Recycling and Reuse of Polypropylene Fiber Waste

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The carpet waste fibers and waste glass that create a serious environmental problem can be converted into useful products. The use of these waste materials in a cement-based composite can be a promising direction for waste reduction and resources conservation. In this study, several tests carried out to investigate the performance of control mortar using recycled glass and fibers as a fraction of aggregates in a cement-based composite. These tests included compressive strength, flexural strength, flexural toughness and water absorption. The results revealed that carpet waste fiber and waste glass could be reused as substitutes for conventional materials in cement-based composites.

Keywords: Cement-based composite, carpet waste, waste glass, polypropylene fibers

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

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. A typical pozzolanic material features three characteristics: it should contain high silica contain, be X-ray amorphous, and has a large surface area .Compared to fly ash and silica fume, glass has a sufficient silica content and is amorphous in nature. The glass might satisfy the basic requirements for a pozzolan if it could be ground to a size fine enough to passify the alkali-silica reaction and to activate the pozzolanic behaviour [7-12].

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 both the alkali reaction and the reactive silica in glass [15].

Therefore, the reduction of glass particle size reduced the expansion that occurs due to the alkali reaction [16]. Partial replacement of fine aggregate in concrete by crushed glass reduced the mechanical strengths by approximately 5 to 10% [17]. Fly ash and silica fume have been also used as supplementary cementing materials to partially replace cement for many years. Both materials have shown beneficial pozzolanic reaction in concrete, which contribute substantially to concrete's strength and durability [18] .The glass might satisfy the basic requirements for the pozzolan if it could be ground to a size fine enough to active pozzolanic behaviour [11].

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 [19]. Natural and other synthetic fibers are added to cement as secondary reinforcement to control plastic shrinkage [20-22]. 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 [23].

Some results such as : permeability, abrasion and impact resistance are significantly improved by the addition of polypropylene fibers [24] but according to others the effect of polypropylene fibers on flexural, compressive, tensile strength , toughness and elastic modulus is not quite clear. Quite often, reports show either no effects or modest improvements of these properties. However, in some cases the addition of polypropylene fibers has been known to decrease the ultimate strength of hardened concrete [25-28].

Although many researchers studied the reuses of glass and polypropylene fibers in cement-based composite (table 1) but admixture of waste glass in fiber-reinforced cement-based composite have never been the issue.

Therefore, the main objective of this study is to evaluate the compressive and flexural strength, flexural toughness and water absorption of cement-based composite using recycled carpet fiber (polypropylene) and recycled glass.

Experimental part

Material and methods

Materials used in this study included ordinary portland cement type 1(OC), standard sand, silica fume(SF), glass with two particle size, rice husk ash(RHA), 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 2 and figure 1.

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Authors	Recycled material used	Authors	Recycled material used
Harrision, W.H.,1974[7]	Waste glass aggregates	Gerzibusky,Shan,1990	Recycled fiber
Johnston, C.D.,1974[8]	Waste glass as course aggregates	Balaguru, P.N.,1992[24]	Recycled fiber
Panchakarla,V.S.1996[15]	Recycled glass	WangY,&Cho,B.1993[27]	waste fiber
Meyer,C.& Baxter,S.1997[16]	Recycled glass in masonry block	Wang & youjiang,1994	Waste carpet
Reindl,J.1998[13]	Waste glass recycling	Kumar,S.,1994[25]	carpet fiber
Shao,Y,& Lefort,T.,2000[11]	Ground glass in concrete	Wang,Y.,1994[26]	Waste carpet
Wei,M.S. & Hung,K.H.2003[1]	Waste glass in concrete	Naaman,A.E., 1996,[23]	PP waste carpet fibers
Park, S.B. & Lee, B.C.,2004[14]	Mortar containing waste glass	Auchey,1996[21]	PP fiber
Shayan,A. & Xu,A,2004[12]	Waste glass in concrete	Wu.H.C.&Lim.Y.M,1996[22]	Recycled fiber
Chen,C.H & Huang,R.,2005	Ground waste glass	Wang ,Y.&Wu.H.C,2000[20]	Recycled fiber

Table 1
HISTORY OF MOST EXPERIMENTAL WORKS REPORTED ON WASTE GLASS AND PP FIBER

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

Table 2
PROPERTIES OF POLYPROPYLENE FIBERS REUSED IN THIS STUDY

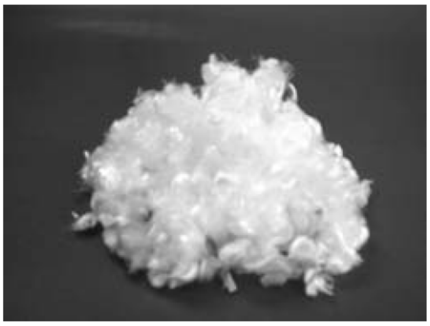

Fig. 1. Polypropylene fibers used in this study.

Table 3
CHEMICAL COMPOSITION OF MATERIALS

	Content (%)		
Oxide	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	-

Silica fume and rice husk ash used in this study contained 91.1 and 92.1% SiO_2 with average size of 7.38 μm and 15.83 μm respectively .Superplastizer was sika-viscocrete1 that density and *p*H were 1.05 kg/lit and 6. Curve size diagram was in according to ASTMC33. Density and finesse modulus were 2.62 and 2.83 gr/cm^3 respectively. Densities of SF and RH were 2.32 and 2.09 cm^2/gr, and specific surfaces 35500 and 9768 cm^2/gr. 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 (table 3).

The ground waste glass used in our laboratory is shown in figure 2. Size distribution of waste glass samples are represented in figure 3. To study the particle size effect, two different ground glasses (GI and G II):

-GI: ground glass having particles passing a #80 sieve (180 μm);

-G II: ground glass having particles passing a #200 sieve (75 μm).

Fig. 2. Ground waste glass samples used in this research

In figure 3, the particle size distribution for two types of ground glass, silica fume, rice husk ash and ordinary Portland cement were described using laser particle size set. As it can be seen, 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 GI and GII respectively have 42 and 70% fine particles smaller than 45μm that causes pozzolanic behaviour. Particle shapes of two kinds of glasses used in our research laboratory are illustrated in figure 4.

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). They were used to examine the effects of pozzolanic materials on mechanical properties of PP reinforced mortars. Based on our recent published results, the amount of pozzolans was 10% by weight of cement [28] which is an acceptable range and is most often used [29].

Meanwhile, polypropylene fibers were added by volume of specimens (contains 0.5%, 1 and 1.5% by total volume).

In the control mixes with no fibers, water to cementitious ratio of 0.47 was used whereas in modified mixes (with different amount of PP fibers) this ratio increased to 0.6 due to water absorption of fibers. The mix proportions of mortars used in this work are given in table 4.

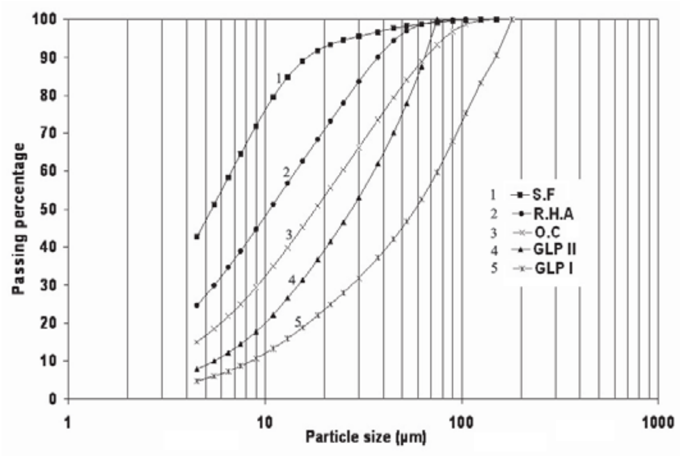

Fig. 3. Particle size distribution of ground waste glass G I, G II, silica fume, rice husk ash and ordinary cement

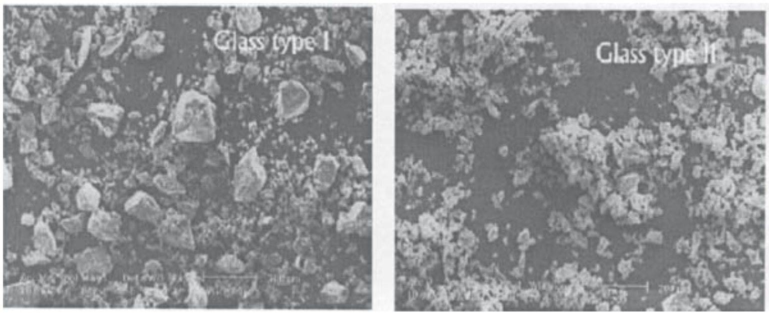

Fig. 4. Particle shape of ground waste glass type I and II (G I, G II)

Table 4
MIXTURE PROPORTIONS

Batch No	sand/c	w/c	Content (by weight)					PP fibers	Batch No	sand/c	w/c	Content (by weight)					PP fibers
			O.C	GI	GII	SF	RH	(by volume)				O.C	GI	GII	SF	RH	(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

The strength criteria of mortar specimens and impacts of polypropylene fibers on characteristics of these specimens were evaluated at the age of 7, 28 and 60 days.

In research laboratory, the test program was conducted as follows:

- the correct proportion of fibers was placed in the mixer attentively;
- three-quarters of the water was added to the fibers while the mixer was running at 60 rpm; mixing continues for one minute;
- the cement was gradually added while the mixer was still running. After adding the cement, the mixer is allowed to run for two minute to allow the cement to mix with the water;
- 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 x 50 x 50 mm for compressive strength tests and 50 x 50 x 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 h, the specimens were demoulded and cured in water at 20°C.

Results and discussions

Compressive strength

The variations of compressive strength with age are presented in figure 5. The compressive strength of the specimens containing composite cement in comparison with control specimens, without any fiber is represented in figure 5a. A significant decrease in compressive strength can be observed. In view of the above, the lowest decline belongs to the composite containing 10% silica fume (SF) and the highest is obtained for the composites containing 10% glass I (GI) and rice husk ash (RH). The compressive strength of SF specimens is in close agreement to target specimens due to the finest particle size and highest pozzolanic behaviour. This is however confirmed according to ASTM C618. In table 5 pozzolanic characteristics of three materials are presented that provide standard conditions. Meanwhile, glass GI exhibits low pozzolanic behaviour due to coarse particle size.

Nevertheless, the pozzolanic behaviour of rice husk ash in early age is low but by ageing the specimens, this effect will rise slightly.

The variation of compressive strength with age shows a continuous increase by decreasing the amount of polypropylene fibers in matrix (figs.5.b, c and d.). The specimens contain 1.5% PP fiber by volume exhibit 50% reduction in compressive, in compression to control specimen. It should be noted that the variation of strength in mortars contained 0.5% PP by volume is not significant. Despite of compressive strength decrement in reinforced matrix contained PP fiber, the specimens which contains silica fume (SF) and PP fiber have shown greater compressive strength than the others. Moreover GII approximately indicates the same results to target specimens.

Table 5
POZZOLANIC CHARACTERISTICS OF MATERIALS

Characterestics	Test results			Standard requirements
	S.F.	R.H.	W.G.	
$SiO_2+Al_2O_3+Fe_2O_3$	94.66%	92.84%	73.92%	>70%
SO_3	0.54%	-	0.18%	< 4%
Humidity	0.50%	1%	0%	< 3%

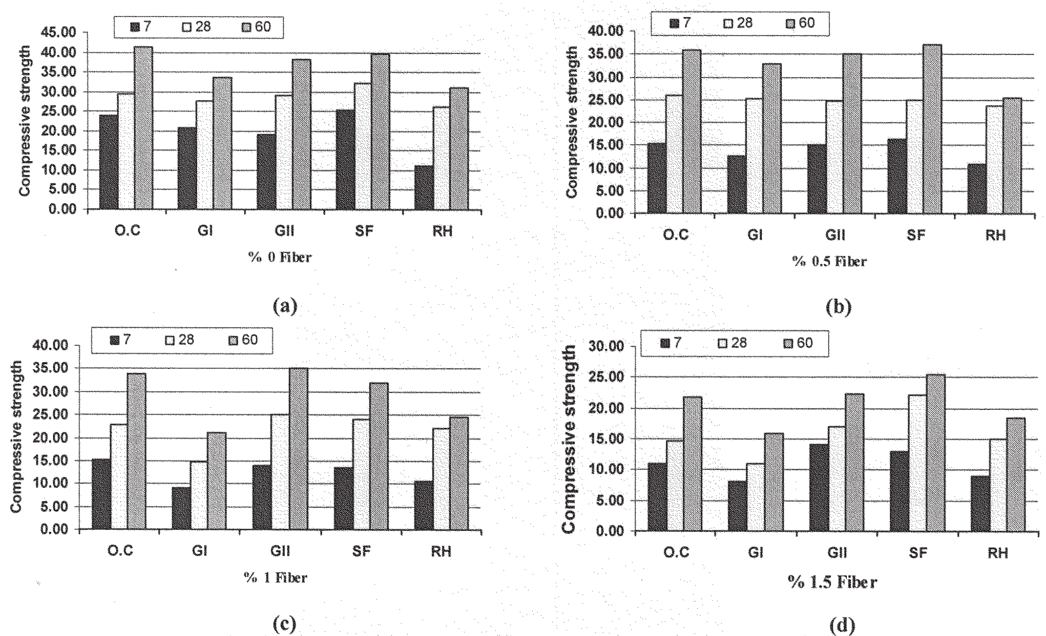

Fig. 5. Compressive strength of cement composite versus curing time

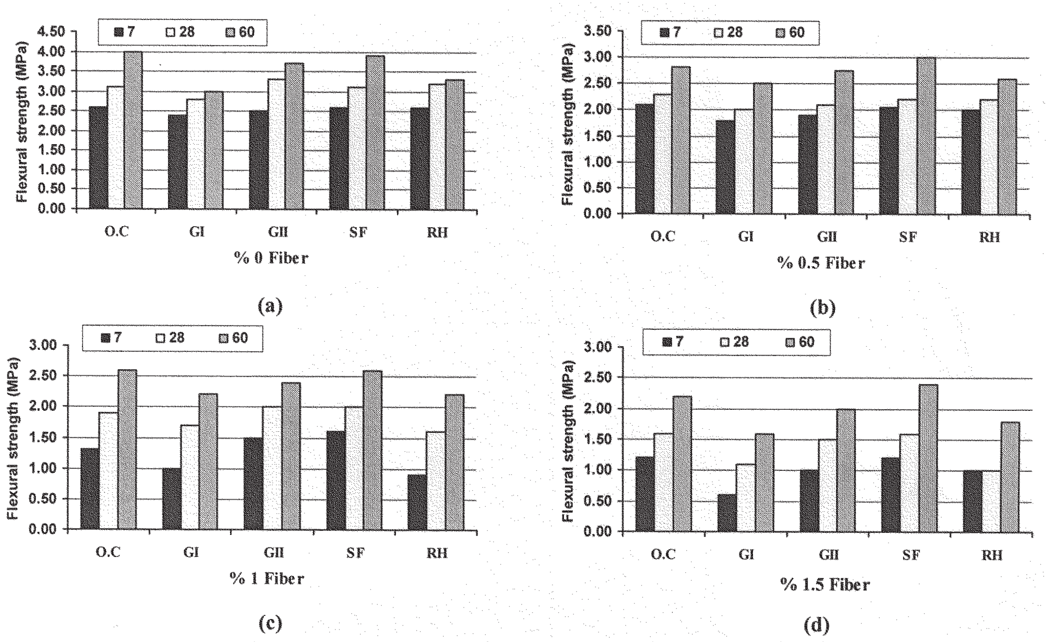

Fig. 6. Flexural strength of cement composite versus curing time

In general, results indicate that silica fume and glass G II have an appropriate potential to apply as a part replacement in cement due to their respective pozzolanic activity index values (according to ASTM C618 and C989, and table 3).

Flexural strength

The effect of fiber volume fraction, and the age of the mortar matrix on the flexural strength are presented in figure 6.

The 50 x 50 x 200 mm beam was tested in three-point (i.e., center-point) bending with the span of 180 mm. The test results are shown in figure 7. The test was controlled automatically by computer with a constant cross head movement of 1 mm/min. Results show, by increasing the amount of fiber in matrix of specimens, the flexural strength tends to decrease.

According to above results, the highest flexural strength was observed in O.C, 10%SF and 10%GП, which is due to pozzolanic activity mentioned before.

The flexural strength of specimens containing 0.5% PP fiber doesn't show considerable increment. Nevertheless,

Batch No	Water absorption	Batch No	Water absorption	Batch No	Water absorption	Batch No	Water absorption
1	5.83	6	7.10	11	8.50	16	10.80
2	5.30	7	7.42	12	8.80	17	10.52
3	5.16	8	6.59	13	8.12	18	10.22
4	4.36	9	5.42	14	6.37	19	8.15
5	4.77	10	5.30	15	6.79	20	8.42

Table 6
WATER ABSORPTION OF ALL MIXES

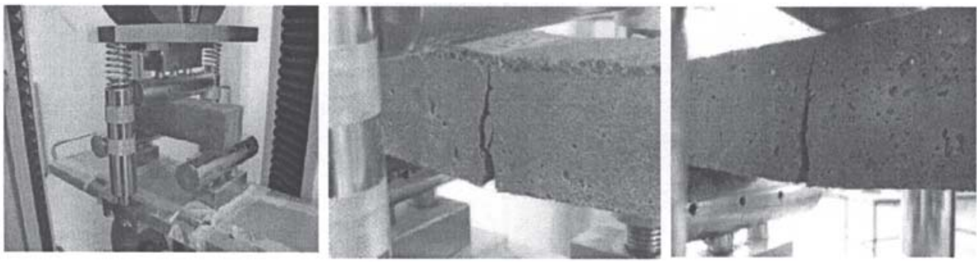

Fig. 7. Cracking of flexural specimens and bridging effect of fiber on cracks

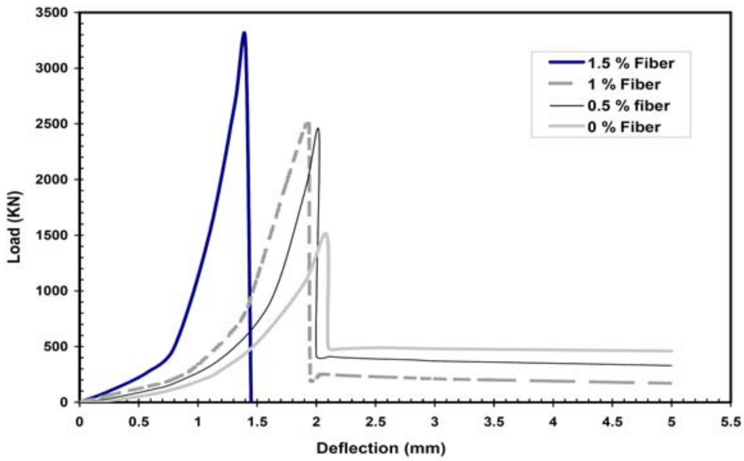

Fig. 8. Load-Deflection Response of plain and polypropylene fiber reinforced mortar

the composite containing 1 and 1.5% PP fibers, presents a relative increment in flexural strength.

It is also observed that the lowest strength is related to GI in all mixes due to coarse particle size and low pozzolanic behavior.

Flexural toughness

Toughness is defined as the ability of materials to sustain load after initial cracking and is measured as the total strain experienced at failure. Upon cracking, fibers are able to bridge the initial crack and hold the crack together and sustain the load until the fibers either pull-out from the matrix (in early age) or fracture that say flexural toughness. According to figure 7 it can be observed that after crack initiation, fibers can still carry load and absorb the energy.

Figure 8 represents typical load-deflection responses of control mortar and mixtures contained 0.5, 1, and 1.5% fibers.

For control mortars, the behaviour was in a brittle manner. When the strain energy was high enough to cause the crack to self-propagate, fracture occurred almost while the peak load was reached (this is due to the tremendous amount of energy being released). According to figure 8, the fiber bridging effect helped to control the rate of energy release significantly. Thus, fibers still can carry load even after the peak. With the effect of fibers bridging across the crack surface, fibers were able to maintain the load carrying ability even after the mortar had been cracked. These are in according to ASTM C1018, in which toughness or energy absorption defined as the area under the load-deflection curve from crack point to 1/150 of span.

Our laboratory results indicate that, by increasing the amount of fiber in matrix flexural toughness rise up.

Water absorption

Water absorption of specimens is measured and evaluated in table 6 according to ASTM C642.

At 28 days curing in water surfaces of specimens were dried with towel, and weighted. The surface dried specimens were kept in oven at 110°C for 48 h. After drying and cooling , we determine weight of dried specimens. Absorption was less than 0.5%. In general, the incorporation of SF improves the water absorption properties of the material because of the reduction of capillary porosity. The same behaviour was reported by Aguilar et al [31] when they studied steel and nylon fiber reinforced Portland cement matrixes with additions of SF and GGBS (granulated blast furnace).

A reduction in water absorption is expected when a pozzolanic material is added to the cement matrix. SF addition had the greatest effect, followed by RH and GII addition but GI does not show a significant effect on water absorption. This is due to particle size and then, pozzolanic activity of materials.

This explains that by increasing the fiber percentage in the matrix of mortars, water absorption will increase, as well.

Conclusions

This research concerns the feasibility of the use of glass as aggregates replacement and PP fibers for composite reinforcement. Based on the experimental results of this investigation the following conclusions can be drawn.

Application of fibers in matrix causes the noticeable reduction in compressive and flexural strength.

Adding of high reactive pozzolans like silica fume and well grounded glass has a significant effect on the toughness. Increasing polypropylene fiber volume fraction resulted in an improvement in post-peak flexural strength of fiber reinforced pozzolanic mixtures.

Mixture of cement based composite with GII and SF containing different percentage of fibers shown close properties to target specimens. So results show the great possibility of usage of ground glass and silica fume in mortars as a replacement in cement.

Increasing the fibers in matrix causes low compressive strength, but it increases the flexural toughness substantially. In fact the ability for absorbing the energy rises up.

Water absorption will decrease by addition of pozzolanic materials in to the matrix because of fine particle size and covering the permeable voids.

According to the laboratory results it is obvious that the ground glass GII has a high pozzolanic activity deal with silica fume and rice husk ash.

The reduction in compressive strength of mixtures with carpet waste fibers may limit its use in some structural applications, but fibers matrix reinforced has some desirable characteristics such as lower density, enhanced ductility and toughness resistance.

According to our study, addition of pozzolans to the cement-matrix, can improve the mechanical properties of fiber reinforced specimens.

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