The Mechanical Properties of Ferrocement Mortar with Waste Plastic Fibers at Elevated Temperatures

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Abstract-The main aim of the current research was to investigate the behavior of ferrocement mortar reinforced with waste plastic fibers at elevated temperatures. The use of PET residues in ferrocement mortar at normal temperatures could be a viable option. However, the utilization of PET-containing ferrocement mortar in high-temperature applications requires more research. In this study, one reference mix was made along with 3 other mixes containing Polyethylene Terephthalate (PET) fiber by volumetric ratios of 0.5, 0.75, and 1%. Compressive and flexural strength tests were performed on the samples before and after being exposed to elevated temperatures. Each batch of ferrocement mortar samples was heated to the requisite temperature for roughly 60 minutes, then was progressively cooled to room temperature before being tested. The compressive and flexural strengths of some samples were evaluated at room temperature (25°C). Other samples were evaluated after being exposed to high temperatures in an electric furnace (100°C, 200°C, 400°C, and 600°C). Both compressive and flexural strengths were found to be significantly reduced after being exposed to a temperature greater than 400°C. Results proved that the addition of 0.75% PET was determined as the optimum percentage that enhanced the mechanical properties of the produced ferrocement mortar at 25°C. At 200°C, the ferrocement mortar samples retained their original color. As a result of the combustion of PET fibers, black spots formed on the top surfaces of the tested specimens that were heated to 400°C.

Keywords-elevated temperature; ferrocement mortar; flexural strength; compressive strength; PET; mechanical properties

I. INTRODUCTION

Ferrocement is a thin water-cement mortar that has been reinforced with close layers. It is considered the best regarding the resistance to compression, tensile strength, and fracture parameters. Also it is light weight, easy to operate, and economical. Ferrocement technology was introduced in the '70s; damaged parts of concrete structures were reinforced with this mortar [1]. Cement mortars are a main component of the construction industry, used in many applications and in the manufacturing of ferrocement elements [2]. The mortar is the resulting material for the proposed mixture (intimate mixture) of sand grains, binder, and water. Its properties depend mainly on the nature of the compounds of the binder in it [3]. Cement mortar is used as a binder for building units in walls or to protect building surfaces. When making ferrocement, the mortar has a 95% or more effect on the behavior of the final product. Ferrocement mortar has practical uses in strengthening concrete structures damaged by loads and stresses.

Managing waste is a global major challenge, as various human activities result to the production of significant amounts of waste of different kinds [4]. The residues of mineral water bottles and PET beverage containers consist a major source of solid trash. Sustainable materials are being developed with economic and environmental benefits in order to reduce pollution, including CO_2 emissions, and recycle waste by incorporating environmentally friendly materials into civil engineering projects. The use of post-consumer plastics in concrete production is an economical alternative and consumption of resources. The global widespread use of PET as well as the long-term degradation of this plastic type in nature has prompted researchers to investigate PET recycling solutions. The incorporation of plastic waste into concrete to enhance the qualities of hardened concrete and solve the problem of brittleness has garnered considerable research interest. The inclusion of plastic wastes, such as polypropylene fibers, in concrete can prevent cracking and improve the resistance of concrete components to cracking [5]. The usage of hand-cut PET fibers with length of 6cm, width of 1.2cm, and various geometric shapes, increases the strength of hardened concrete [6].

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When structural elements deteriorate as a result of exposure to high temperatures, the risk of a structure collapsing increases. As a result, the selection of fire-resistant materials to limit heat damage to structural elements is critical. The research on the behavior of concrete at elevated temperatures has showed that elevated temperatures degrade the mechanical characteristics of concretes. The behavior of concrete at high temperatures depends on a few parameters, including the constituents of the materials used for the concrete mixture and the permeability of the concrete [7]. Exposure to temperatures above 300°C can drastically reduce the mechanical characteristics of concrete. The calcium hydroxide content of the cement material can be dehydrated at temperatures above 400°C. Consequently, the water vaporizes, which causes the physical qualities of concrete to deteriorate [8].

The effect of rising temperatures on the characteristics of strengthened cement mortar by adding waste plastic fibers from soft drink bottle recycling is studied in this paper. These fiber types were added in volumetric proportions (0.5%, 1%, 1.5%, and 2%) and a reference mixture was utilized for comparison. The specimens of cement mortar from each group were heated to the desired temperature before being evaluated. Some samples were tested for compressive and flexural strength at room temperature, while others were studied after being exposed to increased temperatures of 100, 200, 400, and 700°C. After exposure to temperatures over 400°C, the compressive and flexural strength values decline significantly [9]. The main objective of this study is to investigate experimentally the effect of high temperatures on the mechanical properties of concrete and the effect of the added fibers to the ferrocement mortar as a solution to increase the resistance and to control cracking during fire exposure.

II. MATERIALS

A. Cement

Ordinary Portland Cement (OPC) Type I with 3.15g/cm^3 specific gravity was used as a binder in all mixes. Cement is the most important component in concrete production [10]. The physical properties of OPC are shown in Table I, according to the Iraqi [IQS No.5/ 2019].

TABLE I. PHYSICAL CHARACTERISTICS OF OPC

Physical characteristics	Test result	IQS, No.5/ 2019
Fineness using Blain method (cm^2/g)	3344	>2500cm^2/gm
Initial setting time (min)	164	>45min
Final setting time (min)	222	<600min
Soundness (mm)	1	<10mm

B. Fine Aggregates

Local sand passing through 2.36mm with specific gravity of 2.65g/cm^3 was used. Table II shows the characteristics of the used sand according to the Iraqi specifications [11].

TABLE II. CHARACTERISTICS OF FINE AGGREGATES

Type aggregate	Sand
Passing Sieve	2.36
Specific gravity	2.65
Salt content %	0.11

C. Water

Tap water was used to create and cure concrete in this research.

D. Polyethylene Terephthalate (PET)

The type of waste plastic considered in this study came from waste plastic soft drink bottles. The waste plastic bottles were sliced to small uniform pieces with an average length equal to 30mm, width equal to about 3mm, and thickness equal to 0.3mm. The density of the waste plastic fibers was 1300kg/m^3, the aspect ratio was 28, and the tensile strength 103Mpa. The volumetric ratios used in this study were 0, 0.5%, 0.75%, and 1%.

III. TYPES OF MOLDS

A total of 120 cube and prism specimens were cast. The dimensions were 70×70×70mm cubes for compressive strength testing and 40×40×160 mm prisms for flexural strength testing.

IV. MIX DESIGN

Several experimental mixtures were produced to choose the optimal mixing water ratio by using a mold of mortar 50×50×50mm to determine the compressive strength after 7 days. The chosen design was 1:3:0.45 cement, fine aggregates, and water/cement ratio respectively by weight. The designed strength was 30MPa.

V. CASTING AND CURING

To prevent the mortar from adhering to the inside surfaces of the molds, they were cleaned and pre-coated with coating oil. All the specimens were covered with nylon sheets to avoid water evaporation immediately after the concrete was mixed. The samples were de-molded and immediately submerged in the treatment water basin for 28 days after the nylon sheets were removed.

VI. HEATING PROCESS

At the age of 28 days, the specimens were withdrawn from the water cure and were left to dry in the laboratory for one day. The concrete specimens were then dried in a vented oven before being exposed to high temperatures. The first group with 24 cube and prism samples (3 samples for each mixture) was assessed and utilized as a comparison standard at room temperature (25°C). In the laboratory furnace, 4 more groups were exposed to temperatures of 100, 200, 400, and 600°C for 1h. After the exposure, the specimens were allowed to cool at room temperature before being tested.

VII. TESTING PROGRAM

A. Compressive Strength Test

Based on [12], compressive tests on the cubic samples were carried out to find the concrete's compressive strength after 28 water-curing days. All samples were tested in the ELE-Digital testing compression machine with a maximum capacity of 2000KN at the rate of 3KN/s. Three cubes were tested for each case (room temperature, 100°C, 200°C, 400°C, and 600°C) and the average strength was considered.

B. Flexural Strength Test

Flexural strength was measured according to [13]. A machine with a capacity of 5KN was used to determine flexural strength (Center-Point Loading Method) on the prismatic samples after 28 water-curing days. Three prisms were tested for case and their average strength was considered.

VIII. RESULTS AND DISCUSSION

Figure 1 shows the relationship between temperature and compressive strength for all ferrocement mortar mixes. In general, it can be clearly seen that all cement mortar mixes exhibited a loss in compressive strength as temperature increased. As the temperature increases above 400°C there is a major decrease in compressive strength, which can be attributed to the loss of cement paste plasticity at high temperatures [14]. At room temperature (about 25°C), the mixes with Vf value equal to 0.75% exhibited higher compressive strength by 17.63% than the reference ferrocement mortar mix. At the same temperature, the mix with Vf = 1% had lower compressive strength than the reference mix by 12.28%. That decrease in compressive strength might be caused by the forming of segregations on the mixes containing waste plastic fibers, leading to form stiff bonds about these bulks. Also, the plastic fibers reduced the density of cubes, and that leads to a decrease of the compressive strength of the composite [15]. Using of waste plastic fiber with Vf = 1% increased the porous inside the mortar structure and that reduced the compressive strength.

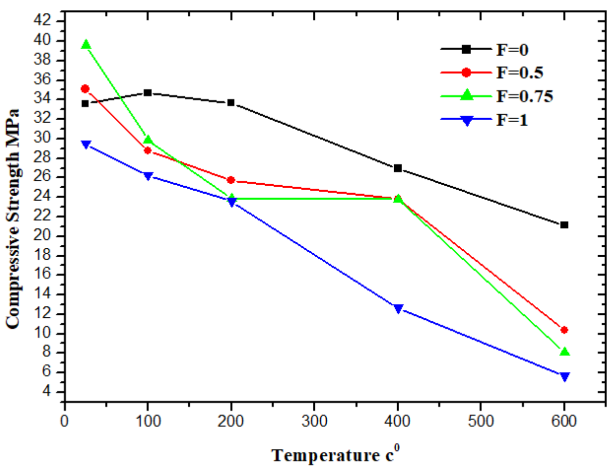

Fig. 1. Relationship between temperature and compressive strength for all ferrocement mortar mixes.

Flexural strength results of ferrocement mortar mixtures at the age of 28 days are shown in Figure 2, which shows a decrease in flexural strength with the elevation of temperature for all 4 mixes. As the temperature increases above 400°C there is a major decrease in flexural strength. At room temperature, the addition of waste plastic fiber to mixes had a positive effect on flexural strength in compared with the reference mix, in accordance with the findings of [16]. This can be attributed to the increase of homogeneity, the decrease in voids, and the increase of the bond strength between the waste plastic fibers and the other components of concrete mixture. Fibers resist the generation of cracks and bridging of these cracks. The test results showed increase in flexural strength by 2.81%, 5.45%, and 1.08% when waste plastic fibers were added by Vf equal to 0.5%, 0.75%, 1% respectively. When the volumetric ratio of waste plastic fibers is equal to 1%, the decreasing in flexural strength is still greater than that of the reference mixture. The reason for this is that increasing the volumetric ratios of fiber reduces flexural strength due to the irregular distribution of fibers. The samples (cubes and prisms) which were heated to a temperature equal to 200°C maintained their original color, while in specimens heated to 400°C, black spots appeared on the top surfaces of the cubes due to the burning of PET. At 700°C, the black spots disappeared due to the evaporation of the burned PET residuals and the specimens suffered noticeable color changes with a spalling occurred on the samples surfaces.

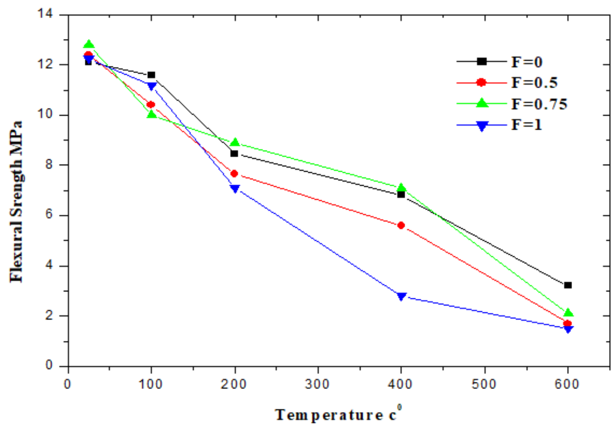

Fig. 2. Relationship between temperature and flexural strength for all ferrocement mortar mixes.

IX. CONCLUSIONS

The following conclusions could be drawn from the current research work:

- The addition of PET fibers is an effective method for recycling plastic waste.
- The compressive and flexural strength values of reference cement mortar and mortar containing waste plastic fibers reduced by an amount depending on the value of the exposing temperature.
- For specimens evaluated at temperatures up to 200°C, the loss in compressive strength was relatively small.
- A severe decrease in the compressive and flexural strength values occurred when the specimens were exposed to temperatures higher than 400°C.
- The samples which were heated to temperature equal to 200°C maintained their original color and no apparent visual discoloration occurred in the ferrocement mortar.
- Due to the combustion of PET fibers, black patches form on the surfaces of mortar cubes and prisms heated to 400°C.

- At 700°C the black spots disappear due to the evaporation of the burned PET residuals and the specimens suffered noticeable color changes with a spalling occurring on the sample surfaces.

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