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RESEARCH NOTE

Sustainable Use of Polypropylene Fibers as a Cement Mortar Reinforcement

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ABSTRACT

Reinforcing cement mortars with fibers is an essential step to enhance their flexural strength. This study compares the fresh properties and mechanical characteristics of cement mortars reinforced with polypropylene fibers and recycled polypropylene fibers. The reinforcing fibers ratio were (0, 0.5,1, and 1.5) % by weight of cement mortar for both types of fibers. The casted samples were tested by means of flow test for fresh mortar, compressive strength, flexural strength, and toughness for hardened mortars. The results from this experimental program showed that both types of fibers caused a reduction in the mortar flow and enhanced its mechanical characteristics. The results were statistically tested to measure the significance of the difference. The cement mortar reinforced with recycled fibers exhibited approximately similar results as compared to the mixtures containing raw polypropylene fibers at 95% confidence level. However, it shows a significant increase in flexural strength when comparing to the mixtures with new polypropylene fibers that may be attributed to the fiber shape and cross section area.

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1. INTRODUCTION

The cementitious materials as cement mortar or cement concrete exhibit strong resistance to compression [1] whereas show weak performance in bending and tension [2]. The need for concrete elements with higher tensile or flexural strength spur researchers and engineers' effort to strengthen these properties. Different techniques have been adopted to eliminate this drawback in concrete. The most widely used method is fiber reinforcement [3]. Bio-fibers as palm fibers [4, 5] sheep wool [6], jute, coconuts, and kelp fibers [7], and hemp fibers [8] have been used as a reinforcing material since ancient ages. It acts as a controller of plastic shrinkage cracking in addition to enhancement of tensile and fatigue resistance.

The development of building materials over the last years leads to the development of synthetic fibers. Many fibers have been introduced and used successfully as nylon fibers [9], steel fibers [10, 11], glass fibers [12], chopped carbon fibers [13] and polypropylene fibers [14-18]. The use of polypropylene fibers has many advantages since it is very effective in reducing the plastic shrinkage cracks and post-cracking [19] that limit the cracks formation, thereby, extending the concrete service life. It also showed higher flexural and tensile strength.

On the other side, these developments in building materials and industry resulted in accumulation of waste materials. These synthetic materials are non-biodegradable [20] that means it will accumulate over the land and cause land and marine pollution. Fortunately, these waste materials can be recycled and used as concrete fibers. Examples of these recycled fibers are nylon fibers recycled from fishing nets [21-23], recycled brass fiber [24], carbon fibers [25, 26] textile, acrylic, and waste glass fibers [27], etc. Previous works showed that the recycled fibers are also effective in a similar way of the new fibers.

In Iraq, the country's ability for waste management is 4000 tons daily, which comprise approximately 13% of daily trash [28]. This deficiency in waste management requires more attentions and implementing strategies to overcome the anticipated environmental crisis. The most common type of the waste materials is plastic. Different

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polymers as polypropylene, polyethylene, polystyrene, and polyethylene terephthalate form plastic materials. This study deals with recycling plastic materials made from polypropylene. Since, there is relatively few studies to compare the cement mortars reinforced with new fibers and recycled fibers. This work focus on comparing the experimantal test results of cement mortar to determine the applicability of utilizing the recycled fiber instead of the new one to achive sustainability, reduce pollution, and conserve natural resources.

2. MATERIALDS AND METHODS

2. 1. Materials The materials used for the reinforced cement mortars were tab water, cement, and sand, in addition to PPF either raw or recycled RPPF. The descriptions of each material are:

2. 1. 1. Cement an ordinary Portland cement, brought from Almass company was used in this work.

2. 1. 2. Sand the natural river sand is used as a fine aggregate.

2. 1. 3. Raw Polypropylene Fibers the physical properties are summarized in Table 1.

2. 1. 4. Recycled Polypropylene Fibers plastic bags, used for packaging pantry supplies, were used in this study. These bags, made from ribbons of polypropylene material, were shredded to a length similar to that of PPF, which is 19 mm, and used as mortar reinforcement.

Both types of fibers are shown in Figure 1.

A total of seven set of mixtures has been prepared with the mix design stated in Table 2 for the reference mix and three dosage rates for each fiber type. The essential materials for cement mortar production (cement: sand) were kept constant as (1:3) with 0.5 of water/cement ratio. Whereas, the two types of fibers were used in different proportions (0, 0.5, 1.5) % of weight of the total mix.

TABLE 1. Physical properties of polypropylene fibers (PPF)

Form	Virgin Polypropylene Fiber
Specific gravity	0.91
Air entrainment	Air content of concrete will not be significantly increased
Young modulus	(5500-7000) MPa
Tensile strength	350 MPa
Melting point	160 ºC
Fiber length	19 mm

(a) (b)

Figure 1. (a) Polypropylene Fibers and (b) Recycled Polypropylene Fibers

TABLE 2. Nomination of cement mortars reinforced with fibers

Mix code	Fiber type	Fiber content
R	None	0
PP0.5	Raw PP	0.5%
PP1	Raw PP	1.0%
PP1.5	Raw PP	1.5%
RPP0.5	Recycled PP	0.5%
RPP1	Recycled PP	1.0%
RPP1.5	Recycled PP	1.5%

2. 2. Specimens Preparation Initially, the mix design for the cement mortars were set as (1: 3) for cement: sand which is the common mortar mixtures prepared in Iraq. These ratios are kept constant for both reference and the reinforced mixes. The only difference of the fiber-reinforced mixes was the inclusion of the three proportions (0.5%, 1%, and 1.5%) of the fiber (either PP or RPP) as a percentage from the mixture weight. The proportion of PP fibers are limited to 1.5 % as recommended by Sohaib et al. [29] because this ratio was found as the optimum ratio that achieves higher strength as compared to other ratios. Increasing this ratio would result in a negative impact on strength properties. The water-cement ratio was designed as 0.5 for all the mixtures. When the materials were prepared and carefully weighted, the dry cement and sand were mixed together in the mixer for 1-2 minutes. Then, the specified amount of water was poured gradually and stirred with the mixture for another 2 minutes, until a homogeneous mixture would appear. These steps are set for the reference mixture. Regarding the fiber-reinforced mixtures, the same procedure was adopted, and the specified quantities of the fibers were added gradually to the mixture and mixed thoroughly to maintain homogeneity. Afterward, the mixtures of fresh mortar were divided into sections, the first one was tested for workability, and others were poured into different molds 50×50×50 mm cubes and 40×40×160mm prisms for compressive strength and flexural strength tests, respectively. Then, these molds were subjected to vibration for 10 seconds at a frequency of 300Hz, to ensure homogenous consistency. The molds were sealed by plastic sheets and kept under ambient laboratory temperature for 24 h. Then, mixtures were de-molded and cured by submerging in a water bath of 20-24 ℃ for 28 days (the testing age).

2. 3. Testing Program

2. 3. 1. Fresh Mortar Properties The consistency of the fresh mortar was measured by flow value consistency test to investigate the influence of fibers on the workability of cement mortar. This test was conducted in accordance with ASTM C1437 [30].

2. 3. 2. Physical Properties of the Hardened Mortar In order to determine the effect of PP fibers type and content on the physical properties of cement mortars, the ASTM C 642-13 standard was utilized. The average results of three cubes with 28 days age was used to measure the bulk density and water absorption.

2. 3. 3. Mechanical Properties of the Hardened Mortar In order to evaluate the mechanical properties of the cement mortars, the compressive strength and the flexural strength were tested. The compressive strength of cement mortar was conducted in accordance with ASTM C 109 [31]. The cement mortar cubes were subjected to a load increment of 0.5 KN/s until failure. Whereas, the flexural strength test was performed in accopmliance with ASTM C348 [32]. The cement mortar prisms were subjected to a displacement of 0.5 mm/minute until failure.

2. 4. Statististical Analysis The t-test was used for testing the significance difference between two data set. This test is applicable for comparing the means of two samples that having a small data points. Equation (1) explains the t-test.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1{}^2}{n_1}} + \sqrt{\frac{S_2{}^2}{n_2}}} \tag{1}$$

where :

$\bar{x}_1$, and $\bar{x}_2$ are the mean of the tested property for PP, and recycled PP-fiber reinforced mortar, respectively.

S_1, and S_2 are the standard deviation of the tested property for PP, and recycled PP- fiber reinforced mortar, respectively.

n_1, and n_2 are the total number of the tested property for PP and recycled PP-fiber reinforced mortar, respectively.

3. RESULTS AND DISCUSSION

The test results for the fresh and hardened PPF-reinforced cement mortar are summarized as:

3. 1. Flow Test The flow value of the PPF and RPPF reinforced cement mortars were tested, and results are presented in Figure 2. This figure shows that there is a slight decrease in the workability of the fiber-reinforced cement mortar. The presence of fibers tends to hinder the mortar flow, thereby reduce workability. The reduction in workability with the RPP reinforced mortar is found to be more that than observed with the raw fibers. This behavior may be attributed to the dimension of the fiber. The flow value decrease by approximately 16%, 16%, and 22% for the raw PP fiber content of 0.5, 1, 1.5% by weight, respectively. Whereas, the percent reduction of recycled PP cement mortar is found as 19%, 25%, and 31%, for the same aforementioned ratios, respectively.

3. 2. Bulk Density The unit weight and bulk density is one of the physical parameters that have to be checked for cementitious mixtures. The density of PP and RPP fibers reinforced mortars have been tested and results are presented in Figure 3. It is clear to notice that the inclusion of PP fibers resulted in density reduction, except for RPP0.5. This may be attributed to the lower unit weight of fibers as compared to the cement mortar.

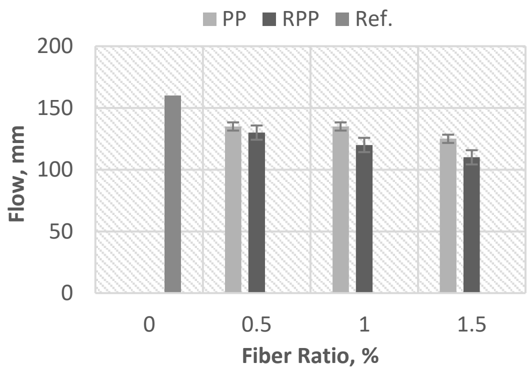

Figure 2. Effect of fiber type and proportion on the workability of the PP fiber-reinforced mortar

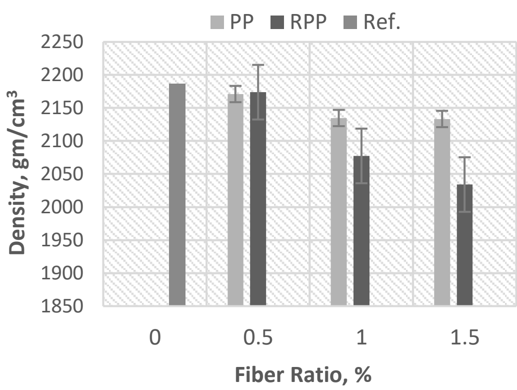

Figure 3. Effect of fiber type and proportion on the density of the PP fiber-reinforced mortar

Comparing the density of reinforced mortars with PP and RPP fibers, there is slight difference, not significance at 95% confidence level, in bulk density for cement mortar reinforced with PP or RPP fibers with the same dosage rate.

3. 3. Water Absorption The absorption rate of cementitious material is another important criterion that needs to be investigated. It is an indicator of material durability. Lower absorption rate means lesser ability of water and other liquid materials to infiltrate through cement mortar and thereby the adjacent structure. The water absorption for the cube mortars were tested and results are presented in Figure 4. It is clear to notice that the addition of fibers reduces water absorption ability. The presence of fibers in cement mortars block continues voids thereby reducing water absorption. The fiber geometry also impacts this property. The reduction of recycled PP fibers is higher than mixtures having raw PP fibers.

3. 4. Compressive Strength The compressive strength of the cubic cement mortars were tested and presented in Figure 5 as an average value for three samples as a function of fiber type and content. The compressive strength of PP-reinforced cement mortar increase with increasing the PP fiber content no matter the fiber type and the dosage rate. The percent of the increase is 3, 8, and 68% for 0.5, 1, and 1.5% of the raw PP fiber reinforced mortars, respectively, considering the non-reinforced mortar as a reference mix. Similarly, the compressive strength of the RPPF mortars also enhances with the fiber addition, especially, at high proportions. The percent enhancement is found as 32, 52, and 61% for 0.5, 1, and 1.5% of fiber content, respectively. This improvement in compressive strength of fiber-reinforced cement mortar may be attributed to the fibers that interlocking the cement mortar matrix. This can be noticed in Figure 6 that shows the failure mode of PPF and RPPF mixes.

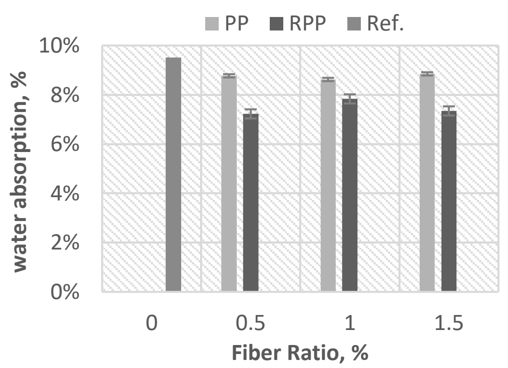

Figure 4. Effect of fiber type and proportion on the water absorption of the PP fiber-reinforced mortar

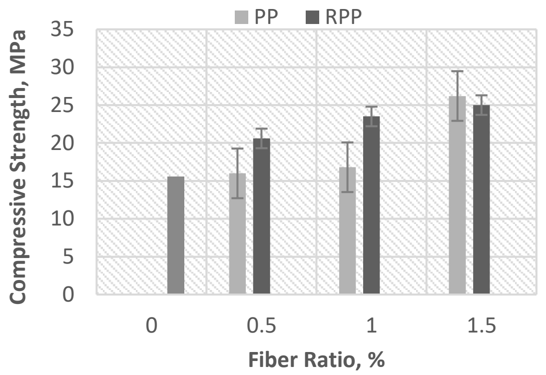

Figure 5. Effect of fiber type and proportion on the compressive strength of PP fiber-reinforced mortar

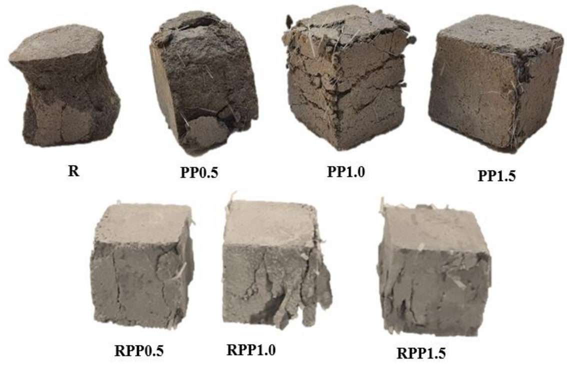

Figure 6. Mode of failure of PP and RPP- reinforced cement mortar

3. 5. Flexural Strength Regarding flexural strength, the beam samples were tested and presented in Figure 7 to show the average values for the different mixes. Even though the PPF 0.5 mix has higher flexural strength compared to the reference mix, there is a slight decrease in the flexural strength of the raw PPF mortars PPF1 and PPF 1.5. This behavior may be attributed to the geometry of PP fiber. The fibers shape of new PP is a combination of tiny hairlines that are connected together. These hairlines entrain air bubbles inside. These voids represent weak points in the mixture besides weaker bonds within the cement – sand- fiber matrix. Thereby, reinforcing cement mortar with 0.5 % of PPF can be used as the optimum dosage rate. In contrast, the cement mortars reinforced with RPPF exhibits higher flexural strength to double fold as compared to the reference mixture. This may be attributed to the fiber's ability to bridge the cracks at high level of strain [33]. In addition, the RPPF has larger cross- sectioal area, therby sustain more stress, beside it higher brittleness as compared to the new PP fibers. Figure 7 shows specimens containing PPF and RPPF after testing. So, there is a significant enhancement in the modulus of rupture for the RPPF mixtures s compared to PPF-mixes.

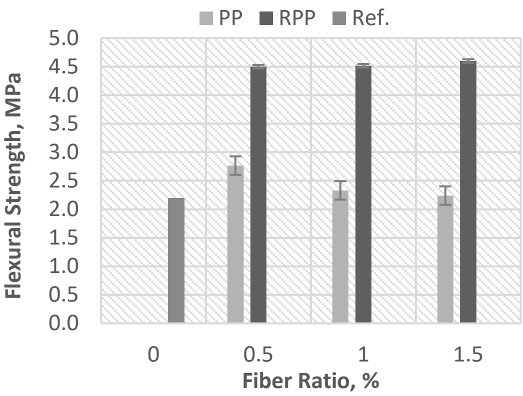

Figure 7. Effect of fiber type and proportion on the flexural strength of PP fiber-reinforced mortar

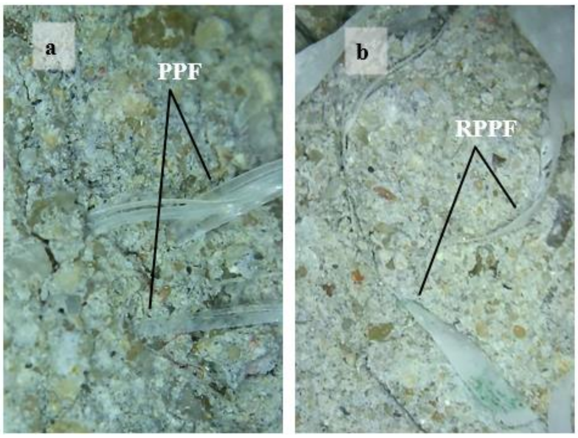

Figure 8. Cement mortar reinforced with (a) Polypropylene Fibers and (b) Recycled Polypropylene Fibers

3. 6. Toughness The ratio of compressive to flexural strength of mortar is an important indicator for mortar toughness [34]. The values for fiber-reinforced cement mortars are presented in Figure 9. It is clear to notice that the PP- mortars have higher toughness as compared to the RPP- mortars. However, mixtures contain RPP fibers tend to have lower toughness when compared to reference mixtures. The variation in toughness between PP-mortars and RPP- mortars is insignificant.

3. 7. Statistical Test Results The experimental results for each test were fed into STATISTICA v. 12 software for comparision. The output results of the t-test are summarizred in Table 3.

The test results in this table reveal that the workabilility, bulk density, and toughness for cement

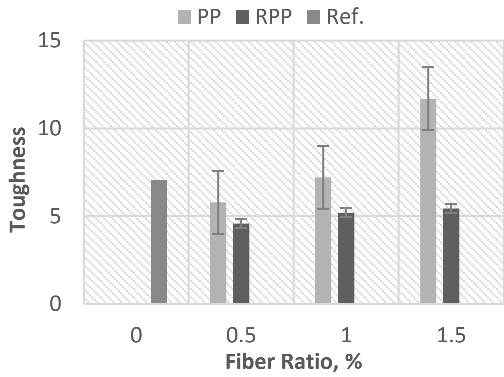

Figure 9. Effect of fiber type and proportion on the toughness of PP fiber-reinforced mortar

TABLE 3. Statistical Test for differences in properties of the PP and recycled PP fiber-reinforced mortar

Property	Variables	mean	Std. Dv.	Difference	Std. Dv. Dif.	t	P	Significance
Workability	PPF	131.667	5.773	11.667	5.773	3.50	0.073	No
	RPPF	120.000	10.00					
Bulk Density	PPF	2143.3	16.03	41.15	67.76	1.05	0.403	No
	RPPF	2102.2	83.34					
Water absorption	PPF	0.0875	0.0012	0.0128	0.004	5.214	0.035	**Yes**
	RPPF	0.0747	0.0032					
Compressive strength	PPF	19.663	5.676	-3.37	4.094	-1.426	0.29	No
	RPPF	23.033	2.237					
Flexural strength	PPF	2.446	0.281	-2.093	0.323	-11.224	0.007	**Yes**
	RPPF	4.539	0.054					
Toughness	PPF	8.228	3.087	3.156	2.719	2.010	0.182	No
	RPPF	5.072	0.443					

mortars reinforced either by PP or recycled PPF are approximetaly the same, with slight difference towards the PP-fiber reinforced mortars. However, this difference is not significant at 95% confidence level. Whereas, the compressive strength of the RPP fibers cement mortars are slightly higher than those mixes reinforced with new PP fibers. However, it is still insiginificant within 95% confidence level. From this test, it can be conclud that the recycled fibers made from PP can be used efficiently for renforcing since it provides approximately the same results as the new ones. This behavior may be attributed to the same inherent properties of the fibers that made from the same polymer type.

Moreover, there are significant differences in water absorption, and flexural strength. The water absorption of cement mortars with PPF is higher than thos with RPPF by about 13.7%. In addition, the flexural strength of cement mortars reinforced with RPPF is found to be higher than those reinforced with raw PPF by about 85.5% which can be considered as a great enhancement. The mean difference is significant at 95% confidence level. This finding may be atrributed to the fiber shape and cross section area.

Thereby, it can be concluded that the RPPF not only give similar results as new PPF when it used as reinforcing material with cement paste, but also give better results with two main properties which are water absorption and flexural strength. This serve as a sustainable solution to overcome the anticipataed environmental crisis.

4. CONCLUSIONS

This study compares the fresh properties and mechanical characteristics of cement mortars reinforced with polypropylene and recycled polypropylene fibers. The fibers` dosage was limited to 1.5% of mixture weight. The experimental and statistical test results reveal:

1. The flow values, density, and water absorption rate reduced with the addition of PP fibers either recycled or new. The reduction is higher with RPPF-reinforced mortars.
2. The mechanical properties like compressive and flexural strength increased with the inclusion of PPF and RPPF. The rate of an increase in is higher with the recycled fibers.
3. Some properties as the workability, bulk density, and toughness for cement mortars reinforced either by PP or recycled PPF are approximately the same, with slight difference towards the PP-fiber reinforced mortars.
4. The water absorption, and flexural strength test reveal a significant difference between PPF and RPPF mixtures.
5. The water absorption of cement mortars with PPF is higher than those with RPPF by about 13.7%.
6. The flexural strength of cement mortars reinforced with RPPF is higher than mixtures with raw PPF by about 85.5%

Thereby, this work shows the efficiency of using the recycled fiber since it provide similar strength as compared to new fibers. Moreover, cement mortars reinforced with recycled fibers exhibit better flexural strength than cement mortars reinforced with new PP fibers. The reinforcement tends to be effective at each dosage rate with optimum at 1.5%. This confirm the feasibility of using waste PP as a sustainable practice in addition to their desired characteristics for cementitious material reinforcement.

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Persian Abstract

چکیده

تقویت ملات سیمان با الیاف یک مرحله ضروری برای افزایش مقاومت خمشی آنها است. این مطالعه به مقایسه خواص تازه و ویژگی‌های مکانیکی ملات سیمانی تقویت‌شده با الیاف پلی‌پروپیلن و الیاف پلی‌پروپیلن بازیافتی می‌پردازد. نسبت الیاف تقویت کننده (۰، ۰.۵، ۱، و ۱.۵) درصد وزن ملات سیمان برای هر دو نوع الیاف بود. نمونه‌های ریخته‌گری شده با استفاده از آزمایش جریان برای ملات تازه، مقاومت فشاری، مقاومت خمشی و چقرمگی برای ملات‌های سخت شده آزمایش شدند. نتایج حاصل از این برنامه آزمایشی نشان می‌دهد که هر دو نوع الیاف باعث کاهش جریان ملات و افزایش ویژگی‌های مکانیکی آن می‌شوند. نتایج از نظر آماری برای اندازه‌گیری معنی‌داری تفاوت مورد آزمایش قرار گرفتند. ملات سیمانی تقویت شده با الیاف بازیافتی نتایج تقریباً مشابهی را در مقایسه با مخلوط‌های حاوی الیاف پلی پروپیلن خام در سطح اطمینان ۹۵٪ نشان داد. با این حال، در مقایسه با مخلوط‌های با الیاف پلی‌پروپیلن جدید که ممکن است به شکل الیاف و سطح مقطع نسبت داده شود، افزایش قابل‌توجهی در استحکام خمشی نشان می‌دهد.