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A Study on Cement-Based Composite Containing Polypropylene Fibers and Finely Ground Glass Exposed to Elevated Temperatures

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***Abstract*—**High strength concrete has been used in situations where it may be exposed to elevated temperatures. Numerous authors have shown the significant contribution of polypropylene fiber to the spalling resistance of high strength concrete.

When cement-based composite that reinforced by polypropylene fibers heated up to 170 °C, polypropylene fibers readily melt and volatilize, creating additional porosity and small channels in to the matrix that cause the poor structure and low strength.

This investigation develops on the mechanical properties of mortar incorporating polypropylene fibers exposed to high temperature. Also effects of different pozzolans on strength behaviour of samples at elevated temperature have been studied.

To reach this purpose, the specimens were produced by partial replacement of cement with finely ground glass, silica fume and rice husk ash as high reactive pozzolans. The amount of this replacement was 10% by weight of cement to find the effects of pozzolans as a partial replacement of cement on the mechanical properties of mortars. In this way, lots of mixtures with 0%, 0.5%, 1% and 1.5% of polypropylene fibers were cast and tested for compressive and flexural strength, accordance to ASTM standard. After that specimens being heated to temperatures of 300, 600 °C, respectively, the mechanical properties of heated samples were tested.

Mechanical tests showed significant reduction in compressive strength which could be due to polypropylene fiber melting. Also pozzolans improve the mechanical properties of sampels.

***Keywords*—**Mechanical properties, compressive strength, Flexural strength, pozzolanic behavior.

I. Introduction

As the world population grows, so do the amount and type of waste being generated. Many of the wastes produced today are non-biodegradable and will remain in the environment for many years to come. The creation of nondecaying waste materials, combined with a growing consumer population has resulted in a waste disposal crisis.

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Many efforts have been made to use industry by-products such as fly ash, silica fume, ground granulate blast furnace slag (ggbs), glass cullet, etc., in civil constructions for many years[1-6].

The potential applications of industry by-products in concrete are to be partial aggregate replacement or partial cementitious materials, depending on their chemical composition and grain size [7-12]. In this study, the performances of ordinary Portland cement using recycled glass and fibers as a fraction of aggregates used in a cement-based composite were investigated in laboratory.

A. Recycled Glass

Glass has been used as aggregate in road constructions, building and masonry materials [13]. Recent studies have shown that reuse of very finely ground waste glass in concrete has economical and technical advantages [11-14]. Also researches found that, application of waste glass as a partial replacement of coarse and fine aggregates in concrete is not satisfactory, due to the strong reaction between the alkali in cement and the reactive silica in glass (ASR) [15].

Also they found that, if the glass was ground to a partial size of 300 μm or smaller, ASR-induced expansion could be reduced [16]. Partial replacement of fine aggregate in concrete by crushed glass was already attempted and strength loss due to the sand substitution by the crushed glass was reported to be between 5 to 10% [17].

The glass might satisfy the basic requirements for the pozzolan if it could be ground to a size fine enough to active pozzolanic behavior [11].

B. Recycled Fibers

A great amount of fibrous textile waste is discarded into landfills each year all over the world. More than half of this waste is from carpets, which decays at a very slow rate and which is difficult to handle in landfills.

One promising reuse of these wastes lies in concrete reinforcement and construction applications.

Waste carpet fibers have been used in cement-based composites concrete since the past decades [18]. Natural and other synthetic fibers are added to cement as secondary reinforcement to control plastic shrinkage [19-21]. The effect of polypropylene fibers on the properties of cement-based composites varies depending on the type, length, and volume fraction of fiber, the mixture design, and the nature of materials used [22].

Some results are that permeability, abrasion and impact resistance are all significantly improved by the addition of polypropylene fibers [23] but some results reported that the effect of polypropylene fibers on flexural, compressive and tensile strength as well as on toughness and elastic modulus is not quite clear. Most work shows either no effect or modest improvements in these properties. However, in some cases the addition of polypropylene fibers has been known to decrease the ultimate strength of hardened concrete [23,24].

C. Effect of High Temperature on Cement-Based Matrix

In the other hand, during the lifetime, many civil structures are exposed to elevated temperature conditions. Examples of such structures are nuclear reactors, industrial furnaces, and buildings exposed to accidental fire conditions. Therefore, since fire resistance of structural elements has become an integral part of design, the properties of all building materials at ambient and elevated temperature conditions are of interest, therefore, received special attention in the literature [25–32]. The main objective of this investigation was to study the effect of elevated temperature on mechanical properties of tow kind of mortar: one mortar containing polypropylene fibers and one without fibers. Also the effects of different pozzolans such silica fume and rice husk ash and finely ground glass on properties of heated and unheated specimens were assessed.

II. Materials Properties

Materials used included Ordinary Portland cement type 1, standard sand, silica fume, glass with tow particle size, rice husk ash, tap water and finally fibrillated polypropylene fibers.

The fibers included in this study were monofilament fibers obtained from industrial recycled raw materials that were cut in factory to 6 mm length. Properties of waste Polypropylene fibers are reported in Table I and Fig. 1.

TABLE I
PROPERTIES OF POLYPROPYLEN FIBERS

Property	Polypropylene
Unit weight [g/cm3]	0.9 - 0.91
Reaction with water	Hydrophobic
Tensile strength [ksi]	4.5 - 6.0
Elongation at break [%]	100 – 600
Melting point [°C]	175
Thermal conductivity [W/m/K]	0.12

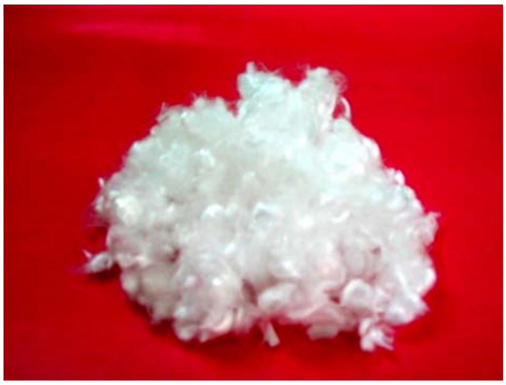

Fig. 1 Polypropylene fiber used in this study

Also the silica fume and rice husk ash contain 91.1% and 92.1% SiO2 with average size of 7.38μm and 15.83μm respectively were used. The chemical compositions of all pozzolanic materials containing the reused glass, silica fume and rice husk ash were analyzed using an X-ray microprobe analyzer and listed in Table II.

In accordance to ASTM C618, the glass satisfies the basic chemical requirements for a pozzolanic material especially clean glass. To satisfy the physical requirements for fineness, the glass has to be grounded to pass a 45μm sieve.

TABLE II
CHEMICAL COMPOSITION OF MATERIALS

Oxide	Content (%)		
	Glass C	Silica fume	Rice husk ash
SiO_2	72.5	91.1	92.1
Al_2O_3	1.06	1.55	0.41
Fe_2O_3	0.36	2	0.21
CaO	8	2.24	0.41
MgO	4.18	0.6	0.45
Na_2O	13.1	-	0.08
K_2O	0.26	-	2.31
CL	0.05	-	-
SO_3	0.18	0.45	-
L.O.I	-	2.1	-

Fig. 2 Ground waste glass

To obtain this aim recycled windows clean glass was crushed and grinded in laboratory, and sieved the ground glass to the desired particle size (Fig. 2). To study the particle size effect, two different ground glasses were used, namely:

- Type I: ground glass having particles passing a #80 sieve (180μm);
- Type II: ground glass having particles passing a #200 sieve (75μm).

In addition the particle size distribution for two types of ground glass, silica fume, rice husk ash and ordinary Portland cement were analyzed by laser particle size set, have shown in Fig. 3. As it can be seen in Fig.3 silica fume has the finest particle size. According to ASTM C618, fine ground glasses under 45µm qualify as a pozzolan due to the fine particle size. Moreover glass type I and II respectively have 42% and 70% fine particles smaller than 45µm that causes pozzolanic behavior. SEM particle shape of tow kind of glasses is illustrated in Fig. 4.

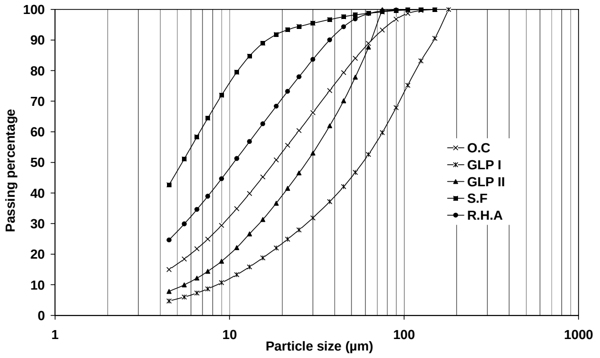

Fig. 3 Particle size distribution of ground waste glass type I, II, silica fume, rice husk ash and ordinary cement

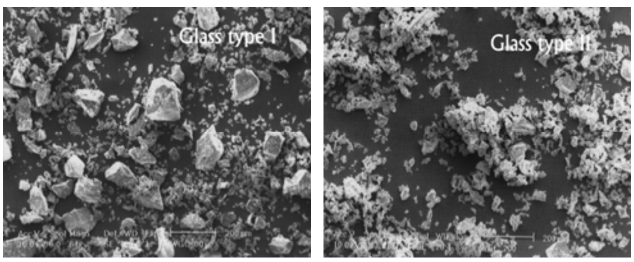

Figure.4: Particle shape of ground waste glass type I, type II

III. Test Program

For the present study, twenty batches were prepared. Control mixes was designed containing standard sand at a ratio of 2.25:1 to the cement in matrix. A partial replacements of cement with pozzolans include ground waste glass (GI,GII), silica fume(SF) and rice husk ash(RH) were used to examine the effects of pozzolanic materials on mechanical properties of PP reinforced mortars at high temperatures. The amount of pozzolans which replaced were 10% by weight of cement which is the rang that is most often used.

Meanwhile, polypropylene fibers were used as addition by volume fraction of specimens. The reinforced mixtures contained PP fiber with three designated fiber contents of 0.5%,1% and 1.5% by total volume.

In the plain batches without any fibers, water to cementitious ratio of 0.47 was used whereas in modified mixes (with different amount of PP fibers) it changed to 0.6 due to water absorption of fibers. The mix proportions of mortars are given in Table III.

The strength criteria of mortar specimens and impacts of polypropylene fibers on characteristics of them were evaluated at the age of 60 days.

In our laboratory, the test program mix conducted as follows:

1. The fibers were placed in the mixer.
2. Three-quarters of the water was added to the fibers while the mixer was running at 60 rpm; mixing continues for one minute.
3. The cement was gradually the cement to mix with the water.
4. The sand and remaining water were added, and the mixer was allowed to run for another two minutes.

After mixing, the samples were casted into the forms 50×50×50 mm for compressive strength and 50×50×200 mm for flexural strength tests. All the moulds were coated with mineral oil to facilitate demoulding. The samples were placed in two layers. Each layer was tamped 25 times using a hard rubber mallet. The sample surfaces were finished using a metal spatula. After 24 hours, the specimens were demoulded and cured in water at $20^{\circ}C$. The suitable propagation of fibers in matrix is illustrated in Fig. 5.

TABLE III
Mixter Properties

batch No	sand/c	w/c	Content (by weight) O.C	GI	GII	SF	RH	PP fibers (by volume)	batch No	sand/c	w/c	Content (by weight) O.C	GI	GII	SF	RH	PP fibers (by volume)
1	2.25	0.47	100	-	-	-	-	0	11	2.25	0.6	100	-	-	-	-	1
2	2.25	0.47	90	10	-	-	-	0	12	2.25	0.6	90	10	-	-	-	1
3	2.25	0.47	90	-	10	-	-	0	13	2.25	0.6	90	-	10	-	-	1
4	2.25	0.47	90	-	-	10	-	0	14	2.25	0.6	90	-	-	10	-	1
5	2.25	0.47	90	-	-	-	10	0	15	2.25	0.6	90	-	-	-	10	1
6	2.25	0.6	100	-	-	-	-	0.5	16	2.25	0.6	100	-	-	-	-	1.5
7	2.25	0.6	90	10	-	-	-	0.5	17	2.25	0.6	90	10	-	-	-	1.5
8	2.25	0.6	90	-	10	-	-	0.5	18	2.25	0.6	90	-	10	-	-	1.5
9	2.25	0.6	90	-	-	10	-	0.5	19	2.25	0.6	90	-	-	10	-	1.5
10	2.25	0.6	90	-	-	-	10	0.5	20	2.25	0.6	90	-	-	-	10	1.5

Fig. 5 Porpagation of polypropylene fibers in mortar matrix (Left: 0.5% fiber, Right: 1% fiber)

The heating equipment was an electrically heated set. The specimens were positioned in heater and heated to desire temperature of 300 and 600 °C at a rate of 10-12 °C/min .After 3 h, heater turned off. It was allowed to cool down before the specimens were removed to prevent thermal shock to the specimens. The rate of cooling was not controlled. The testes to determine the strength were made for all specimens at the age of 60 days. At least three specimens were tested for each variable.

IV. Results and Discussions

A. Density

The initial density of specimens containing polypropylene fibers was less than that of mixes without any fibers. Density of control mixes without any replacement of cement at 23,300 and 600°C are reported in Table IV. According to the results, density decrease of fiber reinforced specimens was close to that of plain ones. The weight of the melted fibers was negligible. The weight change of mortar was mainly due to the dehydration of cement paste.

TABLE IV
Density of Control Specimens

Heated at	23°	300°	600°	PP fibers
Density (gr/cm^3)	2.57	2.45	2.45	0%
Density (gr/cm^3)	2.50	2.36	2.36	0.5%
Density (gr/cm^3)	2.44	2.28	2.27	1%
Density (gr/cm^3)	2.41	2.23	2.21	1.5%

B. Compressive Strength

In order to asses the effect of elevated temperatures on mortar mixes under investigation, measurements of mechanical properties of test specimens were made shortly before and after heating, when specimens were cooled down to room temperature. Compressive strength of reference specimen and heated ones at the age of 60 days are illustrated in Fig. 6.

According to the results, by increasing the amount of polypropylene fibers in matrix the compressive strength of specimens reduced. Also, it's clear that the compressive strength of specimens were decreased by increasing the temperature to 300 and 600°C, respectively as supported by previous literatures.

The rate of strength reduction in fiber reinforced specimens is more than the plain samples and by rising the temperature it goes up.

The basic factor of strength reduction in plain specimens is related to matrix structural properties exposed to elevated temperature, but this factor for fiber reinforced specimens is related to properties of fibers. Fibers melt at temperature higher than 190°C and generate lots of holes in the matrix. These holes are the most important reasons of strength reduction for fiber reinforced specimens.

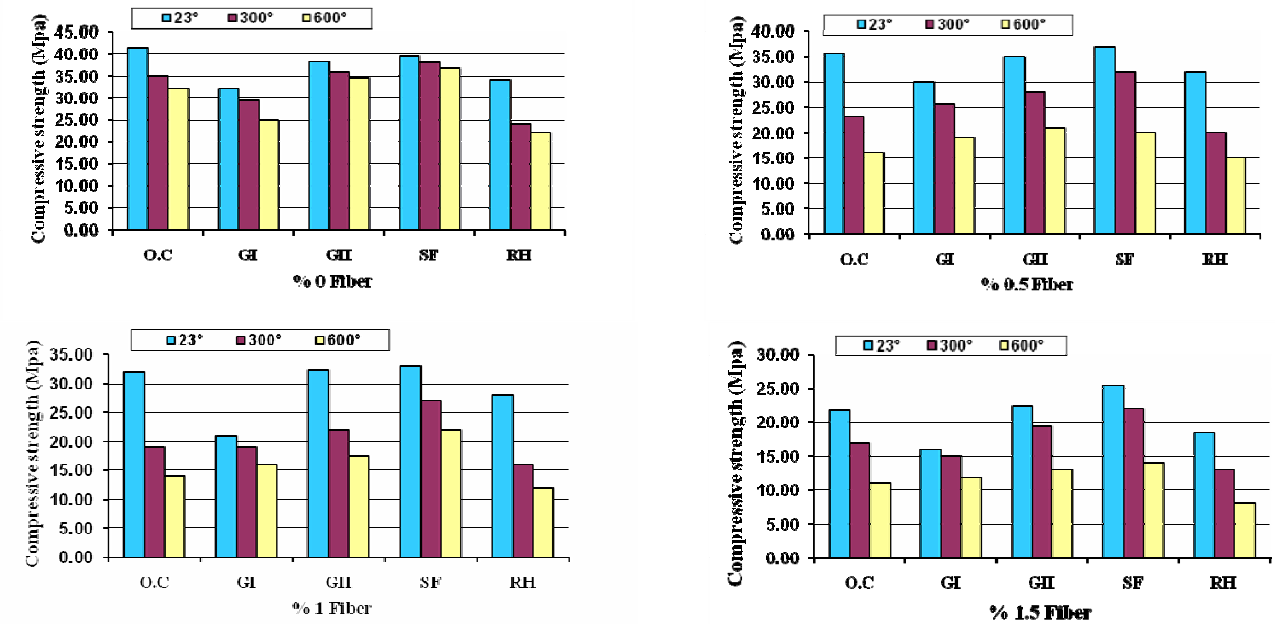

Fig. 6 Compressive strength of samples at different temperatures

Also, results indicate that silica fume and glass type II have an appropriate potential to apply as a partial replacement of cement due to their respective pozzolanic activity index values (according to ASTM C618 and C989, and Table II).

C. Flexural strength

The specimens were used for flexural testes were $50\times50\times200$ mm. The results of plain specimens and samples containing 1.5% fibers are shown in Table V. The heat resistance of the flexural strength appeared to decrease when polypropylene fibers were incorporated into mortar. This is probably due to the additional porosity and small channels created in the matrix of mortar by the fibers melting like compressive strength. However the effect of the pozzolans on flexural strength is not clear but it seems that silica fume and glass types II have better impact on strength in compare with control specimens than rice husk ash and glass type I.

TABLE V
FLEXURAL STRENGTH OF CONTROL SAMPLES WITH 0% AND 1.5% FIBERS

Batch No	Flexural Strength (Mpa) 23°	300°	600°	PP fibers (by volume)
1	4	3.1	2.8	0
2	3	2.4	2.1	0
3	3.7	3.2	2.7	0
4	3.9	3.4	2.7	0
5	3.3	2.8	2.6	0
16	2.2	1	0.7	1.5
17	1.6	0.8	0.6	1.5
18	2	1.1	0.8	1.5
19	2.4	1.3	0.8	1.5
20	1.8	1	0.6	1.5

V. CONCLUSION

This research proves the effects of elevated temperature on polypropylene fiber reinforced mortar as a cement-based composite and improving impacts of some pozzolanic materials like silica fume, rice husk ash and especially finely ground glass on the strength of composite at high temperatures.

Based on the experimental results of this investigation the following conclusion can be drawn:

- Application of fibers in matrix causes the noticeable reduction in compressive and flexural strength.
- Mixture of cement based composite with GII and SF containing different percentage of fibers shown close mechanical properties to target specimens. So results show the great usage possibility of ground glass and silica fume in composite as a partial replacement of cement.
- According to the results, there was a significant different between the compressive strength of specimens which include Polypropylene fibers deal with plain specimens when expose to high temperature.
- In plain specimens by rising the temperature, size and rate of compressive strength reduction were not considerable. But results show that these difference rise up by increasing the fibers volume fraction in the matrix.
- The basic factor for strength reduction of fiber reinforced specimens is the melting of polypropylene fiber at temperature more than 190°C and generation of holes in the matrix.
- Also it's clear that increasing the temperature and fiber volume fracture in matrix, have a negative impact on density of specimens.

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