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MECHANICAL STRENGTH OF SELF COMPACTING MORTAR AT HIGH TEMPERATURES

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Abstract

Nowadays, the ecological trend is directed towards restricting the utilization of natural resources materials in the construction sector. This study examines the impact of high temperatures on the mechanical properties of self compacting mortars (SCMs) that include marble dust (MD). For this aim, four SCMs were prepared with the objective of replacing the cement with MD at varying proportionsof 0, 10, 15 and 20% by weight and compared to reference mortar. The mechanical properties of SCMs are investigated separately at different curing days (2, 7, 28-d) and high temperatures (300°C, 600°C and 900°C) over a period of 1hour. Based on the results, it was established that maintaining a temperature of 300°C is crucial for achieving optimal mechanical properties in the cured SCMs, as any temperature beyond this range leads to a decline in its performance.

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Keywords: Self compacting mortar, marble dust, mechanical properties, high temperatures

1. Introduction

High temperatures, whether caused by accidents or natural events, can negatively impact the structural characteristics of concrete. This exposure may lead to changes in the pore structure, resulting in cracking and spalling. As a result, the stability, strength, and durability characteristics of concrete structures are impacted.

Table 1. Impact of high temperatures on characteristics of cement matrix.

Temperature	Series of alterations
100°C	The water that is free and within the capillaries of the cement matrix will evaporate. [3], [4]
Bellow 300°C	Any significant strength loss [5].
Above 300°C	Degradation of C-H and dehydratation of C-S-H gel [6].
300°C - 400°C	Los strength 15%-40%, formation of microcracks [7], [8].
Above 400°C	C-H is desydrated as CaO and water [9].
550°C -650°C	Los strength 70% [10].
700°C -900°C	Los strength 70%-90% [11].

To overcome this problem, Okamura suggested at Kochi University (Japan) in 1986 a Self-Compacted Concrete (SCC). SCC is composed of a considerable amount of binder and a high dosage of chemical admixtures, which greatly enhance its flow passing capacity and workability. This particular mortar is highly advantageous owing to its capability to effortlessly spread and fill substantial structures under its own weight. Nowadays, SCC mixes consist of large quantities of fine-powder byproducts (marble, glass, sludge) that are often considered

waste materials with limited practical applications, resulting to expensive disposal costs. Using these waste as cementitious materials in SCC or SCM helps in reducing CO_2 emissions. Pure limestone (CaCO3) undergoes a transformation process, leading to the creation of marble, a type of sedimentary rock. During the cutting process, a significant quantity of fine powder is produced. If this dust is not properly managed, it can lead to various environmental challenges. The inclusion of $CaCO_3$ in marble powder can enhance the initial hydration rate of cement and inhibit the transformation from ettringite (AF) to monosulphate (AFm). The addition of approximately 8%–10% marble powder can lead to enhancements in mortar properties. Alyamac & Ince [12] studied the use of marble waste in mix design for self-compacting concrete. It was established by the authors that marble waste material has the potential to be economically and effectively utilized as a supplementary filler material in SCC technology. Karakurt et al. [13] and Rasekh et al. [14] found that the use of marble powder in SCC mixtures resulted in improved fresh properties. (viscosity and workability) of the mixture. Sudarshan et al. [15] in their study repported that, use of marble powder (MD) at a level of 10% replacement of cement does not have a negative impact on the properties of concrete or mortars.
Therefore, The objective of the present investigation is to analyses the possibility of utilizing locally waste materials like MD as supplementary cementitious materials to produce SCMs which provide good durability under high temperatures (300°C to 900°C). Hence, a detailed experimental investigation was carried out to examine the impact of MD on the workability and mechanical characteristics (flexural and compressive strength) of SCMs.

2. Experimental

2.1. Materials used

The common cement used in all mortar mixes is a ordinary cement conforming to standard [16]. The waste marble used to replace part of cement in mortar mixes was obtained as an industrial byproduct directly from the deposits of marble factories. This waste marble results from the sawing, shaping, and polishing procedures involved in marble production. The marble powder was ground and sieved through an 63 µm sieve. The chemical properties of the marble dust and cement are given in Table 2.

Table 2. Chemical properties of cement and marble powder.

Oxides compounds (mass %)	OPC	Marble
SiO_2	22.05	5.3
Al_2O_3	5.8	0.45
Fe_2O_3	3.1	0.75
CaO	61.86	43.2
MgO	2.54	14.8
K_2O	0.23	0.03
SO_3	1.5	0.04
Los of ignition	2.45	33.1
Density	3.10	2.75

A high water-reducing superplasticizer (SIKA MONOTOP TEMPO-12), that meets standard [17] was utilized to achieve the required workability of the mixtures. Polypropylene fibers measuring 12 mm in length were added during the final stage of mixing the mortar. The river sand utilized has a diameter of 1mm and a density of 2.36.

2.2. Mixtures proportion

Assessing the impact of MD as a filler on the properties of fresh and hardened mortars, four mortar samples with 0%, 10%, 15% and 20% MD were prepared in a laboratory and compared to reference mortar.

Table 3. Mixing proportion of mortars

Designation	Cement	Marble	Binder	Water	Sand	Water/Binder	SP	Fibers
MD-0	565	0	565	226	1275	0.4	4.1	1.2
MD-10	508.2	56.5	565	226	1275	0.4	4.1	1.2
MD-15	480.25	84.75	565	226	1275	0.	4.1	1.2
MD-20	452	113	565	226	1275	0.4	4.1	1.2

The water to binder ratio for all mixtures was 0.40, with a total binder content of 565 kg/m^3 and a volume fraction of polypropylene fibers at 1.2%. Determination of these values was achieved by conducting trial flowability tests.

2.3. Testing methods

To assess the slump flow of the SCMs, a mini truncated cone was used . According to the specifications and guidelines of EFNARC [18] a mortar is qualified as self-compacting if its flow diameter varies from 240 to 260 mm.

In this test, a mini V-funnel was completely filled with mortar . For self-placing mortars, EFNARC suggests a flow time of between 7 and 11 seconds.

Compressive and flexural strength tests were carried out prismatic samples with dimensions 40x40x160 mm at different curing days (2, 7, 28), in accordance with standard [19]. To assess the performance of mortar mixes under high temperatures, prismatic samples measuring 40x40x160 mm were produced. Following a 28-day curing period, the samples underwent exposure to high temperatures during 1 hour. Prior to performing the mechanical strength tests, the samples were cooled to room temperature.

3. Results

3.1. Flow

The results of the slump flow, obtained using the mini cone, are shown in Figure 1. The figure shows the evolution of slump flow of elaborated SCMs.

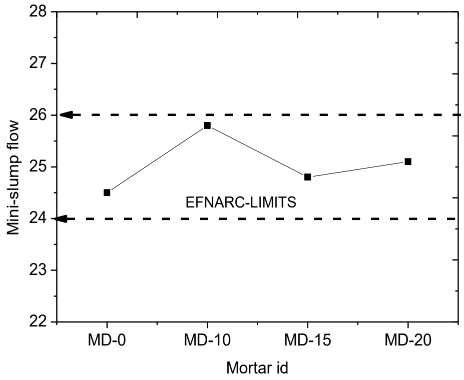


Fig. 1. Influence of granite residue on slump flow of mortars.

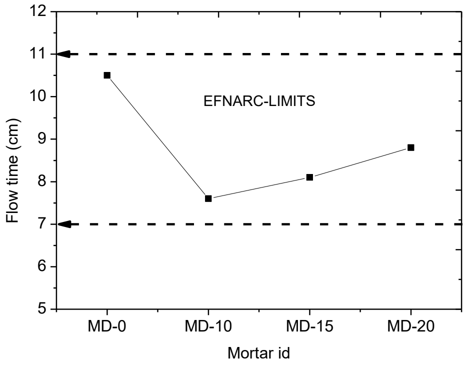


Fig. 2. Influence of granite residue on flow time of mortars.

It can be seen that the slump flow value of all the mixes is within the range of self-compacting mortars, according to EFNARC (25 ± 1 cm). The increase in the slump flow value of the mortar mixes with marble powder compared to plain mortar is probably attributed to the difference between the density of the two materials. This result is consistent with that published by Tobbala et al. [20].

The mortar flow time results obtained using the mini V-Funnel is shown in Figure 2. It can be seen that the utilization of MD as filler reduces the flow time of the mixtures compared to mortar without marble powder, indicating that viscosity was influenced. For example, the mini V-funnel value for plain mortar was 10.85s, whereas; mortars made with 20% MD gave value of 10.61s. It is important to highlight that all of these values are within the acceptable range specified by the EFNARC (7-11s).

3.2. Mechanical properties

Figure 3 shows the evolution of the compressive strength of mortars with and without MD.

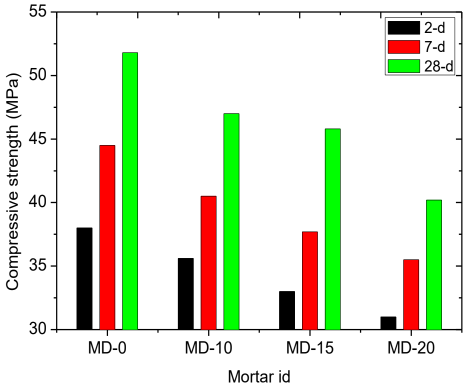


Fig. 3. Compressive strength evolution as a function of the MD replacement content

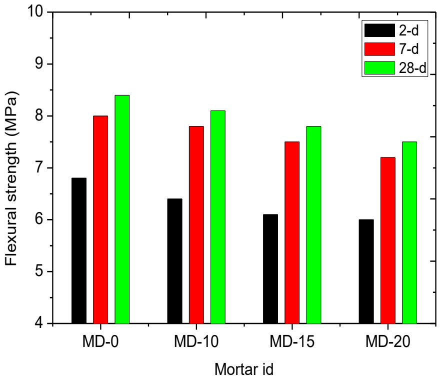


Fig. 4. Flexural strength evolution as a function of the MD replacement content

The Figures show a continuous increase in strength with increasing age. The compressive strength enhancement of mixes containing MD is related to the calcium carbonate content ($CaCO_3$) present in this waste material. For instance, at early age (2 days), replacing the cement with 10%MD contributed positively on the compressive strength development. The slight decrease in the compressive strength value of the MD-10 mortar compared to that of the control mortar is only 6.3%.

This is probably due to the fineness of the MD particles and the amount of C_3A. Same pattern of results were also explained by Wang et al. [21]. At the age of 7 and 28 days, the reductions values in compressive strength for the MD-10 mortar compared to the plain mortar were about 8.9% and 9.2%, respectively.

When the cement was replaced by high contents of MD (i.e. 20% MD), the compressive strengths were reduced compared to that of the reference mortar by 18.4, 20 and 22%, respectively at the age of 2, 7 and 28 days. The significant drop in the compressive strength of the WMP-20 mix can be attributed mainly to the low reactivity of the marble powder.

The flexural strengths values of the SCMs depicted in Figure 4, almost follow the pattern observed for the compressive strength results.

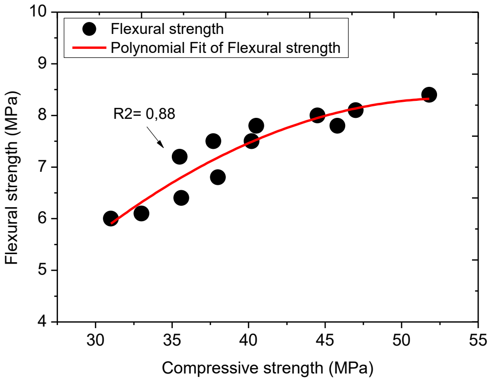
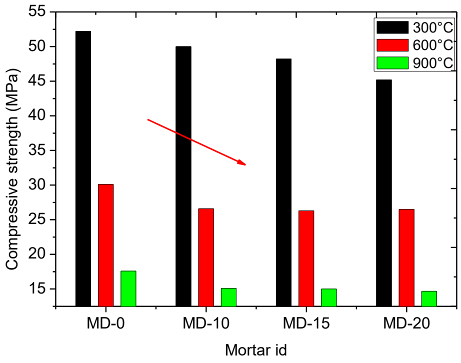


Fig. 5. Correlation between flexural and compressive strength of SCMs.

The enhancement of flexural strength (Figure 5) may be attributed to the nucleation occurring around the fine particles and additives that replace the large, oriented crystals of $Ca(OH)_2$ with numerous, smaller, and less oriented crystals. In addition, it was found in Figure 6 that there was a good correlation between flexural strength and compressive strength with a correlation coefficient R^2= 0.88. The influence of high temperatures on the development of compressive strengths of mixes is depicted in Figure 6.



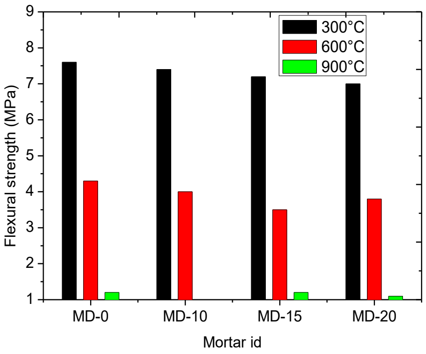


Fig. 6. Compressive strength evolution as function of high temperatures.

Fig. 7. Flexural strength evolution as function of high temperatures.

According to the results presented in figure 6, it can be observed that exposure of mortars to temperatures below 300°C did not affect the compressive strengths. It should be noted that this temperature did not cause any appearance of micro-cracks in the mortar samples and the results were comparable to those observed at 28 days under ambient conditions (21°C) (Figure 6). [5] Sikora et al. (2018) reported similar results. Beyond 300°C, mortar samples undergoes microstructural changes leading to cracking, as the expansion causes failure of mortars owing the decomposition of C-H and dehydratation of C-S-H gel. The findings align with the results reported by [10], [11]. For example, between 600°C and 900°C, is the final stage which is the result of the complete decomposition of the calcium silicate. At this temperature level, the strength of the control mortar decreased from 30.1 MPa to 17.6 MPa, respectively. However, when 10% MD replaces cement, the strength decreases from 26.6 MPa to 15.1 MPa.

The influence of high temperatures on the development of flexural strengths of mortars is depicted in Figure 7. The flexural strengths demonstrate a comparable trend to the compressive strength results.

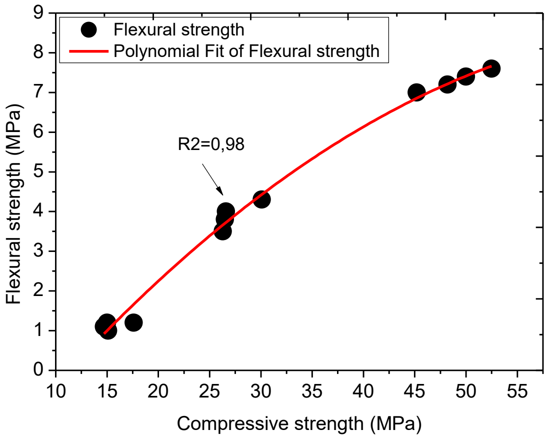


Fig. 8. Relationship between flexural and compressive strength of SCMs under elevated temperatures.

Moreover, Figure 8 shows that compressive strength of mortar mixes is correlated with the flexural strength and the correlation coefficient is R^2= 0.98.

4. Conclusions

This study examined the influence of marble dust (MD) on fresh and hardened states of SCMs was studied and the results can be drawn as follows: The replacement of OPC with MD in SCMs results with better workability. In fact, when inclusion of MD was 10%, the highest influence was observed on slump flow of SCMs. In general, replacing the cement with 10%MD contributed positively on the compressive strength development.

The decrease in the compressive strength value of the MD-10 mortar compared to that of the control mortar is about 6.3%, 8.9% and 9.2%, respectively at 2, 7 and 28-d. The compressive strengths of mortars subjected to temperatures up to 300°C were similar to those at 28 days (ambient temperature of 21°C). At temperatures surpassing 300°C, the mortars exhibited a significant decrease in strength, ranging from 50% to 70%.

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