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Determination of Mechanical Properties of Marble Cement Mortar using Pozzolanic Material

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***Abstract*—** In the marble production, huge quantity of marble is lost in the pattern of strange blocks of varying dimensions and dirt containing water and fine particles. When dry, the effluent turns into powder. Both mud and powder have negative impact on the surrounding. This experimentation focuses on the beneficial use of waste marble dust (WMD) to convert it into a valued binding material. To accomplish the objective, WMP and clay were gathered and tested to achieve their physical and chemical properties. A blend of WMP and clay was put together and burned at 1300oC. The burnt mixture was powdered to obtain marble cement (MC). The chemical formulation shows that MC contains 52.5% calcium silicate (C2S), 3.5% tri-calcium silicate (C3S) and 23% free lime. The marble cement was then incorporated in mortar with various proportions of blast furnace slag 20%, 30% and 40%. The compressive and flexural strengths of mortar cubes and prisms were examined. Aside from this, X-ray diffraction (XRD) analysis and thermo-gravimetric analysis (TGA) were also carried out. The compressive strength of MC mortar at 28 days is 156.12 psi is comparison to 885.27 psi of normal cement mortar, which is 82% less. Likewise, 91 and 182 days later, the compressive strength of MC mortar is 77% and 62% lesser than normal cement mortar. The addition of various proportions of blast furnace slag (20%, 30%, 40%) as marble cement replacement in MC mortar increased its compressive strength at all curing periods. The highest increment in compressive strength was observed in 40% blast furnace slag substituted mortar (B40) at 182 days curing. The similar strength development pattern was observed in case of flexural strength as well.

***Keywords*—** Marble Powder; Binding Material; Cement; Blast Furnace Slag; Mortar; Mechanical Properties.

I. INTRODUCTION

Water Marble has been utilized for construction and aesthetic reasons since ages [1]. Requisition for these characteristics have developed substantially due to the late corporate advancements. Pakistan is among the major producers of marble on the planet. It has about 400 thousand million tons of marble backlog, and the factual resources could be even higher [2]. Marble factories in Pakistan excavate and process about 10 lac tons of marble annually. During excavations, the exploding approach is frequently applied, resulting in the loss of about half of the entire production [3]. The debris originated in the excavations is in the form of strange blocks of different dimensions [4]. Nonetheless, there is no suitable course to discard the debris, and thus the debris continues to scatter around the excavations.

Large sized raw marble blocks are transported from the mines to marble refinement sections to generate marble slates and other precious blocks of various measurements and profiles [5]. There are many marble refinement sections in Pakistan which have different types of instruments and gear that work for the handling of these rocks. In the course of carving and shining of rough marble blocks, debris is also caused as an outgrowth. The debris is in the type of strange rocks of various sizing, shapes and dirt, containing fine particles of marble. About one-fifth of these rocks are lowered to microfine particles, which differs with refinement mechanism [6].

Debris is commonly discarded in open territories in the vicinity of plants. There is no organized pattern to get rid of dirt. Thus, it is the result of vast mounds of waste. As a result, the slush dries and turns into a fine dusting.

At the time high gusts, strong winds can readily convey delicate granules of marble and bring about numerous fettle problems [7]. In addition, piles of dirt are widespread throughout the manufacturing zone and spoil the whole region appearance [8]. In addition, when dissolved in water, sludge results in water contamination [9]. Moreover, it lessens the transmissivity of the surface soil, causing water to accumulate in the region [10]. Fine marble granules lessen the productivity by enhancing the basicity of the soil. In addition, there is damage to plants and animals. That is, pre-grown trees and shrubs dry up owing to the accumulation of minute-marble particles on plants and plant leaves [11].

To resolve the above challenges, various scholars have utilized waste marble sludge and powder in different building materials. Sutco et al. [12] and Sabaoya et al. [13] used WMD in the creation of clay blocks. The scholars determined that the weight of clay blocks is significantly reduced, although its shrinkage strength is slightly reduced. Gancel et al. [14] utilized WMD in the creation of concrete pavement blocks. He ascertained that the growth in the magnitude of marble mud was the result of a decrease in compressive strength. Despite that, this decline is inside the tolerable margins. In addition, the summation of WMD enhanced the toughness and freezing resilience of concrete blocks. Rahman etc. [5] utilized marble sludge in the masonry bricks. Additionally, dirt, OPC, plaster of Paris, sand, crushed stone and acrylic fibers were also utilized. They fulfilled that whilst useless marble sludge, sand and OPC are utilized in a proportion of 80, 5 and 15 correspondingly, with acrylic fibers. An utmost compressive strength of 7.98 MPa was attained, adequate for construction operations where eminent power is not needed. In addition, these bricks are cheaper than traditional bricks. Kabir and Vyas [15] substituted the sand with WMD in the mortar in different proportions up to a limit of 100 percent. He indicated a significant increase in the features of the mortar such as compressive strength, elastic strength and density modules. Sadat et al. [16] examined the substitution of dolomite with WMP in mortar for tiles and heat proof boards. Similarly, the 28-day elastic strength of 100% substitution by MP was 8.45 MPa, that is higher than the least needed value of 0.077 MPa of the European Standards Institute EN-1348. Furthermore, the researchers analyzed the expenses and stated that the binding material with MP containing dolomite was 25% low-cost.

Topco et al. [17] and Alemic & Anis [18] combined WMD as a filling agent to self-compacting concrete. He pointed out that waste WMD does not impact the working capacity of self-compacting concrete.

Khodebakhshian et al, [19] changed cement with MP which loses up to 20% in concrete. They saw a substantial rise in compressive and elastic strength with concrete flexibility modules, when cement was substituted with 6 % WMD. Despite that, with more than a 10% increase in the WMP conversion rate, the mechanical properties decreased. In addition, the cement was replaced at different proportions of silica foam (SF) and WMD combine. When 15% SF is utilized then the mechanical properties of concrete are improved by a maximum of 20% for any percentage of WMP powder. Singh etc. [20] cement was replaced by WMD in concrete blocks, up to utmost of 25% in different percentages. They also changed the ratio of water to binder for all blends. The scholars registered a 15% change in the mechanical and durability attributes of the concrete block.

Aliabdoet al. [21] emphasized on the utilization of WMD in the manufacture of cement together with concrete. WMD was blended with OPC in varying proportions up to an utmost of 20% by weight. Samples of blended cement paste and mortar were set up and examined. It was noticed that WMD blended in cement meets the provisions of Egyptian regulations. Likewise, sand was substituted by WMD in concrete in varying proportions up to a maximum of 15 percent. It was pointed out that the substitution of WMD with low W/C ratio has superior physical and mechanical attributes in concrete as compared to the ordinary concrete.

Argon [22] utilized WMD and diatomite as partly substitution of OPC in concrete. Concrete specimen were correctly corrected and tested. Test outcomes show that concrete having 10% WMD and 5% diatomite or 5% WMD and 10% diatomite because OPC has superior elasticity and compressive strength than ordinary concrete.

Ma et al. [23] cement was partly converted into mortar by WMD and nano-silica (NS). In accordance, the flow and setting time of mortar was extended when the OPC was substituted with WMD only. Nonetheless, the compressive strength of mortar was notably diminished when the substitution was greater than 15%.

Mechanical properties improved significantly when OPC was substituted with a blend of WMD and NS. Maximum conversion of OPC with 10% WMD and 3% N-S was proposed. Muneer et al. [24] with WMD, cement was partially converted to mortar by 0, 10, 20, 30 and 40 by mortar. Mortar was less capable of working with WMD than a controlled mix. Likewise, the compressive strength of mortar with 10% WMD was higher than that of the control mix, which lowered with furthermore rise in WMD content.

Kawas and Olgan [25] partially replaced the cement with these materials to mix marble dust and crushed bricks. Different properties such as timing, volume dilation, elastic and compressive strength of both mixed cement and mortar were established by different tests. Scanning electron microscopy (SEM) analysis was performed to identify the micro-pattern of the mortar. The setting time was retarded with WMD and OPC crushed bricks. Although, the summation of WMD and crushed bricks to the OPC remarkably enhanced the compressive strength of the mortar. It was pointed out that partly substitution of OPC by WMD and crushed bricks gave very optimistic outcomes. Arontas et al. [26] Prepared waste marble dust blended cement (WMDCs) using waste marble dust (WMD) in different percentages in cement. Cement clinkers were replaced with WMD with 10% weight. Specimen of cement mortar were set and fixed. The chemical, mechanical and physical attributes of the mortar were found out passed 7, 28 and 90 days, correspondingly. It was stated that WMDCs meet the EN-197-1 regulations, which explains the 10% changes of OPC clinker with WMD in the manufacture of blended cement.

Khan et al. [3] waste marble dust (WMD) was used in the manufacture of burnt clay bricks. In accordance with the scholar, the chemical formulation of WMD and soil is provided in the Table 1.

As reported by Neville and Brooks [27], OPC comprises of about 60 to 66% calcium oxide, 22 to 27% silica and 6 to 10% alumina. Moreover, as stated by the authors, $CaCO_3$ is used as the main origin of CaO in the manufacture of OPC. When CaO acts with SiO_2 at 1450 to 1650 ^oC, it produces calcium silicates (CS), which reacts with water to form calcium silicate hydrate (CSH), which is highly bound. The chemical formulation of limestone and marble is almost the same, both contain huge amounts of CaO. Therefore, WMP / sludge and silica sufficient materials, for example, clay can be utilized in the preparation of binding material.

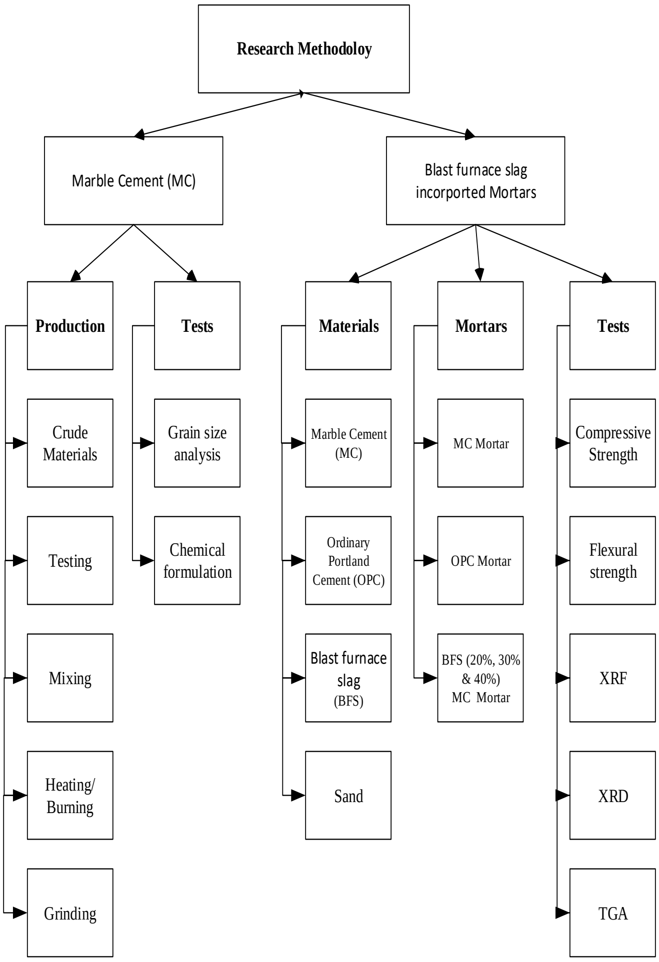
Limestone is the main crude material utilized in the manufacture of OPC. Though, extensive cement production needs huge amount of limestone. Consequently, the organic wealth of limestone is getting reduced. Making binding material from waste can lead to additional materials for OPC, and is hence a vital pace in the direction of longer-lasting of natural wealth. In addition, precarious waste materials can be transformed into useful materials. According to the best knowledge of the authors, there is no published research work on the transformation of minute marble powder into binding material. This study seeks to make the best use of WMP. Marble powder and clay has been addressed so that marble cement can be utilized in the building sector. Different procedures such as grain size analysis, X-ray diffraction (XRD) and thermogravimetric analysis (TGA) were employed to examine the various attributes of marble cement (MC) and paste. In addition, mechanical properties such as marble cement and blast furnace slag compressive and flexural strength of the mortar were also examined.

TABLE I. CHEMICAL FORMULATION OF WMD AND CLAY [3]

Major Elements	Clay (wt%)	Marble Dust		
		Buner	Muhmand Agency	Blend
SiO_2	57.55	0.77	0.42	0.31
TiO_2	0.3	0.01	0	0
Al_2O_3	15.84	0.24	0.07	0.04
Fe_2O_3	3.32	0.05	0	0.03
MnO	0.04	0	0	0
MgO	2.35	0.94	0.24	0.3
CaO	6.77	54.08	55.65	55.07
Na_2O	1.39	0.39	0.36	0.29
K_2O	1.59	0.02	0.01	0.01
P_2O_3	0.12	0.01	0.03	0.02
LOI	10.73	43.49	43.23	43.93

II. METHODOLOGY

Flow chart of the methodology is provided in Figure 1.



A. Collection and Testing of Raw Materials

In this phase, crude materials were gathered, consisting of WMP and clay. Waste was received from Marble refining industry at Marble Industrial zone, Hayatabad, Peshawar.

Meantime the clay was gathered from South Bypass Road Peshawar.

After the crude materials were gathered, X-ray fluorescence (XRF) review and grain size analysis were used to test their chemical and physical properties.

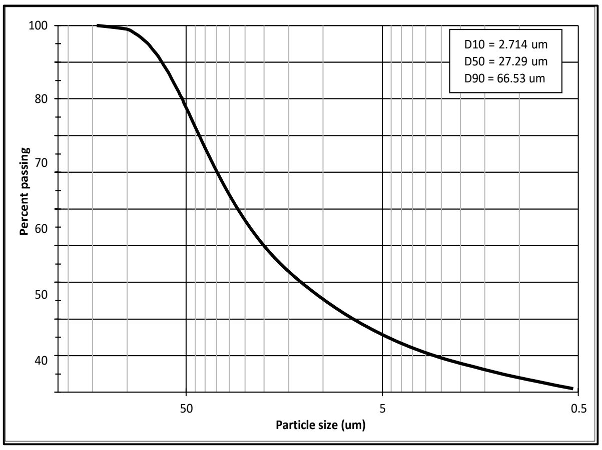


Figure 1. Grain size dispersion of WMP

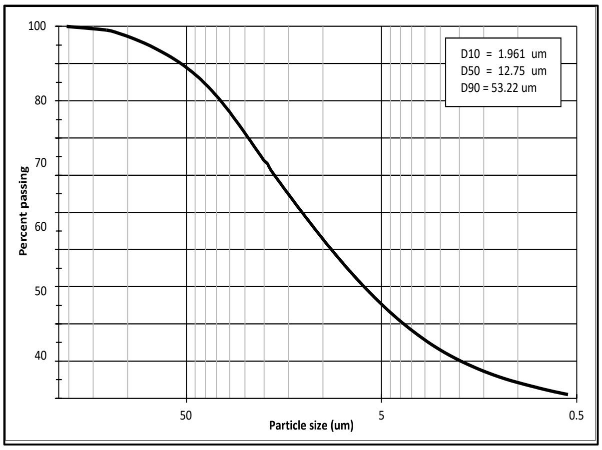


Figure 2. Grain size dispersion of clay

B. Chemical formulation of Crude Materials

I. Chemical formulation of WMP and clay were examined by X-ray fluorescence (XRF) analysis. The outcomes are shown in Table 2.

TABLE I. CHEMICAL FORMULATION OF CRUDE MATERIALS

Item	WMP Weight (%)	Clay Weight (%)
Na_2O	0.04	4.14
Al_2O_3	0.19	14.2
MgO	2.73	4.32
CaO	49	3.46
SiO_2	0.4	56.73
K_2O	0.01	1.01
MnO	0	0.05
P_2O_5	0.01	0.12
Fe_2O_3	0	3.23
TiO_2	0	0.55
Loss on ignition (LOI)	47.44	12.19

The amount of CaCO3 in WMP is 96.44%. Of which free lime is 49%, while LOI, i.e., CO2 content is 47.44%. The chemical formulation of WMP is comparable to that of limestone. Hence, it has been utilized as a vital crude material in the manufacture of new binding materials. In addition, the soil contains 56.73% SiO2, which combines with CaO at elevated temperatures to form tri-calcium silicate and di-calcium silicate. Therefore, the crude material is rich in CaO and SiO2, which makes it an appropriate basis of binding material.

C. Physical Properties of Crude Materials

II. Grain size analysis of WMP and clay were conducted by grain size analyzer. The outcomes are given in Figures 2 and 3.

D90 of WMP and clay is 66.53 µm and 53.22 µm correspondingly. Generally, the D90 of the crude blend in the manufacture of OPC is held less than 90 µm. As the D90 of materials is less than 90 µm. This is why, there is no need to grind.

D. Proportioning of Crude Materials

At this stage, the crude materials were blended in certain fractions, subject to their chemical formulations. The ratio was acquired depending on the saturation factor of the lime. In the manufacture operation of OPC, the saturation factor of lime is usually held between 0.91 and 0.99, so that the CaO formed by the ignition of calcium carbonate (CaCO3,) is completely converted to SiO2. The goal was to maintain the conclusive outcome CaO-free. The purpose was to acquire a lime saturation factor of 0.91 to 0.99. Derived from the chemical formulation, 25 kg of WMP and 7 kg of clay were blended to achieve a saturation of 0.97 lime.

E. Blending of Crude Materials

After the determination of blending ratio, the crude material was first blended well in a dried manner in a ball mill. Later, they were blended in moist form with the aid of sugar-cane husk and water. This wet blend was turned into pellets. In addition, the pellets were placed in sunlight for three days to completely remove the water.

TABLE II. MIXTURE PROPORTIONS FOR MORTAR

Mixture notation	OPC	Marble cement	sand	w/c ratio	W/(M.C) ratio
Controlled	1	0	2.75	0.5	0
MCM	0	1	2.75	0	0.72

* Specimen size:
(i) = 50 mm cube (Compressive strength);
(ii) = 40×40×160 mm (Flexural strength).

F. Burning of Crude Materials and Grinding of Clinkers

At this stage, the pellets were put into a rotary furnace. At first, the furnace temperature was low. Nevertheless, the temperature was slowly elevated to the utmost at hand capacity of 1300 OC. The pellets were burned in the furnace at about 1300 OC for 2.5 hours.

There was no set-up to cool the red-hot pellets swiftly. Hence, they were kept in the rotary furnace for a day and slowly cooled. When cooled, the burned pellets were brought out from the furnace and turned into a powder in a ball mill. The associated powder is a dedicated binding material called marble cement.

G. Testing of Binding Material

In this phase, the phase formulation of marble cement was examined by X-ray diffraction (XRD) test. The aim of this step was to validate whether the marble cement contained sufficient amounts of calcium silicates, which were necessary to develop the binding attributes. The grain sizes of both marble cement and OPC was examined using of grain size analyzer.

Mortar cement and OPC powder were utilized in the manufacture of mortar. Both mortars were made by blending one unit of cement in 2.75 units of sand as described in ASTMC 109 / C 109 M-02 and ASTMC 348-14. Has gone According to ASTM standard, the ratio of water to cement was kept at 0.5. However, the ratio of water to marble cement in marble cement mortar was not 0.5. Therefore, the ratio of mortar cement to water was held 0.72 to have a workable mortar as shown in Table 3. The mortar was readied manually as no automated blender was accessible. To ascertain the compressive strength of mortar, 50 mm cubes were made from both OPC and MC mortar according to ASTMC 109 / C 109 M-02. Similarly, 40 mm x 160 mm prisms were made from both OPC and MC mortar in accordance with 40 mm ASTMC 348-14 to determine the elastic strength of mortar.

After 24 hours, the specimen were taken out from the molds. Immediately after removing the OPC mortar specimen from the molds, they were submerged into the curing tank. Owing to the high content of CaO in marble cement, it dispersed if dipped in water. So, the samples of marble cement mortar were held in a moist cloth for fourteen days. Past fourteen days, the specimen were submerged in the water tank. All specimen were submerged in the water tank till the the time of the test.

To perform X-ray diffraction (XRD) analysis and thermodynamic analysis (TGA), samples were prepared from pastes containing marble cement, OPC and blast furnace slag. Samples of OPC paste were submerged in the water tank after 1 day, while specimen of paste containing marble cement and blast furnace slag were wrapped with a moist cloth for fourteen days. Later, the specimen were submerged in a water tank.

III. Result and Discussion

A. Phase Formulation

The phase formulation of marble cement and OPC powder was found out by X-ray diffraction analysis. The outcomes are shown in Table 4.

TABLE III. PHASE FORMULATION OF MARBLE CEMENT AND OPC

S.No.	Items	Marble cement	OPC
		Weight (%)	Weight (%)
1	Alite [C_3S]	3.73	59.51
2	Belite beta [C_2S]	52.50	17.14
3	Ferrite [C_4AF]	9.26	8.20
4	Aluminate cubic [C_3A]	2.48	2.81
	Aluminate ortho [C_3A]	3.38	5.59
5	Free lime [CaO]	23.09	0.00
6	Portlandite [$Ca(OH)_2$]	1.49	1.50
7	Periclase [MgO]	3.66	3.10
8	Acranite [K_2SO_4]	0.00	1.78
9	Aphthitalite [$K_3Na(SO_4)_2$]	0.41	0.37
10	Calciolangbeinite [$K_2Ca_2(SO_4)_3$]	0.00	0.00

The results show that marble cement has 3.73% C3S, 52.51% C2S and 23.09% CaO The lower content of C3S, the higher the percentage of C2S and CaO is due to the retarded cooling operation. The marble cement pellets were calmed very sluggishly. As a result, after C3S reached 1100 oC, it changed to C2S and CaO. In the production of OPC, cement clinkers are chilled very swiftly to maintain the high temperature C3S. Thus, OPC marble contains less percentage of C2S than cement and free lime, as shown in Table 4.

B. Grain Size Analysis

The grain size of marble cement and OPC was examined using grain size analyzer. The outcomes are given in Figures 4 and 5 reveal that the D90 of marble and OPC is 33.26 µm and 60.44 µm. Because marble cement is very fine, its surface area is large. Due to the high surface area, the ratio of marble cement to water is more than the ratio of OPC to water, as given in Table 3. In addition, owing to the high surface area of marble cement, hydration begins instantly. Thereby, extra water is needed to retain its viablilty.

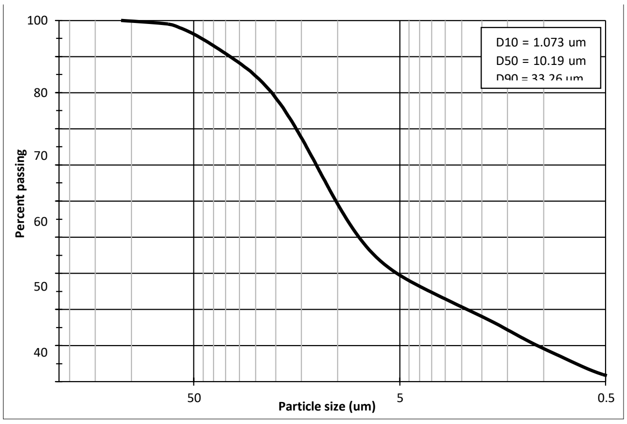


Figure 3. Grain size dispersion of marble cement

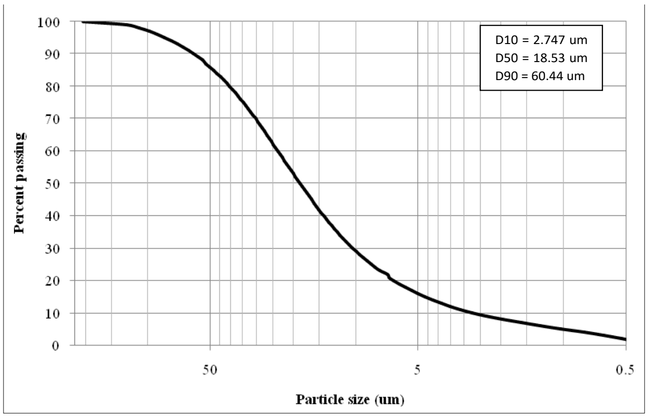


Figure 4. Grain size distribution of OPC

C. Compressive Strength of Mortar

Samples of marble cement, OPC mortar and mortar designed to detect the compressive strength of blast furnace slag were taken out from the water tank right before the testing. These tests were performed at 28, 91 and 182 days of age, correspondingly. The loading was employed at a gauge of 1.2 KN / sec according to ASTM C109-02 [28]. The outcomes are given in Table 5 and Figure 6.

TABLE IV. COMPRESSIVE STRENGTH OF MARBLE CEMENT, OPC AND BLAST FURNACE SLAG MORTARS (ALL UNITS IN PSI)

Age	MC	OPC	B20	B30	B40
28	156.1	885.27	232.15	235.0	303.0
91	302.3	1359.1	369.17	385.7	391.2
182	925.5	2501.5	1414.2	1589.6	1907.4

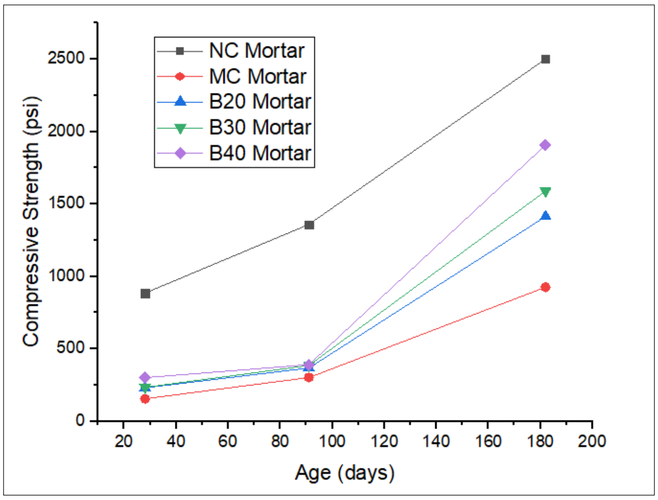


Figure 5. Compressive strength of Marble cement, OPC and blast furnace slag mortars

The compressive strength of MC mortar is 156.12 psi in 28 days as compared to 885.29 psi of NC mortar. Thus, after 28 days of treatment, the compressive strength of MC mortar is 82% low than the NC mortar strength. Likewise, 91 and 182 days later, the compressive strength of MC mortar is 77% and 62% lesser as of NC mortar.

From Figure 6, it is clear that mortar with conventional ingredients gave higher compressive strengths than all mortars and all blast furnace slag mortars gave higher compressive strength than the MC mortar at all ages of curing. The pattern of the strength establishment curve is almost same for all types of mortars. Generally, the strength with the addition of blast furnace slag content in MC mortar increased its compressive strength. For B20 mortar, the increase in MC mortar compressive strength is 48.69% past 28 days, for 91 days the increase in strength is 22.11% and for 182 days the increase is 52.77%.

By incorporating blast furnace slag as a marble cement substitution (30 % by weight of cement) the test outcomes showed an increment in compressive strength for all ages. For B30 mortar, the increase in MC mortar compressive strength is 50.58 past 28 days, for 91 days the increase in strength is 27.58% and for 182 days the increase is 71.73%.

By incorporating blast furnace slag as a marble cement substitution (40 % by weight of cement) the test outcomes showed an increment in compressive strength for all ages as well. For B40 mortar, the increase in MC mortar compressive strength is 94.11% past 28 days, for 91 days the increase in strength is 29.40% and for 182 days the increase is 106.08%.

It can finally be concluded that all MC mortars in which marble cement was substituted with different contents of blast furnace slag, increased the compressive strength and can also be decided that higher the blast furnace slag content, higher was the percentage increment in compressive strength especially at extended curing period i-e 182 days.

D. Flexural Strength of Mortar

To find out the flexural strength of marble cement, OPC mortar and blast furnace slag mortar (B20, B30 & B40), the samples were taken out from the water tank right before the testing. These tests were performed at 28, 91 and 182 days of age, correspondingly. The outcomes are given in Table 6 and Figure 7.

TABLE V. FLEXURAL STRENGTH OF MARBLE CEMENT, OPC AND BLAST FURNACE SLAG MORTARS (ALL UNITS IN PSI)

Age	MC	OPC	B20	B30	B40
28	99.5	570.8	119.4	132.7	132.7
91	172.5	663.7	185.8	199.1	220.3
182	318.6	796.5	278.7	345.1	371.7

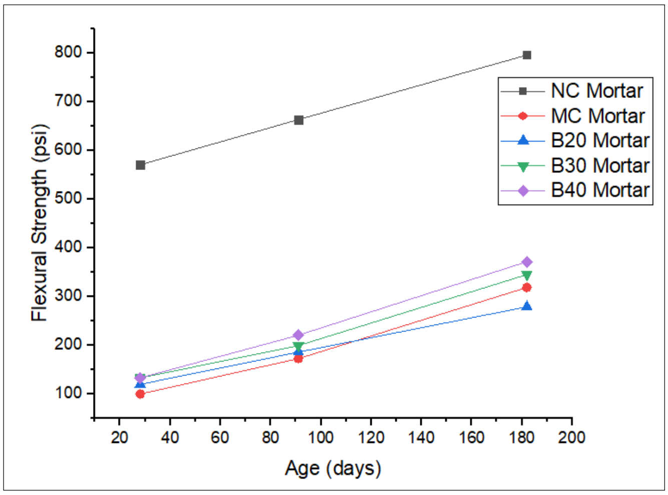


Figure 6. Flexural strength of marble cement, OPC and blast furnace slag mortars

The flexural strength of marble cement mortar is 99.56 psi in 28 days as compared to 570.83 psi of NC mortar. Thus, at 28 days of age, the flexural strength of MC mortar is 82.55% less than that of NC mortar. But this difference in strength decreases with time so after 91 and 182 days, the flexural strength of MC mortar is 72.98% and 60% less than NC mortar.

From Figure 7, it is found that mortar with conventional ingredients gave higher flexural strength than all mortars and blast furnace slag mortars gave higher flexural strength than the MC mortar except for B20 mortar at 182 days curing. The pattern of the strength establishment curve is almost same for all types of mortars. Generally, the strength with the addition of blast furnace slag content in MC mortar enhanced the flexural strength. For B20 mortar, the increase in MC mortar flexural strength is 20% at 28 days curing, for 91 days the increase in strength is 7.69% and for 182 days the flexural strength decreased by 12.5%.

By incorporating blast furnace slag as a marble cement substitution (30 % by weight of cement) the test outcomes showed an increment in flexural strength for all ages. For B30 mortar, the increase in flexural strength is 33.34% past 28 days, for 91 days the increase in strength is 15.38% and for 182 days the increase is 8.33%.

By incorporating blast furnace slag as a marble cement substitution (40 % by weight of cement) the test outcomes showed an increment in flexural strength for all ages as well. For B40 mortar, the increase in flexural strength is 33.34% at 28 days later, for 91 days the increase in strength is 27.69% and for 182 days the increase is 16.66%.

Ultimately, it can be concluded that all MC mortars in which marble cement was replaced with various blast furnace slag proportions, in addition to B20 mortar, increased flexural strength in 182 days of treatment. The 28 days flexural strength values of MC mortar, B20, B30 and B40 mortar were higher than the minimum requirement of 47 psi (0.33 MPa) of M1 mortar of BCP [29].

E. X-Ray Diffraction (XRD Analysis)

X-ray diffraction analysis of marble cement, OPC and blast furnace slag mortar (B20, B30 & B40) was performed. After 28 days of curing, the results are provided in Figure 8.

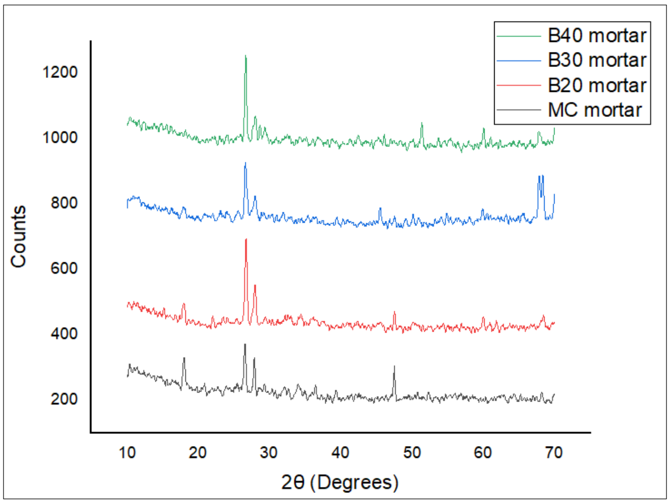


Figure 7. XRD analysis of marble cement, OPC and blast furnace slag mortars

The peaks of 18o and 47.5o in MC mortar in Figure 8 show Ca (OH)2 due to hydration of CaO and calcium silicates in marble cement. These peaks have been significantly reduced in the B20 mortar and have completely disappeared in the B30 and B40 mortars, due to the reaction between amorphous silica (present in blast furnace slag) and Ca (OH)2, which has resulted in CSH gel. Figure 8 shows the peaks of 27o in all graphs, the small peaks between the silica (quartz) in the sand and the 28o-32o, that C2S remains unaffected by the slow hydration reaction.

F. Thermo-Gravimetric Analysis (TGA)

Thermogravimetric analysis (TGA) of marble cement, OPC and blast furnace slag mortar (B20, B30 & B40) was performed. Results 28 days after curing are given in Figure 9.

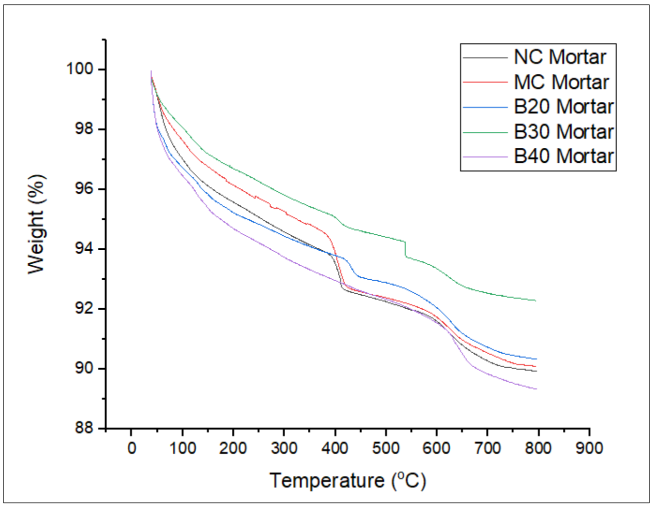


Figure 8. TGA analysis of marble cement, OPC and blast furnace slag mortars

As the temperature rises from 0oC to 100oC, the external water in all materials is pumped out. As materials were placed in water before the test, the amount of free water they have is almost the same and thus the weight loss is almost the same. As the temperature rises from 100oC to 400oC, the water in the C-S-H gel, ettringite and C-A-H gel is expelled. OPC mortar has higher levels of C-S-H and ettringite than marble cement paste, so OPC mortar has more weight loss in this range than marble cement mortar. Weight loss from 400-450oC is owing to dehydration of Ca (OH)2. Marble cement paste contains more Ca(OH)2 than OPC mortar. Therefore, in this extent, the weight deficit in marble cement mortar is higher than in OPC mortar. All in all, the weight deficit in OPC mortar is 2.03% higher than MC mortar, indicating that hydration of OPC mortar is swifter as compared to the MC mortar.

Also, in the case of blast furnace slag mortars B20, B30 and B40, as the temperature rises from 0oC to 100oC, the surface water present in all the material is expelled. As all the samples are placed in water before the test, the amount of free water in all of them is almost the same and thus the weight loss is almost the same. As the temperature rises from 100oC to 400oC, the water in the C-S-H gel, ettringite and C-A-H gel is expelled. Compared to B20 and B30 mortars, B40 mortars have more weight loss in this range, as there is more C-S-H owing to the availability of large amounts of silica for the silica portlandite (calcium hydroxide) reaction. Weight loss from 400 - 450oC is owing to dehydration of Ca(OH)2, so in case of B20, B30 and B40 mortars there is very little weight loss in this range like Ca (OH)2 Marble cement has been converted to CSH gel with the addition of blast furnace slag. Overall, the weight loss in B40 mortar is 0.76% higher than MC mortar and 1.24% lower than OPC mortar, which depicts that hydration of B40 mortar is swifter than MC mortar and slower than OPC mortar.

CONCLUSIONS

The objectives of this experimental study were to investigate the mechanical properties of marble cement mortar and blast furnace slag incorporated in marble cement mortar in different proportions (20%, 30%, 40%) by using standard procedures. The different phase identification analysis (XRF, XRD and TGA) on the mortars permitted us to assemble a clear concept at microstructure level and to feature the connection between the parameters seen by this investigation and the properties of mortars studied. On the basis of the experimental outcomes, the succeeding conclusions were outlined.

The total content of C2S and C3S in marble cement is 56.23%. Both are very important in establishing binding properties. Therefore, it can be utilized as a binding material.

The lately produced marble cement can be utilized in mortar with confidence, as the compressive strength of mortar is 925.68 psi 182 days later. However, the 28-day compressive strength of the mortar is 156.12 psi, which is higher than the M1 mortar of Pakistan Building Code. Also, blast furnace slag replacement has considerably enhanced the mechanical properties of the marble cement mortars.

- The highest increment in compressive strength was observed in B40 mortar at 182 days curing. After 182 days, the compressive strength of B40 mortar is 1907.38 psi which is 52% more than the MC mortar and 23% less than the NC mortar at the same curing period respectively.

- The maximum increase in flexural strength was observed at 182 days curing in B40 mortar which is 15% more than the MC mortar and 62% less than the NC mortar at the same curing period respectively.

- Due to the high content of C_2S, the hydration of marble cement is calmer than that of OPC and thus is highly suggested for hot weather and large-scale concreting.

- It is recommended to build a small marble cement production unit in marble processing plants which will not only give a beneficial construction material but will also consume the marble waste generated as a result of marble processing.

CONFLICT OF INTEREST

The authors proclaim no conflict of interest.

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