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Characteristics of High-Strength Concrete Incorporating Marble Waste as a Partial Replacement of Cementitious Materials

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Abstract : *Marble-cutting factories and mining industries generate a significant amount of wastes. Because these wastes have such a severe impact on our environment, it is critical to discover a safe manner to dispose of them or a viable solution for their use. Marble waste reduces the cement content of concrete, resulting in green concrete and decreasing costs. This study provides an environmentally appropriate option for the disposal of marble waste and contributes to the preservation of our environment. Marble waste (MW) was used to substitute cementitious materials weight in the following proportions: 5%, 10%, 15%, and 20%. Silica fume (SF) and fly ash (FA) were used to replace 10% and 5% of the weight of the cementitious material in high-strength concrete (HSC), respectively, with constant water to binder ratio of 0.4. Compressive strength, flexural strength, and splitting tensile strength were tested at 7, 28, and 56 days of curing to determine mechanical characteristics. After 7, 28, and 56 days of curing, the rate of water absorption was measured. To determine the consistency of fresh concrete, a slump test was performed. Mechanical characteristics were best achieved at a substitution level of 10% MW, 10% SF, and 5% FA of the total binder content, the compressive strength and the flexural strength increased by 12.93 % and 15.2 % at 56 days of curing compared to the control mix, respectively. The combination of MW and SF along with FA improved mechanical characteristics while reducing the rate of water absorption.*

Keywords: High-strength concrete, Compressive strength, Marble waste, flexural strength

1 .INTRODUCTION

Marble is economically valuable as it is industrially produced, cut, polished, and used for decorative purposes. Stones are cut into blocks in marble quarries using various ways. 20-30% of a marble block is wasted marble powder during the cutting process. Marble powder is a waste product that is produced in large quantities around the world. Marble waste is a significant environmental issue. As a result, the use of waste marble as an additive material or aggregate in concrete manufacturing is becoming increasingly essential. Waste marble powder was discovered to be used in (1) control concrete mix, (2) self-compacting concrete mix, and (3) polymer concrete mix. As a result, it was observed that using waste marble as an additive material or aggregate in a control concrete mix can improve some properties of the hardened concrete. Although, the use of waste marble in self-compacting and polymer concrete mixes has no effect on the concrete's hardened properties [1]. Marble cutting waste (MCW) and fly ash (FA) both can improve concrete performance and use as a partial replacement for cement. With this aim, a total nine numbers of high-strength concrete (HSC) mixes were prepared to evaluate the efficiency of MCW and FA in HSC with silica fume (SF) as a distinctive and blended replacement of cement. MCW was used to replace cement in the following proportions: 10%, 20%, and 30%. In HSC, FA was substituted at a 15% substitution level of total cement. A constant water to binder ratio of 0.33 was kept throughout the research to achieve HSC mix, which included 5% SF as a cement substitute. Compressive and flexural strength tests were performed at 7, 28, and 90 days after curing to assess mechanical properties. After 28 days of curing, water permeability and abrasion resistance were assessed. Scanning electron microscope (SEM) examination was also used to investigate the microstructure. The incorporation of MCW and FA improved workability. In terms of fresh, mechanical, and durability performance, a substitution level of 10% MCW, 15% FA, and 5% SF of the total cement content obtained the best results [2]. The usage of additives in the cement manufacturing is increasing, and this metal addition materials we obtain from natural sources or remains of industrial materials is frequently referred to. The use of these additives reduces used clinker and helps in solving ecological problems in a straightforward and cost-effective manner. With a 10% replacement of marble powder, the compressive strength improved. Based on the findings, 10% cement substitutions using waste glass and marble are ideal [3]. The results of the experiments on concrete with 15% marble powder and a fineness modulus of 11500 cm2/g in a presence of chloride demonstrated that it contributes favourably to the perfect of mechanical properties, durability against chloride ion emigration, and oxygen permeability. It may be deduced that marble powder is appropriate to produce high-performance concretes (HPC) with significantly improved characteristics over the conventional concrete (RC) [4]. Seven concrete mixtures were made by partial replacement cement and sand with WMP at weight ratios of 0 %, 10%, and 15% singly and in combination. The samples were recorded at the curing ages of 7, 28, and 90 days to evaluate the compressive strength, flexural strength, and split tensile strength of concrete produced from waste marble powder. Ultrasonic pulse wave test, absorption, and sorptivity were among the durability tests performed on the samples. All the data were compared for further analysis, and it was observed that using WMP as a substitute of sand and cement in defined proportions improved the mechanical characteristics of the concrete mix. Furthermore, environmental health problems will be solved [5]. The main objective of this research is to study the properties of concrete containing MW as fine aggregate in ratios of 0 %, 20%, 40 %, 60 %, 80 %, and 100 % by weight of cement. The findings of the various experiments reveal that as the percentage level of MW rises, the slump value rises. Strength was steadily increased until it reached 60 % MW substitution and then gradually decreased. As a result, it is suggested that MW be used as a fine aggregate up to 60% of the time. replacement ratio [6]. The physico-mechanical properties of concrete prepared with mineral addition (glass powder and marble powder) were investigated when GP and MP were used as partial substitute for cement in various proportions (0, 5, and 10). The addition of crushed mineral improves the physical characteristics of binary concrete, according to the findings (grading, low porosity, high compactness). When compared to the conventional concrete, there is a significant improvement in mechanical resistance when using the adjuvant; this improvement is due to the adjuvant's influence [7]. Carbon dioxide emissions are reduced significantly when waste materials such as bottom ash and marble powder are partially replaced with cement. In terms of building safety, the expected quality of materials to be employed in the concrete sector is essential. Due to existing specifications, new building materials and binder materials offered as alternatives are frequently unable to meet these requirements [8]. The use of waste marble as mineral additions or fine/coarse aggregate in conventional or self-compacting concrete improved the concrete's durability characteristics. Although, when comparing the concrete mixes' resistance to carbonation to reference concrete mixes, no effects were found [9]. The viability of using marble waste as a coarse aggregate in concrete was investigated through experiments. Marble aggregate was substituted for natural coarse aggregate in various quantities ranged from 0% to 100% by weight. A constant water–cement ratio of 0.60 was used to produce the concrete mixtures. The workability of concrete mixes including marble aggregate was found to be 14% higher than control concrete. At 7 and 28 days, the average compressive strength of all concrete mixtures including marble aggregate enhanced by 40% and 18%, respectively [10].

2. WORK OBJECTIVE

The main objective of this paper is to study the effect of waste marble powder as a partial replacement of cementitious material on the mechanical and physical characteristics of high strength concrete using silica fume and fly ash.

3. EXPERIMENTAL WORK

3.1. Materials

The different materials used in this investigation are: -
Cement: The cement utilized to make the samples for this investigation was Ordinary Portland Cement (OPC), cement grade 42.5 N, which is widely accessible.
Fine Aggregate: The fine aggregate used in this study came from a local source and has a fineness modulus of 2.75.
Coarse aggregate: The coarse aggregate used for this experiment is dolomite and maximum nominal size is (19 mm).
Water: Both mixing and curing for samples were done using fresh tap water.
Plasticizer: Sikament- 163M (ASTM C-494 Type A& F) was used to enhance consistency of concrete.
Fly Ash: FA acts as a cement replacement agent. Table (1) shows the chemical composition and physical properties of fly ash.

Table 1 The chemical composition and physical properties of fly ash.

Parameters	values
Sio_2	87.2%
Fe_2O_3	0.16%
Al_2O_3	0.15%
Cao	0.55%
MgO	0.35%
So_3	0.24%
C	5.91%
L.O.I.	5.44%
Fineness (m^2/kg)	353
Mineralogy	Non crystalline
Shape	Irregular

Silica fume (SF): Table (2) shows the physical and chemical properties of silica fume.

Table 2 The physical and chemical properties of silica fume

Chemical composition%	
Constituent	**Content (%)**
SIO_2	91.4
FeO_3	0.3-0.5
Al_2O_3	1.1
CaO	0.7
MgO	1.3
SO_3	0.4
K_2O	0.5
Na_2O	0.8
Physical properties	
Specific gravity	2.2
Fineness (m^2/kg)	955

Marble powder: The marble powder used in this study was produced during the polishing and cutting of marble in the processing plants.

Table 3 The chemical properties of marble powder

Chemical composition%	
Constituent	**Content (%)**
SIO_2	7.27
FeO_3	.45
Al_2O_3	0.11
CaO	50.87
MgO	0.84
SO_3	0.37

Table 4 The physical properties of marble waste

Physical properties	
Colour	White
LOI (%)	38.33
Fineness (m^2/kg)	492
Loose bulk density (kg/m^3)	1375
Specific gravity	2.71

3.2. Concrete Mixes

The purpose of this experiment was to study the effect of MW, SF, and FA performed as partial substitutes of cementitious materials on HSC. The concrete mixture was weighed and mixed for 2 minutes in a mechanical mixer. For various tests, the concrete mixture was cast in steel molds. After 24 hours, the test specimens were demolded and cured. A control mix was included in each of the ten binder mixes. In all mixtures, fly ash was replaced with 5% of the cementitious materials weight. The water to binder ratio was 40%. The used dosage of Sikament- 163M was 2 % of total cementitious materials weight. The combined effect of MW, SF, and FA on the fresh and mechanical properties of HSC was studied. For mixes C, M1, M2, M3, and M4, the cementitious materials were replaced with MW at the ratios of 0%, 5%, 10%, 15%, 20%, and SF was 0% by weight. For mixes M5, M6, M7, M8, and M9, the cementitious materials were replaced with MW at the ratios of 0%, 5%, 10%, 15%, 20% and SF was 10% by weight. Materials required per cubic meter of high strength concrete are shown in table (5).

3.3. Testing

3.3.1. Fresh Concrete

3.3.1.1. Slump Test

A workability test was carried out for this research to study the impact of using marble waste on workability. The aim of the workability test is to determine if the concrete is effective enough to be compacted and placed. Filling the typical slump cone with three layers of mixed concrete and rodding each layer 25 times was used to evaluate its workability. The slump is performed in accordance with ASTM C143[11].

3.3.2. Hardened Concrete

3.3.2.1. Compressive Strength Test

The compression test was performed on the cube specimens of 15*15*15 cm in size by a 1500 KN capacity testing machine to determine the strength properties of each mixture. Concrete strength tests were carried out at 7, 28, and 56 days of age. The average of three (3) specimens for each age was used to arrive at the results [12].

3.3.2.2. Flexural Strength Test

The beam specimens of 10*10*50 cm in size were subjected to two-point loading on a universal testing machine to simulate pure bending. The modulus of rupture is determined. Three (3) specimens were prepared and cured in water for each age. For 7, 28, and 56 days, the strength was measured [13, 14].

cured in water for each age. For 7, 28, and 56 days, the strength was measured [15].

3.3.2.4. The Rate of Water Absorption Test

At the ages of 7, 28, and 56 days, cube specimens with dimensions of 10*10*10 cm were cured, and then the concrete samples were dried in an oven at a temperature of 100 to 110 °C for at least 24 hours. The mass of each specimen was determined after it was removed from the oven and cooled in dry air. After final drying, cooling, and mass determination, samples were immersed in water at around 21°C for at least 48 hours. After removing the samples from the water, the excess water was towelled off and the samples were weighed. The formula below is used to estimate the rate of water absorption [16]: -

Absorption after immersion%= [(B-A)/A] *100

Where A= The mass of oven-dried sample in air

B=The mass of surface dry sample in air after immersion

Table 5 Quantity of materials (Kg/m^3)

Mix	Marble waste MW	W/C	Water	Cement	FA	SF	Coarse aggregate	Fine aggregate	Plasticizer Sikament-163M
Control	-			475		-			
M1 0SF-5%MW	25			450		-			
M2 0SF-10%MW	50			425		-			
M3 0SF-15%MW	75			400		-			
M4 0SF-20%MW	100			375		-			
M5 10%SF-0%MW	-	0.40	200	425	25	50	1098	549	10
M6 10%SF-5%MW	25			400		50			
M7 10%SF10%MW	50			375		50			
M8 10%SF-15%MW	75			350		50			
M9 10%SF-20%MW	100			325		50			

3.3.2.3. Splitting Tensile Strength Test

On a compression testing machine with a 1500 KN capacity, the cylinder specimens of 15*30 cm in size were tested. The load was increased at a steady rate until the specimen's resistance to the growing load broke down. The maximum load that could be applied to the specimen was measured. Three (3) specimens were prepared and

3.3.2.5. Unit Weight Test

The purpose of the hardened concrete density tests was to evaluate what influence using marble waste had on high strength concrete. After the 28th days of curing, the concrete cubes specimens with dimensions of 15*15*15 cm were taken from the water bath and placed on a dry surface until surface dried, while weighted concrete cubes specimens were used to calculate the unit weight of the concrete cubes. The following is the formula for estimating unit weight for hardened concrete [17].

ρ= Mass of samples(kN)/Volume of cube(m^3)

4. RESULTS & DISCUSSION

4.1. Fresh Concrete

4.1.1. Slump Test

Slump test was used to assess the workability of various mixes. The results are demonstrated in figure (1). For the control mix, the slump value reached 40 mm. The results revealed that, as compared to the control mix, the workability of a concrete mix reduced with the marble powder dust content increased. This could be because MW and SF have a higher specific area, resulting in increased friction and decreased workability. The minimum slump value was in mix M9 of (10%SF-20%MW).

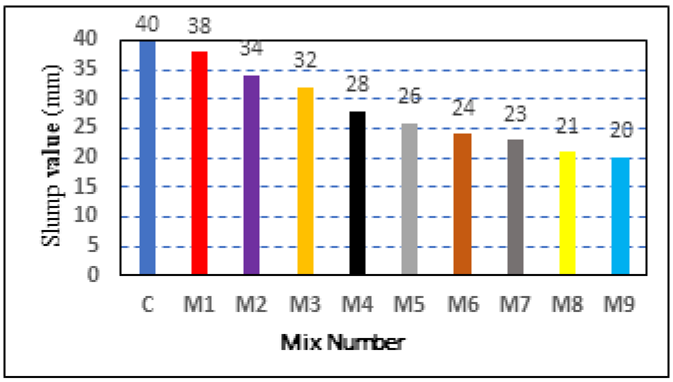

Fig-1: Slump flow test for different mixes

4.2.1. Compressive Strength Test

Table (6) shows the acquired concrete compressive strength values for various percentages of SF and MW, as well as a graphical representation in figure (2). In the case of 0% SF and MW (5%, 10%, 15%, and 20% of total binder content) along with FA, a positive effect of MW found up to 10% incorporation for mixes M1 and M2. Results revealed higher compressive strength for mix M2. It was 2.8%, 2.65%, and 5.17% than the compressive strength of the control mix at 7, 28, and 56 days curing periods, respectively. The increased compressive strength was due to pore filling achievement by MW. Marble does not take part in the hydration process. However, further replacement of cement up to 10% with MW in HSC resulted in decreased compressive strength. This could be attributed to a decrease in binder content and dilution of the available cement. The combined use of 10% SF and MW (5%, 10%, 15%, and 20% of total binder content) along with FA revealed the highest compressive strength compared to the control mix. The maximum compressive strength reached in the mix M7 of (10%SF-10%MW). It increased by 11.1 %, 11.5%, and 12.93% of compressive strength for the control mix at the age of 7, 28, and 56 days, respectively. It was because of SF's pore filling ability and pozzolanic behaviour.

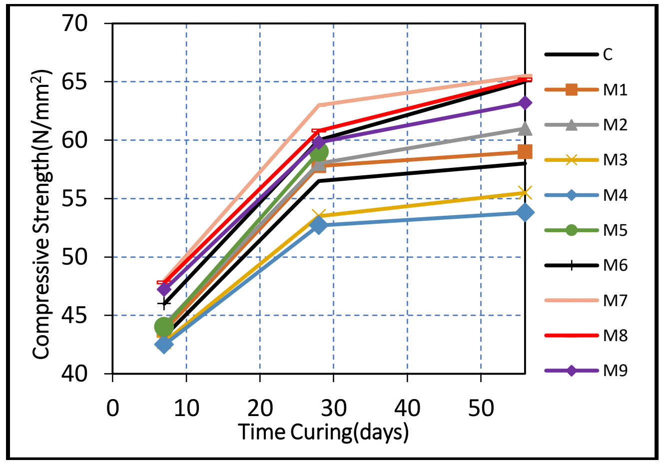

Fig- 2: Compressive strength for different mixes

Table 6 Compressive strength (N/mm²) for different mixes

Mix	Compressive strength (N/mm²)		
	Age(days)		
	7 days	28 days	56days
C	43.2	56.5	58
M1	43.7	57.8	59
M2	44.2	58	61
M3	42.7	53.5	55.5
M4	42.5	52.7	53.8
M5	44	59	64.5
M6	46	60	65
M7	48	63	65.5
M8	47.8	60.8	65.2
M9	47.2	59.8	63.2

4.2. 2. Flexural Strength Test

The flexural strength results are reported in table (7), with a graphical representation in figure (3). In the case of 0% SF and MW (5%, 10%, 15%, and 20% of total binder content) along with FA, the flexural strength increased in mixes M1 and M2 compared to the flexural strength of the control mix. Flexural strength of M2 increased by 4.7%, 7%, and 10.67% than the flexural strength of control mix at 7, 28, and 56 days curing periods, respectively. Flexural strength decreased in mixes M3 and M4 compared to the flexural strength of the control mix. The combined use of 10% SF and MW (5%, 10%, 15%, and 20% of total binder content) along with FA revealed the highest flexural strength for mixes (M5, M6, M7, M8 and M9) compared to the control mix. The maximum flexural strength reached in the mix M7 of (10%SF-10%MW). It increased by 10.94 %, 11.8%, and 15.2% of flexural strength for the control mix at the age of 7, 28, and 56 days, respectively.

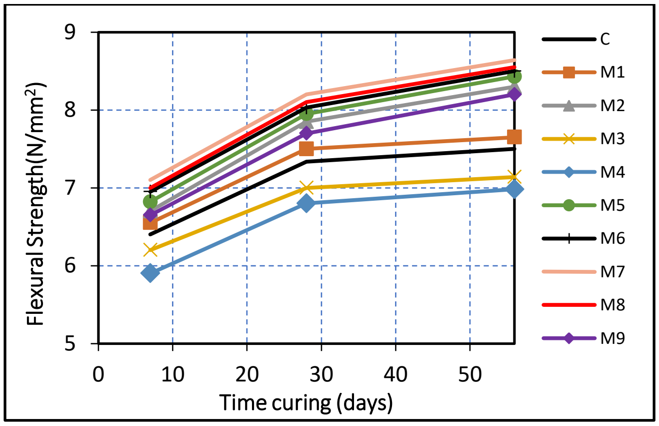

Fig-3: Flexural strength for different mixes

Table 7 Flexural strength (N/mm²) for different mixes

Mix	Flexural strength (N/mm²)		
	Age(days)		
	7 days	28 days	56days
C	6.4	7.34	7.5
M1	6.55	7.5	7.65
M2	6.7	7.85	8.3
M3	6.2	7	7.14
M4	5.9	6.8	6.98
M5	6.82	7.95	8.43
M6	6.95	8.03	8.5
M7	7.1	8.2	8.64
M8	7	8.1	8.55
M9	6.65	7.7	8.2

4.2. 3. Splitting Tensile Strength Test

The behaviour of SF, MW, and FA in splitting tensile strength appears to be like that in flexural strength. Table (8) shows the results of the splitting tensile strength test, and figure (4) shows the graphical representation. In the case of 0% SF and MW (5%, 10%, 15%, and 20% of total binder content) along with FA, the splitting tensile strength increased in mixes M1 and M2 compared to the splitting tensile strength of the control mix. Splitting tensile strength of M2 increased by 13.63%, 10.41%, and 5.82% than the splitting tensile strength of control mix at 7, 28, and 56 days curing periods, respectively. Splitting tensile strength decreased in mixes M3 and M4 compared to the splitting tensile strength of the control mix. The combined use of 10% SF and MW (5%, 10%, 15%, and 20% of total binder content) along with FA revealed the highest splitting tensile strength for mixes (M5, M6, M7, M8 and M9) compared to the control mix. The maximum splitting tensile strength reached in the mix M7 of (10%SF-10%MW). It increased by 33.3 %, 22.9%, and 20.4% of splitting tensile strength for the control mix at the age of 7, 28, and 56 days, respectively.

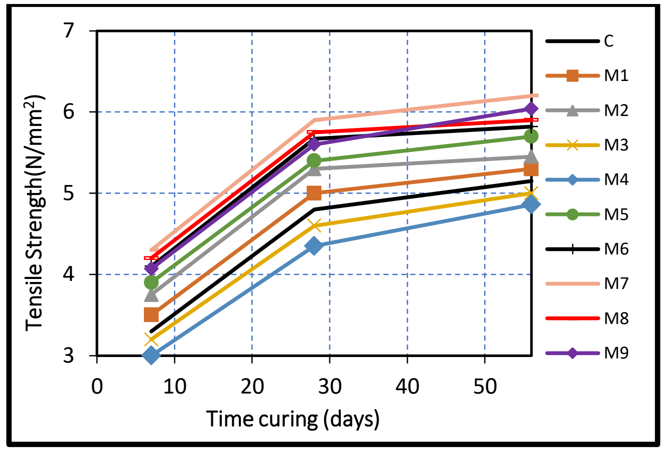

Fig-4: Splitting tensile strength for different mixes

Table 8 Splitting tensile strength (N/mm²) for different mixes

Mix	Splitting tensile strength (N/mm²)		
	Age(days)		
	7 days	28 days	56days
C	3.3	4.8	5.15
M1	3.5	5	5.3
M2	3.75	5.3	5.45
M3	3.2	4.6	5
M4	3	4.35	4.86
M5	3.9	5.4	5.7
M6	4.1	5.67	5.82
M7	4.3	5.9	6.2
M8	4.2	5.75	5.9
M9	4.07	5.6	6.04

4.2.4. The Rate of Water Absorption Test

Figure (5) shows the rates of water absorption for concrete after 7, 28, and 56 days of curing. Rate of water absorption decreased for all mixes compared to the rate of water absorption for the control mix. At the age of 56 days, mix M7 (10%SF-10%MW) had the lowest rate of water absorption; it decreased to 2% compared to the control mix which its rate of water absorption was 3.5%. This could be because of the presence of MW, which fills voids, and the production of calcium silicate hydrate, which fills internal gaps and capillary pores.

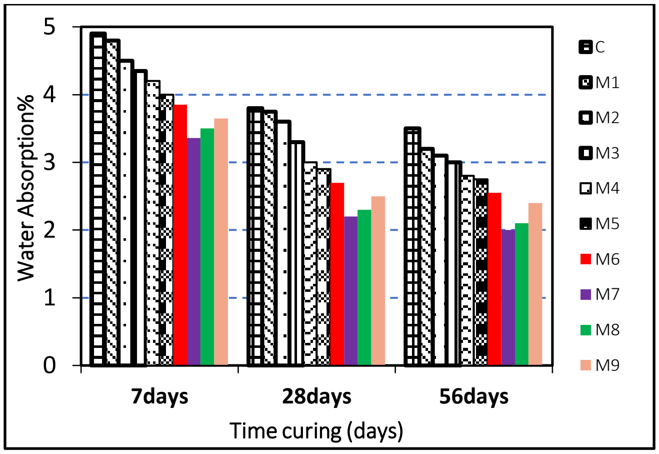

Fig- 5: The rate of water absorption for different mixes

4.2.5. Unit Weight Test

Figure (6) shows the density of the concrete after 28 days of curing. In the case of 0% SF and MW (5%, 10%, 15%, and 20% of total binder content) along with FA, the values of density varied. Mix M2 had the maximum density compared to the density of the control mix. The combined use of 10% SF and MW (5%, 10%, 15%, and 20% of total binder content) along with FA showed that mix M7 had the maximum density compared to the density of the control mix.

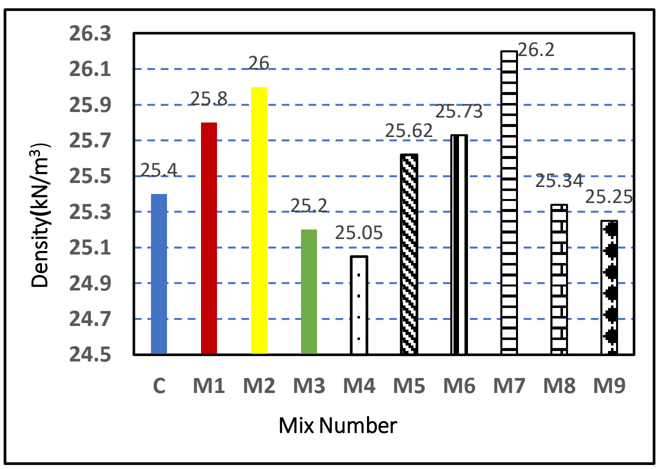

Fig-6: The density for different mixes

5. CONCLUSIONS

Based on the analysis and discussion of the experimental results, it can be concluded that:

1. When compared to the control mix, the combination of 10% SF and 10% MW with FA produced the maximum compressive strength, flexural strength, and splitting tensile strength. A combination of 10%SF and MW along with FA improved the mechanical properties of concrete.
2. In comparison to the control mix, the workability of a concrete mix reduced as the marble powder dust content increased.
3. Rate of water absorption decreased with using SF and MW along with FA compared to the control mix.
4. The use of SF and MW in combination offers a lot of potential for producing green concrete that is also environmentally friendly.

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