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Effect of PET Plastic Cut Pieces' Aspect Ratio on Fresh and Mechanical Properties of Cement Mortar

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Abstract - Polyethylene terephthalate (PET) fibers are generally used as a discrete reinforcement in the substitution of steel fibers for improving certain properties of cementitious materials. The aim of this paper is to investigate the effect of fibers' content and dimensions on the fresh and mechanical properties of mortar. For this purpose fibers obtained from the previously consumed water PET bottles with four various percentages of 0, 0.25%, 0.5%, and 0.75% were incorporated in mortar mixtures. In addition, the fibers had 3 different dimensions of 2×10 mm, 2×20 mm, and 5×20 mm. Therefore, the width, length, and content of PET fibers were selected as the experimental variables. The fresh properties such as workability and fresh density were measured along with mechanical properties (compressive, flexural, and splitting strengths). The results indicate that both workability and fresh density of mortar mixtures have considerably decreased with the incorporation of PET fibers. While this reduction was more significant for longer fibers than shorter ones and thinner fibers compared to the wider ones. Moreover, the mechanical properties were improved with the incorporation of fibers compared to the control specimens and this improvement was more remarkable for longer fibers. The samples containing PET fibers showed more ductile behaviors in comparison to the brittle performances of reference samples.

Keywords**:** Mortar, PET plastic fibers, Fibers dimensions, Fresh properties, Mechanical strengths

1. Introduction

Recently, the huge amount of low biodegradability wastes, practically waste plastic resulted in serious challenges to environmental pollution and public health. Hence, the reuse of plastic wastes could be counted as one of the important ways of sustainable waste management and helps to save natural resources and decrease environmental pollution [1–3].

Polyethylene Terephthalate (PET) is one of the widely used and most known types of plastics, particularly for the production of beverage bottles, packing, etc. In addition, this kind of plastic has high mechanical strength, impact resistance, rigidity, good durability resistance against severe environments, etc. Overall, the consumption of PET bottles was 250,000 million bottles which is equal to 10 million tons in 2007 and this amount has increased by 15% every year. These bottles are thrown away after single usage which is causing many environmental problems [4–6].

There are many solutions to this huge amount of plastic waste but one possible and effective way could be the usage of plastic wastes in cementitious materials. Mainly, researchers utilized plastic wastes in two different methods as aggregates replacement or as incorporated fibers in cementitious mixtures. While these incorporated materials can be obtained from polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polystyrene, etc. [7].

Applications of waste plastic to cementitious materials are common and many researchers have studied the effect of such wastes on various properties of cementitious materials [8,9]. For instance, research work was performed to investigate the physical and mechanical properties of PET fiber-reinforced mortar. The authors found that the bulk density of mortar has considerably decreased with the increase of PET fibers, while the incorporation of fibers resulted in better and improved compressive and flexural strengths [10]. Besides, the effect of polypropylene/polyethylene (PP/PE) blended fibers was investigated on certain properties of mortar. The results observed that slump value and apparent density have decreased remarkably for fiber-based mortar compared to the control ones [11].

On the other hand, the geometry and dimensions of fibers are important aspects and have a remarkable effect on various properties of cementitious materials. For instance, it was studied to investigate the effect of volume fraction and aspect ratio of PET fibers on the fresh, physical, and mechanical behaviors of concrete. The outcomes clearly demonstrate that the workability and dry density of concrete containing fibers have reduced significantly compared to the control ones and decreased further with the increase of fibers content. The compressive, flexural, and split tensile strengths have improved to somewhat percentages but decreased back for a higher amount of fibers. As a comparison reduction in the slump and dry density was more for thinner fibers than the wider ones. Moreover, the improvement in mechanical properties was more for fiber with a high aspect ratio compared to the lower ones [12]. Furthermore, the effect of fibers dimensions on some properties of concrete was studied, and found that the mixtures with longer fibers had reduced workability compared to the shorter ones. However, the compressive, flexural, and tensile strength was improved with the incorporation of fibers, but small size fibers had better mechanical properties compared to the ones with longer fibers [13]. Likewise, researchers found that the physical and mechanical properties of concrete strongly depended on the dimensions of PET fibers. They found that the workability has decreased with the increase of fiber content and length, while such value increased with the increase of fiber width. The compressive strength decreased with the increase of fiber content and this reduction was more significant for wider fibers than the shorter ones. But the flexural strength improved considerably with the incorporation of PET fibers, and such property was increased further for longer fibers, but decreased back with the increase of fibers width [14].

This article mainly explains the incorporation of PET fibers derived from mineral water bottles and cut by hand into various dimensions. The main variables were the percentage, length, and width of fibers, in order to investigate the effect of such variables on the workability, fresh density, compressive strength, flexural strength, and split tensile strength.

2. Experimental Program

2.1. Materials

Ordinary Portland cement named GHORI was used in the present experimental work conforming to ASTM C150 [15]. The physical properties of GHORI cement are: Fineness (75 micron sieve) = 6.0 %, specific gravity = 3.041, and Blain surface area = 2900 cm^2/gr. Locally available natural sand derived from the river was used as fine aggregates and has a specific gravity of 2.65, water absorption of 1.3 %, and bulk density of 1787 Kg/m^3. Furthermore, PET fibers were obtained from the previously consumed water PET bottles of Alocozay Company [16] as shown in Fig. 1. The fibers were cut by hand with various dimensions of 2 mm, and 5 mm in width, as well as 10 mm, and 20 mm in length, and the thickness of all PET fibers was 0.34 mm.

2×10 mm 2×20 mm 5×20 mm

Fig. 1: Fibers with various dimensions

2.2. Mix Design and Testing Procedures

In order to prepare the mortar mixtures, standard mix proportion was used but with slight modifications. It means that PET fibers with various percentages were incorporated, and then a superplasticizer was also added because of the diverse effect of such fibers on the workability properties of mortar mixtures as presented in Table 1. The amount of fibers for one batch is calculated by taking the mass of cement + sand as 1800 gr. For example, 0.25% fibers content by mass of cement + sand is taken as 0.25×1800/100 = 4.5 gr for one batch of standard mortar.

Table 1. Mix proportion of the mortar mixtures

Materials	**Weight of materials (gr)**			
	0%	**0.25**	**0.5%**	**0.75%**

	%			
Sand	1350	1350	1350	1350
Cement	450	450	450	450
Water	225	225	225	225
PET fibers	-	4.5	9.0	13.5
Superplasticizer	-	3.4	6.8	9.6

Furthermore, the workability of mortar mixtures was measured with the help of a slump cone according to EN 1015-3 [17] specifications. While watertight measuring vessels were used to evaluate the density of mortar at the fresh state based on EN 1015-6/A1 [18] code considerations. The flexural strength was measured using 40×40×160 mm prisms and then the same specimens after the flexural test were used for the compressive strength. Both values were observed with the help of ADR-Auto 250/25 cement machine according to EN 1015-11 [19] code specifications. Finally, the split tensile strength was measured using 75×150 mm cylinders with the help of ADR touch SOLO 1500 machine and EN 12390-6 [20] code considerations.

3. Results And Discussions

3.1. Fresh Properties

3.1.1. Workability

The workability of mortar mixtures containing various percentages and dimensions of PET fibers is shown in Fig. 2. The results underline that the workability of mortar mixtures has considerably decreased with the incorporation of PET fibers and such reduction was more significant for a higher percentage, independent of fiber dimensions. This is because of the higher friction between PET fibers and mortar ingredients. Besides, the large surface area of fibers resulting in the absorption of more cement paste which causes the reduction of mortar slump. However, this reduction was more remarkable for the mixtures containing longer fibers than the shorter ones. Besides, the mortar mixtures containing wider PET fibers were more workable and had a higher slump value compared to the mixtures containing thinner fibers. This is because the slim and longer PET fiber tended to agglomerate mortar mixtures and resulting in the reduction of its fluidity.

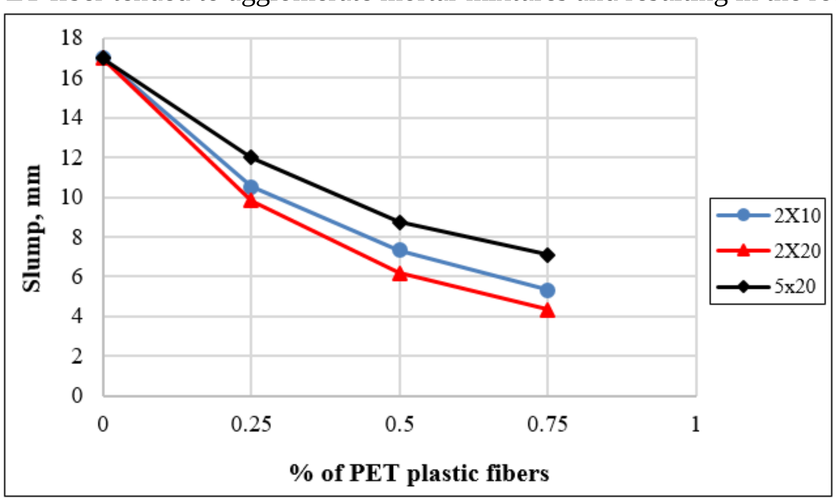

Fig. 2: Slump value versus fiber content of different dimensions

3.1.2. Fresh Density

The outcomes of fresh density for mortar mixtures having 0, 0.25%, 0.5%, and 0.75% of PET fibers with three different dimensions of 2×10 mm, 2×20 mm, and 5×20 mm are shown in Fig. 3. The outcomes clearly demonstrate that the fresh density has remarkably decreased with the incorporation and increase of PET fibers independent of their dimensions.

This could be because of the lower specific gravity of plastic fibers (1.12) compared with cement (3.04) and aggregate (2.65). As a comparison, the fresh density has decreased further for the mixtures containing longer fibers than the shorter ones. This is because of bundling and not uniform dispersion of fibers in mixtures, which is resulting in porous mixtures. Finally, such a decrease was more significant for the mixtures containing 2×20 mm fibers compared to the 5×20 mm fibers due to their high numbers.

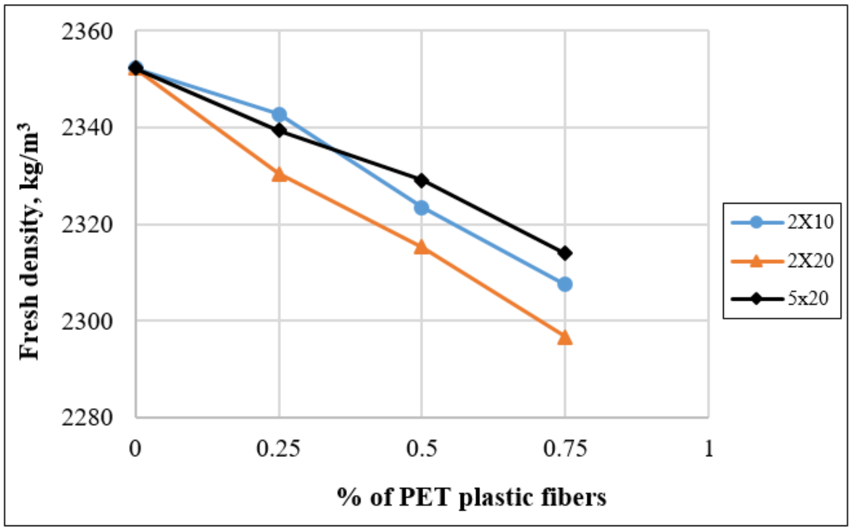

Fig. 3: Fresh density versus fiber content of different dimensions

3.2. Mechanical properties

3.2.1. Compressive strength

The outcomes of the compressive strength are shown in Fig. 4 and illustrate that the incorporation of PET fibers had a negative effect on the compressive properties of mortar. It means that the compressive strength has decreased with the increase of percentage of PET fibers. This can be attributed to the fact of fibers bundling during mixing and pouring mortar mixtures in molds. In addition, the area between fiber surfaces is the weakest point in the mortar which results in early cracks during compression loading. However, there was not much difference in the compressive strength while 2×20 mm fibers were incorporated in the mortar mixtures instead of 2×10 mm. In addition, the compressive strength has decreased more for the specimens containing wider fibers than the ones having thinner fibers. This is because the wider fibers resulted in more slip between aggregates when samples were compressed and caused a reduction in the compressive strength. While the narrow fiber results in less or no slip due to their less contacting area with aggregates. In addition, the control samples displayed the typical brittle type of failure and were completely divided into many fragments, while for fiber-reinforced samples, the failure becomes more ductile and samples were taken from separation into many portions.

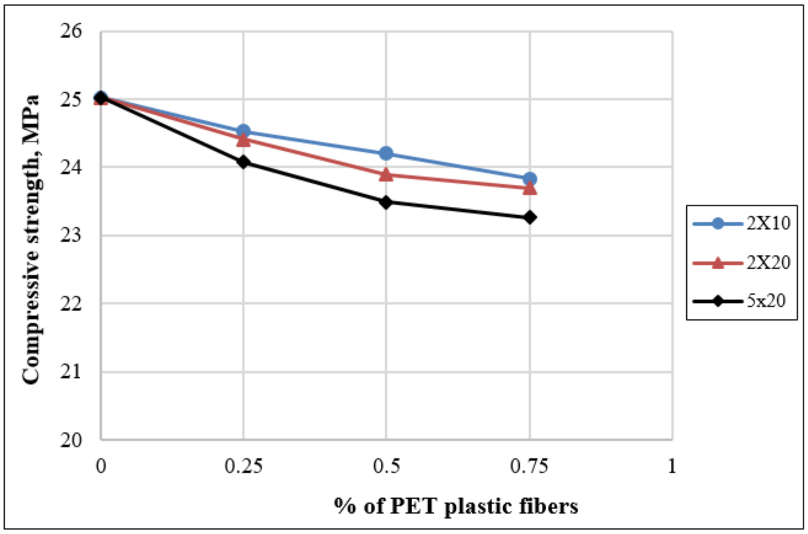

Fig. 4: Compressive strength versus fiber content of different dimensions

3.2.2. Flexural strength

The outputs of the flexural strength are presented in Fig. 5. It can be observed from the results that the flexural strength was improved to somewhat percentages of PET fibers for all types of fibers. This is because PET fibers lead to bridge and delay the crack propagation and more load is required to damage the specimens. Thus, the specimens containing fibers had improved ductility and reduced the crack risk compared to the control ones. However, the flexural strength decreased back for a higher amount of PET fibers but still, these values are higher than reference specimens. This can be because of fibers bundling in higher percentages and decreasing bond strength between fibers and cement paste. As a comparison, this improvement was more for longer fibers compared to the short ones because longer fibers can delay the cracks for a long time resulting in an increase of load capacity. On the other hand, samples with 5×20 mm fibers had the lowest flexural strength among them. This is because of their fewer numbers which cannot prevent the initiation of cracks at all parts of the samples. Overall, the specimens having fibers showed better performances in terms of failure mechanism than those for control prisms. The reference prisms failed in a brittle mode with a little energy absorption; whereas the fiber-reinforced prisms fractured in a ductile flexural manner with very large energy absorption.

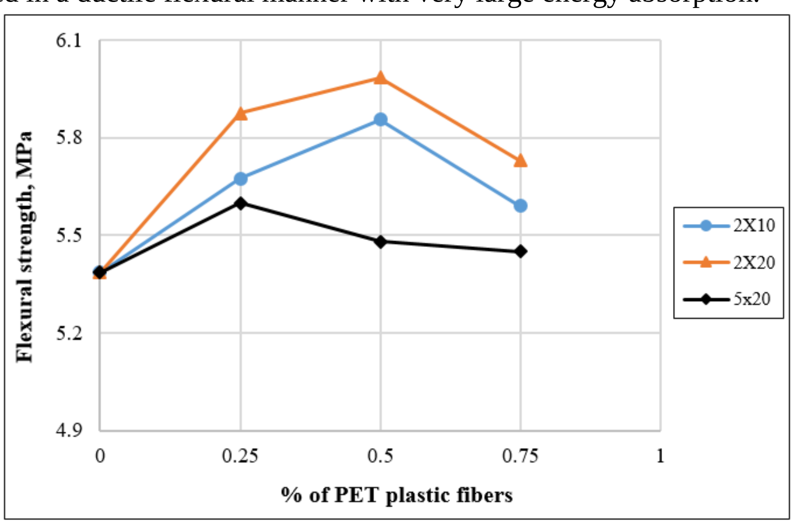

Fig. 5: Flexural strength versus fiber content of different dimensions

3.2.3. Split tensile strength

The results present that the split tensile strength has increased for all types of fibers while incorporated into mortar mixtures, and enhanced further with the increase of volume fraction of fibers as shown in Fig. 6. As a comparison, longer fibers had a better effect than shorter ones. On the other hand, this strength has decreased with the increase of fibers' width because the large surface of wide fibers resulting in the weak adhesion between PET fibers and mortar matrix. In addition, reference samples failed abruptly and separated into many parts, while fiber-reinforced samples could retain their shape after the failure as well.

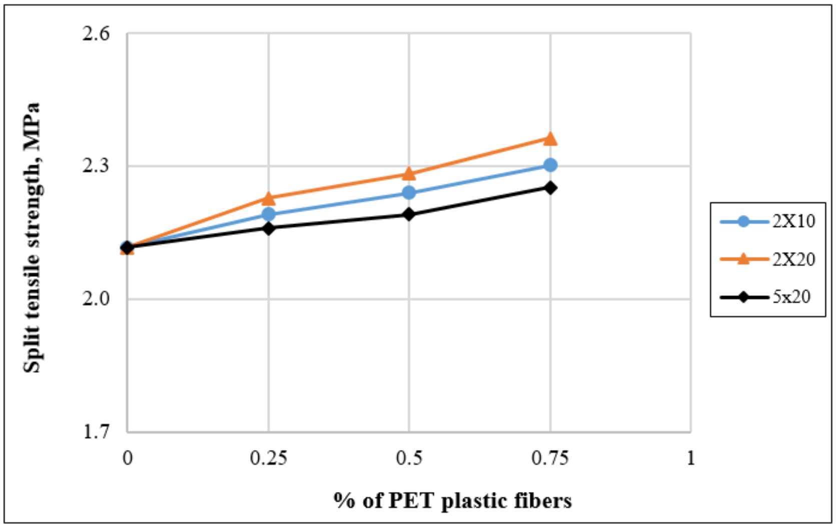

Fig. 6: Split tensile strength versus fiber content of different dimensions

4. Conclusions

The major concluding points drawn from the above experiments are as follows:

- The workability of mortar mixtures has remarkably decreased with the incorporation of PET fibers and reduced further with the increase of fiber content. However, this reduction was more significant in the case of longer fiber compared to the short ones.
- Moreover, a remarkable reduction in fresh density was recorded for the mortar mixtures containing fibers independent of their types. However, this reduction was more remarkable for the mixtures having longer fibers than the short ones and for thinner fibers compared to the wider ones.
- The compressive strength has slightly decreased with the incorporation and increase of fibers content. This reduction was more pronounced for longer and wider fibers compared to the short and thinner fibers.
- Furthermore, the flexural strength has improved to somewhat percentage but decreased back for a higher amount of fibers, but still these values are higher than the control samples. As a comparison, this improvement was more noticeable for longer and wider fibers compared to the shorter and thinner fibers.
- Finally, the split tensile strength has enhanced significantly while PET fibers were added into mortar mixtures and improved further with the increase of percentage of fibers. However, this improvement was more significant for longer and wider fibers compared to the short and thinner fibers.

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