ADVANCES IN MATERIALS SCIENCE, Vol. 22, No. 4 (74), December 2022

DOI : 10.2478/adms-2022-0018

Abderrahmane Ghrieb[1,2] *, Yacine Abadou[2]

[1]*Mechanical and Materials Development Laboratory, University Ziane Achour, 17000, Djelfa, Algeria*
[2] *Department of Civil Engineering, University Ziane Achour, 17000, Djelfa, Algeria*

* ghrieb75@gmail.com

PHYSICAL AND MECHANICAL PROPERTIES OF DUNE SAND MORTAR REINFORCED WITH RECYCLED PET FIBER: AN EXPERIMENTAL STUDY

ABSTRACT

Polyethylene terephthalate is a synthetic material known as PET. PET strapping bands is a material commonly used in all industries for packaging and bundling. The excessive use of this material has led to the pollution of the urban environment, which necessitated the search for effective solutions to dispose of this waste. The treatment and reuse of these materials is among the best solutions that contribute to reducing environmental pollution on the one hand and enabling the obtaining of economical products on the other hand.
The main purpose of this experimental study is to valorize dune sand mortar and PET waste in the manufacture of cement mortar. It also aims to investigate the impact of the inclusion of recycled PET fibers on the physical and mechanical properties of the reinforced mortar. The study was carried out in several phases; after a physical and chemical characterization of the materials used, a method for the composition of mixtures was proposed, which is based on the progressive substitution of dune sand by recycled PET fibers. The quantity of cement added to each mixture is fixed at 450 g, and that of dune sand and fibers is taken as equal to 1350 g. In order to properly examine the influence of the incorporation of fibers on the properties of the reinforced mortar, the substitution rate of dune sand by the fibers varied from 0% to 2.5% with a step of 0.5%. For each mixture, many characteristics of the mortar were tested, such as consistency, bulk density, compressive strength, and flexural strength. The results obtained show that the incorporation of PET fibers has a significant effect on the fresh and hardened properties of the treated mortar.

Keywords: *Mortar; dune sand; recycled PET fiber; workability; mechanical strength*

INTRODUCTION

The study of the valorization and utilization of waste materials in mortar and concrete manufacturing is one of the most significant solutions that contribute to solving the problems of scarcity of natural resources and environmental pollution and achieving sustainable development and circular economy strategy. It also helps in the characterization of the properties of these materials and their control during application in various construction and rehabilitation projects.

Polyethylene terephthalate (PET) is one of the most widely used materials in industry due to its engineering properties and multiple applications. PET is a synthetic material that has good resistance to temperature, tensile and impact force [1]. This material is widely used as

packaging material for different types of products. The excessive use of this material has increased their negative impact on the environment and nature conservation.

In recent years, numerous studies have concentrated on the use of PET waste in mortar and concrete production. [1–4], especially the use of recycled PET as aggregates in mortar and concrete [5–10], and as fiber reinforcement in mortar and concrete [11–14]. Many authors concluded that the use of PET as fiber material enhanced the mechanical behavior of the cementitious mixtures [12, 13].

Tang et al. [11] evaluated the effect of the recycled PET fiber content and fiber length on concrete behavior. The results showed the inclusion of recycled PET fiber increased the compressive strength and density and reduced water absorption. Pereira de Oliveira et al. [14] investigated the utilization of polyethylene terephthalate (PET) bottle fibre recycled as fiber-inforcement mortar. The results indicate that the incorporation of PET fibres significantly improves the flexural strength of mortars. The results also showed that the maximum volume of PET fibre for a desired workability was 1.5%. Małek et al. [15] concluded that the compressive and flexural strength of reinforced concrete increased significantly after the addition of recycled polypropylene fiber. Alrshoudi et al. [16] demonstrated that using waste polypropylene fibers improved the compressive strength and durability while significantly reducing the dry shrinkage of reinforced concrete.

Moreover, according to Thorneycroft et al. [17], the usage of PET plastic aggregates with a replacement rate of 10% by volume exhibited good performance results. Almeshal et al. [18] investigated the effects of utilising poly-ethylene terephthalate (PET) as a partial substitute for sand in concrete. They found that the fresh density values for concrete containing 50% PET (PET50) decreased by 31.6%. Additionally, it was shown that PET50's compressive strength decreased as plastic content increased. In fact, it was found that PET50's compressive strength dropped by 90.6%. Additionally, with a coefficient of correlation (R2) of 0.986, the residual compressive strength of PET50 showed a very significant relationship with the fire exposure period. The ultrasonic pulse velocity (UPV), which decreased from 4.5 km/s to 1.9 km/s, indicates that the quality of the concrete containing plastic material is low.

Although there are many published studies dealing with the use of PET waste in the manufacture of mortar and concrete, the study of the effect of this type of waste on the physical and mechanical properties of dune sand-based mortar has not yet received sufficient attention. In the present study, dune sand and PET waste were chosen for mechanical, economic, and environmental objectives. To understand the effect of the recycled PET fibers, these last were used to replace 0.5, 1, 1.5, 2, and 2.5% of dune sand by weight. To assess the properties of fiber-reinforced dune sand mortar in a fresh and hardened state, consistency, compressive strength, flexural strength, ultrasonic pulse velocity, and water absorption tests were carried out.

The primary objective of this experimental study is to highlight the relevance of recycling PET strapping bands waste in order to prepare an ecologically friendly mortar that can be used in a variety of building applications. The study includes the understanding of the effect of recycled PET fiber inclusion on the physical and mechanical properties of the fiber-reinforced dune sand mortar and evaluates the feasibility of using recycled PET fiber in mortar manufacture.

EXPERIMENTAL

Cement

The cement used in this experimental study is a Composite Portland Cement CEM II/A 42.5 type provided by BISKRIA CEMENT and it is certified according to Algerian standard

NA 442 -2013 and the European standard EN 197-1 [19]. This cement has a bulk and a specific density of 1.96 g/cm^3 and 3.11 g/cm^3, respectively, a specific surface area of 3225 cm^2/g and a regular consistency of about 27%.

Sands

Two sands were used in this experiment; a dune sand was denoted by "DS" and an alluvial sand by "AS". These sands were brought from the region of Djelfa (Algeria). Their physical characteristics are presented in Table 1. Figure 1 shows the grain size distribution of sands used; the DS and AS have grain sizes of 0/0.315 mm and 0/4 mm and a fineness modulus of 0.86 and 2.36 respectively. X-ray diffraction analysis using the powder method finds its main use in the identification of minerals. Each crystalline body produces a spectrum or X-ray diffractogram, which reflects its internal structure and the nature of the minerals [20]. Figure 2 shows the XRD patterns of the dune sand and the alluvial sand. Both sands exhibit a similar tendency. This analysis revealed that the studied sands consist mainly of quartz and illite.Quartz is inert and does not participate in cement hydration process at ambient temperature [21-23].

Table 1. *The physical characteristics of the sands used*

Physical properties	AS	DS
Bulk density (g/cm^3) [NF EN 1097-3]	1.61	1.46
Specific density (g/cm^3) [NF EN 1097-6]	2.60	2.53
Porosity (%) [NF EN 1097-3]	38	43
Compactness (%) [NF EN 1097-3]	62	57
Water absorption (%)[NF EN 1097-6]	0.87	2.35
Visual sand equivalent (%) [NF EN 933-8]	81	79
Sand equivalent with the piston (%) [NF EN 933-8]	80	75

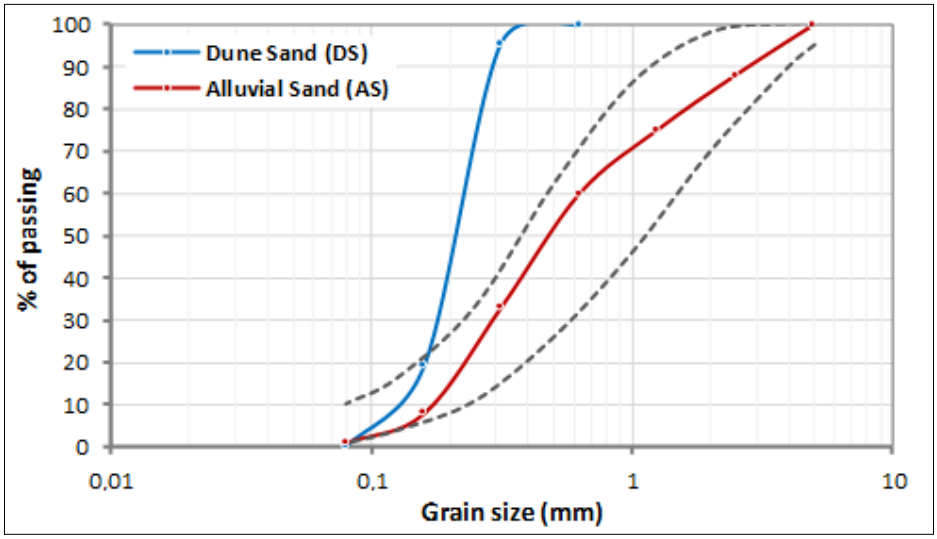


Fig. 1. The particle size distribution of the sands used

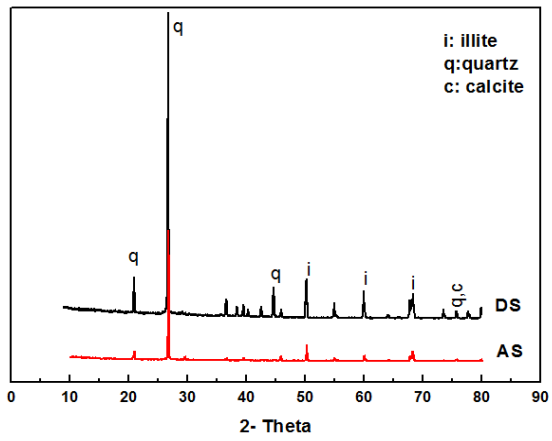


Fig. 2. X-ray diffraction patterns of sands used



Fig. 3. PET strap waste fibers used

Recycled PET fiber

The PET waste used in this study is PET strapping band, commonly used for product packaging. It has a tensile strength of about 36 MPa, a melting point of 255 to 265 °C, and a glass transition temperature ranging from 70 °C to 80 °C [6]. The polyethylene terephthalate (PET) fibres, as shown in Figure 3, were obtained manually by cutting packaging straps. Their dimensions are between 15 and 20 mm in length, 1.0 and 1.5 mm in width, and 0.55 mm in thickness. The fibers used have a density of 1.29 and a water absorption of 0.18% [24]. The fibers obtained were used as reinforcement for dune sand mortar.

Mix proportions and sample preparation

The proportion of mixture used to prepare the investigated mortars was the same as that used to manufacture the standard mortar, according to standard NF EN 196-1 [19].Based on previous experience and literature [11-12], the maximum fiber content was limited to 2.5% by weight in order to achieve adequate workability and mechanical strength.

The experimental procedures used in this study were to determine the mechanical resistance of prismatic specimens of dimensions 4×4×16 cm^3. The mortar mixes were prepared and performed according to the NF EN 196-1 standard; the amount of cement was fixed at 450 g, and that of dune sand and PET fibers was set at 1350 g. To examine the impact of the inclusion of the recycled fiber on the physical and mechanical properties of fresh and hardened mortar, the dune sand was substituted by 0%, 0.5%, 1.0%, 1.5%, 2.0%, and 2.5% PET fibers by weight. A constant w/c ratio of 0.70 was used for all mixtures. Mortar mix compositions are presented in Table 2.

After mixing was completed, the fresh mixtures were molded. They were then clamped on to a vibrating table for 20 s to 30 s. During the first 24 h, the specimens were kept in the ambient laboratory environment (room temperature of 23 ± 2°C, relative humidity of 50% ± 10%). One day after, the samples were demolded, and they were then immersed in drinking water at ambient temperature (23 ± 2 °C) until the test day.

Table2. *Mix composition of mortar studied*

Mixtures	Composition	Ciment (g)	DS (g)	AS (g)	F (%)	F (g)	w/c
MA (control mix)	100% AS	450	-	1350	0	0	0.7
MD	100% DS	450	1350.0	-	0	0	0.7
MF-0.5	84.5% DS + 0.5% F	450	1343.3	-	0.5	6.7	0.7
MF-1.0	84% DS + 1% F	450	1336.5	-	1.0	13.5	0.7
MF-1.5	83.5% DS + 1.5% F	450	1329.8	-	1.5	20.2	0.7
MF-2.0	83% DS + 2% F	450	1323.0	-	2.0	27.0	0.7
MF-2.5	82.5% DS + 2.5% F	450	1316.3	-	2.5	33.7	0.7

Testing procedures

In fresh state, the workability was determined using a CLC maniabilimeter, according to the European standard NF P18-452 standard [25]. The test consists of measuring the flow time of a fresh mortar exposed to a specified vibration. The bulk density of fresh mortars was performed according to the standard NF EN 1015-6 [26]. In hardened status, the mechanical properties were tested at 7 and 28 days using 4×4×16 cm^3 specimens, according to the European standard NF EN 196-1 standard [19]. The flexural strength was measured using the three-point bending test (Figure 4). The half-samples resulting from the flexural test were then subjected to compression in a 4×4 cm^2 test section. The bulk density and water absorption of hardened samples were investigated according to the European standards NF EN 1015-10 [27] and NF EN 1015-18 [28], respectively. Ultrasonic Pulse Velocity (UPV) testing is used to determine the quality of structural mortar by measuring the speed and attenuation of an ultrasonic wave passing through the element being tested according to the ASTM C597- 02 standard [29]. The test was performed after a curing time of 365 days. The measured UPV was also utilized to calculate the dynamic modulus of elasticity. The following equation from Topçu and Bilir (2009) was chosen to evaluate the dynamic modulus of elasticity (E_d) [30, 31].

$$E_d = (V^2\rho/g) \times 10^{-2} \quad (1)$$

where E_d: dynamic modulus of elasticity (GPa), V: UPV (km/s), ρ: density (kg/m^3) and g: acceleration due to gravity (9.81 m/s^2).



Fig. 4. Specimens prepared for the mechanical test and the flexural three-point bending test

RESULTS AND DISCUSSION

The consistency and bulk density of fresh mortar

Figure 5 represents the evolution of the flow time (workability) and bulk density of fresh mixtures according to the quantity of recycled fiber. We notice that, for a fixed water-cement ratio (W/C = 0.7), the mix with alluvial sand (MA) presents a shorter flow time than the mix with dune sand (MD); this is due to the grain size distribution of dune sand, which is very fine compared with that of alluvial sand.

The results of the consistency also demonstrate that the reinforcement rates of 0.5%, 1%, 1.5%, and 2% of recycled fiber do not significantly affect the workability of treated mixes. However, the reinforcement rate of 2.5% resulted in a considerable reduction in flow time. This reduction may be due to the difference in water absorption capacity between dune sand and the recycled waste fibers (The water absorption capacity of the aggregate is one of the factors that affects workability [32, 33]), which increased the amount of excess water and therefore the workability. The decrease in flow time is also attributed to the longitudinal shape of PET waste fibers, which assists the mixed particles to flow over each other [34].

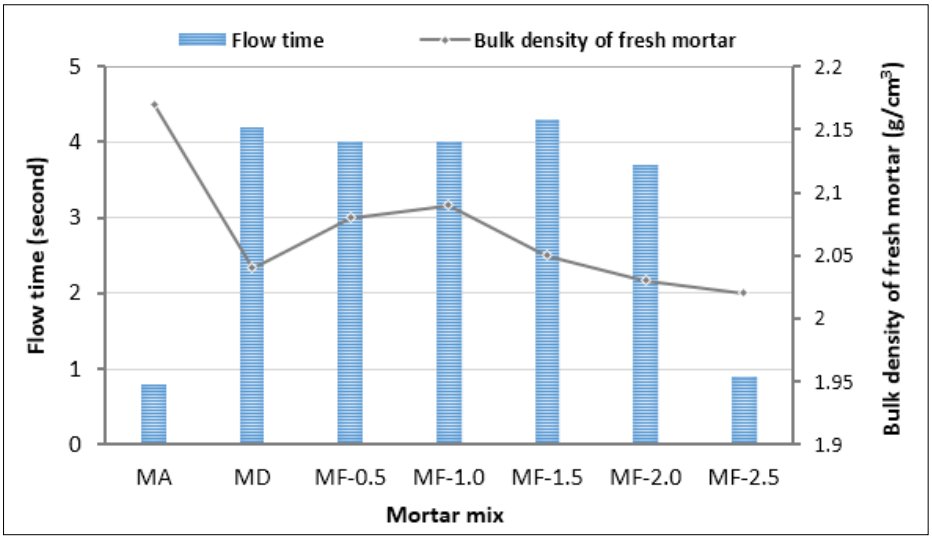


Fig. 5. Results of the flow time and bulk density of fresh mortar

On the other hand, it should be noted that the bulk density in the fresh state of untreated dune sand mortar (MD) is lower than that of control mortar (MA). This difference is attributed to the bulk density of DS, which is lower than that of SA. Furthermore, the density increases slightly for 0.5% and 1% of fiber, then it decreases for higher fiber replacement rates. The inclusion of recycled PET fiber, used in this experiment, varies the density of fresh mortar between 2.02 and 2.09 g/cm^3.

The bulk density and water absorption capacity of hardened mortar

The hardened mortar density results, presented in Figure 6, show that the inclusion of PET fiber leads to a clear increase in bulk density for a reinforcement rate of 0.5% (MF-0.5). Beyond this percentage, a general decrease in bulk density was observed. The specimens with recycled fibers exhibited densities varying from 1.79 to 1.96 g/cm^3. The reinforcement of dune sand mortar with 1%, 1.5%, 2%, and 2.5% PET fibers induces reductions of 0.5%, 2.1%,

1.6%, and 5.8%, respectively, as compared to the untreated mortar. This can be attributed to the specific gravity of PET waste, which is relatively low compared to that of dune sand (1.29, 2.53 respectively). Pereira de Oliveira et al. concluded that the incorporation of PET fibers does not significantly change the bulk density of the hardened mortar [14].

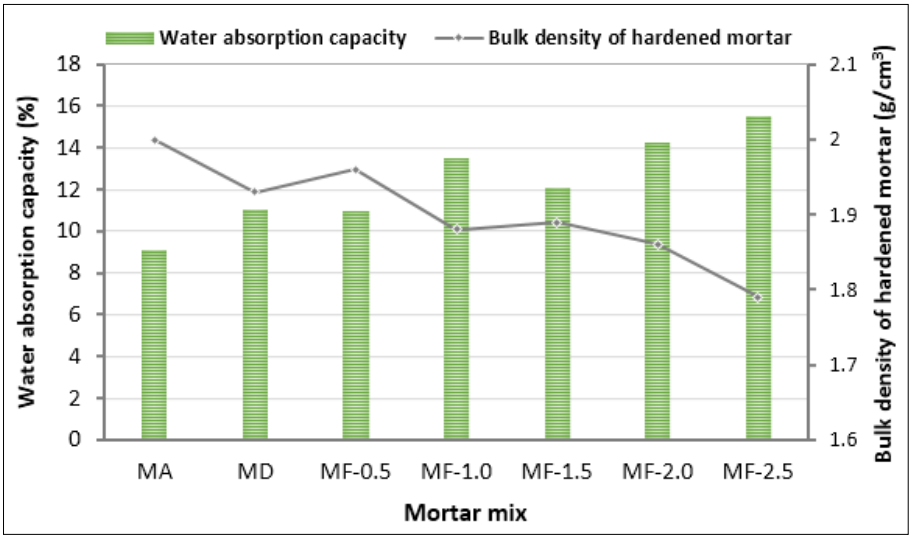


Fig. 6. Evolution of dry bulk density and water absorption capacity of hardened mortar

From the water absorption results, it can be seen that the reinforcement of dune sand mortar with PET fibers results in a continuous increase in the water absorption capacity, which shows that these fibers do not participate in improving the compactness of mortar mixes. The dune sand mortar treated with PET fibers exhibited water absorption capacities varying between 11% and 15.5%. The minimum value of water absorption capacity (11%) was observed at 0% and 0.5% PET fiber. The maximum value was given by the mixture containing 2.5% PET fibers (mixture MF-2.5); the incorporation of PET fibers can generate an important increase in water absorption of the order of 40% as compared to the mortar without fiber (MD).This indicates that the addition of fibers used in the dune sand mortar increases the open porosity.Similar findings were reached by Pereira de Oliveira et al. [14], who found that adding 0.5 to 1.5% PET fibre modifies the mortar porosity. The reinforcement of dune sand mortar with recycled PET fibers does not allow obtaining water absorption values close to those of the SA-based mortar (MA); this may be mainly due to the good particle size distribution of this sand compared with DS sand.

The ultrasonic pulse velocity and dynamic elasticity modulus

The effects of the recycled fibers on ultrasonic pulse velocity and dynamic modulus of elasticity are presented in Figure 7. From this Figure, we note that for a replacement rate of 0.5%, the effect of recycled fibers on the upv is not significant. On the other hand, beyond this percentage, the influence of the fibers on this characteristic becomes significantly negative; the UPV (see Figure 7) for reinforced mortars decreased by 0.9%, 2.3%, 4.8%, and 3.2% for the MF-1.0, MF-1.5, MF-2.0%, and MF-2.5 mortars, respectively, with respect to that of the non-reinforced mortar.In contrast to the water absorption capacity, the addition of PET fiber increased the porosity, which decreased the UPV. It should be noted that the lower

specific gravity of the recycled fibers also contributes to a decrease in the density of reinforced mortars and therefore in UPV [35].

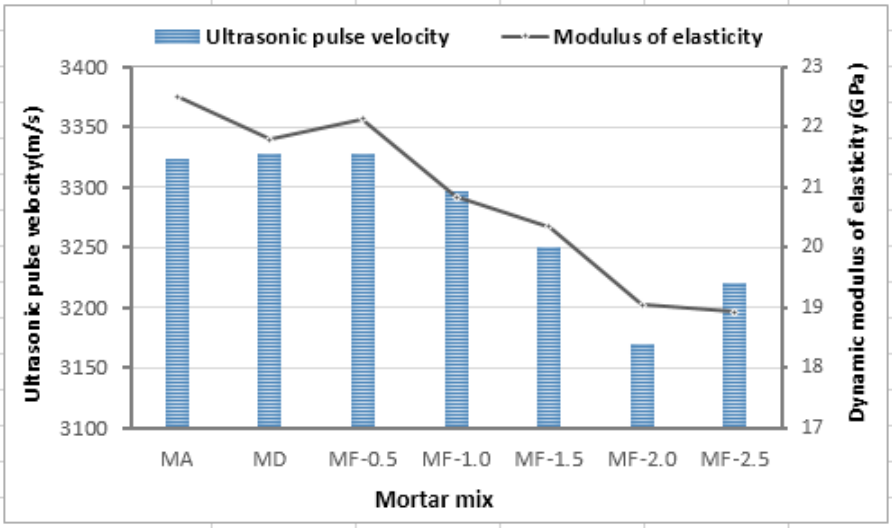


Fig. 7. UPV and dynamic modulus of elasticity results

The results of the dynamic modulus of elasticity (E_{dyn}) at 365 days are presented in Figure 7. From these results, it can be generally revealed that the trend in bulk density of hardened mortar is similar to that in dynamic modulus of elasticity, which confirms the concurrent development and the strong correlation between density and the dynamic modulus of elasticity. These results also showed that for a fixed W/C ratio, the inclusion of recycled fibers with a replacement rate of 0.5% increased the dynamic modulus of elasticity by 1.6% compared to non-reinforced mortar (MD). On the other hand, for higher fiber content, we noticed that the fiber effect was significantly negative.This is mainly due to the increased porosity of the reinforced mortars; the latter became less compact, which reduced the modulus of elasticity. The values of the dynamic modulus of elasticity of the dune sand mortars with and without fibers do not make it possible to reach values higher than those of the control mortar (MA). This could be associated with the difference in porosity between SD and SA sands (Table 1).The decrease in modulus of elasticity when fibers are incorporated in the mortars is also reported by other authors [36].

The mechanical properties of the hardened mortar

Compressive strength

The results obtained for the compressive strength (CS) of the 7-day and 28-day mortar samples are presented in Figure 8. As shown, the mortar samples reinforced with recycled PET fibers induced compressive strength values varying from 11.4 to 16 MPa and 19 to 25.6 MPa at 7 days and 28 days, respectively. At 7 days, the highest strength value was obtained for a replacement rate of 0.5%, with an improvement of 17.7% compared to MD. This enhancement makes it possible to give strength values higher than those of the AS-based mortar (MA). The lowest compressive strength was obtained by MF-1.5, with a reduction of 12.2% as compared to non-reinforced mortar (MD). At 28 days, the inclusion of 0.5% PET fibers induces the highest compressive strength with an enhancement rate of 29.3%. This improvement can make it possible to give strength values higher than those of the control

mortar (MA). These results suggest the potential of using recycled PET fiber as an alternative material for other types of additives, which would not only improve the mechanical properties of the fiber-reinforced mortar but also provide an effective way to recycle the PET waste, which is difficult to degrade.

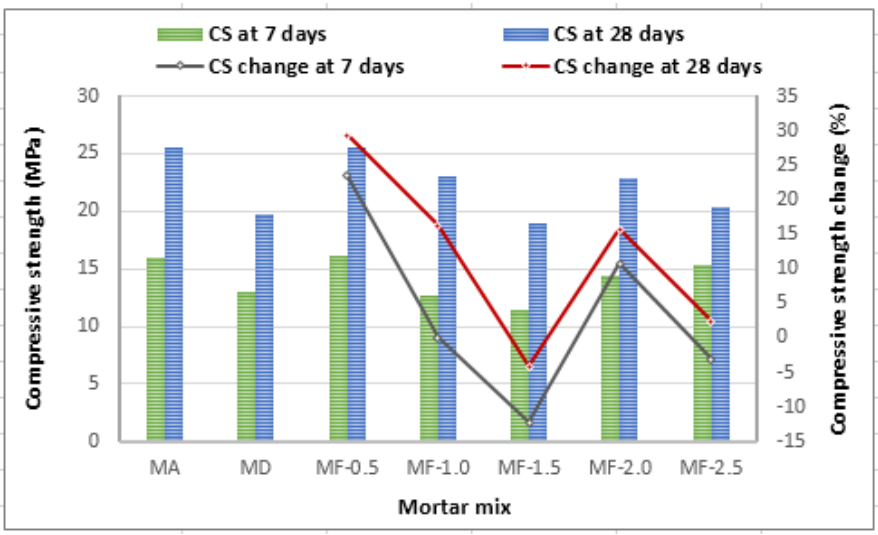


Fig. 8. Compressive strength test results

Compared with MD, the compressive strength at 28 days of the mortar MF-1.5 decreased by 4.1%.Similarly, Ochi et al. [37] and Tang et al. [38] also reported this trend of compressive strength, with the increase of fiber content, the compressive strength increased moderately, but decreased for higher fiber rate.A possible reason for the reduction in compressive strength is that adding an unsuitable amount of fiber cannot bridge the mortar matrix and may generate voids in the matrix, which reduces the adhesion between the fiber and the matrix, thereby reducing the compressive strength of mortar [39,40]. These findings are consistent with the literature [41–43], which reports that excessive or insufficient fiber content can hardly improve the strength.

Flexural strength

The experimental results obtained from the flexural (FS) test are plotted in Figure 9. As shown, the dune sand mortars reinforced with PET waste fibers exhibited flexural strength varying from 2.68 to 3.35 MPa and 2.58 to 3.89 MPa at 7 days and 28 days, respectively. Contrary to compressive strength results, the inclusion of PET fibers in dune sand mortars does not make it possible to achieve a flexural strength higher than that of the AS-based mortar. The highest flexural strength values were recorded for a replacement rate of 0.5%, with enhancement rates of 14.4 and 13.4% at 7 days and 28 days, compared to MD, respectively. This enhancement in the flexural strength of fiber-reinforced mortars could be attributed to the enhanced adherence between PET fibers and the dune sand mortar matrix [44].The same finding was made in similar experiments by Pereira de Oliveira et al. [14], who reported that the PET fiber incorporation in the mortar increases the flexural strength by the order of 30% at 28 days and by the order of 50% at 63 days. Beyond 0.5% fiber, the flexural strength at 7 and 28 days decreased significantly as compared to the non-reinforced mortar (MD). When the replacement rate increased from 1% to 2.5%, the flexural strength at 28 days varied from 2.6 MPa to 2.8 MPa, which decreased by 17.5% to 24.8%. Generally, reinforcing the dune sand mortar with recycled PET fiber content higher than 0.5% resulted in lower

flexural strength. This reduction in strength is related to the increase in porosity with the replacement rate; the values of the water absorption capacity (Figure 6) and elasticity modulus (Figure 7) indicate the effect of the recycled fiber inclusion on the porosity of fiber-reinforced mortars.

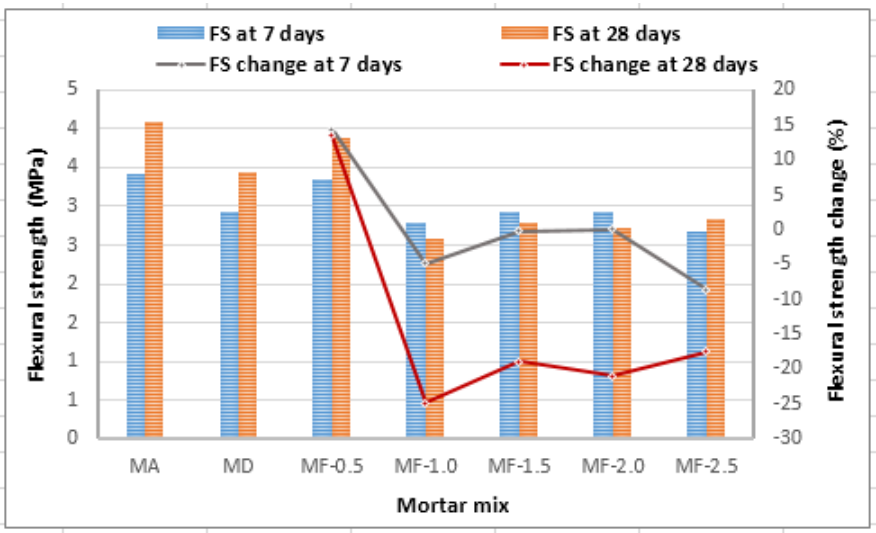


Fig. 9. Flexural strength test results

Statistical Data Analytics

The main statistical method for this purpose is the analysis of variance (ANOVA).It is an essential tool in determining the meaning of a mathematical effect or model. The principle of variance analysis is based on the calculation of the total difference between the different measures of the experimental design and the average of these measurements. The significances of all terms in the polynomial were judged statistically by computing the F-value at a probability (P) of 0.001, 0.01 or 0.05. Models with p values less than 0.05 are considered essential.

The regression coefficients were then used to make statistical calculations to generate contour maps from the regression models. The regression coefficients (R^2 and R^2_{adj}), which indicate the model's ability to adjust the measured data, are the first diagnostic tools (Table 3).Table 3 shows the summary design statistics of all responses for the selected models. The correlation coefficient (R^2) is high, indicating a high level of correlation between the experimental and predicted responses. Besides, it is evidently seen that the scattering of flow time, density of fresh mortar, compressive and flexural strength results of mixes affects Table3 lowest correlation coefficient (0.49, 0.31, 0.04 and 0.47) as well as the highest standard deviation value for these properties' results.

Table 3. *Model summary statistics*

Property	R^2	R^2 Adjusted	Mean value	Standard deviation
Flow Time	0.495	0.369	3.516	1.298
Density (fresh)	0.309	0.136	2.051	0.027
Density (hardened)	0.807	0.758	1.885	0.058
Compressive strength	0.042	0.197	21.76	2.496
Flexural strength	0.467	0.334	3.036	0.509
UPV	0.787	0.734	3265.6	63.77
Dynamic modulus of elasticity	0.913	0.891	20.510	1.340
Absorption (%)	0.8077	0.7595	12.880	1.825

The numerical model of each response was created after examining the response values. Table 4 and 5 show the results of the ANOVA as well as the statistical criteria for the response.

Table 4. *Results of ANOVA for bulk density fresh*

Source	Degrees of freedom	Sum of square	Mean Square	F-value
Model	1	0.0012	0.0012	1.792
Error	4	0.0027	0.19478	p-value
Total	5	0.0039		0.2517

Table 5. Results of ANOVA for flexural strength

Source	Degrees of freedom	Sum of square	Mean Square	F-value
Model	1	0.607	0.607	3.5122
Error	4	0.691	0.172	p-value
Total	5	1.298		0.1342

Table 6. Results of ANOVA for compressive strength

Source	Degrees of freedom	Sum of square	Mean Square	F-value
Model	1	1.316	1.316	0.716
Error	4	29.85	7.464	p-value
Total	5	31.17		0.696

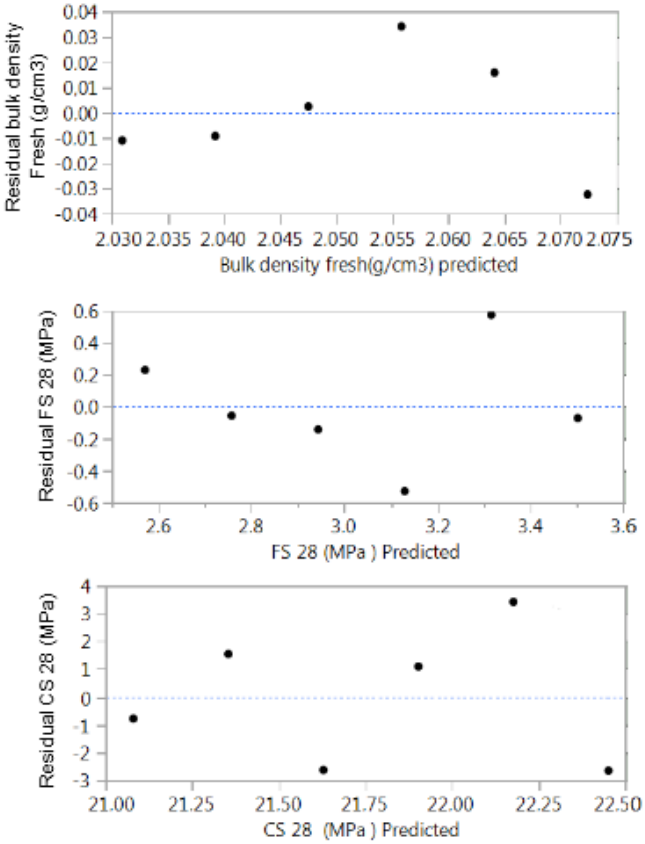


Fig. 10. Residual plot for density, compressive (cs) and flexural strength (FS) model.

For the mortar with waste PET fiber, it is seen that there is no significant effect of polypropylene fiber content on the mechanical strength and bulk density of fresh mortar. This is also confirmed by the result of ANOVA, which is presented in Tables 4, 5 and 6, and the residual plots for the models. A graph of the residuals against the predicted values are shown in Figure10. This result states that the fiber's waste of PET the P-value is statistically non-significant, and it also means that fiber has no effect on the mechanical strength and bulk density of fresh mortar. While, this graph shows random behavior without a tendency towards residuals for predicted values. The residuals plots shown in Figure 10, indicate that the points seem to be distributed randomly for all studied responses.

Figure11 illustrates the relationship between the absorption and Bulk density fresh of dune sand mortar, where water absorption coefficient decreases as density increase. The correlation coefficient R^2 = 0.915 indicates that a very good relationship exists between Absorption and the Bulk density fresh.

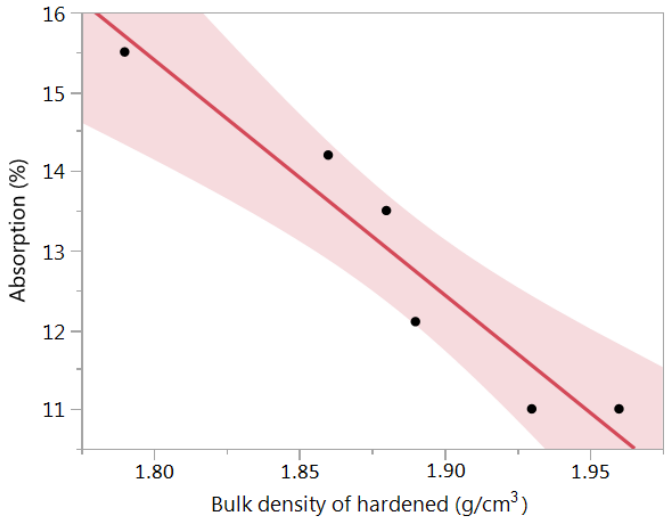


Fig. 11. Fitting curves of absorption and density response results mortar

For the studied samples, the mathematical representation showing the dependence of water absorption coefficient (Abs) on density (D) mentioned here as model is found to be such that:

$$Abs = 68.78 - 29.65 \times \mathrm{D} \tag{2}$$

CONCLUSIONS

In this experimental work, recycled PET fibers were used as reinforcement of dune sand mortar with the aim of preparing economic and ecological mortars based on recycled materials. To understand the impact of fiber inclusion on reinforced dune sand mortar properties, the workability, compressive strength, flexural strength, dynamic modulus of elasticity, and water absorption capacity of mortars have been determined. The main conclusions obtained were:

- The effect of adding recycled fiber on the flow time of the treated mixtures is not significant for replacement rates between 0.5% and 2%. This effect is only effective for 2.5% of fibers. We have concluded that this is mainly due to the difference between dune sand and additives in shape and absorption capacity. On the other hand, we noticed that

the density of fiber-reinforced mortar in a fresh state increases for replacement rates of 0.5% and 1%, and decreases for higher rates.

- The reinforcement of dune sand mortar with 0.5% of recycled PET fibers induces an enhancement in the bulk density of hardened mortar, while the density reduces for the other percentages. Generally, the fibers used generate an important increase in water absorption. An increase of the order of 40% was recorded as compared to the non-reinforced dune sand mortar.
- For replacement rates between 1% and 2.5%, the impact of recycled fibers on the UPV and the dynamic modulus of elasticity is negative. The increase in porosity for these fiber percentages is responsible for this effect. The dynamic modulus of elasticity increased 1.6% for 0.5% fibers.
- The compressive and flexural strengths were significantly improved by adding 0.5% recycled fiber. At 28 days, improvements of 29.3% and 13.4% were seen, respectively. This improvement can make it possible to give compressive strength values higher than those of the control mortar. The improved adhesion between PET fibers and the dune sand mortar matrix is responsible for the increase in mechanical strength of fiber-reinforced mortars.
- The approach of statistical measures provides insights into recycled PET fibers in dune sand mortar for the reuse of materials in civil construction work. All characteristics proprieties is ineffective in the case of PET fibers incorporation. The facts and figures of the coefficient of variation and ANOVA analysis verified this.

REFERENCES

1. Y.W. Choi, D.J. Moon, Y.J. Kim, M. Lachemi, Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles, Construction and Building Materials. 23 (2009) 2829–2835.
2. K. Hannawi, S. Kamali-Bernard, W. Prince, Physical and mechanical properties of mortars containing PET and PC waste aggregates, Waste Management. 30 (2010) 2312–2320.
3. J.M.L. Reis, E.P. Carneiro, Evaluation of PET waste aggregates in polymer mortars, Construction and Building Materials. 27 (2012) 107–111.
4. S. Akçaozoğlu, C. Ulu, Recycling of waste PET granules as aggregate in alkaliactivated blast furnace slag/metakaolin blends, Construction and Building Materials. 58 (2014) 31–37.
5. F.A. Spósito, R.T. Higuti, M.M. Tashima, J.L. Akasaki, J.L.P. Melges, C.C. Assunção, M. Bortoletto, R.G. Silva, C.F. Fioriti, Incorporation of PET wastes in rendering mortars based on Portland cement/hydrated lime, Journal of Building Engineering. 32 (2020) 101506.
6. M. Hacini, A.S. Benosman, N.K. Tani, M. Mouli, Y. Senhadji, A. Badache, N. Latroch, Utilization and assessment of recycled Polyethylene Terephthalate strapping bands as lightweight aggregates in Eco-efficient composite mortars. Construction and Building Materials. 270 (2021) 121427
7. Y. Choi, D. Moon, J. Chung, S. Cho, Effects of waste PET bottles aggregate on the properties of concrete, Cement and Concrete Research. 35 (2005) 776–781.
8. A. Sadrmomtazi, S. Dolati-Milehsara, O. Lot, A. Sadeghi-Nik, The combined effects of waste Polyethylene Terephthalate (PET) particles and pozzolanic materials on the properties of self-compacting concrete, Journal of Cleaner Production. 112 (2016) 2363–2373.

9. E. Rahmani, M. Dehestani, M.H.A. Beygi, H. Allahyari, I.M. Nikbin, On the mechanical properties of concrete containing waste PET particles, Construction and Building Materials. 47 (2013) 1302–1308

10. F. Fraternali, S. Spadea, V.P. Berardi, Effects of recycled PET fibres on the mechanical properties and seawater curing of Portland cement-based concretes, Construction and Building Materials. 61 (2014) 293–302

11. R. Tang, Q. Wei, K. Zhang, S. Jiang, Z. Shen, Y. Zhang, C.W.K. Chow. Preparation and performance analysis of recycled PET fiber reinforced recycled foamed concrete. Journal of Building Engineering. 57 (2022) 104948A.

12. H. Alani, M. A.M. Johari, A.T. Noaman, N.M. Bunnori, T.A. Majid, Effect of the incorporation of PET fiber and ternary blended binder on the flexural and tensile behaviour of ultra-high performance green concrete, Construction and Building Materials. 331 (2022) 127306.

13. A.A. Mohammed, A.A.F. Rahim, Experimental behavior and analysis of high strength concrete beams reinforced with PET waste fiber, Construction and Building Materials. 244 (2020) 118350.

14. L.A. Pereira de Oliveira, João P. Castro-Gomes, Physical and mechanical behaviour of recycled PET fibre reinforced mortar, Construction and Building Materials. 25 (2011) 1712-1717.

15. M. Małek, M. Jackowski, W. Łasica, M. Kadela, Characteristics of recycled polypropylene fibers as an addition to concrete fabrication based on Portland cement, Materials. 13 (2020) 1827.

16. F. Alrshoudi, H. Mohammadhosseini, M.M. Tahir, R. Alyousef, H. Alghamdi, Y. Alharbi, A. Alsaif, Drying shrinkage and creep properties of prepacked aggregate concrete reinforced with waste polypropylene fibers, Journal of Building Engineering. 32 (2020) 101522.

17. J. Thorneycroft, J. Orr, P. Savoikar, R. Ball, Performance of structural concrete with recycled plastic waste as a partial replacement for sand, Construction and Building Materials. 161 (2018) 63–69.

18. I. Almeshal, B.A. Tayeh, R. Alyousef, H. Alabduljabbar, A.M. Mohamed, Ecofriendly concrete containing recycled plastic as partial replacement for sand, Journal of Materials Research and Technology. 9 (3) (2020) 4631–4643.

19. AFNOR standards organisation. Méthodes d'essais des ciments - Partie 1: détermination des résistances mécaniques. NF EN 196-1 (2006).

20. S. Guettala, B. Mezghiche, M. Mellas, Influence of addition dune sand powder to cement, on the properties physical-mechanical and deformability of concrete, Asian Journal of Civil Engineering (Building and Housing). 13 (6) (2012) 765-781.

21. M. Liu, Y. Hu, Z. Lai, T. Yan, X. He, J. Wu, Z. Lu, S. Lv, Influence of various bentonites on the mechanical properties and impermeability of cement mortars, Construction and Building Materials. 241 (2020) 118015.

22. H. Zanni, M. Cheyrezy, V. Maret, S. Philippot, P. Nieto, Investigation of hydration and pozzolanic reaction in reactive powder concrete (RPC) using 29 Si NMR, Cement and Concrete Research. 26 (1) (1996) 93–100.

23. J. Du, W. Meng, K.H. Khayat, Y. Bao, P. Guo, Z. Lyu, A. Abu-obeidah, H. Nassif, H. Wang, New development of ultra-high-performance concrete (UHPC), Composites Part B: Engineering. 224 (2021) 109220.

24. A.H. Alani, M.A.M. Johari, A.T. Noaman, N.M. Bunnori, T.A. Majid. Effect of the incorporation of PET fiber and ternary blended binder on the flexural and tensile behaviour of

ultra-high performance green concrete, Construction and Building Materials. 331 (2022) 127306.

25. AFNOR standards organisation. Bétons - Mesure du temps d'écoulement des bétons et des mortiers aux maniabilimètres NF 18-452 (1988).
26. AFNOR standards organisation. Méthodes d'essai des mortiers pour maçonnerie - Partie 6: Détermination de la masse volumique apparente du mortier frais. NF EN 1015-6 (1999).
27. AFNOR standards organisation. Méthodes d'essai des mortiers pour maçonnerie - Partie 10: détermination de la masse volumique apparente sèche du mortier durci. NF EN 1015-10 (2000).
28. AFNOR standards organisation. Méthodes d'essai des mortiers pour maçonnerie - Partie 18: détermination du coefficient d'absorption d'eau par capillarité du mortier durci. NF EN 1015-18 (2003).
29. American society for testing material. Standard Test Method for Pulse Velocity Through Concrete. ASTM C597-02 (2010)
30. M. Malešev, V. Radonjanin, I. Lukić, V. Bulatović, The effect of aggregate, type and quantity of cement on modulus of elasticity of lightweight aggregate concrete, Arabian Journal for Science and Engineering. 39 (2) (2014) 705–711.
31. T. Gupta, S. Chaudhary, R.K. Sharma, Mechanical and durability properties of waste rubber fiber concrete with and without silica fume, Journal of Cleaner Production. 112 (1) (2016) 702-711.
32. M.B. Leite, J.G.L. Figueire do Filho, P.R.L. Lima, Workability study of concretes made with recycled mortar aggregate, Materials and Structures. 46 (2013) 1765–1778.
33. İ.B. Topçu, S. Şengel, Properties of concretes produced with waste concrete aggregate, Cement and Concrete Research. 34 (2004) 1307–1312.
34. T. Felixkala, P. Partheeban, Granite powder concrete, Indian Journal of Science and Technology. 3(3) (2010) 311–317
35. Z. Laidani, Y. Ouldkhaoua, M. Sahraoui, B. Benabed, Feasibility of marble powder and calcined bentonite in SCM as partial substitution of cement for sustainable production Építőanyag – Journal of Silicate Based and Composite Materials. 74 (2022) 61–66.
36. C.B. Farinha, J. de Brito, R. Veiga, Incorporation of high contents of textile, acrylic and glass waste fibres in cement-based mortars. Influence on mortars' fresh, mechanical and deformability behavior, Construction and Building Materials. 303 (2021) 124424.
37. T. Ochi, S. Okubo, K. Fukui, Development of recycled PET fiber and its application as concrete-reinforcing fiber, Cement and Concrete Composites. 29 (6) (2007) 448–455.
38. R. Tang, Q. Wei, K. Zhang, S. Jiang, Z. Shen, Y. Zhang, C.W.K. Chow, Preparation and performance analysis of recycled PET fiber reinforced recycled foamed concrete, Journal of Building Engineering. 57 (2022) 104948
39. D. Niu, L.i. Su, Y. Luo, D. Huang, D. Luo, Experimental study on mechanical properties and durability of basalt fiber reinforced coral aggregate concrete, Construction and Building Materials. 237 (2020) 117628.
40. X.U.E. Weipei, L.I.U. Xiaoyuan, Y.A.O. Zhishu, H. Cheng, L.I. Haopeng, Effects of different damage sources on pore structure change characteristics of basalt fiber reinforced concrete, Journal of Composite Materials. 37 (9) (2020) 2285-2293.

41. D. Niu, D. Huang, Q. Fu, Experimental investigation on compressive strength and chloride permeability of fiber-reinforced concrete with basalt-polypropylene fibers, Advances in Structural Engineering. 22 (2019) 2278–2288.

42. D. Wang, Y. Ju, H. Shen, L. Xu, Mechanical properties of high performance concrete reinforced with basalt fiber and polypropylene fiber, Construction and Building Materials. 197 (2019) 464–473.

43. Y. Yao, B. Wang, Y. Zhuge, Z. Huang, Properties of hybrid basalt-polypropylene fiber reinforced mortar at different temperatures, Construction and Building Materials. 346 (2022) 128433.

44. A. Toghroli, P. Mehrabi, M. Shariati, N.T. Trung, S. Jahandari, H. Rasekh, Evaluating the use of recycled concrete aggregate and pozzolanic additives in fiber-reinforced pervious concrete with industrial and recycled fibers, Construction and Building Materials. 252 (2020) 118997.