Elevated Temperature Performance of a Novel Eco-Friendly Cementitious Material

Luma A. G. Zghair
Civil Engineering Department, Engineering College, Mustansiriyah University, Baghdad, Iraq
drlumacivileng@uomustansiriyah.edu.iq

Mohammad Z. Yousif
Civil Engineering Department, Engineering College, Mustansiriyah University, Baghdad, Iraq
dr.mohammadalrawas@uomustansiriyah.edu.iq

Rwayda Kh. S. Al-Hamd
School of Applied Sciences, Abertay University, Dundee DD1 1HG, United Kingdom
r.al-hamd@abertay.ac.uk (corresponding author)

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ABSTRACT

This study presents the development of a novel environmentally friendly cementitious material and examines its behavior at elevated temperatures. Ceramic Waste Powder (CWP) and Fly Ash (FA) were utilized as substitutes for cement at a concentration of 10%. Four distinct mix designs were formulated and evaluated. The flow table test was implemented to study the workability of the mortar, while 120 cubes and 39 specimens were shaped into briquettes. The specimens' compressive strength, mass loss, and tensile strength were analyzed after exposure to temperatures ranging from 150 °C to 700 °C, deploying Field Emission Scanning Electron Microscopy (FESEM) testing. The research findings indicate that CWP can function as a sustainable material in construction, diminishing the carbon footprint of construction materials and alleviating the environmental damage resulting from CWP disposal in landfills. Furthermore, it was found that FA can be combined with pulverized ceramic to substitute cement, resulting in a sustainable cement mortar. It was concluded that sustainable mortar production was attained while substituting 20% of cement with alternative materials.

Keywords-elevated temperatures; cement mortar; ceramic powder; fly ash; FESEM

I. INTRODUCTION

The construction industry is a principal contributor (approximately 19%) to the global Greenhouse Gas (GHG) emissions [1], substantially influencing climate change, and hence generating the necessity for urgent mitigation measures [2]. Significant efforts have been made to reduce cement usage in concrete manufacturing, and decrease energy consumption and GHG emissions. One of the most promising strategies is partially substituting cement with Supplementary Cementitious Materials (SCM) [3, 4]. The latter have been extensively studied as alternatives to traditional cement due to the elevated carbon emissions associated with cement production. Using SCM is crucial in tackling the carbon emission challenges and their effects on carbon reduction [5, 6], facilitating a decrease in cement consumption while improving concrete's mechanical properties and durability [7]. Pozzolanic properties lead to the formation of supplementary secondary Calcium Silicate Hydrate (C–S–H). Additionally, one of the most well-known supplementary materials is FA, which has attracted a lot of attention from researchers [8-13]. The properties of blended FA cement fluctuate based on its chemical composition and the extent of FA replacement [14-16]. The effects of exposing concrete and mortar, including FA, to elevated temperatures have been thoroughly examined. Authors in [17] investigated the impact of the extent of degradation on the compressive strength and adhesion of cement mortar with the incorporation of FA. The test findings demonstrated that cement mortar's compressive strength and bonding strength diminished as the temperature rose, with the bonding strength having entirely vanished at 600°C. Authors in [18] incorporated FA alongside silica fume and pumice. The samples were treated at elevated temperatures, and their compressive strengths were subsequently assessed. It was found that elevated temperatures had less influence on the compressive strengths of the mortar using pozzolans than the control mortar. Recent studies have investigated various waste materials, including waste ceramics, to assess their viability as partial substitutes for cement [19-21]. A feasible approach to advancing sustainable development and enhancing environmental quality is repurposing ceramic waste from demolition and byproducts from ceramic manufacturing in concrete production [22]. Utilizing CWP in concrete as a partial substitute for cement presents numerous benefits, including alleviating landfill pressure, decreasing building expenses by substituting expensive cement, and enhancing concrete performance [23]. CWP employment in the production of a sustainable, eco-friendly construction material is attractive, as it offers an alternate method for waste re-utilization while also delivering enhanced performance [24]. Ceramic tiles possess many qualities, each specifically tailored for distinct applications. A thorough comprehension and distinction of these tiles are essential for improving recycling system efficacy [25]. Evaluating the utilization of recovered CWP in construction necessitates examining the performance of cementitious materials incorporating waste ceramic at elevated temperatures.

High temperatures affect concrete structural elements' physical, mechanical, and thermal properties. The nanoscale breakdown of the cement gel structure results in substantial degradation when exposed to elevated temperatures [26]. Moreover, hydrated C-S-H and calcium hydroxide disintegrate at 300°C and 500°C, respectively, influencing cement-based products' overall performance. Authors in [27] found that over 450°C, the amount of Portlandite decreases significantly, and C-S-H breaks down into C2S and C3S over time until all the calcium hydrate content is gone at 750°C. This increases overall porosity, causing a significant loss of mechanical strength and the propagation of detrimental fissures. The C-S-H structure is dissolved at 600°C and deteriorated at 800°C, according to [28], while it is liquefied at temperatures exceeding 1150°C. When exposed to such temperatures, additional minerals in the cement are also crystallized, leading to drastic microstructural changes that diminish concrete strength and durability. Authors in [28], discovered that cement mortars deteriorate in bonding characteristics due to water evaporation from the C-S-H nanostructure. Authors in [29] examined the potential for repurposing Ceramic Stoneware (CS) waste, a specific category of Tile Ceramic Waste (TCW), as recycled aggregate in structural concrete and its effect on concrete performance when subjected to high temperatures (200°C, 400°C, 600°C, and 800°C). Compressive strength was assessed in hot conditions and after air and water cooling. All samples showed comparable strength levels at ambient temperature, but their thermal conductivity decreased as the CS content increased. Authors in [30] investigated concrete, utilizing crushed ceramics as coarse and fine aggregates. Canbaz specimens were subjected to 20°C, 100°C, 400°C, 700°C, and 900°C for 3 hours to examine the impact of elevated temperatures on concrete's physical and mechanical properties. It was demonstrated that including 50% crushed ceramics as fine and coarse aggregates is viable for concrete production subjected to elevated temperatures. Similarly, authors in [31] examined the impact of partially substituting cement with CWP at varying weight percentages (0%, 20%, 40%, and 60%) on concrete's workability, dry density, and compressive strength. The influence of increased temperatures (200°C–800°C) for over 2 hours on concrete residual compressive strength was also explored. It was shown that CWP may be utilized in manufacturing environmentally sustainable concrete with enhanced mechanical qualities.

The present study aims to explore the practical application of recovered TCW and FA as substitutes for cementitious materials and how high temperatures affect the properties of the novel cement mortar produced. The literature analysis indicates that most reviews on concrete and mortar-containing pozzolans have mostly concentrated on their mechanical characteristics and only a few studies have examined these materials' resilience when subjected to extreme temperatures. This work aims to fill the existing knowledge gap by investigating the physical and mechanical properties of cementitious mortars that incorporate FA and waste ceramic as partial substitutes for cement. This investigation will be conducted both before and after high-temperature exposure. The well-being of people inside a building structure during an unforeseen fire is of the utmost significance, and a comprehensive knowledge of the fire response of cementitious mortar composed of pozzolans is crucial to guarantee the structural components' stability and fire resistance integrity. Thus, the current work examines the rising temperature impact on sustainable mortar production utilizing ceramic waste and FA.

II. CHARACTERISTICS OF MATERIALS

This work formulates cement-based composite materials, utilizing Ordinary Portland Cement (OPC) as the principal binder. The primary aggregate is sand, while SCM, such as locally sourced recycled ceramic powder and FA, are added. For this investigation, TCW were ground into particles of about 19 mm in size. The ceramic granules were then ground into a powder, as illustrated in Figure 1.

Fig. 1. Recycling TCW.

Pre-packaged FA material, which was nearing its expiration date, was utilized to save waste and promote sustainability. It was incorporated as a filler in a mixture of ceramics and cement to create an eco-friendly mortar. Table I presents a detailed overview of the chemical and physical properties of cement, recycled ceramic powder, FA, and cement powders. The used sand complies with ISO 9001, ISO 14001, and OHSAS 18001 standards for quality, environmental management, and occupational health and safety, with a grading of 0.08–0.02 and a bulk density of 1.5 kg/Lt. Superplasticizers (SP) are incorporated to improve cement hydration and elevate the overall performance of the mixtures. This study employed BETONAC®1030 (Polycarboxylate Ether), [32], Type F. Table II lists the characteristics of the utilized SP.

TABLE I. CHEMICAL AND PHYSICAL PROPERTIES OF THE BINDER CONTENT

Parameters	Type of product		
	Cement	FA	Ceramic powder
SiO_2	14.53	47.69	65.18
Al_2O_3	3.154	27.86	24.09
Fe_2O_3	3.05	3.919	2.94
SO_3	3.418	1.488	1.46
CaO	65.58	10.85	2.35
MgO	1.099	1.212	1.71
Specific Surface area (c^2mlgm)	3819	3220	4614

TABLE II. CHARACTERISTICS OF THE UTILIZED SUPERPLASTICISER CHARACTERISTICS

Appearance	Light brown liquid or transparent
$CaCl_2$	Nil
Density	1.1±0.02 gm/ml
Viscosity	450 cPs at 20 °C

III. MORTAR MIX DESIGN

Mix design is the process of calculating the quantities of the components in a mixture to achieve the desired characteristics in the final product. The mix design guarantees that the cement mortar satisfies the performance criteria for strength, workability, durability, and other pertinent features. The formulated cement mortar consists of four compositions: one control mixture (reference mix) and three distinct combinations. The control mixture (M-R) lacks ceramic powder and FA; however, the second combination (M-F) comprises FA, substituting 10% of the cement powder. The third mixture (M-CP-F) comprises ceramic powder and FA, substituting 10% of the cement powder for each one. The fourth mixture (M-CP) comprises ceramic powder, substituting 10% of the cement powder. All other variables were kept constant across all combinations to accurately evaluate the impact of the substituted ingredient on the results. The factors encompass water quantity, SP percentage, and water/binder (w/b) ratio. Table III enumerates the utilized cement mortar mix designs.

TABLE III. CEMENT MORTAR MIX DESIGN

Mix no.	Mix design	Cement kg/m^3	FA kg/m^3	Ceramic kg/m^3
M1 (reference mix)	M-R	500		
M2	M-F	450	50	
M3	M-CP-F	400	50	50
M4	M-CP	450		50

a. water (L/M^3) =342, SP% = 8 and w/b = 0.684

IV. SPECIMEN CASTING AND TESTING

This study involved the casting and testing of 159 specimens, as depicted in Figure 2, with 120 specimens having being fabricated into cubes measuring 50 mm × 50 mm × 50 mm. The model dimensions were selected based on [33]. According to [34], 39 specimens were selected and shaped in briquettes. The briquet specimen outlined in this study possesses a "dogbone" configuration, measuring around three inches in length, with a constricted section of roughly one inch in width (0.8) and one inch in thickness.

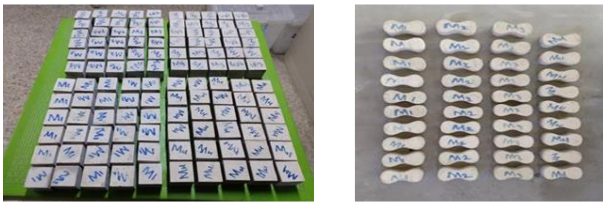

Fig. 2. The cast specimens.

The investigations were carried out in three phases: fresh tests, hardening assessments, and microstructural evaluations before and after exposure to elevated temperatures. Mortar workability was evaluated through a flow table test, a method for measuring the flow characteristics of fresh mortars. The test was performed on the basis of [35]. Figure 3 portrays the flow table test conducted in this study.

Fig. 3. Flow table test.

The hardening tests evaluated the specimens' compressive and tensile properties and mass loss. The mean value of three samples was calculated to evaluate compressive strength, whereas the mean value of two samples was determined to assess tensile strength. Figure 4 depicts the configuration for the compressive and tensile tests.

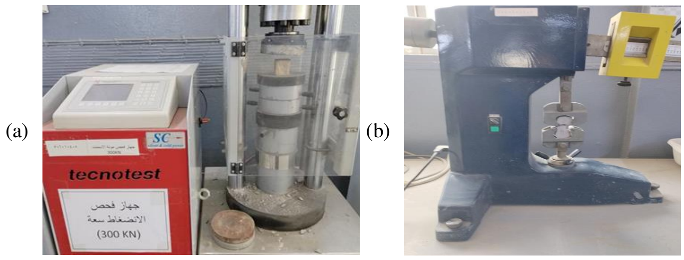

Fig. 4. The setup for: (a) the compressive and (b) tensile tests.

FESEM was deployed for microscopic analysis. It constitutes a high-resolution scanning electron microscope that captures images of sample surfaces by scanning them with a high-energy electron beam in a raster pattern. This allows for the examination of conductive, non-conductive, and vacuum-sensitive materials [36].

V. SUBJECTING SAMPLES TO ELEVATED TEMPERATURES

Following a 28-day curing period, all samples were maintained at ambient temperature and weighed before their exposure to elevated temperatures. The prepared samples were subjected to varying temperatures in an electric oven. Six samples from each mixture were subjected to temperatures of 150°C, 350°C, 550°C, and 700°C ±3°C for the compressive strength test, while two samples from each mixture were subjected to 350°C, 550°C, and 700°C ±3°C for the tensile test. The samples were removed from the oven after approximately 24 hours, they were allowed to cool gradually within the oven, and their weight was recorded post-heating. Figure 5 depicts the sample arrangement within the employed furnace.

Fig. 5. Samples tested in the used furnace.

VI. RESULT AND DISCUSSION

A. Mortar Workability

The workability of the mortar mixtures was evaluated using the slump test, performed in [35]. Figure 6 displays the flow table values for numerous mortar mixes, each corresponding to a distinct design. The aforementioned values ranged from 175 mm to 163.75 mm. The slump measurements for M-R, M-F, M-CP-F, and M-CP were 175 mm, 165 mm, 167.5 mm, and 163.75 mm, respectively. When the ceramic powder replaced 10% of the cement, the slump value dropped by approximately 6.4% compared to that of the control mixture. This result emerged from the high water absorption of ceramic waste, which reduced the available water and decreased mixture workability [37]. In [37], CWP was used as a substitute for fine aggregate. Also, the mixtures containing FA reduced workability by about 5.7%. Authors in [38] examined FA as a substitute for mortar workability and used a flow table for the latter's assessment. They quantified the Flow Table Spread (FTS) values and developed correlations between FA replacement percentages, water volumes, and granulometric distributions of FA. It was reported that the increase in water volume correlated with elevated FTS levels. The original FA was divided into four portions, each exhibiting distinct granulometric patterns. An increase in FTS values was documented as do specific surface, along with a decrease in the FTS values with an increase in FA's mean diameter. In the present study, the cement surface area exceeded that of FA, as illustrated in Table I. The substitution of 10% FA with cement may explain the reduction in workability. When cement was substituted with ceramic powder, FA, or both, the material retained its consistency, with a stiff consistency having been exhibited in all mixtures.

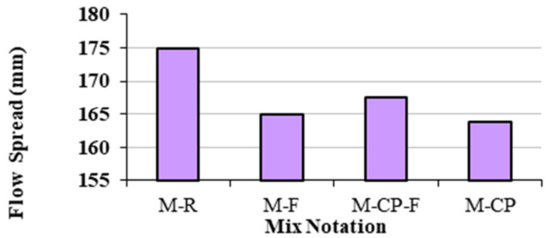

Fig. 6. Flow spread (mm) of the tested mortar mixtures.

B. Mass Loss after Exposure to Elevated Temperatures

The mass loss test is a key measure for evaluating the performance of concrete materials at high temperatures. Upon exposure to elevated temperatures, the examination of the mass changes in mortar mixtures may offer valuable insights into the physical and chemical transformations that occur within the mortar mixture [39]. Figure 7 depicts the mass weight of a mortar mixture incorporating FA and ceramic powder as a partial cement substitute, both before and during exposure to increased temperatures (150°C, 350°C, 550°C, and 700°C). At ambient temperature, the mortar's weight diminished by incorporating CP. Compared to the control mix, mortar weight decreased by about 7%. Authors in [40] stated that the inclusion of ceramic powder resulted in a reduction in the samples' bulk density compared to the mortar devoid of ceramic powder. This pertained to the density of CWP particles, which was lower than that of cement particles. This may explain the decreased weight of mixtures containing CP compared to the reference mixture. In [41], a mixture incorporating FA was explored. It was found that the bulk density of unclassified FA from various sources varied significantly, with a predominant range of 1.9 g/cm^2 to 2.9 g/cm^2. This elucidates the rationale for the reduction in the mass of mixtures with FA, which is relative to that of the reference mixture. That is, the mortar weight diminished by 4.3% for the M-F, while for the M-CP-F combination, the reduction rate was 7.9%.

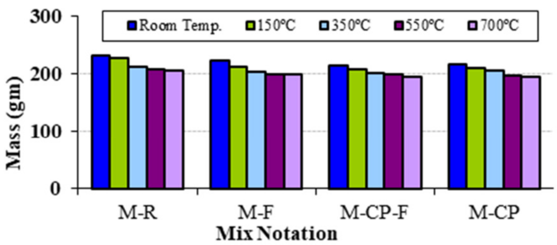

Fig. 7. The mass weight of the evaluated mortar mixtures.

At 150°C, the observed mass loss demonstrated a consistent pattern across each combination, varying between 2.7% and 4.5%. Moisture loss was the primary factor contributing to the mass reduction in mortar specimens. Additionally, the release of unbound water from capillary pores and chemically bonded water from the cementitious paste caused a mass decrease during heating, which resulted from the evaporation of gel water and the release of chemically bonded water from cement hydrates. At temperatures of 350°C, the mass loss varied between 5.2% and 8.6%, as illustrated in Figure 7. The results indicated that mass loss increased consistently up to a 350°C exposure above which the loss rate began to rise at a slightly reduced pace. The mass loss varied between 6.8% and 10.9% at 550°C, increasing to a maximum of 9.5% to 12.1% at 700°C. It was concluded that the evaporation of capillary water caused the initial mass loss, followed by the release of adsorbed and interlayer water. Authors in [42] reported that adsorbed and interlayer water began to escape at temperatures exceeding 65°C–80°C. The mass loss continued to increase from 600 °C to 800 °C, albeit at a marginally reduced rate. Moisture loss occurred because of the chemically combined water release, which is integral to cement hydrate products and is notably challenging to evaporate. Consequently, a reduction in the mass loss rate is anticipated when the hydrates decompose upon heating and concrete releases water.

C. *Compressive Strength before and after Exposure to Elevated Temperature*

Exposure of concrete and mortar to elevated temperatures results in a substantial reduction in strength, while prolonged exposure leads to structural degradation. At elevated temperatures, the thermal properties of concrete are modified due to fluctuations in moisture content, chemical reactions, and the degradation of different hydration constituents. Figure 8 presents the findings of the sample analysis before and after thermal exposure. At ambient temperature, FA incorporation led to a 16% reduction in compressive strength. This reduction may have resulted from the low reactivity of the FA, relative to cement, which mainly influences hydration and pozzolanic reactions. In addition, the FA expiration date diminished its pozzolanic efficacy. The incorporation of ceramic powder resulted in a 30% reduction in compressive strength, which is consistent with [43], where a reduction in compressive strength was demonstrated with incremental increases from 5 to 20% of the white cement's weight.

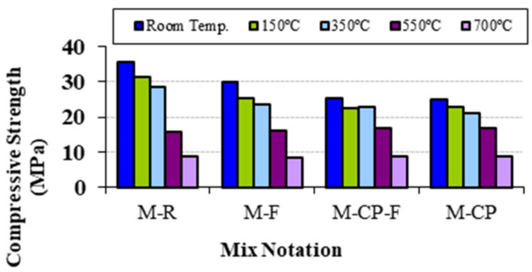

Fig. 8. The compressive strength of the evaluated mortar mixtures.

Having increased the temperature to 150°C resulted in a decrease in the compressive strength of the samples from 8.5% to 14.7%. The escape of the adsorbed and interlayer water may have been the cause of this reduction. At temperatures above 65°C–80°C, adsorbed and interlayer water began to escape, complying with [42]. At 350°C, the compressive strength dropped from 9.1% to 21%. This is probably because the chemical bonds between the C-S-H nano-structural hydrates and sulfoaluminates lose water. Authors in [28] observed a reduction in compressive strength after exposure to a temperature of 300°C, which they attributed to the water loss within the interlayer chemical bonds of C-S-H nanostructure hydrates and sulfoaluminates. They also noted the decomposition of the C-S-H nanostructure, resulting in the removal of water from its chemical bonds. When exposed to heat, the hydrated compounds in cement paste gradually dehydrate, producing water vapor. Authors in [44] indicated that elevated temperatures resulted in an increased porosity of the concrete samples, leading to a gradual deterioration of the pore structure. Furthermore, the compressive strength progressively diminished with a rising temperature. Sulfoaluminate cement concrete was utilized and it was noted that at 550°C, the compressive strength diminished from 32.2% to 55.2%, which is possibly attributable to the increased pressure within the mortar's pores. This is associated with the temperature at which water evaporates from the capillary pores, directly affecting the sample strength, in that it leads to its decrease. All mortar specimens showed a significant decrease in compressive strength at 700 °C, which ranged from 65% to 75.1%, and all samples exhibited a more rapid loss of strength. The decrease in compressive strength is attributed to the dehydration and decomposition of C-H-S and calcium hydroxide, respectively, which occur at temperatures above 500°C [45]. Authors in [46] investigated heat impact on Modified Reactive Powder Concrete (MRPC) and reported that heating to temperatures exceeding 400°C resulted in substantial reductions in compressive strength, attributable to the crack formation in MRPC following water evaporation at elevated temperatures and volumetric expansion in certain RPC constituents. The load-bearing capability of MRPC diminished because of the vapor pressure.

D. *Tensile Strength upon Exposure to Elevated Temperature*

The tensile strength of concrete is significantly inferior to its compressive strength, resulting in the frequent disregard of tensile strength in strength calculations at ambient and increased temperatures. From a fire resistance perspective, this attribute is significant, as cracking in concrete typically results from tensile stresses, and structural damage in tension members commonly arises from the advancement of microcracking [47]. Figure 9 displays the tensile strength of the cement mortar samples at various high temperatures. At room temperature, the tensile strength results were comparable to the compressive strength results. The decline in tensile strength values occurred upon substituting cement with FA or ceramic powder, attributable to the same factors discussed in the compressive strength section. The tensile strength decreased from 9.3% to 24%. At 350°C, the samples containing FA along with ceramic powder exhibited enhanced tensile strength, with an improvement rate between 3 % and 6%, which could be attributed to the completion of hydration and pozzolanic reactions involving the additives. Nonetheless, the increase was minimal across all instances. At 700 °C, the tensile strength value significantly decreased. Notable microstructural alterations at elevated temperatures, involving the dehydration of cement hydrates and the disintegration of C-S-H gel, were responsible for the substantial decrease. The alterations led to an increase in porosity and the induction of microcracking, which significantly reduced tensile strength. This explanation aligns with the findings of [45], where FA and Wood Ash (WA) were utilized as alternatives to cement. The samples exposed to 600 °C showed a substantial reduction in strength, with the mortar samples having lost nearly 90% of their initial strength, while those exposed to 800 °C having experienced full failure.

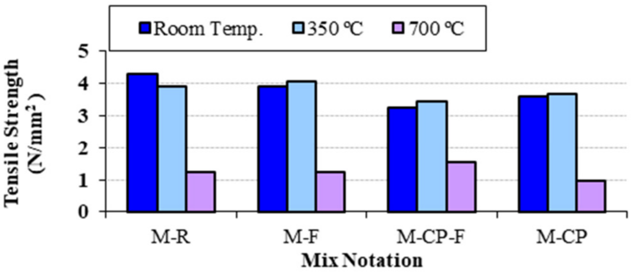

Fig. 9. The tensile strength of the evaluated mortar mixtures.

VII. COLOUR ALTERATIONS AND THE EMERGENCE OF FISSURES DURING HEAT EXPOSURE

During visual inspection, there were not any indications of deterioration in the specimens, including cracks, spalling, or color alterations. All specimens maintained integrity without fragmentation, even at 700 °C. Macro fractures were observed on specimens subjected to 550 °C and 700 °C, as displayed in Figures 10 (d) and (e). Due to the low rate of chemical reactions at a temperature of 150, no significant color changes were observed on the sample surfaces upon exposure to varying temperatures, as evidenced in Figure 10 (b). All specimens at 550°C and 700°C exhibited a light grey color, as shown in Figure 3. The results reveal that the color of the cement mortar surface can serve as an indicator for assessing the intensity and duration of the thermal exposure it has experienced.

VIII. MORPHOLOGICAL ANALYSIS OF SPECIMENS SUBJECTED TO INCREASED TEMPERATURE VIA FESEM TESTING

Figure 11 presents the FESEM images of the samples at room temperature. The hexagonal arrangement of the calcium hydroxide crystals makes them stand out. On the other hand, the porous nanostructure is a sign of C-S-H. At ambient temperature, the specimens show no visible cracking on the sample surface and no defects on the mortar surface. The C-S-H nanostructure is also demonstrated. The progression of this nanostructure over time, along with the advancement of the hydration process, leads to the occlusion of minor apertures and fissures. Chemical and physical changes occurred in the cement paste at 350°C. The Portlandite and C-S-H are still identifiable. Nevertheless, these structures are deteriorating, relative to the control sample. The structural modifications in these phases beggan at 350°C. At approximately 350°C, the expansion of microcracks was initiated due to the total decomposition of free water and the moisture absorbed by the concrete. The decomposition of the C-S-H and Portlandite occurred at a temperature of 700°C.

(a)
(b)
(c)
(d)
(e)

Fig. 10. Specimens at exposure temperature: (a) room temperature (b) 150°C, (c) 350°C, (d) 550°C, and (e) 700°C for M-R (M1), M-F (M2), M-CP-F (M3), and M-CP (M4).

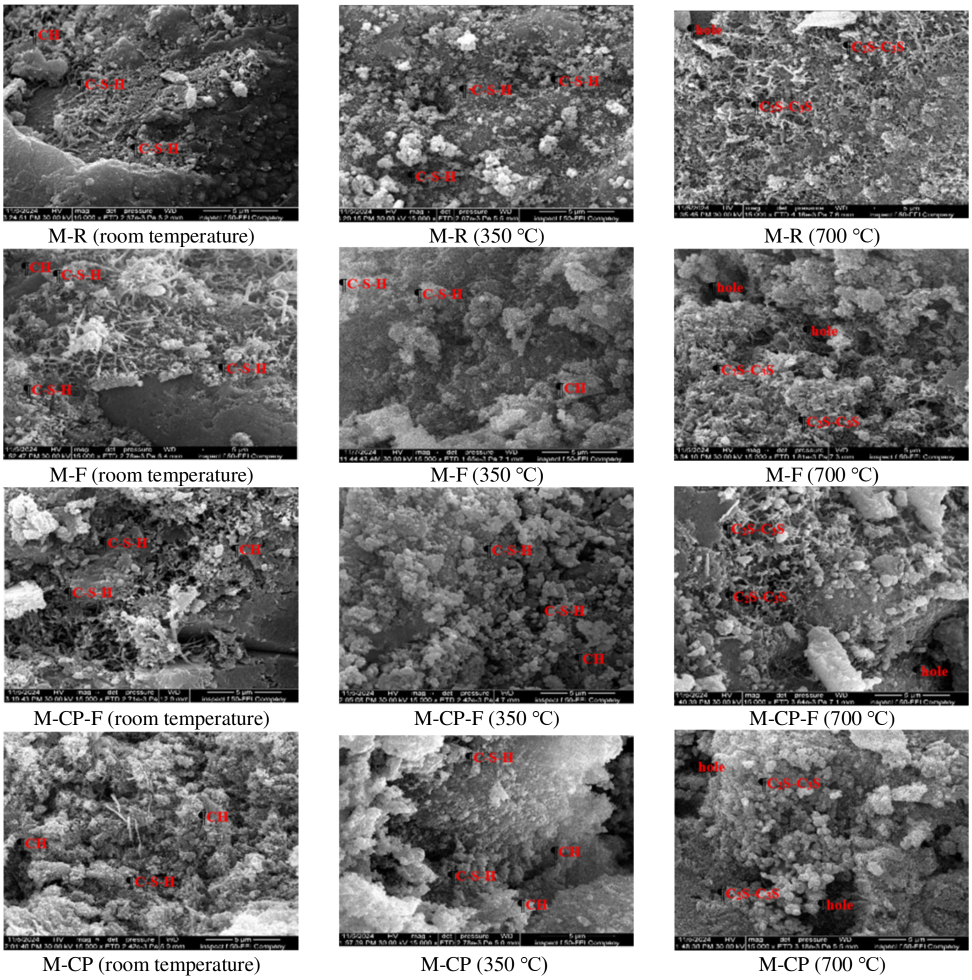

Fig. 11. FESEM of samples (M-R, M-F, M-CP-F, and M-CP) at: room temperature, 350°C, and 700°C.

A significant portion of the cement hydration products were destroyed when the temperature increased to 700°C. As a result, the bonds that hold the particles together became significantly weaker, which resulted in the formation of a mortar structure that was highly broken and porous. A significant portion of the C-S-H cement nanostructure was damaged, transforming the cement into alite and belite. As a result, the cement network lost its cohesive integrity. Additionally, many primary portlandite crystals broke down into smaller fragments. The decomposition of primary portlandite resulted in the release of water and the production of quicklime for use in various applications. The water release when portlandite dehydrated during its reaction with lime, which came from calcium carbonate breaking down, led to the formation of secondary portlandite, which has a weak structure. The typical layered architecture of the main portlandite fully collapsed, revealing the susceptible structure of the secondary portlandite. When portlandite decomposes, crystals of alite (C3S) and belite (C2S) form, creating cracks and holes in the mortar matrix.

IX. CONCLUSIONS

Compressive strength, tensile strength, mass loss tests, Field Emission Scanning Electron Microscopy (FESEM) techniques, and visual inspection were employed to assess the degradation of cement mortar at elevated temperatures. At ambient temperature, the incorporation of CP resulted in a weight reduction of approximately 7% in the mortar compared to the control mix. Additionally, the weight of the mortar decreased by 4.3% for M-F. The reduction rate for the M-CP-F combination was 7.9%. At a temperature of 150°C, the observed mass loss exhibited a consistent pattern across all combinations, ranging from 2.7% to 4.5%. At 350 °C, the mass loss ranged from 5.2% to 8.6%. The results demonstrated a consistent increase in mass loss up to this temperature after which the loss rate began to rise at a slightly diminished pace. The mass loss ranged from 6.8% to 11% at 550°C, increasing to a maximum of 9.5% to 12% at 700°C. Adding Fly Ash (FA) reduced the compressive strength by 16% at ambient temperature before exposure to elevated temperatures. The incorporation of ceramic powder led to a 30% reduction in compressive strength. Raising the temperature to 150°C led to a decrease in the samples' compressive strength from 8.5% to 14.7%. The compressive strength decreased from 9.1% to

20.9% at 350°C. All mortar specimens exhibited a notable reduction in compressive strength at 500°C and 700 °C. The tensile strength results were similar to the compressive strength results, with a reduction in tensile strength values having been noted when cement was replaced with FA or ceramic powder at room temperature. At 700°C, the tensile strength significantly decreased, the dehydration of cement hydrated and the breakdown of C-S-H gel accounted for a substantial reduction. These changes lead to increased porosity and the formation of micro-cracks, which significantly reduced tensile strength. During the ocular assessment of the specimens, it was found that all of them retained their integrity without fragmentation, even at 700°C. Specimens subjected to temperatures of 550°C and 700°C exhibited macro fractures and a pale hue. The FESEM image of the samples at room temperature highlights the prominence of $Ca(OH)_2$ crystals. The porous nanostructure indicates the presence of C-S-H. At room temperature, the specimen showed no visible cracks or defects on its surface. The image distinctly illustrates the C-S-H nanostructure. Chemical and physical transformations transpired in the cement paste at a temperature of 350°C. The Portlandite and C-S-H nanostructures remained discernible. Nonetheless, these structures were deteriorated in comparison to the control sample. The structural alterations in these phases commenced at 350°C, where the complete breakdown of free water and moisture absorbed by the concrete initiated the expansion of microcracks. The C-S-H nanostructure and Portlandite decomposed at 700°C. The temperature reached 700°C, obliterating a substantial fraction of the cement hydration products. The disruption of a significant portion of the C-S-H cement nanostructure resulted in the conversion of the cement into alite and belite.

Comparing the results to those of previous studies, it can be observed that the mass loss rate slowed down when chemically combined water was lost. This is because the hydrates broke down when the concrete was heated, releasing water. On the other hand, the temperature at which water evaporated from the capillary pores caused the pressure inside the mortar to rise. This directly affected strength and caused the sample's compressive strength to drop. At high temperatures, micro changes were seen in the material. For example, the cement hydrates dried out and the C-S-H gel broke down. This caused the porosity to rise and micro-cracks to form, having greatly reduced the tensile strength. It was also noted that the samples exhibited analogous behavior at elevated temperatures, regardless of the 10% and 20% cement substitutions. The findings indicated that Ceramic Waste Powder (CWP) may serve as a sustainable substitute for adhesive construction. This would lessen the carbon footprint of construction materials and alleviate the environmental damage from CWP disposal in landfills. Additionally, FA can be amalgamated with ground ceramic to replace cement, resulting in a sustainable cement mortar.

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