encourage the researcher to a developed new method of disposal. In the cement construction industry, there are many possibilities to used waste materials in concrete [2–5] waste can be used as aggregate or cement in concrete.

For a good concrete mix, fine aggregates need to be clean, hard, strong, and free of absorbed chemicals and other fine materials that could cause the deterioration of concrete. Unfortunately, the majority of the natural sand used (rolled sand: sand of river, dune sand, and sand of sea) is selected for the price and the availability [6–8].

Different industries are the source of waste which are produced as a byproduct during the manufacturing process. It is suggested that Marble can be easily used in the construction industry to prepare cement concrete [9–11]. The subject of this paper is to use waste marble as a cement substitute obtained from the marble industry. Actual figures about the quantity of waste produced in Pakistan from the marble industry are inaccessible since it is not calculated or monitored by the government or any other party. Other references estimate that 20% to 25% of the marble produced results in powder in the form of slurry during the cutting process [12]. These by-products are present in the environment and contribute to pollution.

Since ancient times marble has been frequently used as a building material. The industry's disposing of the marble powder material, which consist of a very fine powder, today composes one of the environmental issues around the globe [13] usage of the marble dust in different industrial areas especially the paper, agriculture, glass, and construction industries would help to protect the environment [4,11,14]. During the mining process and in the polishing of marble stone, marble dust is perceived as a waste material [10].

Many developed countries have put in motion legal regulations concerning the recovery of structural waste aiming to reduce the amount of waste and to ensure waste recycling [5]. We have the example of Japan in front of us; a country that successfully increased the recycling rate of concrete waste up to 98% using waste material as aggregate [15]. They recognized that the marble stone slurry produced during processing corresponds to about 40% of the final product from the stone industry [16]. They also reported that slump decrease with the addition of marble waste. Katuwal et al. also indicate that marble as a fine aggregate decreases slump [17]. They observed that compressive strength is increased up to 50% replacement of fine aggregate with marble waste which is about 12% higher than control mix [18]. Compressive strength and flexural strength of concrete are increased about 28% and 13% respectively at 50% replacement and then gradually decrease with the addition of waste marble powder [19]. Resistance to the acid of concrete containing waste marble was marginally low in comparison to that of control concrete [20]. The resistance to the acid of concrete containing waste marble was marginally low in comparison to that of control concrete [20]. Suggest that marble slurry can be easily used in the construction industry to prepare cement concrete [9].

Existing literature shows that a very scarce number of studies have investigated the effects of marble as binding materials instead of cement in concrete production particularly in Pakistan. Furthermore, no research is present in the open literature to study the bond of concrete with the incorporation of waste marble which is important as a structural engineer. Therefore, more research is essential to explore the properties of concrete modified with marble waste as a binding material. Therefore, the present work used marble waste as binding materials in a proportion of 5%, 10%, 15%, 20%, 25%, and 30% by weight to evaluate fresh and hardened properties of concrete modified with marble waste.

2 Materials and methods

2.1. Materials

2.1.1 Cement

According to ASTM C150 [21], Ordinary Portland cement (OPC) type-1 was used in this research. Its chemical and physical properties are displayed in Table 1.

Table 1. Chemical and physical properties of OPC cement.

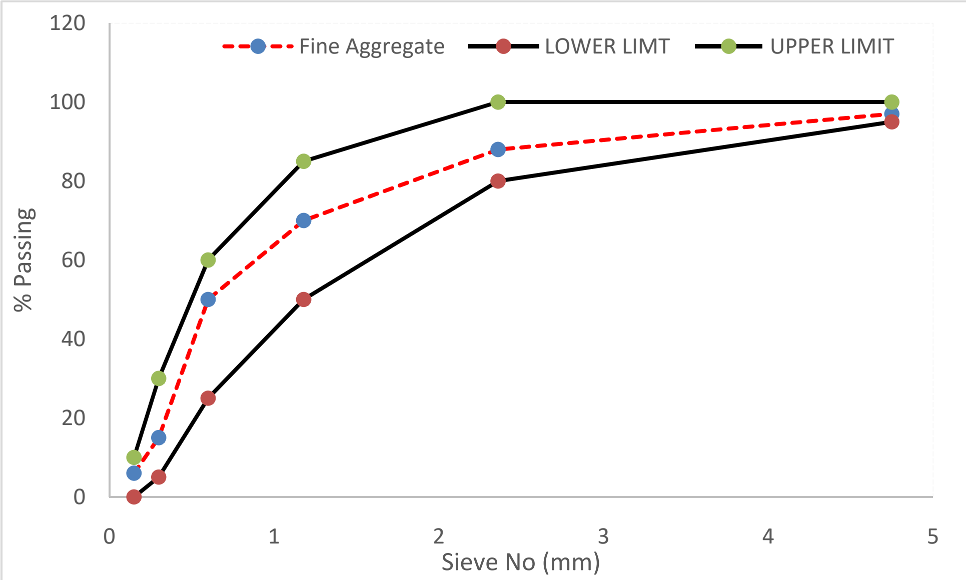
Chemical properties	Percentage (%)	Physical properties	Results
CaO	64.7	Size	≤75 μ
SiO_2	23.9	Fineness	92%
Al_2O_3	5.4	Normal consistency	31%
Fe_2O_3	3.7	Initial setting time	33 min
MgO	3.5	Final setting time	410 min
SO_3	2.9	Specific surface	322 kg/m^2
K_2O	2.4	Soundness	1.70%
Na_2O	1.2	28-days compressive strength	42 MPa

2.1.2 Coarse aggregate and fine aggregate

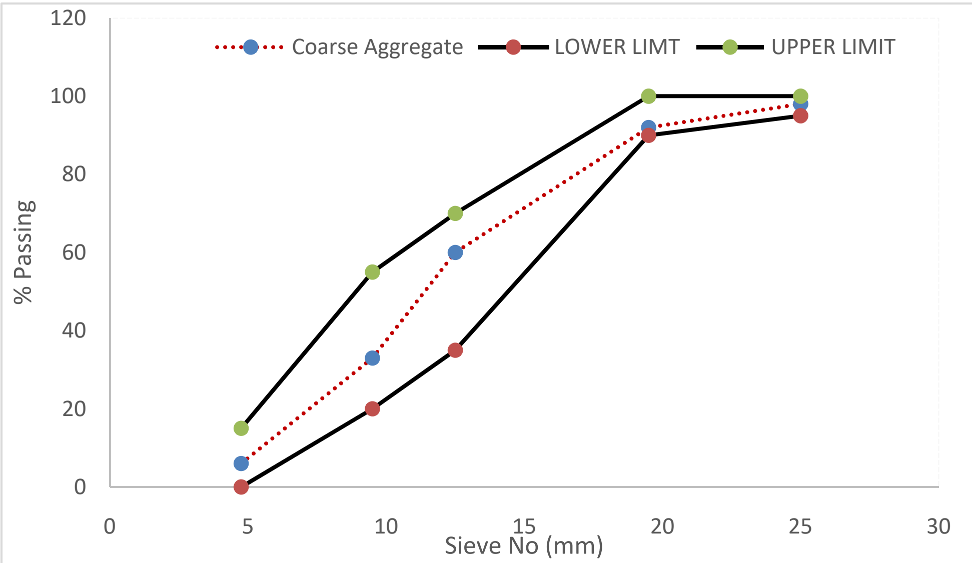
Locally available natural sand was used as a fine aggregate in all the mixes in saturated surface dry conditions (SSD). Normal weight limestone was used as coarse aggregate in a saturated dry condition which was obtained from Margallah Wah Cantt Punjab Pakistan. Different tests were performed on aggregate to evaluate its physical properties as shown in Table 2 while gradation curves are shown in Figure 1 respectively.

Table 2. Physical properties of fine and coarse aggregate.

Physical property	Fine aggregate	Coarse
Aggregate particle size	4.75 mm to 0.075 mm	19.5 mm to 4.75 mm
Absorption capacity	4.10%	2.9%
Fineness modulus	2.63	4.23
Moisture content	1.9%	2.2%
Bulk density (kg/m^3)	1566	1575
Relative density (g/cm^3)	2.65	2.78



(a)



(b)

Figure 1. (a) Gradation curve of fine aggregate, (b) Gradation curve of coarse aggregate.

2.1.3. Waste marble (MW)

Waste marble was procured from the National marble factory industrial zone Peshawar Pakistan and grinded at PCSIR lab Peshawar as shown in Figure 2. Different tests were performed on aggregate to evaluate its physical properties as shown in Table 3.

Figure 2. Marble waste.

Table 3. Physical and chemical properties of marble waste.

Chemical properties	Percentage (%)	Physical properties	Results
CaO	47.55	Color	White
SiO_2	5.13	Specific gravity	2.60
Al_2O_3	22.20	Clay (%)	0.6
Fe_2O_3	8.23	Bulk density (kg/m^3)	1480
MgO	3.32	Absorption capacity	2.30
SO_3	1.07	Moisture content	0.60
K_2O	2.9	Fineness modulus	2.52
Na_2O	2.6	Relative density	2.62

2.2 Size of specimen

A slump cone was used to determine the workability of fresh concrete as per ASTM [22]. ASTM C39/C39M [23]. A cylinder of standard size (150 mm × 150 mm) was be used to measure the compressive strength at 7 days and 28 days. Similar cylinders of standard size (150 mm × 300 mm) were cast and tested to find concrete split tensile strength. Pull out the test was carried out on a cube of size 150 mm to determine bond strength between concrete and reinforcing bar and performed according to ASTM C-234 [24]. The beam of size (150 mm × 150 mm × 500 mm) was cast and tested to find the concrete flexural strength as per ASTM [25]. Three specimens were tested for each test at 7 and 28 days and the mean value of the specimens was considered as final strength.

ASTM C-31 [26] method was followed for the preparation of the specimens and compaction was done manually by tamping rod in three layers having 25 blows per layer. A total of 108 samples having a standard size were cast and then tested. To observe the effect of marble waste on the behavior of hardened and fresh concrete, six mixes were prepared. Details of the mixes are provided in Table 4.

Table 4. Quantification of materials.

Materials	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7
Cement (kg)	425	403	382	362	340	319	298
Sand/F. A (kg)	625	625	625	625	625	625	625
Coarse aggregate (kg)	1275	1275	1275	1275	1275	1275	1275
W/C	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Marble waste (kg)	0	21	42	63	85	106	127

3 Results and discussion

3.1. Fresh property

3.1.1 Slump

Consistency of fresh concrete is a blended property that fuses the various requirements of strength, compatibility, versatility, finish ability, and place ability [27]. It is measure with a slump cone as shown in Figure 3.

Slump value decreased as the percentage of marble waste increased from 0% up to 30% by weight of cement as compared to blank mix (reference concrete) as shown in Figure 3. This can be attributed because marble waste has more surface area than cement which increased workability [28]. Another possible reason for a decrease in workability is due to the rough surface of marble waste which increased the internal friction between the aggregate and hence more water is required for lubrication to reduce internal friction. However, it has also been reported that marble acts like a micro filler that fills the voids in sand and aggregate and it helps to reduce total voids in concrete due which to less water is required for lubricant [29]. Therefore, workability is increased due to the incorporation of marble waste.

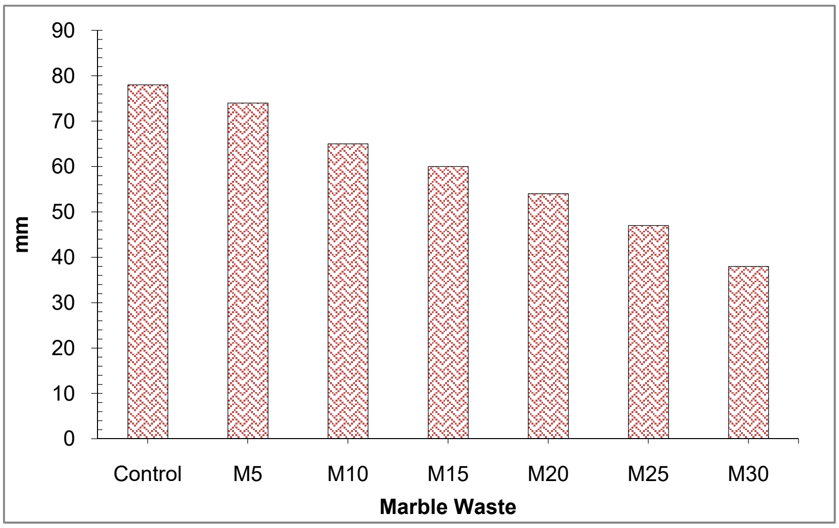


Figure 3. Slump test result.

3.2. *Harden properties*

3.2.1. Compressive strength

Material's compressive strength is the property to resist stresses when it is compressed. The compressive strength test was completed with compliance with the standard procedure of ASTM as ASTM C39/C39M [23] for cylindrical specimens having standard dimensions as 150 mm diameter and 300 mm length. In this test concrete specimens (cylinders) were exposed to compressive axial force at a rate within recommended limit till the concrete failure. Compressive strength was then determined from the highest failure load divided by the X-sectional area of the specimen.

Compressive strength with a varying dosage of marble was shown in Figure 4. Moreover, compressive strength rises as the percentage of marble waste increased up to 20% as a substitute and then reduced as shown in Figure 4. Maximum strength was obtained at 20% replacement and minimum strength was obtained at 0% replacement of marble waste.

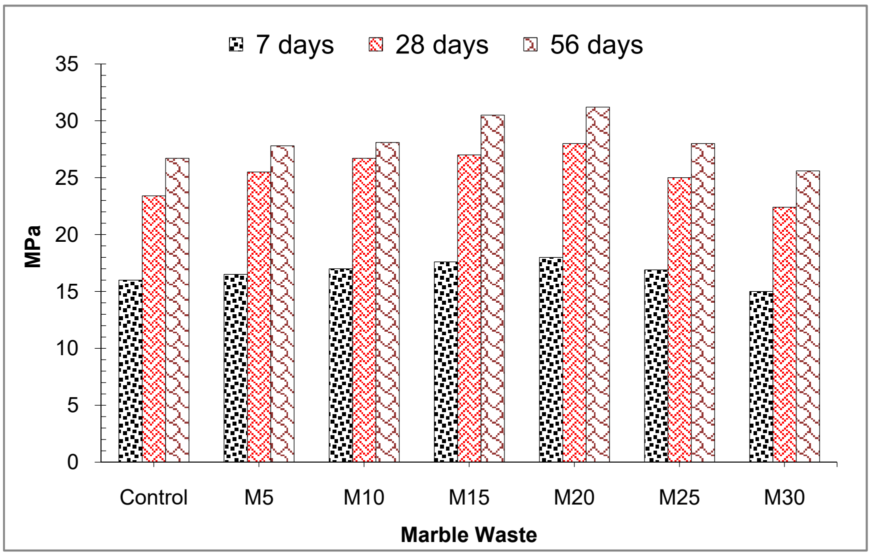


Figure 4. Compressive strength result.

At 20% substitution of marble, compressive strength was 28.5 MPa which was almost 21% higher than blank mix after 28 days of curing. This might be expected the way that marble goes about as micro filler because they less fine modulus as compared to sand which fills the voids giving compact dense mass and as a result strength was increased [29]. Regular aggregate has lower carbonate content than marble aggregate, which enhances concrete aggregate glue bond which is the cause behind the augmentation in concrete compressive strength at different periods of curing [20]. However, a decrease in strength was observed beyond 60% replacements of marble because they have less water retention limit when contrasted with sand which caused bleeding beyond 60% replacement, and as a result strength was decreased.

A relative analysis was also carried out in which 28 days compressive strength of control mix is considered is reference mix, from which different mix of varying percentages of marble waste is compared as shown in Figure 5. At 7 days curing, compressive strength was about 24% less than as compared to control (28 days) at 20% substitution of marble waste. At 28 days curing, concrete compressive strength is only 19% higher than reference concrete/control (28 days) at 20% substitution of marble waste. At 56 days of curing, concrete compressive strength is 34% higher than reference concrete at 20% substitution of marble waste.

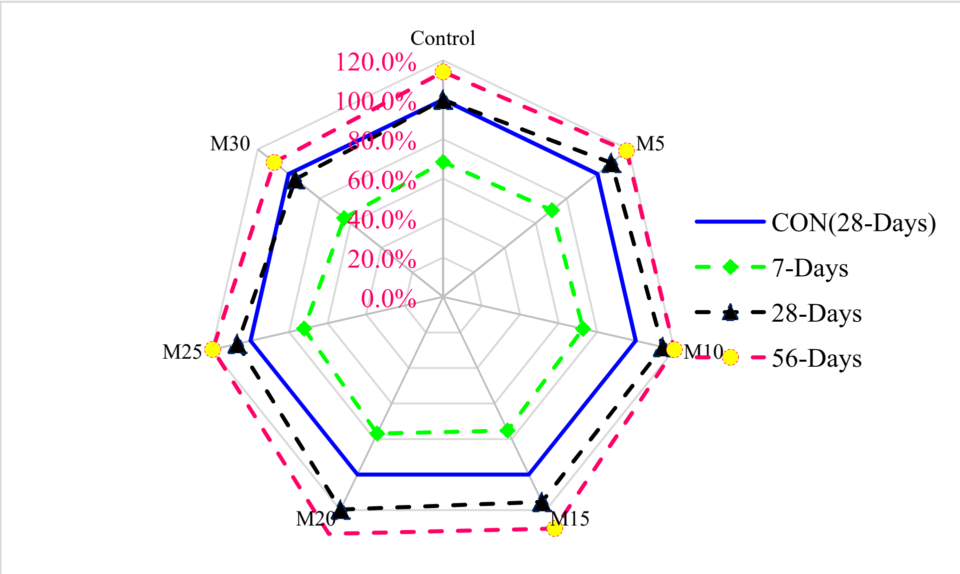


Figure 5. Relative analysis of compressive strength.

3.2.2. Split tensile strength.

Split tensile strength for samples of concrete is known as the tensile stresses created due to applying the compressive load at which the samples of concrete may come up short. It is an indirect method to find the tensile stress in concrete. According to ASTM C496-71 [30], a split tensile test was performed on samples having cylindrical sizes of 150 mm diameter and 300 mm height at the ages of 7-, 28- and 56-days curing.

Split tensile strength with varying dosages of marble waste was presented in Figure 6. Like compressive strength, split tensile was also increased as the percentage of marble waste increased up to 20% substitution and then decreased gradually. According to test observation maximum split tensile strength was obtain with 20% substitution of marble waste and split tensile strength was obtained with 0% substitution of marble waste (blank mix). At 60% substitution of marble, split tensile strength was 3.1 MPa which was almost 25% higher than blank mix after 28 days curing. The marble slurry has more silica (SiO_2) content that reacts with CH (Calcium hydrate) which is form during the hydration of cement giving the additional binding property, which enhances the cement aggregate glue bond which increased the compressive strength of concrete at various curing days [20]. Additionally, because of its finesse, marble waste is a capable substance that goes about as a micro filler in aggregate cement matrix [31].

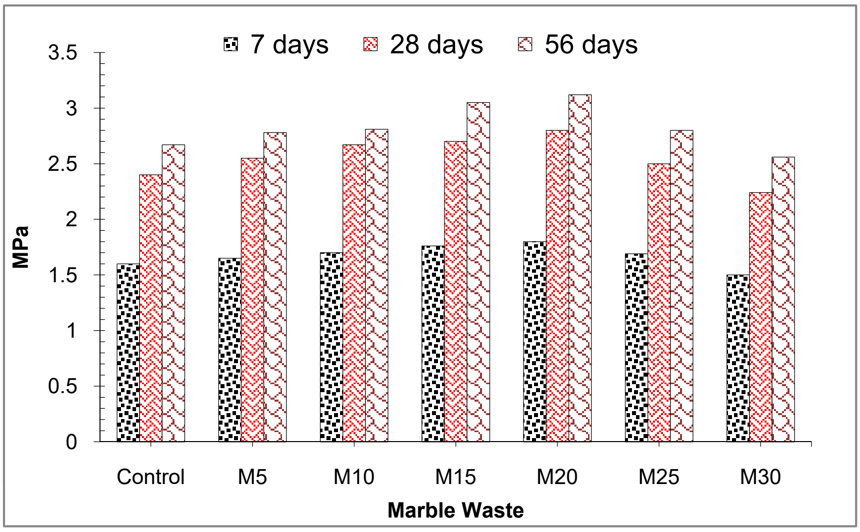


Figure 6. Split tensile strength results.

As already mentioned, that split tensile Strength follows the same pattern as compressive strength. Therefore, a strong co-relation has existed between compressive and split tensile strength having R^2 greater than 90% as shown in Figure 7.

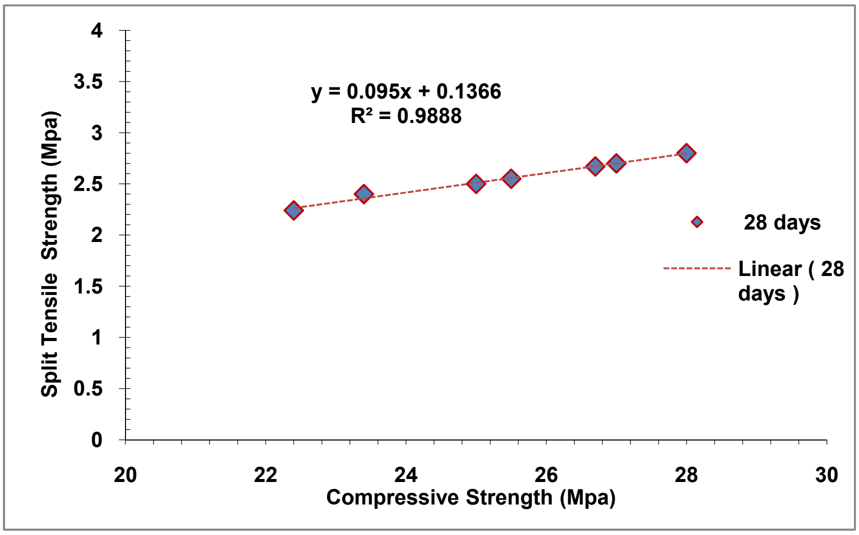


Figure 7. Co-relation between compressive and split tensile strength.

A relative analysis was also carried out in which 28 days compressive strength of control mix is considered is reference mix, from which different mix of varying percentages of marble waste is compared as shown in Figure 8. At 7 days curing, compressive strength is about 24% less than as compared to control (28 days) at 20% substitution of marble waste. At 28 days curing, concrete compressive strength is only 19% higher than reference concrete/control (28 days) at 20% substitution of marble waste. At 56 days o f curing, concrete compressive strength is 34% higher than reference concrete at 20% substitution of marble waste.

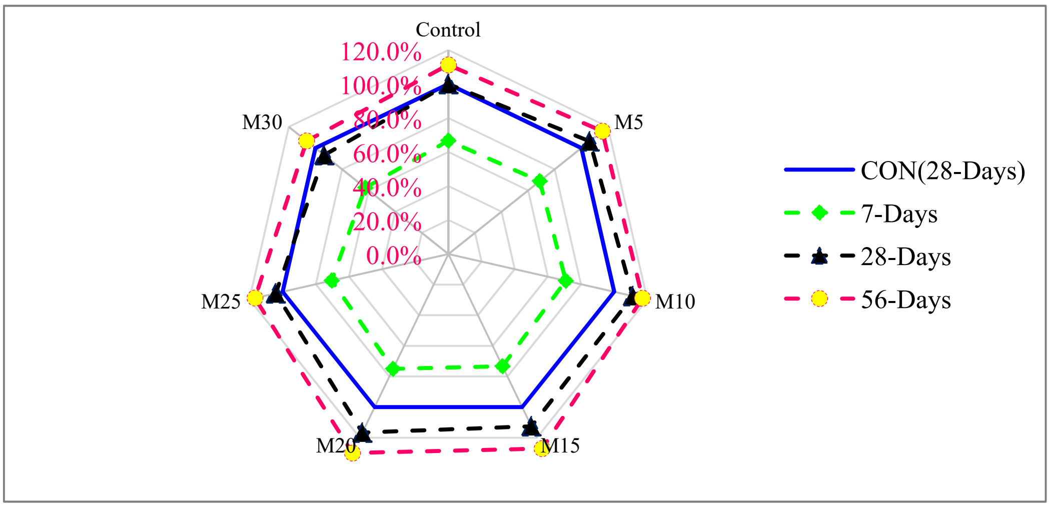


Figure 8. Relative analysis of split tensile strength results.

3.2.3. Flexural strength

Flexural strength, also known as bend strength, or modulus of rupture, is a material characteristic that can be defined as in a flexure test, the stress in a material just before it fails [32]. Flexure examination was performed on samples of a beam of 150 mm × 150 mm × 500 mm at the ages of 7, 14, and 28 days.

Flexural strength with varying dosages of marble waste is presented in Figure 9. Similar to compressive strength, Flexure strength was also increased as the percentage of marble waste increased up to 20% substitution and then decreased gradually. According to test observation, maximum flexural strength was obtained with 20% substitution of marble waste, and flexural strength was obtained with 0% substitution of marble waste (blank mix). At 20% substitution of marble, Flexural strength was 4.15 MPa which was almost 18% higher than blank mix after 28 days of curing. It has been also reported that flexure strength increased with the incorporation of waste marble due to pozzolanic activity [13].

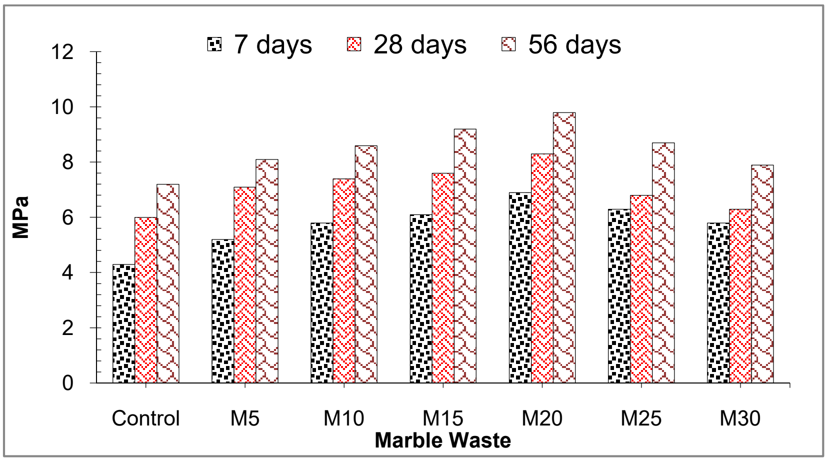


Figure 9. Flexural strength result.

Co-relation between compressive strength and flexural strength with the incorporation of waste marble is shown in Figure 10. It can be observed from the regression model that a strong co-relation was existing in between compressive and flexure strength having R^2 greater than 90%.

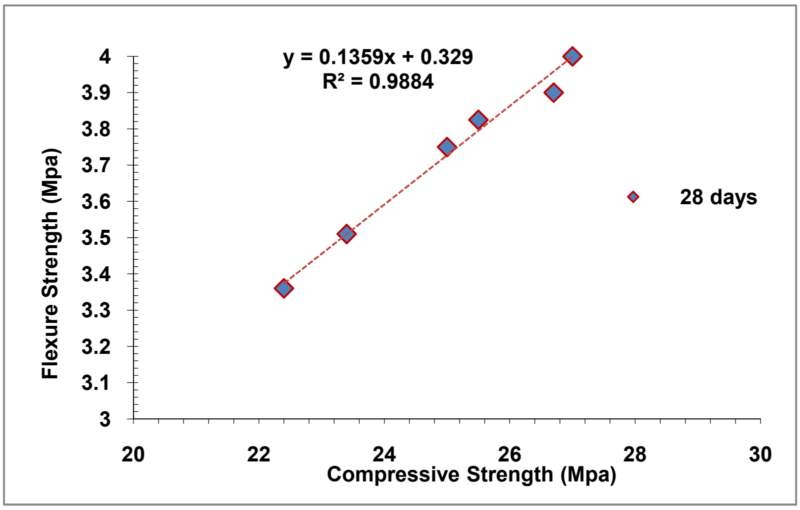


Figure 10. Co-relation between compressive and flexure strength.

A relative analysis is also performed in which 28 days flexure strength of control mix is considered is reference mix, from which different mix of varying percentages of marble waste is compared as shown in Figure 11. At 7 days curing, flexure strength is about 21% less than as compared to control (28 days) at 20% substitution of marble waste. At 28 days curing, concrete flexural strength is only 18% higher than reference concrete/control (28 days) at 20% substitution of marble waste. At 56 days of curing, concrete flexure strength is 26% higher than reference concrete at 20% substitution of marble waste.

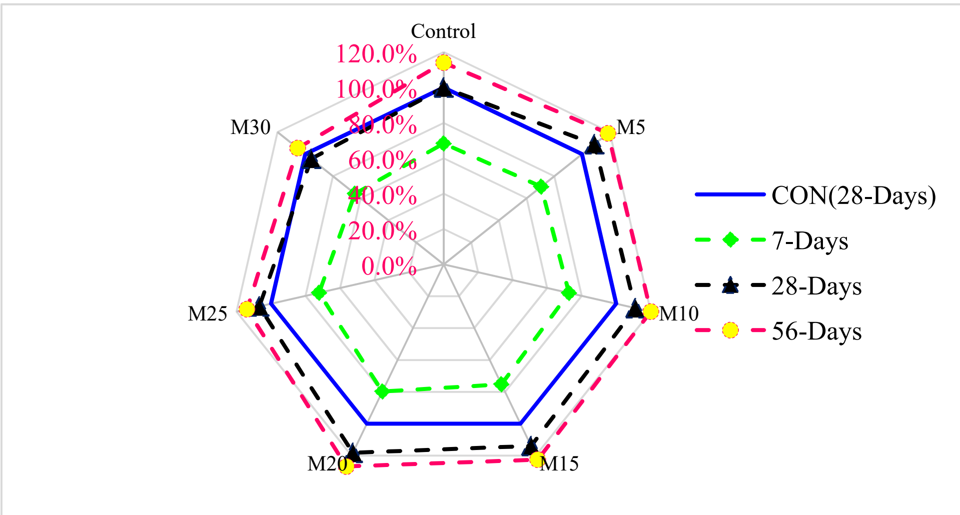


Figure 11. Relative analysis o flexure strength.

3.2.4. Pull out/bond strength.

Pull out the test was carried out on a cube of size 150 mm to determine bond strength between concrete with reinforcing bar and could be performed according to ASTM C-234 [24]. For this test, #4 bars are kept 100 mm from the top as shown in Figure 12, of mold before filling the concrete in the mold.

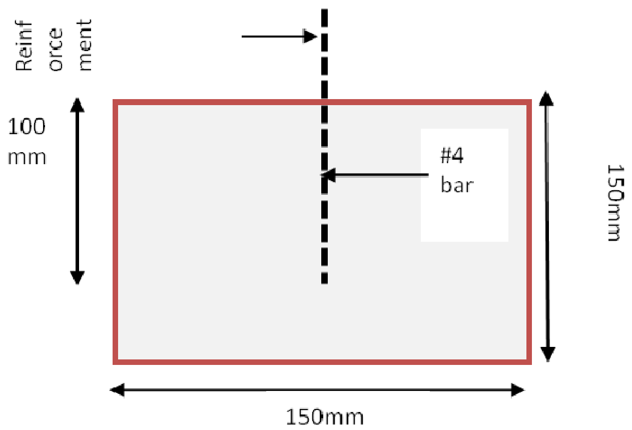


Figure 12. Pull out test sample details.

Bond strength with varying dosages of marble waste was presented in Figure 13. Like compressive strength, bond strength was also increased as the percentage of marble waste increased up to 20% substitution and then decreased gradually. According to test observation maximum, bond strength was obtained with 20% substitution of marble waste, and bond strength was obtained with 0% substitution of marble waste (blank mix). It is due to the pozzolanic activity of marble [33] which gives dense mass, and the bond between reinforcement bar and surrounding concrete improved due to the confinement effect. Additionally, because of its finesse, marble waste is a promising substance that goes about as a micro filler in aggregate cement matrix [31].

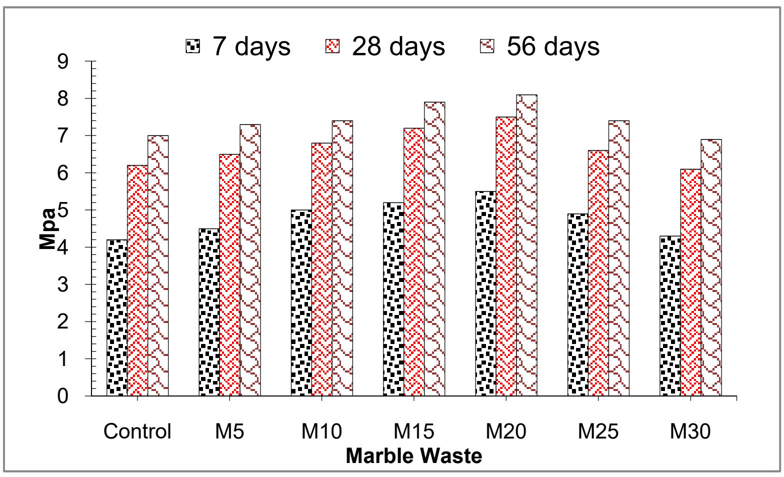


Figure 13. Pull out/bond strength.

Co-relation between compressive strength and bond strength with the incorporation of waste marble is shown in Figure 14. It can be observed from the regression model that a strong co-relation was existing in between compressive and bond strength having R^2 greater than 90%.

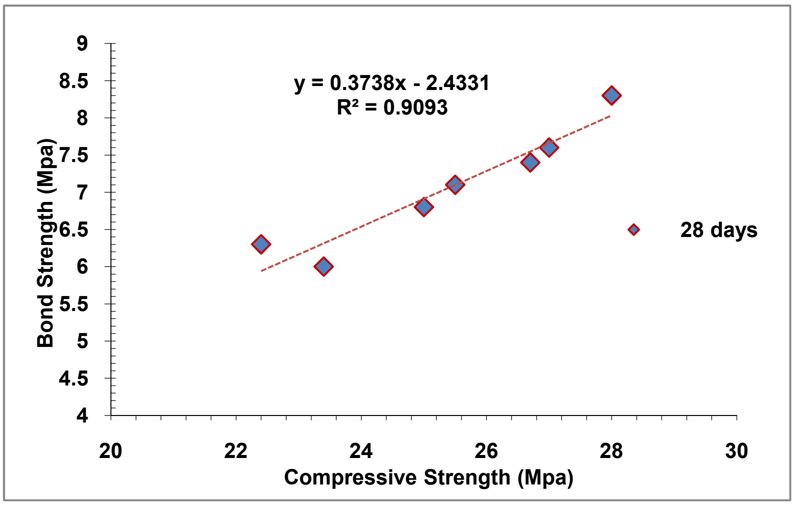


Figure 14. Co-relation between compressive and bond strength.

A relative is also carried out in which 28 d bond strength of control mix is considered is reference mix, from which different mix of varying percentages of marble waste is compared as shown in Figure 15. At 7 days curing, bond strength is about 12% less than as compared to control (28 days) at 20% substitution of marble waste. At 28 days curing, concrete bond strength is 21% higher than reference concrete/control (28 days) at 20% substitution of marble waste. At 56 days of curing, concrete bond strength is 30% higher than reference concrete at 20% substitution of marble waste.

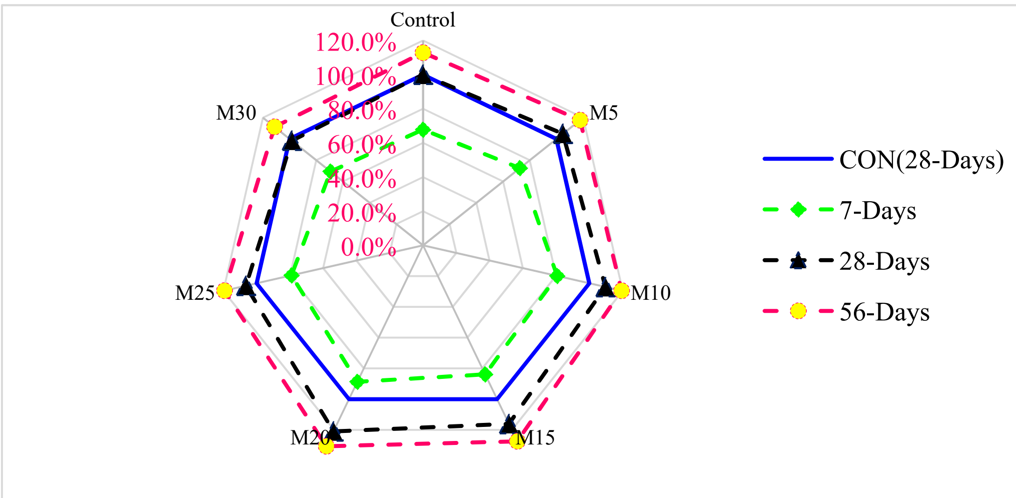


Figure 15. Relative analysis of bond strength.

4. Conclusion

The present study was focused on marble waste which was utilized as a fine aggregate in the proportion of 0%, 5.0%, 10%, 15%, 20%, 25%, and 30% by weight of cement. Based on experimental work following conclusion has been drawn.

- The workability of concrete increased as a percentage of marble waste. The highest slump was achieved at 100% substitutions of marble waste. It is due fact that marble has more water absorption than natural sand. Hence more water is available for lubricant between the coarse aggregate particles.
- Strength (compressive, flexure split tensile and bond strength) increased up to 60% substitution of marble waste and beyond 60% the strength gradually decreased. It is due to fact that marble acts like a micro filler as they have less fineness modulus than natural sand, which fills the voids in sand and coarse aggregate, giving more dense concrete which results to enhance the mechanical performance.
- It tends to be reasoned that, marble waste as fine aggregate can be utilized to improve the mechanical attributes of normal concrete. From the financial and ecological perspective, this waste can be effectively utilized as fine aggregates in the production of concrete.

Acknowledgments

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Conflict of interest

We request to approve that there are no well-known conflicts of interest related to this study.

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