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Research Article

Mechanical Properties of Lightweight Concrete Partition with a Core of Textile Waste

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This investigation is focused on bending experiment of some prismatic perlite lightweight concrete. In these samples, textile waste fibers are confined with textile mesh glass fiber and embedded in the central part of cubic lightweight concrete specimens. Bending experiments revealed that lightweight concrete panels with a core of textile waste fiber have less density than water and high energy absorption and ductility. Furthermore, these composite panels by having appropriate thermal insulation characteristics could be used for partitioning in the buildings.

1. Introduction

In advanced industrialized countries, the utilization of fibers in concrete began in the early 1960s [1]. The type and form of fibers and also the construction of fiber-reinforced concrete (FRC) have improved significantly during the past five decades, and their employment have been on the rise [2, 3]. Improving the mechanical properties of concrete using the random distribution of fibers in it has been the topic of interest of numerous research studies [3–7]. Between 1994 and 2011, Wang et al. carried out several research efforts on adding carpet waste fibers to concrete and soil. In this research, the old carpets were transformed into fibers. These fibers were not necessarily of the same size and were actually used in many different shapes and sizes in concrete and soil. After compressive and bending experiments, the results showed that the usage of waste fibers had significant effects on the resistance of failure, stiffness, and ductility of concrete. The usage of this cheap waste in concrete has also increased the durability of concrete [8–10].

In recent years, dos Reis et al. examined the mechanical properties of FRC with textile waste fibers. In this research, the textile wastes of Nova Friburgo industry, located in Rio de Janeiro in Brazil, were used. The general purposes of this research were exploring the mechanical properties of reinforced polymer concrete and best use of textile waste fibers considering increased production of this kind of waste in Brazil. On an overall result, it was stated that the cutting waste textile fibers mixed with polymer concrete produce a unique composite material which had lower flexural and compressive characteristics as compared to unreinforced polymer concrete. Using these textile wastes in concrete lead to a smoother failure, unlike brittleness failure behavior of unreinforced polymer concrete. Furthermore, the usage of textile waste may solve the problems like environmental pollution and provision of an alternative material for the construction industry [11, 12]. Previous research studies on random distribution of fibers in concrete have been done mainly to prevent the concrete from cracking in the early hours or to improve the mechanical properties of concrete. Moreover, the percentage of fibers used in the concrete has been insignificant (about 1 to 5 percent of volume) [8–13]. However, the present study aims at widespread usage of textile waste as the fiber core in central part of panels, which resulted in more environmental friendliness and more light weighting in nonstructural elements of the buildings.

In this study, textile waste fibers were confined in textile mesh glass fiber and used as central layer of lightweight concrete. Textile mesh glass fibers are ecofriendly materials that are made of alkali resistance fibers and can be used for reinforcing thin and lightweight parts of concrete [14–19]. These properties were major cause of using textile meshes in lightweight concrete.

2. Research Significance

Every year, due to manufacturing process of industrial activities, wide range of wastes generate in the world. This not only poses a threat to the environment but also represents wastes of useful resources. Therefore, in recent decades, most of the efforts have been conducted to recycling and reutilization activities in order to reduce waste materials. One of the waste materials is textile waste. Due to the growth in world population and increase in demand for textile products in different categories of our life, textile wastes definitely make up a significant portion of industrial wastes. These soft wastes in addition to reinforcing properties can be used for filling purpose in cement composites and construction materials. Using textile waste fibers for filling purpose, which is the main aim of this research, not only causes elimination of these voluminous wastes but also introduces a new and low cost alternative in construction industry.

3. Experimental Investigation

3.1. Materials. The following materials were used in the present investigation.

3.1.1. Textile Waste Fibers. With reference to the impressive services of textile industry and its main role in our life, every year a huge amount of waste materials are produced in this industry. Textile waste has been rated as the third in comparison to plastics and cardboards [1, 20]. In this investigation, the least quality of cotton waste fibers was used due to its low density, thermal conductivity, and low cost. Cotton fibers are classified in natural plant fibers which have huge amount of waste in the initial production steps of textile industry [20–23]. Tensile resistance and density of these fibers are insignificant [21–24].

3.1.2. Textile Mesh Glass Fiber. Woven meshes of glass fibers (Textile mesh glass fiber) were used to confine the waste fibers in the lightweight concrete specimens (see Figure 1).

The mentioned meshes are commercially known as 75 g meshes. This number indicates its weight per one square meter. The size of the apertures is 4 × 4 mm. Some usages of these meshes are the strengthening of plaster and concrete parts, walls, floorings and roofs. They also prevent the deformation and extension of cracks in concrete and improve the mechanical properties of polymer pipes. More details are reported in Table 1 [14–19].

3.1.3. Lightweight Concrete. In this investigation, all the specimens were constructed of lightweight perlite concrete. Lightweight concrete was prepared from the volumetric mixture of cement and lightweight perlite aggregate. Type II Portland cement with a bulk density of 1160 kg/m^3 corresponding to ASTM standards was used. Moreover, perlite aggregate due to its bulk density 115 kg/m^3 with a 9.5 mm maximum size was used [1, 23, 24].

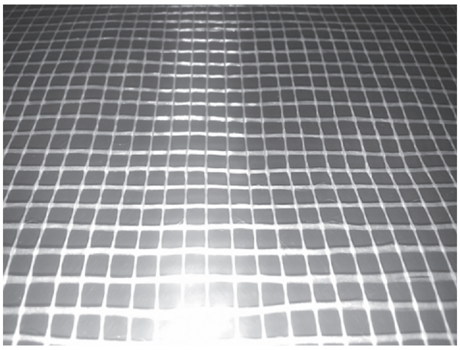

Figure 1: Textile mesh glass fiber (AFM75).

3.2. Mixing, Casting, and Curing. For all mixing, with and without fiber core, a water-cement ratio (w/c) of 0.45 was used, and the amount of perlite and cement were kept constant.

A number of concrete specimens were tested in this study, which are defined below and in Table 2.

(i) PC2: the PC2 specimens were prepared with the dimensions of 50 × 10 × 10 cm. In preparing the PC2s, lightweight aggregate concrete with a volume ratio of 1 cement, 2 perlite, and a water cement ratio of 0.45 was employed [1, 23, 24].

(ii) FPC25: FPC25s were the same as PC2s, but in its inner part, a core of cotton waste fibers, which was confined in a woven grid of glass fibers of 40 × 5 × 5 cm, was placed.

(iii) FPC26: the FPC26 specimens were the same as FPC25s, but in its inner part, a core of cotton waste fibers, which were confined in a woven grid of glass fibers of 40 × 6 × 6 cm, was placed.

Figure 2 showes the schematic view of the FPC specimens.

The process of mixing the specimens is included the following stages. At first, the lightweight perlite aggregates were placed in the mixer and dry-mixed for one minute at constant speed. Then, the cement was added to the mixture, and the materials were dry-mixed for another one minute. At last, the required amount of water was supplied gradually and the mixing process continued for 2 minutes. In order to determine compressive strength of lightweight concrete, which was used in all specimens (with and without fiber core specimens), cubic specimens by dimensions of 100 × 100 × 100 mm were prepared. Three layers of lightweight concrete were placed in the molds and were consolidated. Compressive specimens were tested in accordance to ASTM C39 [25] at 28 days age. This test was performed by digital automatic testing machine with the load rate of 100 kg/sec. The compressive strength of specimens was calculated by dividing the maximum load attained during the test to the total cross-sectional area of the specimen.

Table 1: Properties of textile mesh glass fiber.

Code AFM75	Yarn tex		Density (counts/25 mm)		Tensile strength (N/5 cm × 20 m)		Treated
	Warp	Weft	Warp	Weft	Warp	Weft	Woven mass
	132	132	6	6	>700	>700	75

Table 2: Mix design and properties of specimens.

Specimen	Volume ratio of cement	Volume ratio of perlite	(w/c)	Dimensions of the fiber core
PC2	1	2	0.45	Without central fiber
PC25	1	2	0.45	5 × 5 × 40 cm
PC26	1	2	0.45	6 × 6 × 40 cm

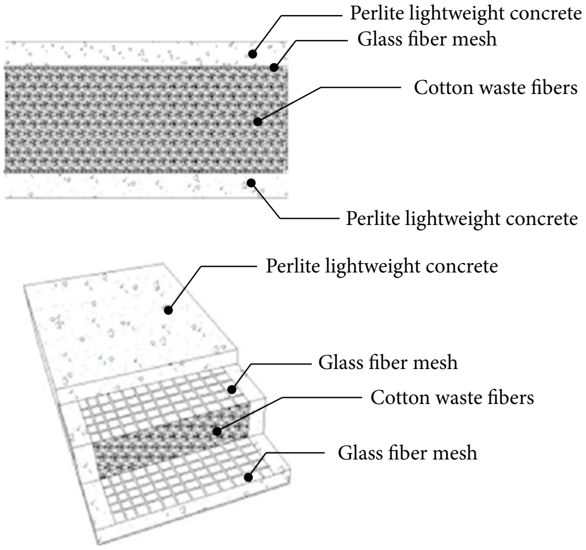

Figure 2: 2D and 3D display of the FPC specimens and their components.

Concrete prisms of 500 × 100 × 100 mm dimensions were also used for flexural testing. In order to make flexural specimens with central fiber core, a layer of concrete with a thickness of 2 or 2.5 cm (depending on the dimensions of central fiber core) was placed in the mold, firstly. Then, the fiber core was very accurately placed in the center of the mold while the concrete was being filled around it. At last, the upper layer was also filled with concrete. All samples were kept for 10 seconds on external vibrator system. After the molding process, the specimens were kept in an average temperature in the testing department for a period of 24 hours. Then, all specimens were demolded and were stored in the water tank at a constant 20 ± 2°C for 28 days until the experiment day.

Bending and compressive samples of lightweight concrete were examined in this study. Perlite lightweight concrete with a core of textile waste fiber was used only for the experimenting bending behavior. Three specimens from each sample were prepared for testing.

In accordance with ASTM C1018 standard test [26], molded or sawn specimens with thick sections shall be turned on their side with respect to the position as cast, before placing on the support system. So for performing the flexural experiments, all the samples were turned 90° and were placed on the support system of flexural testing machine. The distance from one center to another on the support system was 45 cm, and the distance between the two centers of the concentrated loading was 15 cm. The point of effective load was calculated to be one third of the middle span of the beam. The rate of load generated in this experiment was slow in order to get the exact results for future data (this happened at a rate of 2 kg/sec with a deflection gauge of 3 cm and exactness of 0.01 mm, which was placed exactly at the center point of the specimens). After the results were acquired, the load-deflection curves for all specimens were drawn and toughness indices, absolute toughness, residual strength factor (RSF), and all the other related calculations were carried out with respect to the ASTM C1018 standard test method. Calculating the area under the load-deflection curve on specific deflections up to the first crack and up to the specified end point deflection, we can obtain the toughness indices of flexural specimens. More results from load-deflection curves were calculated in accordance to ASTM C1018-97 [26].

4. Results and Discussion

4.1. Compressive and Flexural Strength. Compressive strength of perlite lightweight concrete, which was used in all specimens, was averagely 91.9 kg/cm^2, and its specific gravity was 1269.8 kg/m^3. As per ASTM C331-81 [27], this kind of concrete is known as semi-structural lightweight concrete.

Figure 3 shows the failure behavior of PC2 specimens (without fiber core specimens) after the flexural experiment. Also, Figure 4 shows the failure behavior of FPC25, which shows the failure pattern of FPCs after the flexural experiment.

Considering the figures, overall results are obtained as follows.

(i) The breaking of all samples in the one-third point of the center of the cube is of a flexural breakage type. So, in this regard, all of the standard regulation of ASTM C1018-97 has been regarded.

(ii) As it could be seen, those samples without a fiber core face a brittle break but those with a fiber core break softly. It means that the samples of PC2 collapse immediately after the first crack. In other words, the first-crack point is a coincident with the ultimate failure point. Therefore, the ductility of these samples

Figure 3: Brittle break of specimens without a fiber core (PC2).

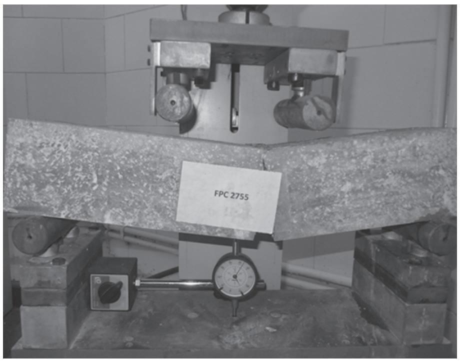

Figure 4: Soft break of FPC25.

is very low. However, after the first crack has initiated in the samples having a fiber core, it can withstand the load until 30 mm deflection without collapsing. This specimen has a high ductility characteristic.

The values of first-crack strength, first-crack deflection, toughness indices, and residual strength factors are reported in Table 3.

4.2. First-Crack Strength. The first-crack strength represents the behavior of fiber-reinforced concrete up to the first crack in cement matrix [28]. It can be seen from the results of Table 3 that the first-crack strength is approximately similar for all the 5 cm fiber core specimens. This amount is more than the first-crack strength of specimens with 6 cm fiber core and lower than the first-crack strength of plain specimens (without fiber core). As per Table 3, first-crack deflections of all specimens are also about 0.3 mm.

4.3. Toughness Indices. The area beneath the load-deflection curve indicates the amount of absorbed energy and toughness indices.

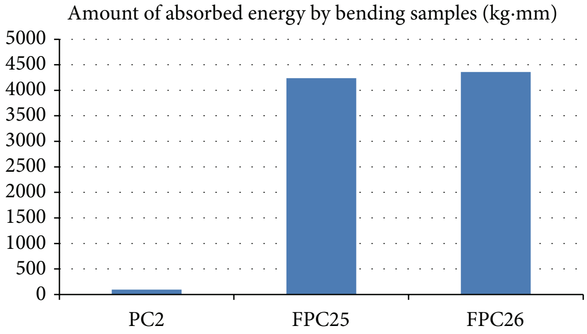

Figure 5: Amount of absorbed energy by bending samples in kg·mm.

Definition of ASTM C1018 for I_5: I_5 is defined as the area under the load-deflection curve up to a deflection of 3 times of the first crack deflection divided by the area until the first crack.

Definition of ASTM C1018 for I_{10}: I_{10} is defined as the area under the load-deflection curve up to a deflection of 5.5 times of the first crack deflection divided by the area until the first crack.

Definition of ASTM C1018 for I_{20}: I_{20} is defined as the area under the load-deflection curve up to a deflection of 10.5 times of the first crack deflection divided by the area until the first crack [25].

It can be seen from Table 3 that the lightweight panel with a 5 cm fiber core consistently has higher toughness indices compared to the lightweight panel with a 6 cm fiber core. This result indicates that the ratio of postpeak crack to prepeak crack area is relatively higher for FPC25 specimens compared to FPC26s.

The absolute toughness is the amount of absorbed energy by materials. This value was estimated by determining the area under the load-deflection curve up to the point of ultimate failure. The absolute toughness or absorbed energy of PC2s, FPC25s, and FPC26s is, respectively, 96.4 kg·mm, 4235.9 kg·mm, and 4360 kg·mm. In other words, the absorbed energy via FPC25 and FPC26 samples is, respectively, 24 and 25 times as much as the PC2 samples (see Figure 5). This significant increase in the amount of absorbed energy indicates a greater ductility and bending ability of FPCs. The difference in the amount of absorbed energy by FPCs compared to plain specimens can be due to using and orientation of the textile mesh glass fiber in the lightweight cement matrix. Moreover, textile warps of glass fiber meshes in the FPC25 and FPC26 specimens were placed in the same direction as the tensile forces. Therefore, higher resistance against deflection and propagation of macrocracks, by transfer forces in the concrete matrix, was achieved.

4.4. Residual Strength Factors (RSFs). The residual strength factors represent the average level of retained post crack strength, over specific deflections, as a percentage of the first-crack strength. These factors, which are acquired directly from toughness indices, were calculated in accordance to

Table 3: The values of first-crack strength, first-crack deflection, toughness indices, and residual strength factors of bending specimens.

Specimen code	Age at test	First-crack strength (kg·f)	First-crack deflection	Toughness indices			Residual strength factor	
				I_5	I_{10}	I_{20}	$R_{5,10}$	$R_{10,20}$
PC2	28 days	563.7	0.335	—	—	—	—	—
FPC25	28 days	459	0.333	4.23	6.84	9.20	52.2	23.6
FPC26	28 days	373	0.313	3.94	5.94	8.97	40	30.3

ASTM C1018 standard test methods using the following equations [25]:

$$R_{5,10} = 20\left(I_{10} - I_5\right),$$
$$R_{10,20} = 10\left(I_{20} - I_{10}\right), \tag{1}$$

where I_5, I_{10}, and I_{20} are toughness indices which are defined in Section 4.3.

The increase in dimensions of central fiber core did not significantly improve the residual strength of the panels. According to Table 3, value of $R_{5,10}$ for FPC25 specimens is higher than FPC26. This result indicates that post peak behavior of FPC25s, interval 3 to 5.5 times of first-crack deflection, is better than FPC26s. Generally, higher values of residual strength factors, near to 100, correspond to perfectly plastic behavior of materials, and lower values show inferior performance [25].

4.5. Load-Deflection Curve. Figure 6 shows the load-deflection curves of the bending specimens. As per this figure, the behaviors of the bending samples are divided into two different types. Type one is the behavior of PC2 samples that are completely linear (elastic) and does not enter into the plastic region. In these specimens, the ultimate load coincides with the maximum deflection point and the ultimate failure point. The load-deflection curve of PC2 specimens is completely on the rise. Type two behavior is displayed by the FPC25s and FPC26s, where the first peak is followed by a drop in the load and then a plateau or hardening with a second peak is continued up to the ultimate failure. These specimens have shown the elastic-plastic behavior and high ductility.

According to the load-deflection curves, the behavior of all samples before the first cracks is approximately the same, and with the use of the fiber core and increase in its dimensions, the first crack deflections of the samples have not much changed. However, the first crack strength decreases, and its reason is the decrease in concrete covering around the central core.

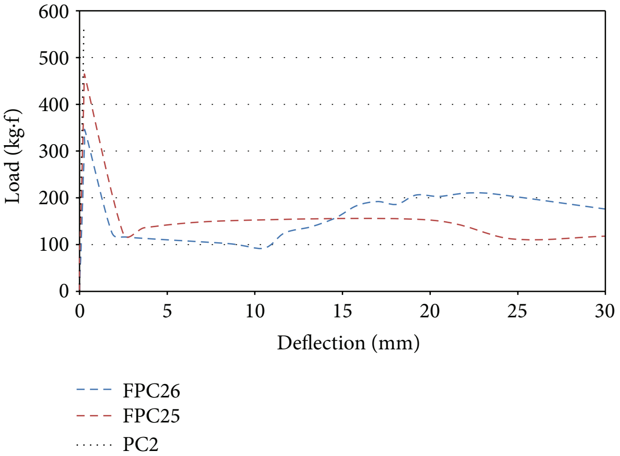

Figure 6: Load-deflection curve of PC2, FPC25, and FPC26 specimens.

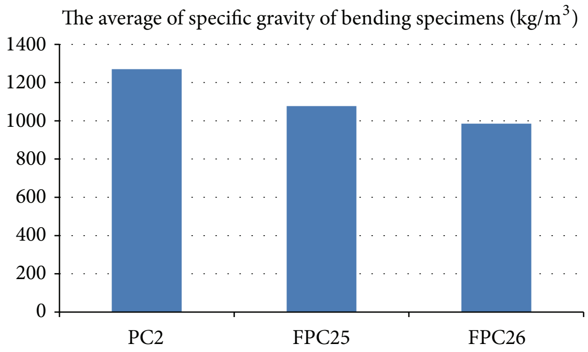

Figure 7: The average of specific gravity of bending specimens in kg/m^3.

5. Light Weighting

The weight of various specimens was determined by using a balance at a precision of 0.5 g. After weighting the specimens, the mean value of density was calculated in accordance with ASTM C138 [29]. Figure 7 shows the specific gravity of different specimens. It can be observed from Figure 7 that fiber composite specimens, with a 5 cm fiber core (FPC25), are 15% lighter than the other sample (PC2). The samples with a 6 cm fiber core (FPC26) are even 22.5% lighter than the PC2 samples. This decrease in density has a positive effect on reducing the dead load of the buildings, which causes a decrease in the resulting forces of earthquake. This not only improves the building's safety factor but also reduces the costs of building construction. Furthermore, lighter material simplifies the construction process and reduces the costs of transport [24, 28, 30].

6. Thermal Insulation

One of the important factors that causes heat energy dissipation in a building is not using the appropriate insulation in the walls. It could be said that a big part of the interior and exterior of a building is composed of walls. If the walls

Table 4: Thermal conductivity of materials forming the perlite lightweight concrete panel.

Material/substance	Thermal conductivity (W/mk)
Cotton wool	0.029
Perlite, vacuum	0.00137
Concrete, lightweight	0.1–0.3

are constructed ideally using suitable materials, they can prevent energy from escaping, effectively. For this purpose, precast concrete sandwich panels have been widely used from 1960 to now [31]. These panels consist of outer concrete or lightweight concrete layers surrounding insulation layer [32, 33]. Lightweight concrete due to its aggregates porosity could be more effective than conventional concrete in heat preservation [30, 34]. Moreover, the insulated layer, which is made of polystyrene or polyurethane, and so forth [35, 36] by control the thermal efficiency of the panels, could reduce the heating and cooling costs of the buildings [31, 32].

The present composite panel in this study is a suitable insulating material to prevent transferring and wasting heat energy due to presence of such elements like perlite porosity lightweight aggregate and textile fiber core [37–39].

According to the 19th part of Iranian national building regulations, thermal conductivity is the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area, due to a unit temperature gradient under steady state conditions. Thermal conductivity of components of lightweight panel is indicated in Table 4 [38, 39].

According to Table 4, the maximum thermal conductivity of lightweight concrete is 0.3 W/mk. Due to small amounts of thermal conductivity of perlite and cotton, thermal conductivity of panel is certainly lower than 0.3 W/mk [38, 39].

7. Conclusion

Textile waste as fiber core in central part of lightweight panels has proven to be an interesting way for deduction of environmental pressure of both the huge amount of solid wastes and extra use of virgin resources, as well. Moreover, experiments showed that by using lightweight materials a light-weighting insulated panel is achieved, and due to the confinement of textile mesh glass fiber, the postcrack behavior of lightweight panel has improved.

It is expected that this research causes an increase in using this kind of low cost textile wastes in construction industry, and further full-scale experiments on indicated panel will be performed.

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