Journal of Al-Azhar University Engineering Sector

Vol. 20, No. 77, October 2025, 1238-1248

EFFECT OF USING SUSTAINABLE MATERIALS AS PARTIAL REPLACEMENT OF SAND ON CHARACTERISTICS OF MORTAR

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Citation:

H. EL-Nesr, Y. A. Awad, I. A. Latif, M. A. Khalaf," Effect of Using Sustainable Materials as Partial Replacement of sand on Characteristics of Mortar", Journal of Al-Azhar University Engineering Sector, vol. 20(77), pp. 1238-1248, 2025.

Received: 13 May 2025

Revised: 25 June 2025

Accepted: 07 July 2025

Doi: 10.21608/auej.2025.385032.1839

ABSTRACT

This study used recycled polyethylene terephthalate (PET) granules to partly replace fine aggregate in mortar. This aims to offer a green solution and reduce the use of natural sand, which may run short. PET was added in different amounts: 0%, 5%, 7.5%, and 15%. The study tested how this change affected the strength and physical features of the mortar. Cube and cylinder samples were used. The cube sizes were 50×50×50 mm and 150×150×150 mm. The cylinder size was 75×75 mm. Tests showed that adding PET changed the mortar's strength and other properties. As the PET amount increased, both the mortar's weight (density) and its strength went down after 28 days. The amount of water the mortar could absorb and how deeply water could enter and propagate also changed based on the PET content. The study found the best PET amount to use as a sand replacement.

KEYWORDS: Recycling plastic waste, Polyethylene Terephthalate (PET), mechanical and physical properties, compressive strength, water absorption.

تأثير استخدام المواد المستدامة كبديل جزئي للرمل على خصائص المونـــة

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الملخص

تم في هذه الدراسة استخدام حبيبات البولي إيثيلين تيريفثاليت (PET) المعاد تدويرها لاستبدال جزء من الرمل في المونة. يهدف ذلك إلى تقديم حل صديق للبيئة وتقليل استخدام الرمل الطبيعي الذي قد يصبح نادرًا في المستقبل. تم إضافة PET بكميات مختلفة: ٠٪، ٥٪، ٧,٥٪، و١٥٪. قامت الدراسة باختبار كيفية تأثير هذا التغيير على قوة وخصائص المونة الفيزيائية. تم استخدام عينات على شكل مكعبات وأسطوانات. كانت أحجام المكعبات ٥٠×٥٠×٥٠ مم و١٥٠×١٥٠×١٥٠ مم، بينما كان حجم الأسطوانات ٧٥×٧٥ مم.أظهرت الاختبارات أن إضافة PET أثرت على قوة المونة وخصائصها الأخرى. مع

زيادة كمية PET، انخفض كل من الكثافة المونة وقوتها بعد ٢٨ يومًا. كما تغيرت كمية الماء التي يمكن أن تمتصها المونة وعمق دخول الماء إليها بناءً على محتوى PET. وقد وجدت الدراسة أفضل كمية من PET لاستخدامها كبديل للرمل.

الكلمات المفتاحية : إعادة تدوير نفايات البلاستيك، بولي إيثيلين تيريفثاليت (PET)، الخصائص الميكانيكية والفيزيائية، قوة الضغط، امتصاص الماء.

1. INTRODUCTION

Reinforced concrete is the most used material in building structures. It needs protection using improved coating materials. Plastics have been widely used in daily life since the 1930s and 1940s. But at first, people ignored how plastics break down slowly. This has harmed people, animals, and the environment. Around 3% of the 300 million tons of plastic waste made each year ends up in the oceans [1, 2].

Plastic waste can be handled in four main ways: landfilling, recycling, composting, and burning. Before 1980, recycling and burning were rare. Most plastic was just thrown away. Burning started in 1980, and recycling grew after 1990. The recycling rate increased by only 0.7% per year. By 2050, it is expected that 6% of waste will still be dumped, 44% recycled, and 50% burned [3].

Mechanical, thermal, or combined methods can turn PET waste into aggregates. The mechanical way is fast and cheap. The thermal or mixed methods give more uniform results [4].

Using PET waste in concrete and mortar is now accepted worldwide. PET can partly replace fine aggregates or be added as fibers [5].

The properties of concrete and mortar were studied using lightweight aggregates waste PET (WPLA) [6]. WPLA had a higher fineness modulus than river sand. It also had low water absorption and low density. WPLA increased the flow of mortar but lowered compressive strength over time. In concrete, higher WPLA content raised the flow and reduced strength. At 25% WPLA, structural efficiency improved. Lightweight aggregates helped reduce density and self-weight but also lowered strength.

Polyethylene terephthalate (PET) granules were used to replace fine aggregate at 0%, 10%, 30%, and 50% [7]. Replacing 10% improved concrete properties. As PET content increased, elasticity went down, but the 10% sample had a small effect. Indirect tensile strength peaked at 10% PET, then dropped. The best performance was seen at 10% replacement. PET's shape and flexibility helped. However, at 50%, the strength dropped because the mix had more air and poor bonding between the PET and paste.

The effect of PET powder on mortar properties was studied [8]. As PET increased, both compressive and flexural strength dropped. But flexural strength improved slightly at 10% PET. Weak bonding between PET and paste hurt the compressive strength. Flexural toughness improved slightly with more PET.

Fine aggregates were replaced by weight at ratios of 5%, 10%, and 15%. After 28 days, the 5% PET mix has with maximum compressive strength. PET mixes have less flexural strength than normal concrete [9]. The first strength gain may be due to strong PET bonding. Later strength dropped over 5% because of weaker paste and larger plastic pieces.

A test was conducted on concrete where 5% sand was replaced by ground PET. PET mixes showed similar workability, slightly lower strength, but better ductility than regular concrete. The results came from the weak bond between cement and plastic [10].

Previous studies have advocated the use of mortar containing PET and polycarbonate waste as partial substitutes for natural aggregates [11].

The effect of replacing polyethylene terephthalate (PET) with sand in different ratios on mortar properties, curing, and particle size was tested. As the sand-to-PET ratio rose, so did mortar density and water absorption. All PET mortars absorbed little water. Mortars with graded sand had better strength than those with single-size sand. Small sand particles filled gaps, reducing air spaces and boosting strength [12].

A previous study was conducted on the effect of replacing sand with 0-50% plastic waste on the bulk density, porosity, water absorption, and strength of mortar. Mortars with 50% plastic waste had the highest density. They were strong enough for lightweight uses. Strength dropped by 15–33% when using 20–50% plastic. This was due to weak bonding and low plastic strength [13].

Shredded polyethylene terephthalate strapping bands (SPETSB) were used to replace sand at 0-60% by volume. Over time, compressive strength improved, but it dropped as SPETSB content rose. This was due to poor bonding and smooth plastic surfaces. Thermal conductivity increased in all mixes with SPETSB. SPETSB also reduced alkaline reactivity of aggregates [14].

Research up to 2019 was reviewed on the use of recycled plastic in concrete as a fine aggregate and whether strength and durability are affected [15].

This study aims to test how replacing natural sand with PET waste granules in different amounts affects mortar properties and to find the best replacement level.

2. METHODOLOGY

This study looks at how different amounts of polyethylene terephthalate (PET) granules, made from industrial waste, affect the properties of mortar. The results are compared to normal mortar that has no PET. Based on earlier studies, part of the sand is replaced by PET granules in four amounts: 0%, 5%, 7.5%, and 15%. The mortar mixes were tested for workability, compressive strength, water absorption, and resistance to water penetration. These results were compared to the mix without PET, as shown in **Fig. 1**. All experiments were done at the Materials Research and Testing Center (MRC), Faculty of Engineering, Ain Shams University, Cairo, Egypt.

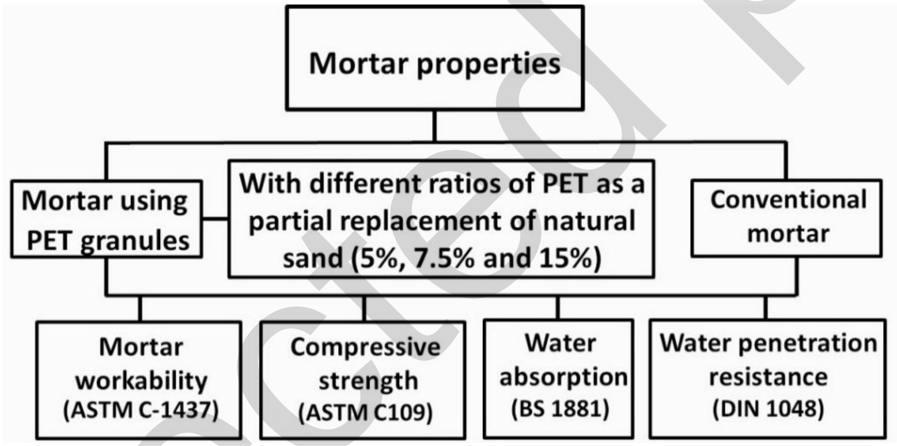


Fig. 1: Schematic of the Experimental Program

3. EXPERIMENTAL PROGRAM

The specimens used in this experimental work were cubic specimens with dimensions 50x50x50mm, 150x150x150mm and cylindrical specimens of 75mm diameter and 75mm length. Moulds in the shape of cubes and cylinders were used for mortar specimens as **Fig. 2**.

Fig. 2: Casting of test specimens for each replacement percentage of PET

3.1. Manufacturing process

PET granules were made from recycled high-density polyethylene plastic, mostly taken from thin plastic bags. They were produced using the extrusion process at a plastic recycling plant. This method gave the granules a uniform size and shape. During recycling, high-density polyethylene was separated from other plastic types. It was then washed, melted, and pushed through an extruder. The melted plastic came out as long strands, then placed in water for cooling then cut into little pieces. The final PET granules were pellet-shaped, mostly smooth, and had a sub-rounded form, as shown in **Fig. 3**, with a 1.47 specific gravity and a 3.75mm maximum size. Their physical properties are listed in **Table 1**.

Fig. 3: Granulated Polyethylene Terephthalate (PET)

Table 1: The physical properties of the PET granules

Characteristics	PET granules
Specific gravity	1.47
Bulk density (kg/l)	1.38
Water absorption %	0.02
Density (g/cm^3)	1.34

3.2. Mixture proportions

The mortar mix design followed ASTM C109 [16] and was split into four groups: groups with PET granules and one group without PET granules, as shown in **Table 2**. PET granules were used to replace fine aggregate by weight at 0%, 5%, 7.5%, and 15%. Dry PET granules were used to prevent extra porosity that could result from moisture in the plastic. Each mix had 500 g of Portland cement. with a 0.484 water-to-cement ratio, and a 2.75 fine aggregate-to-cement ratio.

Table 2: Mixes proportion of mortar for 1m^3

#	Label	PET [%]	Water [mL]	Cement [g]	Water-cement ratio	Sand [g]	PET granules [g]
1	C 1	0	242	500	0.484	1375	0
2	G 5	5				1306	69
3	G 7.5	7.5				1272	103
4	G 15	15				1169	206

The mixing process followed a set order and time control:

- First, cement and water were mixed at low speed for 30 seconds.
- Then, PET granules and fine aggregate were added and mixed for another 30 seconds.
- After that, the mixer ran for 30 seconds at high speed.
- The mix was left for 90 seconds to rest.
- Then, it was mixed again at high speed for 60 seconds.

Finally, a steel mold is used to pour the mortar paste in two layers and compacted using a vibrating table.

4. RESULTS AND DISCUSSIONS

4.1. Mortar workability

The flow test was done according to ASTM C-1437 [17], as shown in **Fig. 4**. The results show that mortar workability gets better when more PET granules are added to the mix. Other studies have also found the same result [18]. When 15% of the sand was replaced with PET, mortar workability increased by 12% compared to the mix with 0% PET, as shown in **Fig. 5**. This is because the PET granules have a smooth surface and a rounded shape, which lowers friction inside the mix and helps it flow better.

Fig. 4: The flow test of the fresh mortar

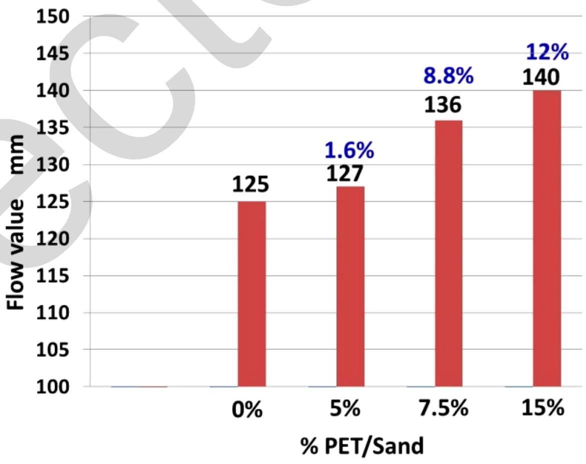


Fig. 5: Relationship between flow value and replacement ratio of PET

4.2. Density

The measurement results of density show that by adding PET waste particles to the mortar mixture the mortar's density reduced. Other researchers [18, 19, 20, 21, 22, 23] have shown outcomes that are similar to these. Because of the PET's low density (1.34 g/cm3), increasing the PET granule percentage to 15% reduced mortar density as compared to conventional mortar (0% PET). **Fig. 6** indicates that the densities of specimens with 5%, 7.5%, and 15% replacement at 28 days are close to each other. Meanwhile, when the PET waste content in mortar increases, the density curve decreases. The 28-day density decreased slightly by roughly 3.1%, 4.26%, and 5.8% in the mixtures with 5%, 7.5%, and 15% sand replacement, respectively. Previous investigations have reached the same conclusion. [18, 19].

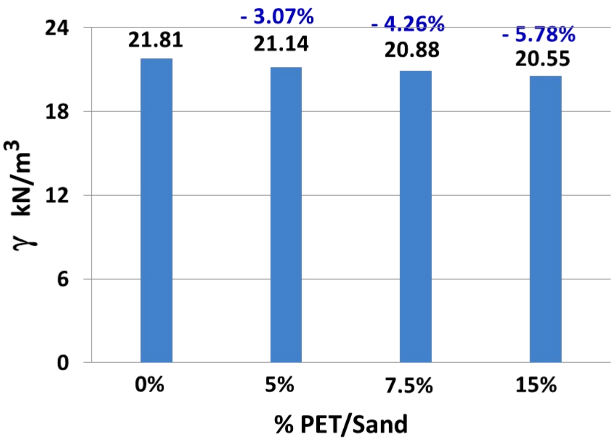


Fig. 6: Relationship between Density and replacement ratio of PET after 28 days

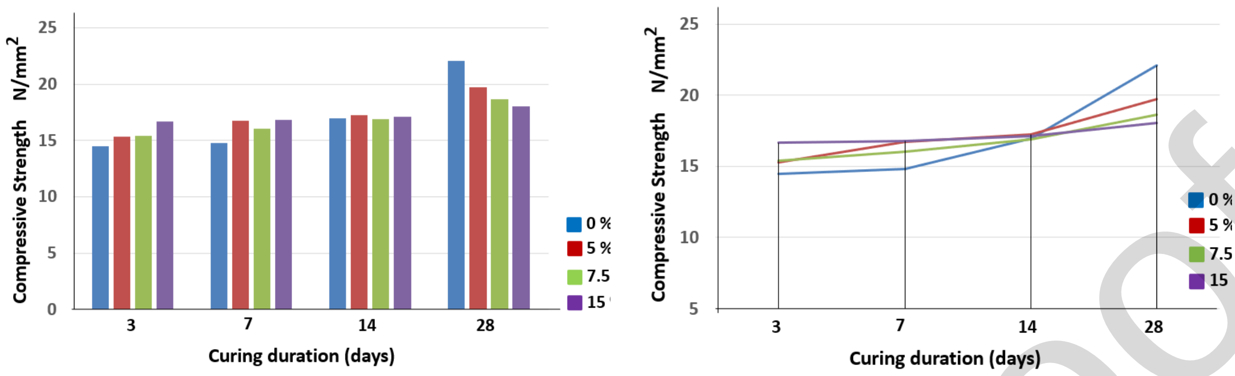
4.3. Mortar Compressive strength

The compressive strength test followed ASTM C109 [16]. **Fig. 7** displays the samples after testing. Mortars with 0%, 5%, 7.5%, and 15% PET by weight were tested. The results are presented in **Table 5** and Fig. 8. At 28 days, the mortar strength decreased as the PET amount increased, compared with no PET. In contrast, at 3 days, mortars with PET showed higher strength than the control mix. This early increase of strength could be linked with the shape and texture of PET. PET has a smooth surface and relatively large particles, which reduce its bonding with the cement paste. Also, PET is hydrophobic, which may limit water movement and affect the cement setting process during curing. These results are in agreement with past studies [18, 19, 24, 25], which also reported a slight reduction in long-term strength when PET replaced part of the fine aggregates. At 3 days, compressive strength increased by 5.9% for 5% PET, 6.4% for 7.5% PET and 15.3% for 15% PET. At 28 days, compressive strength dropped by 10.5% for 5% PET, 15.5% for 7.5% PET and 18.2% for 15% PET. As shown in **Fig. 8**, the strength difference between 3 and 28 days got smaller as the PET percentage increased. The drop in strength difference was 52.7% for 0% PET, 29.0% for 5% PET, 21.2% for 7.5% PET and 8.3% for 15% PET.

Fig. 7: Compression test specimens

Table 5: Compressive strength values of mortars with different ratios of granules PET

SP. #	PET %	Average Compressive Strength (N/mm^2)			
		3 days	7 days	14 days	28 days
C	0%	14.45	14.8	16.97	22.06
G5	5%	15.3	16.72	17.26	19.74
G7.5	7.5%	15.38	16.05	16.9	18.64
G15	15%	16.66	16.8	17.1	18.04



(a) (b)

Fig. 8: Relationship between compressive strength and replacement ratio of PET

4.4. Water Absorption

The water absorption test followed BS 1881 Part 122 [26]. Cylindrical samples measuring 75×75 mm were used. The test was performed after 28 days, as shown in **Fig. 9**. As shown in **Fig. 10**, water absorption increased as the PET content in the mix increased. This finding is supported by earlier studies [27, 28, 29, 30]. The main cause is the weak bond between the cement paste and the PET granules. In addition, the uniform shape of PET particles creates more open spaces in the mortar. These pores and gaps allow more water to enter. However, when PET content exceeded 5%, the water absorption rate was lower than in mixes with 0% to 5% PET. According to **Fig. 10**, the best performance was achieved with a 7.5% PET replacement.

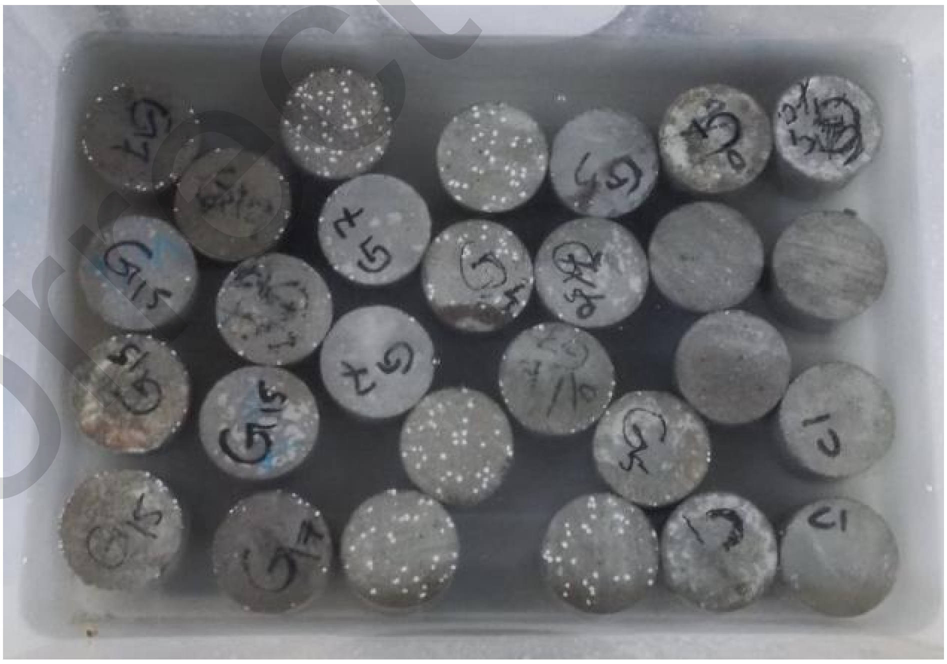


Fig. 9: specimens were submerged in water for 30 minutes

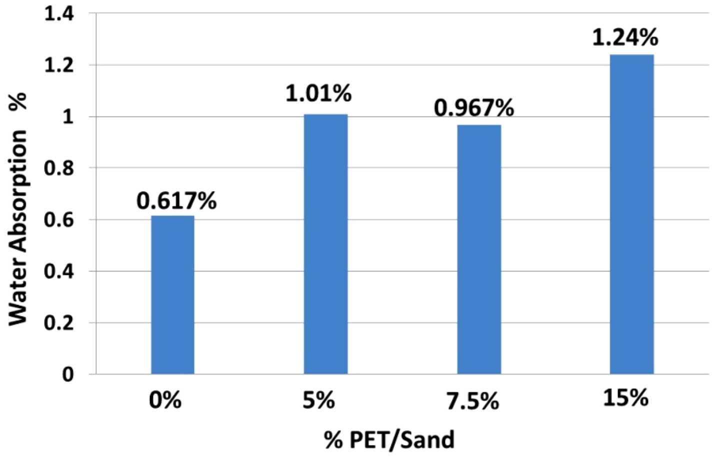


Fig. 10: Relationship between Water Absorption % and replacement ratio of PET

4.5. Water Penetration Resistance

The water penetration resistance test was performed according to DIN-1048-Part 5 [31]. After the test, each cube was split in half, as shown in **Fig. 11**. The final result was taken as the average of the deepest water penetration from three samples. **Fig. 12** shows that the depth of water penetration increased as more PET was added. Some mortar samples cracked either during setup or during the 72-hour test. These samples were removed, and the test was repeated with new ones, as shown in **Fig. 13**. The results showed that mortar with 7.5% PET had less water penetration than mortars with 5% and 15% PET. This suggests that 7.5% PET is the best amount to use as a sand replacement. This behavior may be caused by PET's poor bond with cement and its regular shape, which increases the number of pores and open spaces in the mortar. More pores mean more water can enter, as also found in other studies [24, 32].

Fig. 11: Water Penetration Resistance specimens after test

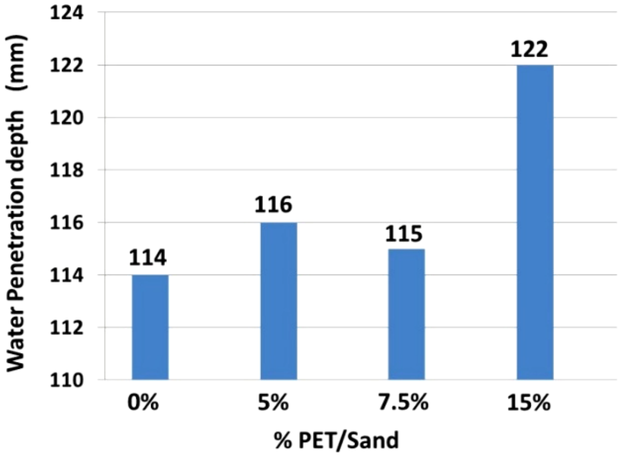


Fig. 12: Relationship between Water Penetration Resistance and replacement ratio of PET

Fig. 13: Cracks were observed in the mortar specimen during testing

CONCLUSIONS

In this study, polyethylene terephthalate (PET) granules were used to partly replace fine aggregates in mortar at four levels: 0%, 5%, 7.5%, and 15%. The goal was to study how PET affects workability, density, compressive strength, water absorption, and water penetration resistance. The main findings are:

1) Workability improved as more PET was added. Flow values increased by 1.6%, 8.8%, and 12% for 5%, 7.5%, and 15% PET, compared to mortar without PET.

2) Density went down with higher PET content. The mixes with 5%, 7.5%, and 15% PET showed density drops of 3.1%, 4.26%, and 5.8%, respectively.

3) At 28 days, compressive strength decreased by 10.5%, 15.5%, and 18.2% for 5%, 7.5%, and 15% PET mixes compared to the control mix.

4) The strength difference between day 3 and day 28 became smaller as PET content increased. The drop in strength difference was 52.7%, 29.0%, 21.2%, and 8.3% for 0%, 5%, 7.5%, and 15% PET, respectively.

5) Water absorption increased with more PET used as sand replacement. However, when PET content was above 5%, the water absorption rate became lower than that of the 0%–5% range. The best result was observed with the use of 7.5% PET. Water penetration depth also increased with higher PET content. However, the best performance was again recorded with the use of 7.5% PET.

CONFLICT OF INTEREST

The authors have no financial interest to declare in relation to the content of this article.

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