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Research paper

INVESTIGATION OF MARBLE POWDER AND WASTE AS PARTIAL REPLACEMENT FOR CEMENT AND SAND ON MORTAR PROPERTIES

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Abstract

In this paper an investigation of marble powder (MP) as partial replacement for cement and marble waste (MW) as partial replacement for sand is presented. MP replaced the cement at the rate of 5%, 10% and 15% of cement by mass. MW was used as a replacement for sand at constant 50% replacement level. Control mixture was prepared without MP and MW. Water to cement (w/c) ratio varied since MP was considered as binder, thus w/b ratio was constant. Fresh properties were determined by air content, workability and density, while hardened properties were evaluated with compressive and flexural strength, absorption and quality. The results indicate a small decrease in workability, but no significant change in compressive strength for samples with 5% and 10% MP addition and 50% MW addition. However, increasing the MP replacement level beyond 10% leads to decrease in compressive strength.

Key words: *marble powder, waste, cement, binder*

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1. INTRODUCTION

Marble waste has emerged in recent years as a suitable material for research as addition in mortars and concrete [1 – 5]. Large number of studies suggest the application of marble powder (MP) as supplementary cementitious material, and marble waste (MW) as substitution for sand or coarse aggregate. The research is in line with Sustainable development goals related to waste reduction, recycling and reuse, i.e. specifically goal 12 [6]. Since concrete industry is one of the largest contributors to waste generation and environmental pollution, the logical conclusion is to reduce consumption of cement and aggregate using waste materials form other industries [7]. In ordinary concrete mix, the aggregate participates with about 70% and cement with about 15%. Considering that concrete production is roughly 0.6 m^3 per capita in EU countries [8], the amount of natural materials needed is enormous.

Marble is one of the most used stones in the construction industry. The use is diverse, from load-bearing elements to decorative material. World production of marble reached 318 Mt in 2021 [9]. In Bosnia and Herzegovina marble production is around 285 Tt in 2023 [10], which is approximately the production level of recent years. During marble processing waste is generated as powder and granulates [5]. Marble powder (MP) is rich in calcium, silicon and aluminum oxides, resembling cement chemical properties. Marble waste (MW) as granulates can be used as replacement for sand, due to particle properties [2].

In work [11], it was found that MP can improve concrete compressive strength up to a 10% replacement, but beyond that, it can cause a decrease in strength. The use of marble powder can also enhance workability characteristics. According to [12], replacing 15% of sand with marble powder led to a 4.5% increase in compressive strength. Additionally, substituting 10% of cement with silica fume or metakaolin in marble powder concrete resulted in a remarkable strength improvement of 60% and 64.3%, respectively. The introduction of marble powder also increased the split tensile strength of the concrete mixtures. Moreover, the concrete mixtures with a replacement of 15% sand with marble powder exhibited improved carbonation depth after 56 days of exposure. Furthermore, the marble powder concrete with silica fume or metakaolin showed superior carbonation resistance and enhanced durability properties in the concrete mixtures. The study by [13] investigated the use of marble dust particles (MDP) as a partial replacement for cement in the concrete mix. The results showed that the optimal percentage range for replacing cement with MDP was between 5% and 10%, leading to significant improvements in the compressive and flexural strength of the concrete mix. The concrete mix with 5% and 10% replacement of cement by MDP exhibited higher values compared to 0%, 15%, and 20% replacements at different curing times (7, 14, and 28 days) for compressive strength. Yifru and Mitikie [14] used marble waste and scoria as partial replacement for sand. Results indicate an increase in compressive strength up to 30% with marble waste replacement level of 22.5%. Also, concrete waste decreased by about 5% without compromising the compressive strength. In the work of Vardhan et al. [15], the sand was replaced with MW in concrete mix. It was found that the presence of 40% MW in the mix led to an increase in compressive strength and reduction in drying shrinkage. MW in the mix leads to denser mixture with better filler effect and binding.

In this paper we used marble powder (MP) as partial replacement for cement and marble waste (MW) as partial replacement for sand in mortar mixtures. MP replaced the cement at the rate of 5%, 10% and 15% of cement by mass, while MW replaced the sand for 50% for all mixtures except reference mix, which had no replacement for cement and sand.

2. MATERIALS AND METHODS

All mixtures were prepared as cement mortar with cement-to-sand ratio of 1:3. As cement, CEM II/A-M (S-V) 42.5N was used. This cement has a density of 3.05 g/cm^3 and specific surface area of 2900 cm^2/g. Ground limestone from local production was used as sand (0/4 mm). This sand has a specific gravity of 2.70 g/cm^3 and meets all the requirements for application in mortar and concrete. MP and MW were taken from a local stone production company located near Mostar, B&H. Due to small particles MP is stored in basins with water, thus liquified samples were taken. Before the mixing process, MP was dried at 105°C until constant mass and sieved through 0.09 mm sieve to eliminate the residuals. MW was taken directly after the stone cutting process. Since it had significant residuals, it was first dried at 105°C and then sieved through 4 mm sieve.

The chemical analysis of MP is presented in table 1. As it can be seen, MP is mostly composed of silicon oxides, with relatively low calcium, iron and aluminum oxides content. However, the sum of pozzolanic oxides (silicon, iron and aluminum oxides) is 71.56%, which meets the requirements of EN 450-1 (requirements for fly ash) as addition for concrete production. Another requirement listed in EN 450-1 is limited Na_2Oeq content (under 5%) which is calculated as Na_2O+0,658K_2O and is 3.63%.

In figure 1, particle size distribution of MP, MW, cement and sand is presented. MP particles are mostly smaller than 10 µm and similar to cement. MW has about 57% of particles smaller than 0.5 mm, opposite to sand which has 36%. Specific gravity of MP was measured 2.833 g/cm^3, while for MW is 2.77 g/cm^3 with compacted bulk density of 1.776 g/cm^3.

Table 1. Chemical analysis of MP

Element	Oxides (%)	Element	Oxides (%)
SiO_2	50.43	Na_2O	2.83
Fe_2O_3	6.86	K_2O	1.22
Al_2O_3	13.96	TiO_2	0.42
CaO	12.73	SO_3	0.05
MgO	5.87	LOI	4.78

For testing procedures four mixtures were prepared with MP addition at the rate of 5% (CM10), 10% (CM11) and 15% (CM12) of cement by mass, while MW replaced the sand for 50% for all mixtures except reference mix. Reference mix (CM1) had no replacement for cement and sand. Detail mix properties are given in table 2. Since cement+MP sinergy was considered as binder, water-to-binder ratio (w/b) was kept constant, thus w/c ratio varied.

All mixtures were prepared in automatic mortar mixer in accordance with EN 197-1. After the tests on fresh mortar, the mixtures were pured in 4x4x16 cm molds with 3 samples. The samples were kept in the molds for minimum of 24h, demolded and placed in water curing tanks unitl testing.

Table 2. Mix proportions

Mix	Cement (g)	MP (%)	MW (%)	Sand (g)	w/b	w/c
CM1	450.0	0	0	1350.0	0.52	0.52
CM10	425.5	5	50	675.0	0.52	0.55
CM11	405.0	10	50	675.0	0.52	0.58
CM12	382.5	15	50	675.0	0.52	0.61

On fresh mortar, workability, bulk density and air content were tested. Workability was tested in accordance to BAS EN 1015-3, on flow table determining average spread in two perpendicular directions. After the test, mixture is pured in 1 liter container, leveled and weighed, thus determing the bulk density. The container is then sealed with with an air content test attachment. Air content was tested according to BAS EN 1015-7 by pressure method.

After the curing process, flexural tensile strength and compressive strength were tested for 7, 14 and 28 days of curing, accoriding to EN 1015-11. Prior to this testing procedures, the UPV and absorption was tested. The samples were dried at 105°C untill constant mass, then by ultrasonic testing aparatures the pulse velocity was measuder and calculated as v=d/T, where d is 16 cm, and T is the time needed for pulse to reach the reciver from transmitter in seconds. After the UPV test, the samples were submerged gradually in water in order to test the absorption. The absorption was calculated as m_w/m_o in percentage, where m_w is mass of absorbed water and m_o is the mass of dried sample.

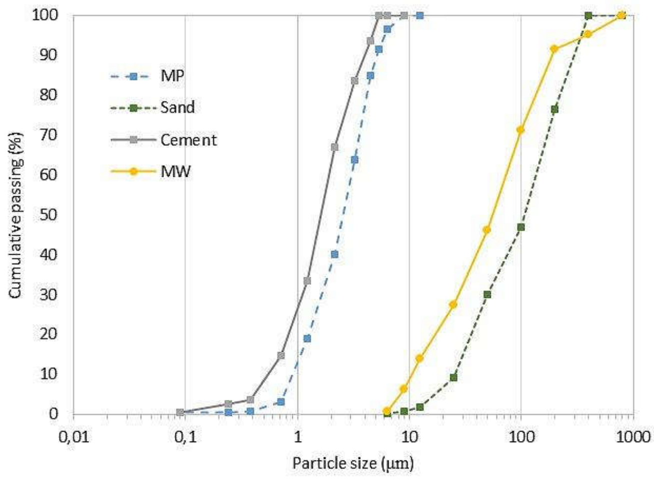

Figure 1. Particle size distribution

3. RESULTS AND DISCUSSION

Workability is one of the most important properties of fresh mortar. The workability can indicate the quality of the installed mortar. By higher bulk density, usually lower air content is expected if no additives were used. The results of workability, bulk density and air content are presented in table 3.

The workability decreases with the increase of MP. The average measured spread is 170 mm in the case of reference mix and gradually decreases to 153 mm for the mixture with

15% of MP and 50% of MW indicating high impact of MP on the workability of the mortar. Similar results can be seen in [16] where the workability is reduced due to small MP particles. As workability decreases, the change in other properties is visible. The bulk density is decreasing, for a small increment but the decrease is observed. Following the decrease in bulk density, the air content is increasing from 2.70% to 3.30% for the CM12 mix. These results are expected due to the presence of MP, but MW had no significant effect on the properties, which can be concluded from the fact that bulk density did not decrease significantly.

Table 3. Workability, air content and density test results

Mix	Spread (mm)	Air content (%)	Bulk density (kg/m^3)
CM1	170	2.70	2306.9
CM10	163	3.20	2229.2
CM11	165	3.20	2228.8
CM12	153	3.30	2220.7

On the following figures (2, 3, 4, 5 and 6) properties of hardened mortar are presented for 7, 14 and 28 days of curing. Compressive strength is generally decreased with the presence of MP and MW. For the 7 days of curing significant reduction in compressive strength is visible, up to 29% for CM12 mix. Similar is registered for 14 days of curing, with 28% of strength reduction for CM12 compared to reference mix. However, after 28 days of curing, mixture with 5% of MP showed similar result as reference mix, with only 0.9% of reduction. Also, mix CM11 has about 6% lower compressive strength, which is negligible. But when adding 15% of MP with 50% of MW reduction is significant of 20% compared to reference mix.

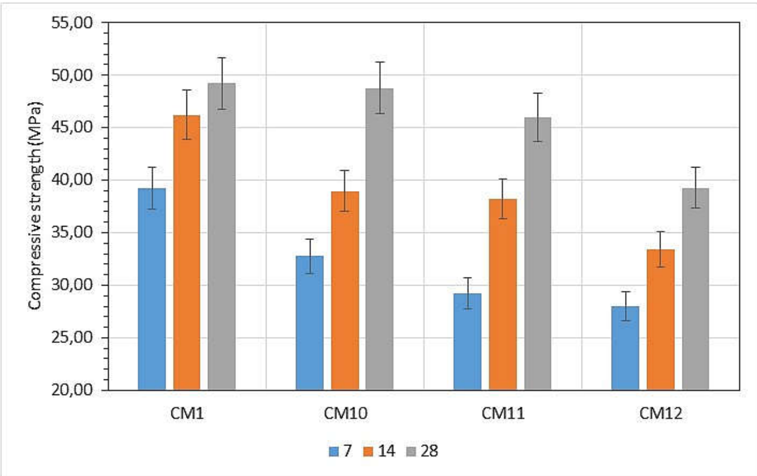

Figure 2. Compressive strength test results

Similar results can be seen for the flexural tensile strength test results for 7 days as for compressive strength for the same period. Reduction in strength is visible for all mixtures with additives, up to 22% for CM12 mix. However, an increase in flexural tensile strength is observed for CM10 and CM11 for the 14 days of the curing period. CM12 has similar results to reference mix. For 28 days of curing an increase of 10% in flexural strength for CM10 mix is registered. CM11 and CM12 have small reduction in strength of 6% and 3% respectively, compared to reference mix.

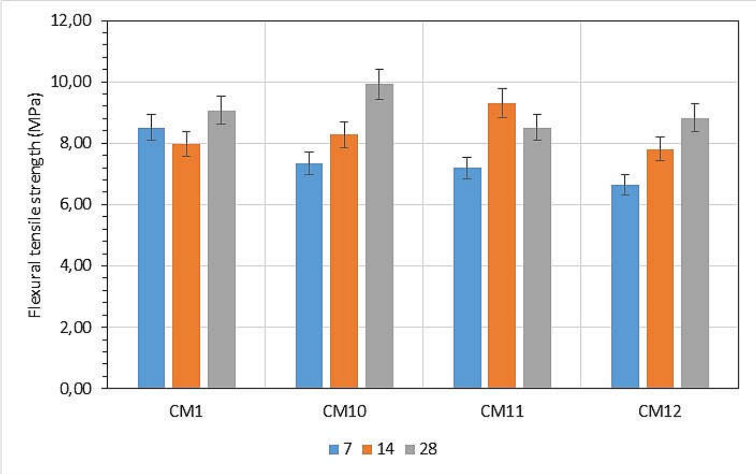

Figure 3. Flexural tensile strength test results

The UPV test results show an increase in the quality of the mixtures when MP and MW are present. Only CM12 mix showed reduction in measured UPV of about 4% compared to reference mix. The results indicate better packaging of the MP particles in the mortar mix, thus increasing the quality of the mixture for all curing periods. Similar results can be seen in [16].

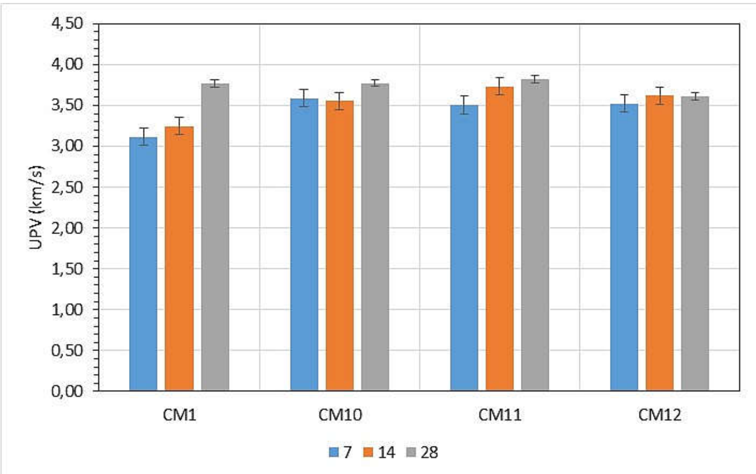

Figure 5. UPV test results

Water absorption test results indicate a reduction in absorption in the presence of MP and MW for small amount of MP. For increased MP content (CM12 mix) an increase in absorption is visible for 7 and 14 days of curing. However, for 28 days of curing constant reduction in absorption is visible, for 7%, 18% and 23% respectively. CM10 and CM11 mixtures exhibit lower absorption for every curing period, for 7% for CM10 and 18% for CM11 at 28 days of curing.

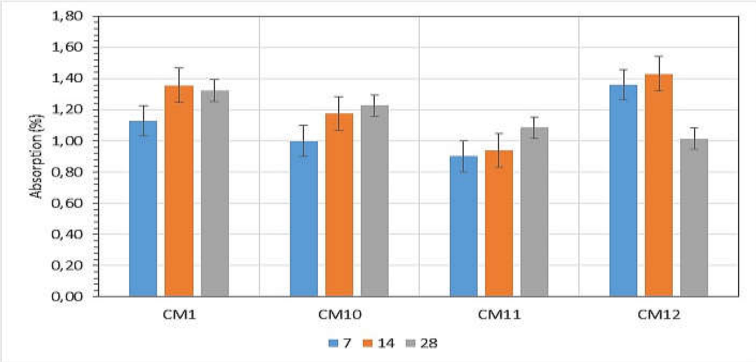

Figure 6. Absorption test results

The results indicate that after the hardening process, the MP particles have filling effect, providing a higher quality mix, as also can be seen in [2]. This is visible from the UPV and absorption test, where the samples have shown higher quality and lower absorption for small amount of MP. Also, filling effect of the smaller particles can help to "glue" the mixture, providing higher flexural tensile strength results. However, for the enhancement of compressive strength MP should participate in hydration process, which is not seen in this case. But the registered reduction in compressive strength is not significant, meaning that the presence of MP did not affect the hydration process itself, and that MW presence had practically no effect on compressive strength. This means that MW is suitable as replacement for sand. This is also confirmed by similar particle size, specific gravity and bulk density of MW and sand. Similar results can be seen in [15].

4. CONCLUSIONS

The paper presents the research results of mortar properties with partial replacement of cement with marble powder (MP) and partial replacement of sand with marble waste (MW). As the results indicate, there is no significant impact on mortar properties when a small amount of MP is added. Since the addition of MW was constant, it can be concluded that even the high content of MW did not impair the tested mortar properties. 28-days compressive strength for mixture with 5% of MP is only 0.9% lower than reference mix. Flexural tensile strength for the same curing period is increased by about 10% for the mixture with 5% of MP. The UPV test indicates higher quality mixtures when MP and MW were added for all curing periods. In addition, water absorption was reduced for mixtures with MP. However, the replacement level of cement with MP should be up to 10% for application, which is also recommended by available literature.

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