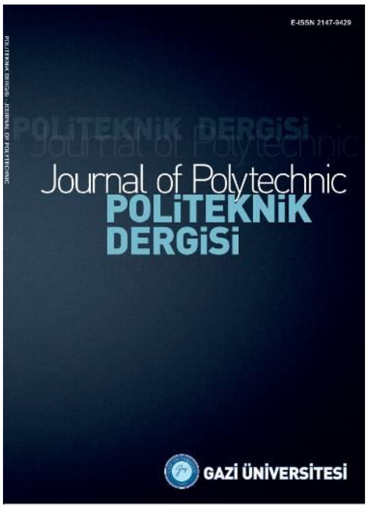

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Effects of elevated temperature for the marble cement paste products for better sustainable construction

Yüksek sıcaklık altında mermer tozu katkılı çimento pastasının daha iyi sürdürülebilir inşaat sektörüne etkisi

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Yüksek Sıcaklık Altında Mermer Tozu Katkılı Çimento Pastasının Daha İyi Sürdürülebilir İnşaat Sektörüne Etkisi

Araştırma Makalesi / Research Article

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ÖZ

Mermer eski uygarlıklardan beri kullanılan bir inşaat malzemesidir. İnşaat sektörünün dünya genelinde ciddi çevre tahribatına neden olan atık malzemelerin etkin kullanımı üzerinde durması gerekmektedir. Çimentolu kompozitlerin yapıları mikro, mezo ve makro seviyede sınıflandırılmaktadır. Çimento matrisinin yüksek sıcaklarda sıcaklığın artmasıyla fiziksel ve mekanik özellikleri makro düzeyde azalma eğiliminde olmaktadır, kompozitlerin iç yapıları bozulmakta ve sonrasında mikro ve mezo düzeyde bozulmalar meydana gelmektedir. Yüksek sıcaklıkların çimentolu kompozitlerinin fiziksel ve mekanik yönden bozulma mekanizmalarını anlamamız ve çimento matrisinin fiziksel ve mekanik özelliklerindeki bu değişimleri iyi algılamamız açısından önemlidir. Mermer tozu 80 % olan sertleşmiş çimento pastasında yüksek sıcaklık altında dayanım kaybı 28-günlük kompozitlerde 81 %, mermer tozu 60 % olan sertleşmiş çimento pastasında ise bu kayıp artarak 84 %'e ulaşmıştır. Yapılan çalışma sonucunda 300 ^{0}C'nin mermer tozlu çimento pastası kompozitlerin için optimum sıcaklık olduğu düşünülmektedir. Çalışma, bu sıcaklık üzerine çıkıldığında fiziksel ve mekanik özelliklerin olumsuz etkilendiği görülmüştür.

Anahtar Kelimeler: Mermer, yüksek sıcaklık, dayanım, pasta, bozulma.

Effects of Elevated Temperature for the Marble Cement Paste Products for Better Sustainable Construction

ABSTRACT

Marble has been effectively used as a building material since the early civilization. The construction sector needs to effectively utilize wastes that cause serious environmental problems around the world. Structure of cementitious composites can be classified into micro, meso, and macro levels. For cementitious matrix subjected to high temperature, with the increase in temperature, physical and mechanical properties tend to decrease at macro-level, internal structures deteriorate, and micro-defects develop at micro and meso-levels. Studying the physical and mechanical properties of cementitious matrix at elevated temperature helps us understand the mechanisms of such deterioration or reduction in both physical and mechanical properties. At elevated temperature, the compressive strength loss of hardened cement paste composites comprising 80% of marble dust was 81% at the end of 28-day curing period, and the reduction increased to 84% for the hardened cement paste composites comprising 60% of marble dust. Its seems that 300 ^{0}C was optimum temperature for hardened marble cement paste composites in that physical and mechanical properties above this level were adversely affected.

Keywords: marble, high temperature, strength, paste, deterioration.

1. INTRODUCTION

Sustainability has been an important issue since ancient times. However, nowadays, the sustainability is considered much more in the manufacturing and use of natural resources, which are required for human beings. Strategic long-term plan on waste management needs to consider the ethical, environmental, and global issues in order to improve the quality of human life [1]. The introduction of the concept of "sustainability" in the building sector has gradually led to the production of insulation products made of natural or recycled material. Some of them are already present in the market while others are still at an early stage of production or study. These approaches could be particularly important and useful in developing countries, which do not have well-defined recycling policies, and they are affected by disposal issues due to large quantities of agricultural and industrial by-products [2].

The disposal problem of industrial wastes due to the growing construction sector has been pressuring the

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world leaders to consider the implementation of new sustainability strategies to reduce environmental effect of such wastes. The improvement in the recycling rate of industrial wastes, increased landfill taxes, and site waste utilization based on guidelines and code of practice are such examples. Additionally, the waste can be treated or managed on site to allow the concrete producers use those wastes efficiently to improve the green building technologies [3].

The positive implementation of new sustainability strategies, especially on site, can support the sustainable development of the construction sector, which uses 20-25% of annual world energy during the production of cement, plastic, and steel. During the production of concrete, approximately 1.5 billion tons of cement, 1 billion tons of water, and 10 billion of fine and coarse aggregates are being used annually around the world [5]. The concrete annual production has reached 25 billion tons. China and India are the top-ranking countries for such production, responsible for approximately 50% of the world production and thus for the waste production [5].

However, rapid urbanization and customers' expectations and desires have affected the construction sector. To successfully implement the sustainability strategies, concrete producers and institutions should work together. At this time, changing the current bad scenario (continuous CO_2 emission) in building construction to a sustainable solution does not seem to be a pessimistic approach. More research needs to be conducted to show that "concrete is an environmentally friendly material" that can be manufactured using large amount of industrial wastes, such as marble powder, fly ash, bottom ash, coconut husk ash, rice husk ash, and various fibers [6-9].

During the production of the marble cutting and shaping, a powder in slurry form of marble accumulates near the plant. Current studies have proven that if those marble powders are collected and utilized for concreting purposes, the physical and mechanical properties of the final products can be improved. The two different forms of wastes, i.e., fine materials of less than 2 mm and large marble particulates especially in granular forms, are produced during manufacturing process. During cutting operation of one cubic meter of marble block, roughly 25% of fine particles are produced as wastes. This is the main reason for trying to find a sustainable solution to this problem (i.e. waste utilization rate) [15].

Most laboratory studies evaluated the marble dust in mortars and concrete. The effects of marble dust on workability and strength have been compared with those of the control samples [10-21]. Valeria and Moriconi [22] evaluated the marble powder with very high Blaine fineness and observed that the marble powder had positive effect on mortar and concrete strength, especially in self-concreting applications. Binici et al. [11] found that the concrete composed of marble powder has higher compressive strength compared to concrete produced with limestone dust.

The marble powder is used in precast concrete industry at elevated temperature and self-concrete applications. Large numbers of precast units are produced this way. The researches noticed that adequate curing is necessary to prevent the secondary ettringite formation. The scanning electron microscopy investigation showed that pastes temperature below 105 ^{0}C form coarser calcium silicate hydrate gel in early age compared with the same pastes cured in water. The thickness of the calcium silicate hydrate near the cement grains tends to increase with increasing elevated temperature. However, the thickness of the inner calcium silicate hydrate was denser than its outer hydrate products for paste prepared at 80 ^{0}C [23]. At elevated temperatures, a greater proportion of Portlandite was found to form dense clusters, as opposed to the more usual lamellar type morphology observed in ambient conditions [23, 24].

The loss of water due to elevated temperature can cause microstructural changes in concrete, such as increase in porosity, and weaken the calcium silicate hydrate gels. The previous findings showed that the loss of bound water occurs around 100-300 ^{0}C, causing the development of micro-cracks in mortar and concretes. The strain differences in composites due to temperature rise cause expansion, shrinking upon cooling. The few data are available for cement pastes at elevated temperatures [25].

The performance of the composites is said to be durable when exposed to chemical attacks, such as sulfates, chlorides, and acidic environment, if the porosity is lower. However, the behavior under elevated temperatures needs more attention to qualities like durability. The spalling is the form of deterioration in structures, especially the concrete, at high temperatures. The density of concrete, moisture content, mineral admixtures, and the rate of temperature affect this behavior under elevated temperatures. Thermal stress, water vaporization, and high pore pressure are the consequences of the elevated temperature [26].

After long-term exposure, cement paste prepared at elevated temperature undergoes microstructural changes leading to cracking, as the expansion causes failure of the composites. Physico-chemical transformation and thermal strains are the two main phenomena that have to be considered. It was reported that the mechanisms involved in alkali aggregate reactions are a widespread problem in nuclear plants and other concrete structure [27-32]. The elevated temperature adversely affects the compressive strength, modulus of elasticity, resistance to abrasion, and resistance to sulfate attack, among others.

The elevated temperature affects the hardened cement paste the consistency of which depends mostly on the degree of hydration and available moisture. Beyond the 300 ^{0}C, the interlayer calcium silicate hydrate water and some of the bound water from the hardened gel might be lost. After this formation, decomposition of the $Ca(OH)_2$ begins around 500 ^{0}C and the final stage is the result of the complete decomposition of the calcium silicate hydrate at 900 ^{0}C [24, 29]. As temperature increases, water to cement ratio tends to decrease while the porosity increases [33]. Further, the pore system in hardened cement paste also changes with degree of hydration and chemical changes.

Pores are created and become larger by thermal micro-cracking as the elevated temperature increases. At elevated temperature, porosity of cement paste increases due to non-uniformly distributed hydration products. The hydration products at elevated temperatures are coarser and porous compared to those at normal temperature [24, 30]. Lower bound water content and high rate of dissipation of water at elevated temperature cause the formation of a coarser and more uneven hardened cement paste (HCP) structure. Additionally, capillary suction of water especially into the microcracks results in the formation of a less dense matrix [23]. The hydrates are stable at low temperatures while at higher temperatures, they consist of destabilized water molecules. Upon self-desiccation, the exerted force created by the chemically bound water to the adjacent sides causes crystallization. At high temperature, the hydrates are more crystalline compared to those formed at lower temperatures (i.e., denser with low surface area). The decrease in surface area causes more hydration with the help of physically bound water. This can be used for better understanding of the low and normal water-cement ratio systems. At low water to cement ratio, the available water is inadequate for hydration (i.e., in the case of self-desiccation). The reduction in absorption increases the available water for hydration [24, 33, 34].

The reduction in compressive strength at elevated temperatures due to the quick arrangement of denser inner hydrate products on the surface of the cement grain resulted in a decreased hydration rate and increased porosity. Pozzolanic materials reactions caused no remarkable changes in the water phase distribution, but they did bind a large portion of the accessible water originally in the mixture through surface absorption. Thus, the effects of pozzolans on the water phase distribution include reducing the existing w/c ratio. Therefore, the presence of a filler in the system initially increased the w/c ratio, and the critical effect reduced the amount of water available for cement hydration, thereby causing a large reduction in strength [19, 23-25].

The aim of this study was to determine the physical and mechanical properties of pure marble cement paste at elevated temperatures, as construction materials, to determine the effects of marble dust in both fresh and hardened states and minimize the environmental pollutions for better sustainability. For this purpose, various amounts of marble dust were used to investigate the physical and mechanical properties of cement paste composites at elevated temperatures. Most published literature has dealt with mortar and concrete whereas only limited research on marble powder in cement paste has considered the increasing trend in sustainability.

2. MATERIALS AND METHODS

2.1. Materials

The chemical compositions and selected physical properties of the components employed are presented in Table 1. Ordinary Portland cement of grade 42.5 that conforms to ASTM C150M-15 [35] was used in this research. The Blaine fineness of the cement was 305 m^2/kg, and its specific gravity was 3.15.

The marble slurry was collected from a dumpsite near a marble processing plant. The marble slurry consisted of powder and lumps. Before its use, the slurry was dried at room temperature for 72 h, and the dried lumps were then completely reduced to powder (i.e., most particles having a diameter of less than 50 μm). The specific gravity was 2.49, and the fineness of the powder was 335 m^2/kg. Its chemical composition is presented in Table 1.

Table 1. Chemical compositions of marble dust and cement

Oxide	Marble dust (%)	Cement (%)
SiO_2	5.1	21.2
Al_2O_3	0.5	5.1
Fe_2O_3	0.7	2.5
CaO	43.5	64.7
MgO	14.6	0.9
K_2O	0.03	0.2
SO_3	0.04	1.5
Loss on ignition	33.5	2.5

Tap water was used as the mixing and curing liquid in all the mixtures. The water was free from deleterious materials.

2.2. Preparation, Casting of Test Specimens and Mixture Proportioning

Cement paste composites were mixed in a Hobart mixer (planetary laboratory mixer MA-52X mixer type, Gilson Company, USA) with 4.7-liter capacity. Marble dust and cement were mixed together in dry form for 30s, and tap water was then added to the mix. The mixtures were then cast and consolidated by vibration for 1 min.

Table 2. Marble-cement paste composites

Group	Marble dust (%)	Cement (%)	Water/binder (w/b)	Temperature(C°)
G1	80	20	0.43	0
G1.1	80	20	0.43	300
G1.2	80	20	0.43	600
G1.3	80	20	0.43	900
G1.4	80	20	0.43	1050
G2	60	40	0.43	0
G2.1	60	40	0.43	300
G2.2	60	40	0.43	600
G2.3	60	40	0.43	900
G2.4	60	40	0.43	1050

Figure 1. (a) Flow Table Test **(b)** Mini slump test for fresh composites

Specimens were extracted from the molds after 1 to 2 days and kept in a curing room at 20 ± 1°C and 70% relative humidity for the entire curing period until testing (at 28 days). Two different mix groups were prepared, first group (G1) comprised marble dust (80%) and cement (20%), and the second group was prepared by mixing 60% of marble dust and 40% Portland cement. The water/binder (w/b) was fixed at 0.43 to achieve the required slump for both groups.

Each group was tested at different temperatures (Control (0 C°, room temperature), 300 C°, 600 C°, 900 C°, and 1050 C°) using high temperature oven and tested for water absorption (WA), density, and compressive strength.

Workabilities of specimens were determined using a flow table and mini slump cone tests according to ASTM C230M-14 [36] and WK27311-10 [37], respectively. Dry bulk density and WA experiments were performed according to ASTM C127-15 [38]. A fresh sample was placed in the conical shape mold in three equal layers, and each layer was tamped 25 times. The mold was removed, and then the table was lifted and dropped 15 times, each cycle taking approximately 4 sec. As a result, the fresh paste spread, and the maximum spread parallel to the two edges of the table was measured as the flow table. For the mini slump test, the same procedure from the slump test was applied to a fresh sample. The drop in height was reported as the mini slump value.

Cubic 50-mm molds were used for unconfined compressive strength (UCS) tests and 40-mm × 40-mm × 160-mm prismatic molds for flexural strength (FS). UCS and FS tests conforming to ASTM C109M-13e1 [39] and ASTM C348-14 [40], respectively, were conducted. A third point loading test was carried out for flexural strength test. The mixture proportioning and elevated temperature regime of the mixture groups are presented in Table 2. Six samples were used for each test and average used in Tables and Figures.

The flow table test, mini slump test and preparation of fresh marble-cement paste mixture composites are shown in Fig. 1a, Fig. 1b and Fig. 2, respectively

Figure 2. Preparation of fresh marble-cement paste mixture composites

3. RESULTS AND DISCUSSION

The fresh unit weight, flow table and inverted slump test results for cement paste composites are presented in Table 3.

Table 3. Fresh unit weight, flow table and inverted slump for marble cement paste composites

Group. No	Fresh Unit eight (kg/m^3)	Flow Table (cm)	Inverted
G1	1745	13.00	
G1.1	1745	14.00	
G1.2	1745	13.00	
G1.3	1745	13.00	
G1.4	1745	14.00	
G2	1723	16.00	
G2.1	1723	16.00	
G2.2	1723	15.50	
G2.3	1723	15.00	
G2.4	1723	16.00	

Water content is a key factor affecting the fresh properties. It should be noted that the relationship between slump and water content for a given set of materials is nonlinearly proportional [33, 41]. Since the slump affects the ease with which the mixture will flow during placement, most mix design procedures rely on slump as a crude index of workability [41]. The hardened marble-cement paste composites after elevated temperature are shown in Figure 3. The dry unit mass (DUM) before and after elevated temperature for marble cement paste composites are presented in Table 4.

Figure 3. Hardened marble cement composites after elevated temperature

Table 4. Dry Unit mass for marble cement paste composites for before and after elevated temperature

Group Name	Dry Unit Mass (kg/m^3) before elevated temperature	Dry Unit Mass (kg/m^3) after elevated temperature	Elevated temperature(C°)
	1350	1350	0
G1.1	1332	1304	300
G1.2	1260	1116	600
G1.3	1376	1145	900
G1.4	1292	844	1050
G2	1316	1316	0
G2.1	1394	1206	300
G2.2	1270	1190	600
G2.3	1476	1170	900
G2.4	1313	861	1050

The reductions in DUM values were calculated as 2.1%, 11.4%, 16.8%, and 34.7% for G1 and 8.4%, 9.6%, 11.1%, and 34.6% for G2 at 300°C, 600°C, 900°C, and 1050°C, respectively, when comparing the initial and elevated temperatures.

The DUM of G1 was 1350 kg/m^3 at 0 C° but decreased to 844 kg/m^3 at 1050C°. The mass loss by the elevated temperature was non-linear. The cement paste composites comprised various sizes of connected and disconnected pores. The mixture proportions affected the pore size distribution, and the use of marble dust or other supplementary cementious materials led to a formation of the densified matrix and pore size refinement. The highest mass loss reported in mixture groups at 1050 C°. This is due to the loss of free combined water which was removed around 1000 C°. Water that remains in small pores is difficult to remove. When temperature increases, the mass loss occurs in three stages, drying, evaporation, and decompostion. The increase in dry unit mass in G1.3 is due to water absoprtion value. The increase in porosity of paste, which absorbs readily available water, leads to the formation of more hydration products. The rate of water loss from hardened cement paste due to the increasing elevated temperature affects the surface/volume ratio of the structure. Higher loss of water from the final composite can cause a reduction in its dry unit mass. Increasing elevated temperature reduces the particle surface area of the cement-marble composites, which can cause weakening of the interface bond at high temperatures. This can cause a reduction in the DUM values at elevated temperature [23, 30]. A DUM value of the final composites indicates that the final composites are in the range of lightweight concrete. This lightweight composite with dry unit mass ranging between 1210 – 1670 kg/m^3 is quite lower compared to those of conventional construction materials, promising beneficial outcomes in terms of construction costs and earthquake safety. The final product can be used satisfactorily in the manufacturing of lightweight aggregates and semi-isolating materials. Based on the DUM values of mix groups, the final composites can be used satisfactorily in manufacturing of aerated composites. Density of aerated composites varies from 300 to 2100 kg/m^3. They are widely used in the manufacture of lightweight concrete wall panels, the manufacture of light commercial structures and residential houses [41, 42]. The air-void system of the HCP was found perform better. The water absorption test results for marble cement paste composites is presented in Fig. 4.

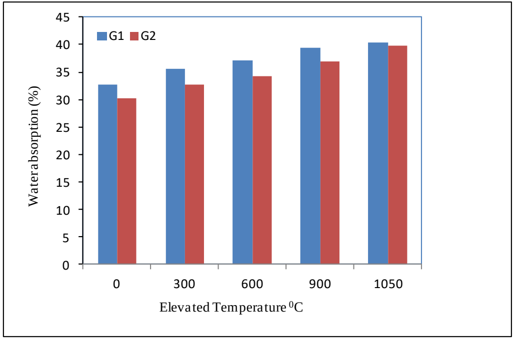

Figure 4. Water Absorption values of marble cement paste composites

The increases in WA values were calculated as 8.7%, 13.3%, 19.5%, and 23.1% for G1 and 8.2%, 13.3%, 22.3%, and 32.2% for G2 at 300°C, 600°C, 900°C, and 1050°C, respectively, when comparing with initial and elevated temperatures.

Reduction of marble dust decreases water absorption due to amount of cement particles, which helps increase the degree of hydration and thus the rate of calcium silicate gel that fills the voids and prevents or reduces water absorption. From the result of experiment for mixture proportion 2, which are shown in Fig.4, it can be clearly observed by increasing elevated temperature the water absorption rate dramatically reduced.

For G1, the water absorption increased from 32.77% to 40.34% by increasing room temperature (21 C° -23 C°) to 1050 C°. For the same temperature, water absorption rate increased from 30.17% to 39.87% for G2. WA values of HCP composites increased with elevated temperature for all slump classes. This could be due to the increased porosity of hardened cement paste and microstructural changes of the hydrated paste upon heating [23]. A water absorption property is also related to the bonding capability of the matrix, which diminished over time when in contact with elevated temperature. Evaporation of water causes the emptying of pores of the matrix and shrinkage due to the elevated temperature. Additionally, loss of water molecules in hardened cement paste, which adheres to the angular cement grains before elevated temperature, increases the WA values. Increasing temperature weakens the matrix bond. The distance between the atomic molecules of cement grains and mineral admixtures in the matrix increases, and many capillary channels develop throughout the surrounding structure, and as a result of this phenomenon, WA values increases.

The various types of water are readily lost due to increasing temperature of cement paste composites. The breakage of the bond between the matrixes can increase WA. The compressive strength test results at 28-days for various elevated temperatures are shown in Fig.5. The highest compressive strength value in Group 1 (G1) was 5.2 MPa, which contained 80% of marble dust, while the highest value in group 2 (G2) was 7.4 MPa, which contained 60% of marble dust. This means that by reducing marble dust for the same paste volume, compressive strength is reduced. The compressive strength for group (G1.2) at 300 C° was 3.7 Mpa, which decreased to 1 MPa at 1050 C°. The results indicate that by increasing the elevated temperature, the compressive strength decreased.

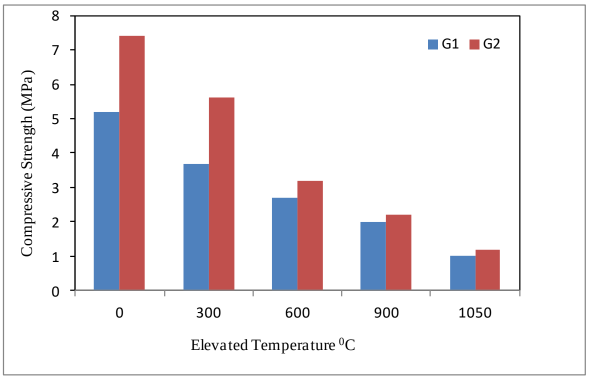

Figure 5. Compressive strength of marble cement paste composites

The reductions in compressive strength values were calculated as 28.8%, 48.1%, 61.5%, and 80.8% for G1 and 24.3%, 56.8%, 70.3%, and 83.8% for G2 at 300°C, 600°C, 900°C, and 1050°C, respectively, when comparing the initial and elevated temperatures.

The increase in temperature is associated with strength loss, which can be minimized by using finer grain size distribution. The coarser grain size can cause particle damage at high temperatures, especially above 600 C°. The weakening of the cement paste bond due to increased porosity, breakdown of the calcium silicate hydrate gels, and microstructural modification are the main reasons for such a decrease at elevated temperature. Generally, the marble cement paste composites seem to be more stable at around 300 C° and above this temperature, the weakening starts by collapsing of the interparticular bonds, thus decreasing the strength. Comparable results have been reported in literature [24-28, 41]. Water to cement ratio does not seem to affect the decrease in strength. Some research has shown that water to cement ratio has little effect up to 600 C°. Compressive strength tests results showed that marble cement paste composites have adequate strength for the use in low to medium technology applications, such as in manufacturing of bricks, tiles, road bases, and structural fill applications. For structural fill applications, the required minimum compressive strength may vary from 0.7 MPa to 8.3 MPa [43]. The flexural strength test results at 28-days for various elevated temperatures are shown in Fig.6.

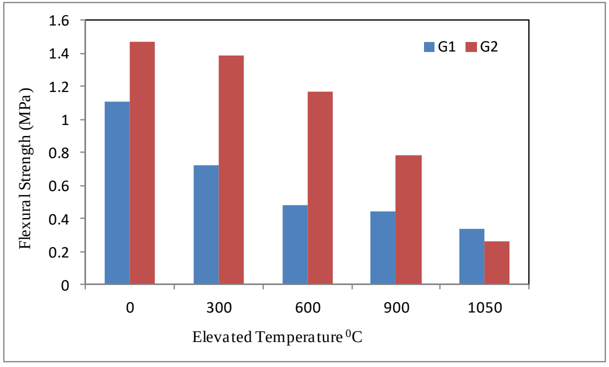

Figure 6. Flexural strength of marble cement paste composites

The reductions in flexural strength values were calculated as 35.1%, 56.8%, 60.4%, and 69.4% for G1 and 5.4% 20.4%, 46.9%, and 82.3% for G2 at 300°C, 600°C, 900°C, and 1050°C, respectively, when comparing the initial and elevated temperatures.

Based on the flexural strength (FS) test results, behavior similar to that in UCS was observed. FS values increased with temperature increasing up to 300 ^{0}C and then decreased upon elevated temperature. The porosity is higher at higher temperatures, which reduces the FS of the cement paste. The marble dust influenced the degree of strength loss [24, 44].

Final composites meet the requirements for performance, cost, and practicability, and they can satisfactorily be used for different civil engineering purposes [45-51]. Extra calcium hydrate is formed due to the addition of marble powder. Higher marble dust replacement percentage is associated with decreased reduction of calcium hydrate content. At elevated curing temperatures, the calcium hydrate reduction reaches a very high level in a short time. From the strength point of view, the binder ratio (i.e., cementitious material amount in paste) porosity relation is undoubtedly the most important factor. The strength of the matrix improves significantly at very low water/cement ratios, and the size of $Ca(OH)_2$ crystals becomes smaller with decreasing water/cement ratios [24, 41].

4. CONCLUSIONS AND RECOMMENDATIONS

The compressive strength of marble-cement paste composites used in this study is very low. The marble wastes obtained from the factory was directly used without any treatment. The study considered the use of marble waste as controlled-low strength applications. The growing attractiveness of using environmentally friendly, low-cost, lightweight construction materials conveys the need to examine how this can be attained by promoting environmental issues, while still meeting the requirements affirmed in the relevant standards. In order to promote those novel based composites in construction industry either testing methodology or level of replacements mentioned in these standards need to be re-evaluated.

1. By increasing elevated temperature, the compressive strength of cement paste declined dramatically. This might be due to burning calcium silicate hydrate gel, which is responsible for bond characteristic of cement paste.
2. DUM varies from 1260 kg/m^3 to 1395kg/m^3. Water absorption varies from 30.2% to 40.3%, which is advantageous for insulation purposes.
3. Increasing elevated temperature reduced hardened density of cement paste. Water absorption increased from 30.17% to 39.87% due to increase in temperature from room temperature (23±1) C° to 1050 C°.
4. The compressive strength of cement paste was reduced when using marble dust as a partial replacement of cement (more than 15%). The compressive strength increased when using marble dust in cement paste as a partial replacement of coarse particles. The compressive strength was reduced by increasing elevated temperature of cement paste; the compressive strength was 7.4 MPa in ambient temperature (23±1) C° but decreased to 1.2 MPa in 1050 C°. This might be due to burning calcium silicate hydrate gel, which is responsible for bond characteristic of cement paste.
5. Lowest compressive strength value was 1 Mpa and the highest value was 7.4 Mpa. By increasing marble dust, it is believed that the rate of (C-S-H) gel responsible for bonding property of cement increased. Adding fiber slightly increased compressive strength of cement paste.
6. For structural fill application; required minimum compressive strength value varies from 1.16 Mpa to 3.56 Mpa. The 28-day compressive strength values for the final products are also adequate for those applications. Based on the compressive strength requirements, final products can be used for foundation support. Additionally, final products are adequate for low to medium technology applications, such as road bases, manufacturing of bricks, tiles, and ceramic applications.
7. Flexural strength varies from 0.26 Mpa to 1.47 Mpa. By increasing marble dust and cement, the hydration reaction processes become faster. Adding fiber to the mixture slightly increases flexural strength.
8. Since the environmental pollution is a big problem in the world, and one of the major sources of environmental pollution is solid waste, to reduce this problem as well as to improve cement paste properties, further studies are needed to find best optimization for durability of the marble cement paste composites. Additionally, to better understand fresh properties of such composites, the rheology of the marble cement paste composites should also be investigated.

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