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EVALUATION OF PROPERTIES OF CARBON FIBER SCMS CONTAINING FLY ASH AND MARBLE DUST AFTER HIGH TEMPERATURE

ABSTRACT

In this experimental study, the effect of high temperature on the samples produced by substituting marble dust (MD) and fly ash (FA) to CEM-I 42.5R portland cement (PC) in carbon fiber SCMs was evaluated. The amount of chopped carbon fiber of 5mm length used in the study was taken as 2.35kg/m^3 in all SCM sets. In addition, MD and FA were substituted into the cement as single and double by mass. After lime-saturated water cure to 28 days curing the specimens were divided into 3 groups and unit volume weight, porosity and axial compressive strength were determined. As a result of the study, it was determined that high temperature treatment was effective on porosity and unit volume weight for all double and single substitution cases. When the compressive strengths of double and single substitutes of FA and MD after high temperature were analyzed; it was found that the sets presented values close to the reference mix.

Keywords: Marble Dust, Fly Ash, Self-Compacting Mortar, High Temperature, Carbon Fibre

1. INTRODUCTION

The growing world population and advancing technology bring innovations in the construction industry. The most important cost items of the sector are labor, raw materials and energy needs. One of the most innovative applications developed to reduce the need for inadequate and high-cost labor is self-compacting systems [1]. These systems, which have the ability to settle under their own weight, consist of self-compacting concrete (SCC) and self-compacting mortar (SCM) systems. The two most important parameters that distinguish these systems from conventional concrete and mortar systems are the amount of superplasticizer and fine material used in the design [2]. Offering the advantage of easy placement in narrow molds, SCMs greatly reduce labor costs. In recent years, the reuse and recycling of most materials considered as waste is an important research topic [3 and 4]. Sustainability and recycling processes are at the center of these studies. The construction industry is another important sector where waste and industrial by-products are utilized. This is because the construction industry, which is growing every year, usually sources its main components such as aggregates and cement from natural resources. The main component procurement process of the sector is often faced with significant environmental problems. The most important source of environmental problems is the cement production process. Therefore, the search for alternative products to cement is important [5 and 6]. The most preferred method to reduce CO_2 emissions from the sector is the use of alternative products to natural resources. For this purpose,

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industrial by-products such as Fly ash (FA), blast furnace slag, silica fume as well as recycled materials are frequently preferred [7]. The use of mineral admixtures with cement, which do not show binding properties when used alone, is considered both economical and environmentally friendly [8]. Widely used as a substitute for cement, FA is an important industrial by-product. Thermal power plants using pulverized coal as fuel for electricity generation are an important source of FA. Approximately 75-80% of the ash produced by combustion is discharged through chimneys along with gases released into the environment. FAs are usually spherical in shape and 0.5-150 µm in size [9]. FAs are classified as F and C [10]. FA of the type specified in TS EN 197-1 is obtained by electrostatic or mechanical precipitation [11]. Another alternative to cement is marble dust (MD). This waste product, which attracts attention with its large volumes in marble processing plants, is an inert material [12]. MD can be used as a mineral admixture in concrete production [13] and as a substitute for cement [14 and 15]. Fibers are one of the most preferred additives to improve the mechanical performance of concrete and mortar elements [16, 17 and 18]. Many types of fibers such as carbon, glass, polypropylene, natural, etc. are used to improve mechanical and durability performance [19, 20, 21 and 22].

Fibers of different sizes and forms are usually used in proportion to the amount of cement or total design volume [23 and 24]. Optimum values of flexural strength, flexural toughness, impact resistance and impact toughness were observed for the addition of 4% for the use of 1%, 2%, 3% and 4% by volume in mortar composites [23]. FA is widely used as a substitute in cement systems containing different pozzolans [25]. Also, when FA is used in fibrous SCCs with double and triple substitution in cement, the negative effect of fibers on fresh state properties can be reduced [24]. The use of 0-40% FA in SCCs has a positive effect on self-compatibility and compressive strength losses under the influence of high temperature (maximum 900°C). The use of up to 20% FA is also considered to be beneficial [26]. It was also found that the 28-day strength of concretes with 25%, 40% and 55% FA admixtures decreased by approximately 21%, 30% and 46%, respectively, compared to the control group. For the same replacement ratios, the compressive strength difference caused by FA decreases with progressive water curing in the range of 3 to 28 days [9]. The 28-day compressive strength of SCCs produced by substituting 40%, 50% and 60% of FA with cement is in the range of 26-48MPa [27]. Substitution of more than 25 wt% FA as a mineral admixture in cement reduces the compressive strength of SCCs [9]. Replacing cement with up to 10% marble powder helps to improve the workability of the mix and the compressive strength of the mix is maintained [13]. The use of marble powder also has a significant impact on durability [28]. One of the most important durability parameters of marble dust is carbonation. The highest carbonation due to the use of MD in conventional concrete was found at 15% MD substitution rate. It was also observed that the highest compressive and flexural strengths belonged to specimens containing 5% MD, while the lowest compressive and flexural strengths belonged to specimens containing 15% MD [29]. Substitution of MD with filler material in the range of 25% to 100% by volume increases the compressive strength of concrete up to 75% substitution [30]. In mortar mixtures in which waste MD was substituted into cement at 0%, 5%, 10% and 15%, it was determined that the mechanical performance could be achieved with a maximum of 10% MD substitution [31]. Increasing MD substitution decreases the compressive strength at early ages (up to 7 days), but the loss of compressive strength decreases with increasing curing time. The use of MD increases porosity and leads to a decrease in compressive strength.

2. RESEARCH SIGNIFICANCE

In this study, the change in mechanical properties after high temperature due to the use of waste MD and FA and carbon fiber in SCMs, which have come to the forefront with their energy saving feature in recent years, was evaluated. In this way, the study aims to evaluate SCM-based productions aiming both the sustainability of waste products and the reduction of labor costs.

Highlights:

- Mechanical and physical properties of mortars produced with waste were evaluated.
- The effect of high temperature on mortar after marble dust and fly ash substitution was investigated.
- The properties of carbon fiber reinforced mortars with different properties were evaluated after high temperature.

3. EXPERIMENTAL METHOD

3.1. Materials

CEM I 42.5 R cement (PC) [11], marble dust (MD), F class fly ash (FA) [10] and municipal water [32] were used in the experimental study. The properties of PC and FA are given in Table 1. The fresh state properties of the SCMs produced comply with EFNARC criteria [33]. For this purpose, polycarboxylate-based plasticizer (HRWR) was used [34]. The specific gravity of PC, FA and MD, HRWR were 3.15, 2.00, 2.7, 1.06, respectively. CEN standard sand [35] was used as aggregate and sieve analysis [36] is given in Figure 2. In addition, chopped carbon fiber with a length of 5mm, whose technical specifications are given in Table 2, was used in all SCMs.

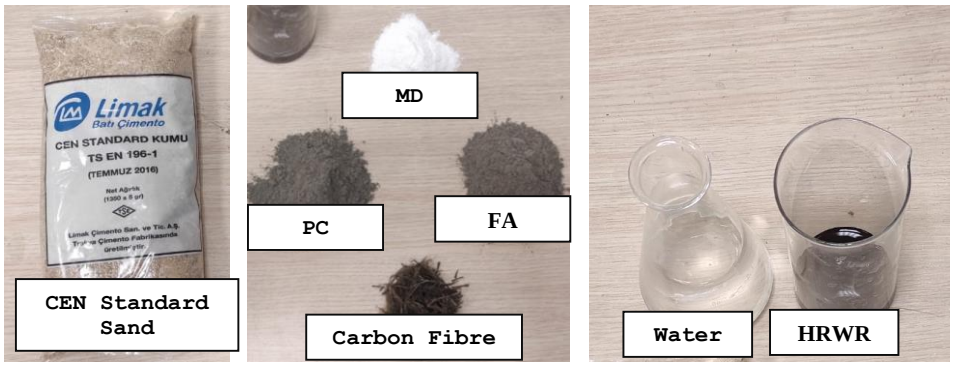


Figure 1. Materials used in the experimental study

Table 1. Properties of PC, FA and MD

	PC(%)	FA(%)	MD(%)
CaO	63.57	2.32	56.00
SiO_2	19.34	60.94	0.43
Al_2O_3	3.75	20.66	0.10
Fe_2O_3	4.15	7.95	0.04
MgO	2.9	-----	0.15
SO_3	3.15	0.11	0.12
K_2O	0.81	---	0.02
Na_2O	0.41	1.56	0.93
TiO_2			0.02
Loss of ignition	1.92	1.92	42.18
Blaine (cm^2/g)	3804	3790	3600

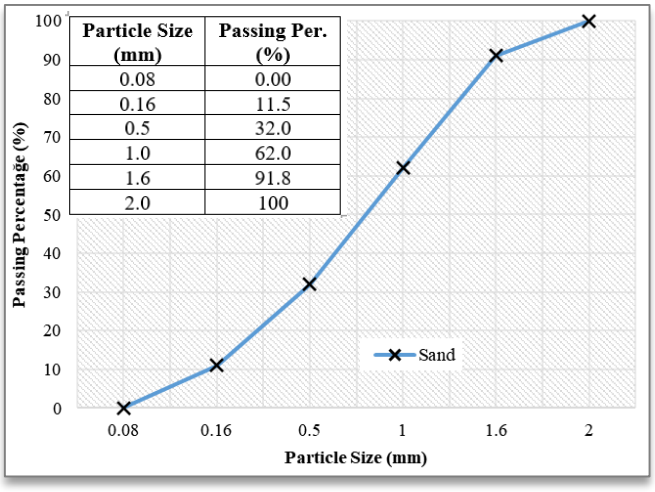


Figure 2. CEN standard sand sieve analysis

Table 2. Carbon fibre technical properties

Tensile strength (MPa)	3800
Modulus of Elasticity (GPa)	228
Melting temperature (°C)	---
Specific gravity (g/cm^3)	1.81
Fiber diameter (micron)	7.2
Electrical conductivity (ohm-cm)	0.00155
Percent carbon	%95

3.2. Method

The amount of water was kept constant and taken as 305kg/m^3 in all SCM sets prepared with appropriate equipment. Also, the amount of PC used was 565kg/m^3 in the reference set (M1). In the other substitution sets, mass substitution of MD and FA to cement was applied and the utilization rate is given in Table 3. The use of 5mm long crushed carbon fibre is constant in all SCM sets and is 2.35kg/m^3. HRWR was used for the fresh state properties of EFNARC criteria. The amount of HRWR used in all SCMs is variable and ranges between 5.41-6.47kg/m^3.

Table 3. Mix design of SCM samples

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
PC (%)	100	92.5	85.0	77.5	92.5	85.0	77.5	92.5	92.5	77.5	77.5
FA (%)	0.00	7.5	15.0	22.5	0.00	0.00	0.00	2.5	5.0	4.5	18.0
MD (%)	0.00	0.00	0.00	0.00	7.5	15.0	22.5	5.0	2.5	18.0	4.5

All specimens were produced without vibration as 9 cube specimens of 50x50x50 mm for each SCM mix. The specimens were demolded after 24±2 hours and kept in lime saturated water cure at 20±2°C for 28 days. After water curing, the physical properties (unit volume weight and porosity) of all specimens were determined. A total of 99 cube samples were divided into 3 groups. Specimens in group 1 were subjected to compressive strength test (ASTM C109/C109M, 2007)after 28 days of water curing. Specimens in the 2nd and 3rd groups were subjected to high temperature at 375°C and 750°C respectively. The high temperature oven was heated at a rate of 6 minutes/°C and the specimens were kept in the oven for 60 minutes after stabilizing the temperature. After the high temperature, the specimens were weighed with an accuracy of 0.01, mass losses were recorded, and then compressive strength test was performed (ASTM C109/C109M, 2007). A universal test press machine with a capacity of 250kN was used for the compressive strength test. Three specimens were

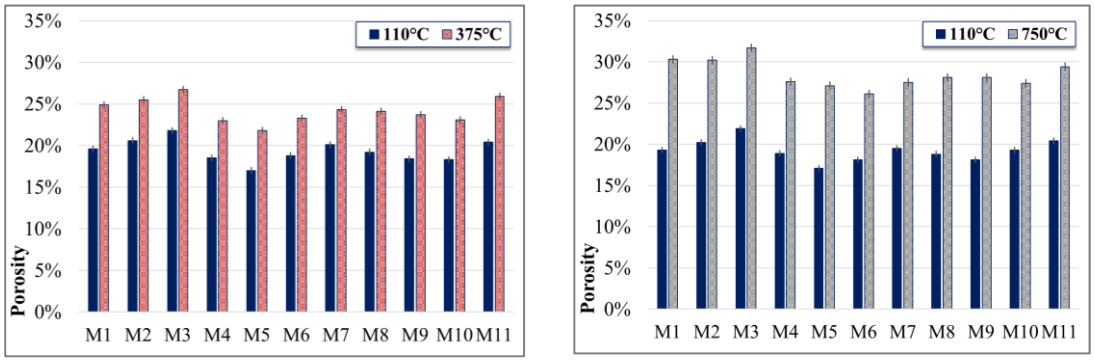
used for each SCM set and the results were averaged. Figure 3 shows the production of SCMs, determination of their physical properties, high temperature application and general view of the specimens after testing.

a) b) c)

Figure 3. a) Production of SCMs, b) Determination of physical properties, c) High temperature application

4. FINDINGS AND DISCUSSIONS

The results of the experimental studies carried out after 28 days of lime-saturated water curing of SCMs produced by substituting PC with MD and FA in the range of 0-22.5% are presented in this section. After 28 days of water curing, all sets were exposed to temperatures (110, 375, 750°C) and their physical properties were determined. All specimens were divided into 3 groups. For the 1nd, 2nd and 3rd group specimens, compressive strength tests were performed after 110, 375 and 750°C respectively.



a) b)

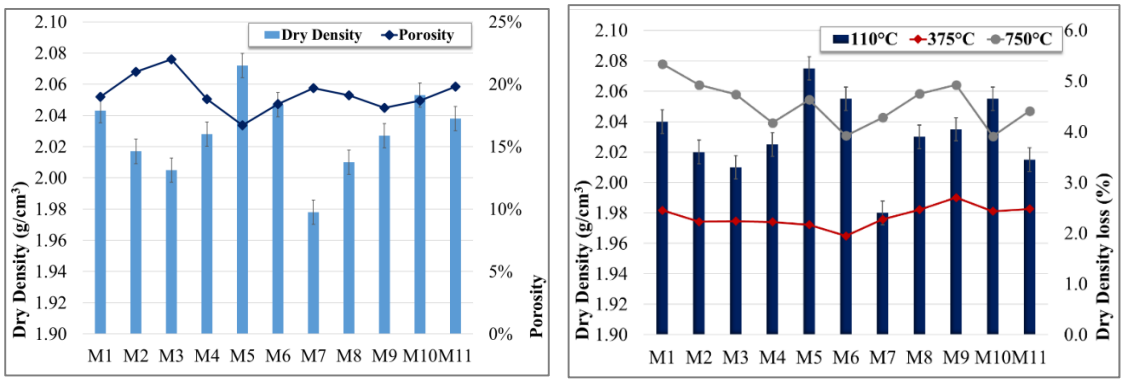
Figure 4. Porosity results

Figure 4 presents the porosity data for all SCM sets for Groups 1, 2 and 3. The porosity increases as the applied temperature increases in the range 110-375-750°C. This is related to the evaporation of free water. When 110 °C is applied and only FA substituted sets (M2, M3, M4) are analyzed, porosity increases up to 15% substitution, but porosity decreases in the M4 set with 22.5% substitution. The porosity rate in the reference set is 19.3%. The highest porosity rate belongs to the M3 set with 21.9%. When the sets with only MD substitution (M5, M6, M7) are analyzed, only set M7 with 22.5% MD substitution has a higher porosity rate than the reference set (M1). Only substituted to FA increases porosity by only 22.5%. However the use of marble powder has an impact on porosity [31]. After 375°C temperature, porosity rate is lower than M1 set in all sets except M2, M3, M11 sets. After 750°C temperature, the porosity rate in all sets except set M3 is lower than set M1. Increasing porosity from Group 1 to Group 2 and Group 3 is evident in all sets. The increase in the applied temperature increases

porosity. The use of 15% FA has a higher porosity rate than the M1 set in all 3 groups. The porosity range for Groups 1, 2 and 3 is 17.0-21.8%, 21.8-26.7% and 21.6-31.7%, respectively.

The oven dry unit weight data of all SCMs after 110, 375 and 750°C are given in Figure 5. The relationship between oven dry unit weight and porosity is given in Figure 5a and the relationship with unit weight loss is given in Figure 5b. There was a decrease in oven dry unit volume weight with increasing temperature application. Among the 11 SCM sets, these results follow a similar trend. Compared to Group 1, the unit weight loss of (%) Group 2 is in the range of 1.94-2.70%, while the unit weight loss of Group 3 is in the range of 3.91-5.33%.

Compared to Group 1, the lowest and highest losses in Group 2 belong to sets M6 and M9, respectively. When a similar evaluation is made for Group 3, it is seen that the lowest and highest unit volume weight loss is in sets M10, M1 (Figure 5b). The unit weight loss after 750 ^{0}C is significantly higher than the unit weight loss after 375^{0}C. These results are not only related to porosity but also to the decrease in the amount of free water. Comparing the M2-M5, M3-M6 sets, FA decreases the unit volume weight while MD increases it. Moreover, when the M4-M7 sets are compared, the opposite result is observed for the 22.5% substitution case (Figure 5a). In the double substituted sets (M8, M9, M10, M11), the highest unit volume weight value belongs to the M10 set with 18% MD and 4.5% FA.



a) b)

Figure 5. Unit volume weight results

The compressive strength results for all groups of all SCM sets are given in Figure 6. According to these data, the loss in compressive strength with increasing temperature is in the range of 25.24-41MPa, 19.4-35.3MPa, 12.6, 6.5MPa for group 1, group 2 and group 3, respectively. Increasing FA and MD usage decreases the compressive strength. The lowest and highest compressive strength was recorded for M7 and M1 sets in all groups, respectively. The compressive strength loss in set M3 with 15% FA substitution was higher than the compressive strength loss in set M4 with 22.5% FA substitution. As in similar studies, the substitution of FA as a mineral additive to PC has an effect on the compressive strength [9].

When the single substitution cases of FA and MD were analyzed; the lowest compressive strength loss compared to M1 was obtained in sets M2 and M5 (12.43) with 7.5% substitution. The compressive strength loss was 9.12% for set M2 and 12.43% for set M5. In the double substituted sets, the least compressive strength loss (10.8%) was recorded in set M11 compared to set M1. The positive contribution of FA to compressive strength compared to MD was more pronounced when double substituted sets were compared (M8-M9, M10-M11).

When the compressive strength data of Group 2 compared to Group 1 are analyzed, it is seen that the compressive strength loss is in the range of 10.4-26.4%. The lowest and highest losses belong to sets M8 and M11, respectively. When group 1 and group 2 are compared, there is a compressive strength loss of 5.68 MPa for set M1. Sets M4 (4.56MPa), M5 (4.85MPa), M6 (4.92MPa), M8 (3.32MPa) had less compressive strength loss than set M1, while the other sets caused more compressive strength loss than set M1.

When the compressive strength loss of group 3 compared to group 1 is analyzed; it is seen that the change is between 60.6% and 74.4%. The lowest loss belongs to M8 set and the highest loss belongs to M7 set. The highest compressive strength loss belongs to set M1 with 28.38 MPa and the lowest compressive strength loss belongs to set M7 with 18.78 MPa. The compressive strength loss of 41 MPa in group 1 decreased to 13.8% in group 2 and 69.2% in group 3. Sets M4, M5, M8 for group 2 and sets M4, M5, M6, M8, M10, M11 for group 3 have less compressive strength loss than set M1. The data that 10% substitution preserves the mechanical performance and causes compressive strength loss in substitution cases after 15% MD substitution coincide with the data of this experimental study [29, 31 and 38]. It is also accepted that the negative effect of MD on compressive strength is since it contains much less SiO_2 than PC. [31]. FA substitution of more than 25% significantly reduces compressive strength, while up to 20% is considered suitable for high temperature and compressive strength [9 and 26]. These assessments are similar to the data presented in Figure 6.

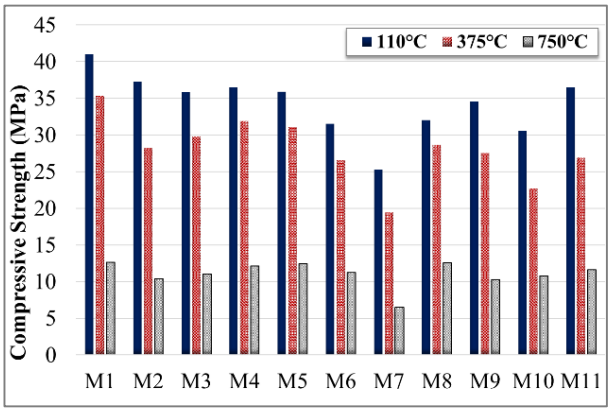


Figure 6. Compressive strength results

5. CONCLUSION AND RECOMMENDATIONS

For M2, M3, M4 sets with only FA substitution, porosity increases and oven-dried unit volume weight decreases in M2 and M3 sets. However, in M4 set, porosity decreases, and unit volume weight tends to increase. The use of FA up to 15% increases porosity. However, when the compressive strength data are analyzed, the compressive strength decreases with increasing FA content for sets M2, M3, M4. The porosity range for Groups 1, 2 and 3 is 17.0-21.8%, 21.8-26.7%, 21.6-31.7%, respectively. High temperature application increases porosity and decreases unit volume weight. When the MD-substituted sets (M5, M6, M7) are analyzed, it is seen that only the M7 set with 22.5% MD substitution has a higher porosity ratio than the reference set (M1). MD substituted to PÇ alone increases porosity at only 22.5% utilization rate. For these 3 sets, the unit volume weight decreases, porosity increases and compressive strength is lower than the reference set. The use of 15% FA has a higher porosity rate than the M1 set in all 3 groups. The compressive strength of M6, M7 and M10 shows the highest loss in group 1 compared to M1. However,

in group 2 and group 3, the effect of high temperature has a more variable effect on the compressive strength. M2 set with 7.5% FA substitution has higher compressive strength than M3 and M4 sets in group 1, while in group 2 it gives lower compressive strength than these two sets. In MD substituted M6 and M7 sets, compressive strength decreases proportionally with increasing temperature application as MD increases. The closest compressive strength to set M1 was obtained in sets M11 in group 1, M4 in group 2 and M8 in group 3. Thus, it can be seen that the double and single substitutions of FA and MD are the sets that offer values close to the reference mixture under high temperature.

CONFLICT OF INTEREST

The authors have no conflicts of interest to be disclosed.

FINANCIAL DISCLOSURE

The authors declare that this study has received no financial support.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require an ethical committee.

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