USE OF POLYETHYLENE TEREPHTHALATE (PET) PLASTIC WASTE IN MORTAR.

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Submission date: 18-Jul-2025 12:30PM (UTC+0700)
Submission ID: 2690365895
File name: IJAR-52857.docx (1.37M)
Word count: 3198
Character count: 17695

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Manuscript Info

Manuscript History
Received: xxxxxxxxxxxxxxxx
Final Accepted: xxxxxxxxxxxx
Published: xxxxxxxxxxxxxxxx

Key words:-
Composite mortar, plastic waste, PET, density, mechanical properties.

Abstract

The increasing generation of plastic waste and its low recycling rate constitute a major worldwide environmental and economic challenge. With a view to sustainable recovery, this study examines the incorporation of polyethylene terephthalate (PET) plastic waste as a partial substitute for sand in mortars. The aim is to evaluate the impact of these additions on the physical and mechanical properties of the material, with a view to developing more sustainable and environmentally-friendly cementitious composites.

PET fibers were introduced as a volumetric replacement of sand at rates of 0.5%, 1%, 1.5%, and 2%. Mortars were prepared with cement dosages ranging from 250 g to 500 g (in 50 g increments) and four water/cement (W/C) rates per dosage. The experimental program included tests on fresh density, water absorption coefficient, flexural strength, and compressive strength.

The results reveal that the fresh mortar density remains relatively stable despite the gradual addition of PET. The water absorption coefficient generally decreases with higher W/C ratios but increases with higher cement dosages. In terms of mechanical performance, lexural performance is generally lower after the incorporation of PET. On the other hand, compressive strengths are improved for incorporation rates of 1%, 1.5% and 2%, with measurable gains compared with control mortars. Even in cases of reduction, the performance loss does not exceed 1.5%. These results indicate that the controlled addition of plastic fibres from PET waste may be a promising way of manufacturing composite mortars with a reduced environmental impact.

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Introduction:-

The increasing consumption of plastic and its non-biodegradable nature are creating growing pressure on the environment. The COVID-19 pandemic has also led to increased use of single-use plastic products such as masks and gloves, resulting in a significant increase in plastic waste [1]. It is therefore urgent to find ways to absorb plastic waste in order to mitigate the environmental problems caused by its use.

Several previous studies have demonstrated the potential use of plastic waste in mortar and concrete, such as polyethylene terephthalate (PET) bottles [2], [3], [4], [5], [6], [7]. Other authors have explored alternative plastic forms, including latex [8], polypropylene (PP) [9], polyvinyl chloride (PVC) pipes [10], high-density polyethylene (HDPE) [11], [12], thermosetting plastics [13], shredded and recycled plastic waste [14], expanded polystyrene foam (EPS) [15], glass-reinforced plastic (GRP) [16], and polycarbonate as aggregate, filler, or fiber [17].

Some authors also agree that using plastic waste as fine plastic aggregate, instead of fibers, has led to improved impact resistance of concrete [3], [18].

This study aims to evaluate the effect of incorporating recycled PET fibers on mortar properties. The experimental approach is based on partial substitution of sand by PET at various rates (0.5%, 1%, 1.5%, and 2% by volume), combined with different cement dosages (250 to 500 g) and water/cement ratios. Tests were carried out include fresh-state density, water absorption, and flexural and compressive strengths.

The objective is to determine optimal mortar formulations for combining satisfactory mechanical performance with an effective recycling approach, based on a comparative analysis with the results obtained in recent scientific literature.

I. Experimental Procedure

A. *Materials*

Portland cement CEM II B/L 32.5 R, produced in Togo by the CIMTOGO plant of the Heidelberg Cement group is used throughout this study. The cement has a density of 3100 kg/m³ and was employed without any specific additives that might react with the plastic waste. A natural fine rolled sand (SR 0/4) served as the fine aggregate. This sand was sourced from a tributary of the Zio River located at TOGBLECOPE, a locality on the outskirts of the city of Lomé, 5 km from the city centre. Granulometric analysis of the sand was performed via sieving in accordance with the NF P 18-560 standard. The results obtained are presented in Figure 1 and Table 1.

Table 1: Physical properties of the sand

Property	**Value**
Absolute density	2.66
Bulk density	1.35
Water content (%)	0.2
Sand equivalent (%)	23.71
Water absorption coefficient (%)	5.71
Fineness modulus	1.53

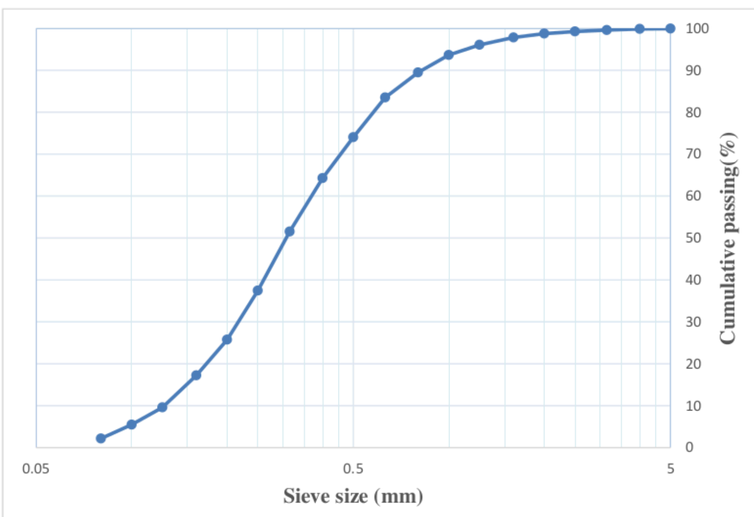


Figure 1: Sand particle size distribution curve

The polyethylene terephthalate (PET) fibers incorporated in this study were derived from post-consumer plastic bottles collected by AGR, a company specializing in plastic waste collection and recycling. The bottles were thoroughly washed and dried at ambient temperature. They were cut by hand to produce fibres of varying dimensions (Figure 2), with widths of between 2 and 4 mm and lengths of between 3 and 6 cm. The physical properties of the PET fibers are presented in Table 2.

Figure 2: Manually cut PET fibers

Table 2: Physical Characteristics of Plastic Waste Fibers

Length (mm)	30-60
Width (mm)	2-4
Absolute density	1.58
Bulk density	0.112

B. Mix Design and Specimen Preparation

Mortar mixtures were formulated with cement dosages ranging from 250 g to 500 g, in increments of 50 g. For each cement dosage, four water/cement (W/C) ratios were selected at intervals of 0.05 to ensure appropriate workability of the fresh mortar. Four PET fiber substitution rates were evaluated: 0.5%, 1.0%, 1.5%, and 2.0%, expressed as mass percentages of the fine aggregate. The fibers were incorporated in a dry state before the addition of mixing water.

Specimens were prepared following the NF EN 196-1 standard. The mortar was moulded in prisms measuring 4 × 4 × 16 cm^3. It was filled in two successive layers, each compacted by 60 impacts using an impact device. The surface was levelled with a metal ruler in a transverse movement. Molds were covered with a non-absorbent lid, inert to the cementitious matrix, and cured at 20 ± 2 °C for 24 hours. After demolding, specimens were submerged in water at ambient temperature until mechanical testing.

II. Results and Discussion

A. Fresh mortar density

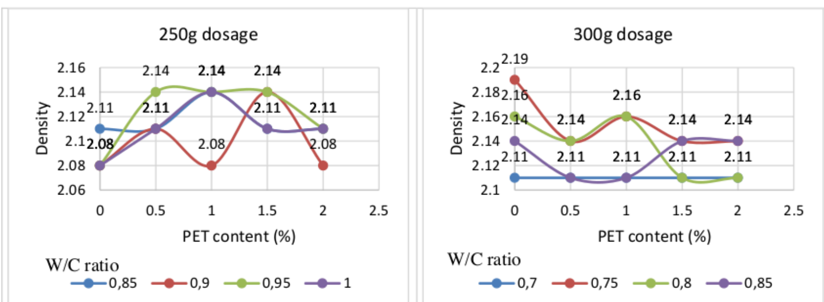
Given the relatively small variation in PET mass across the mixtures, the fresh mortar density exhibited minimal fluctuations between formulations. An overall increasing trend in density was observed with higher cement dosages and lower water content. This behavior is consistent with findings reported in studies on PET fiber-reinforced concrete, where density remained relatively stable despite fiber incorporation.

When the mixing water content was progressively increased, fresh mortar density generally followed a rising trend initially, followed by a decrease in most cases.

- For the 250 g dosage, density ranged from 2.08 to 2.14
- For the 300 g dosage, from 2.08 to 2.14
- For the 350 g dosage, from 2.11 to 2.19
- For the 400 g dosage, from 2.11 to 2.27
- For the 450 g dosage, from 2.14 to 2.21
- For the 500 g dosage, from 2.14 to 2.21

These results confirm that fresh mortar density tends to increase with cement content, regardless of PET inclusion.

Figure 3 presents the variation of fresh mortar density as a function of PET content, for each cement dosage, and emphasizes the influence of different water/cement (W/C) ratios.



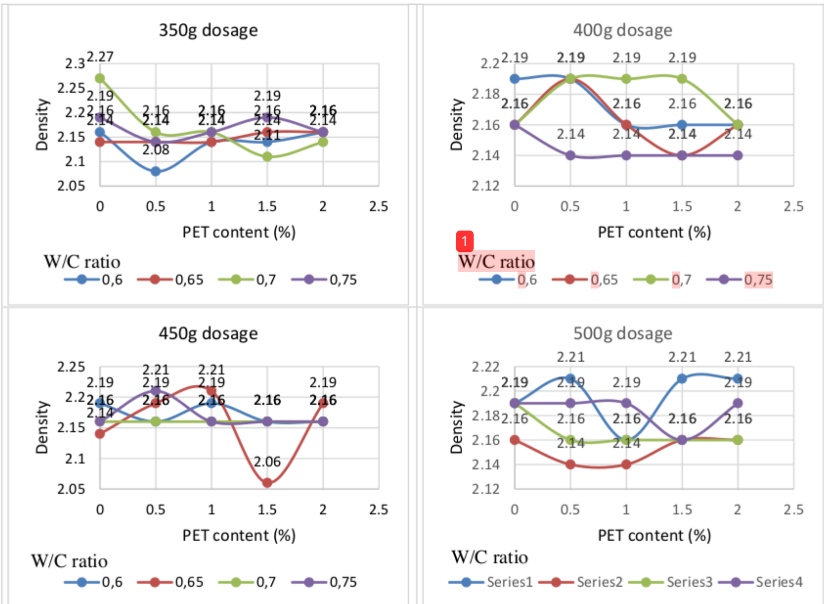
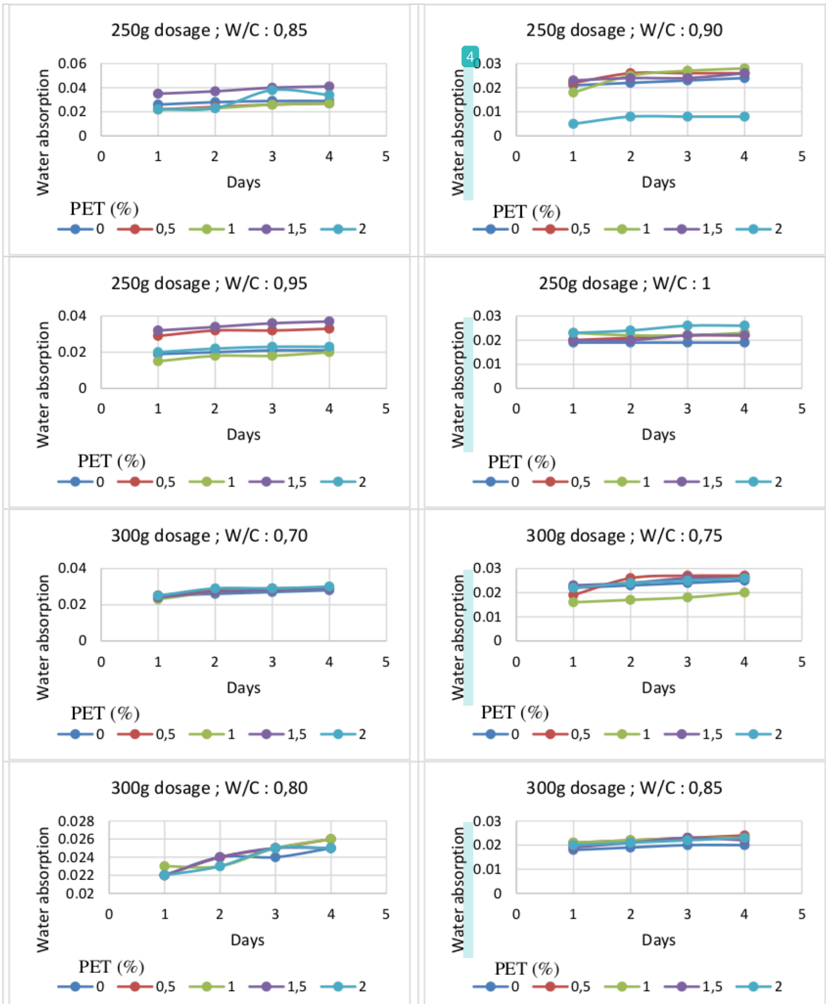
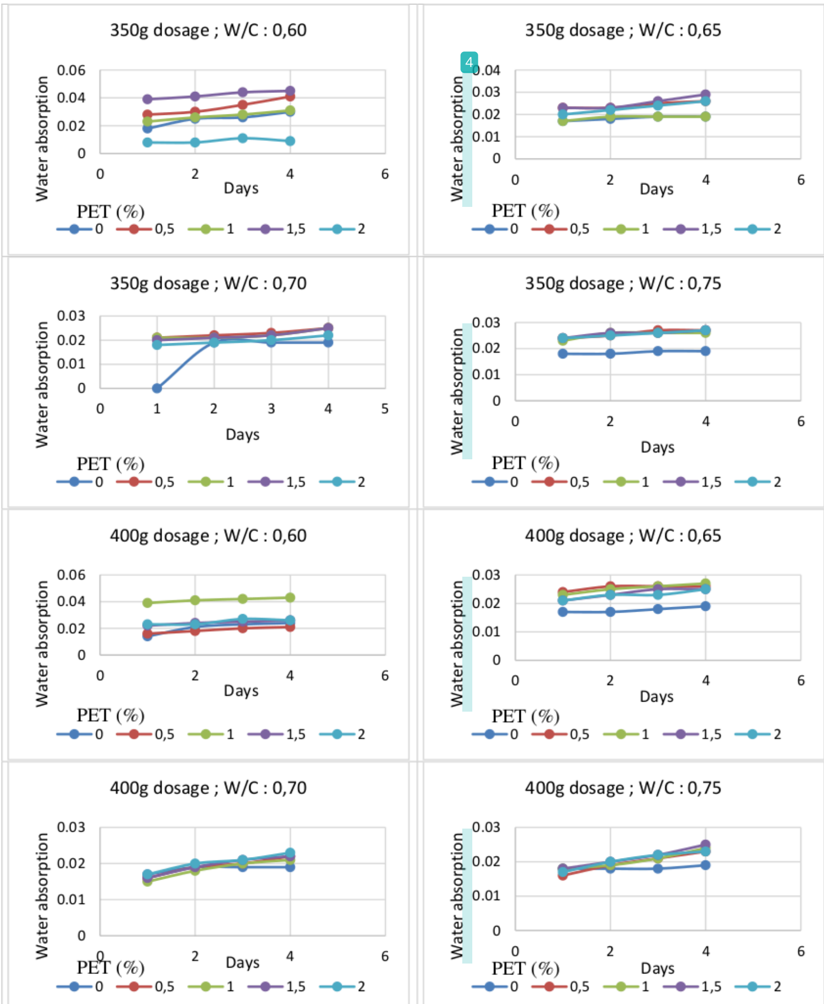


Figure 3 : Fresh mortar density curves

B. Water absorption

The results show a rapid increase in water absorption between the 2nd and 3rd day, followed by gradual stabilization from the 4th day for most formulations. Reference mortars (without fibers) show a more moderate evolution and reach a quasi-stable state earlier than mortars containing PET. In general, fiber incorporation tends to increase water absorption values, especially at high substitution rates (≥ 1.5%), which is explained by greater internal porosity. These observations are consistent with the work of Semiha Akçaözoğlu et al. [19], who highlighted the impact of PET on the porous microstructure of cementitious materials. This increase in porosity could negatively affect the long-term durability of composite mortars. The curves in Figure 4 show the variation of the water absorption coefficient with the percentage of plastic waste, for each dosage and water/cement (W/C) ratio.


250g dosage ; W/C : 0,85
250g dosage ; W/C : 0,90
250g dosage ; W/C : 0,95
250g dosage ; W/C : 1
300g dosage ; W/C : 0,70
300g dosage ; W/C : 0,75
300g dosage ; W/C : 0,80
300g dosage ; W/C : 0,85
Water absorption
Days
PET (%)
0
0,5
1
1,5
2


350g dosage ; W/C : 0,60
350g dosage ; W/C : 0,65
350g dosage ; W/C : 0,70
350g dosage ; W/C : 0,75
400g dosage ; W/C : 0,60
400g dosage ; W/C : 0,65
400g dosage ; W/C : 0,70
400g dosage ; W/C : 0,75
Water absorption
Days
PET (%)
0
0,5
1
1,5
2

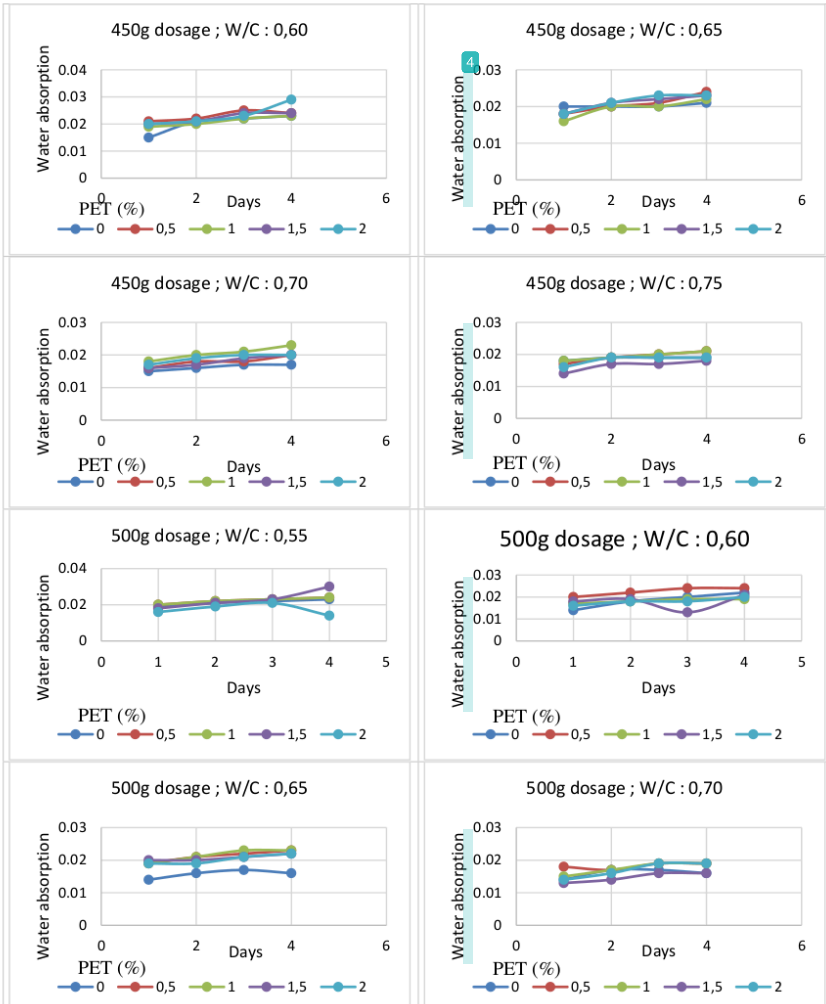


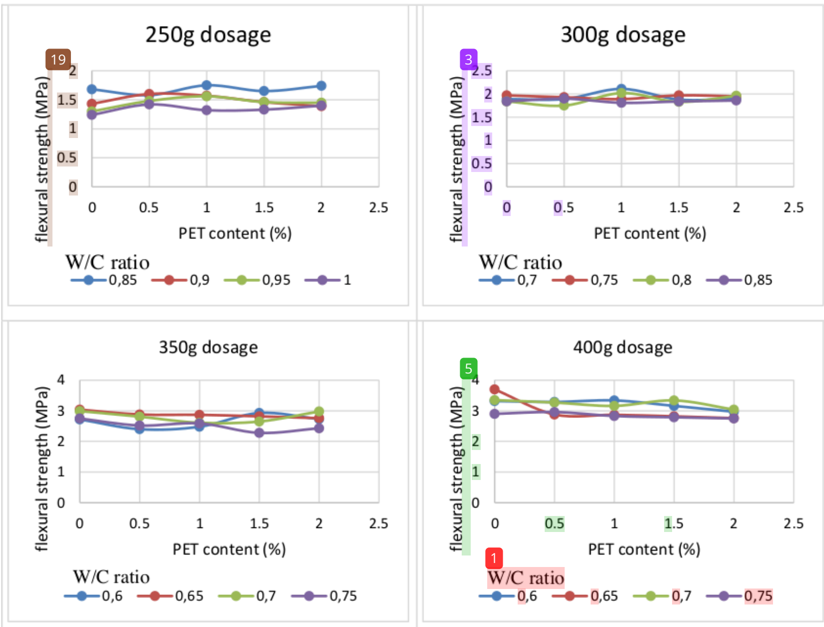
Figure 4 : water absorption coefficient curves

C. Flexural strength

An overall increase in flexural strength was observed with rising cement content. For most control mortar mixes, flexural strength initially increased and subsequently decreased as the water-to-cement (W/C) ratio rose. However, following PET incorporation, peak strength values occurred at lower W/C ratios, followed by a decline. This behavior can be attributed to the reduced sand content in PET-modified mixtures, which decreases the required mixing water, since excess water adversely affects strength development.

Regarding PET content, specimens containing 1% and 1.5% PET exhibited superior flexural strength compared to control samples. In cases where control mortars showed higher strength, the difference with PET-containing mortars remained marginal.

Figure 5 illustrates the 7-day flexural strength as a function of PET content and cement dosage, highlighting the influence of varying W/C ratios.



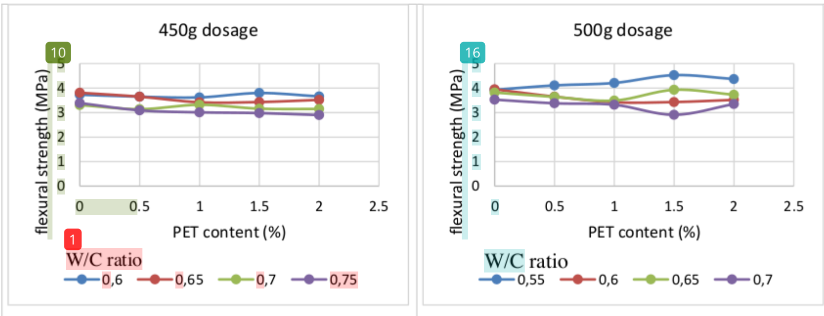


Figure 5 : Flexural strength at 7 days curves

- At a cement dosage of 250 g, the highest strengths were generally achieved at a W/C ratio of 0.85, except for the 0.5% PET content, where deviations were observed. The optimal strengths corresponded to 0.5% and 1% PET incorporation, with a maximum recorded strength of 1.75 MPa at 1% PET and W/C = 0.85.
- For 300 g cement dosage, the maximum flexural strengths were noted at W/C = 0.75, with the highest strength (2.11 MPa) obtained at 1% PET and W/C = 0.70. Minor exceptions were observed at 1.5% PET (W/C = 0.75) and 0.5% PET (W/C = 0.85).
- At 350 g cement, the best performance occurred predominantly at W/C = 0.65, except for 1.5% and 2% PET contents which peaked at W/C = 0.60. Control mortars showed superior strength overall, though the PET-modified sample with 1.5% PET and W/C = 0.60 approached control values with only a 4% reduction (from 3.04 MPa to 2.93 MPa).
- At 400 g dosage, peak strengths were found near W/C ratios of 0.60 and 0.70, with the control mix peaking at 0.65. The highest flexural strength (3.70 MPa) was achieved by the control at W/C = 0.65, while PET-modified mortars with 0.5%, 1%, and 1.5% PET showed slightly lower but comparable values.
- For 450 g dosage, optimal strengths were attained at W/C = 0.65 (with exceptions at 0.60 for lower PET contents). Both control and 1.5% PET specimens exhibited the highest flexural strengths, with a marginal difference between the top two values (3.81 MPa control vs. 3.80 MPa at 1.5% PET).
- At the highest cement dosage of 500 g, the best strengths corresponded to W/C = 0.55 for PET-modified mixes and W/C = 0.60 for control. Specimens with 1.5% PET generally showed superior strength compared to control, except at W/C ratios of 0.60 and 0.70. The peak strength was 4.37 MPa at 1.5% PET and W/C = 0.55.

D. Compressive strength

Compressive strength increases with higher cement content, consistent with the trends observed in flexural strength tests. Generally, an increase in water content results in reduced strength values, with some exceptions. The highest compressive strengths were obtained at PET incorporation rates of 1.5% and 2%. This aligns with findings reported by Seisuke Okubo et al. [21], who identified optimal compressive strength at substitution levels of 1% and 1.5%.

Figure 6 illustrates the compressive strength at 7 days as a function of plastic waste content for each cement dosage, emphasizing the influence of varying water-to-cement (W/C) ratios.

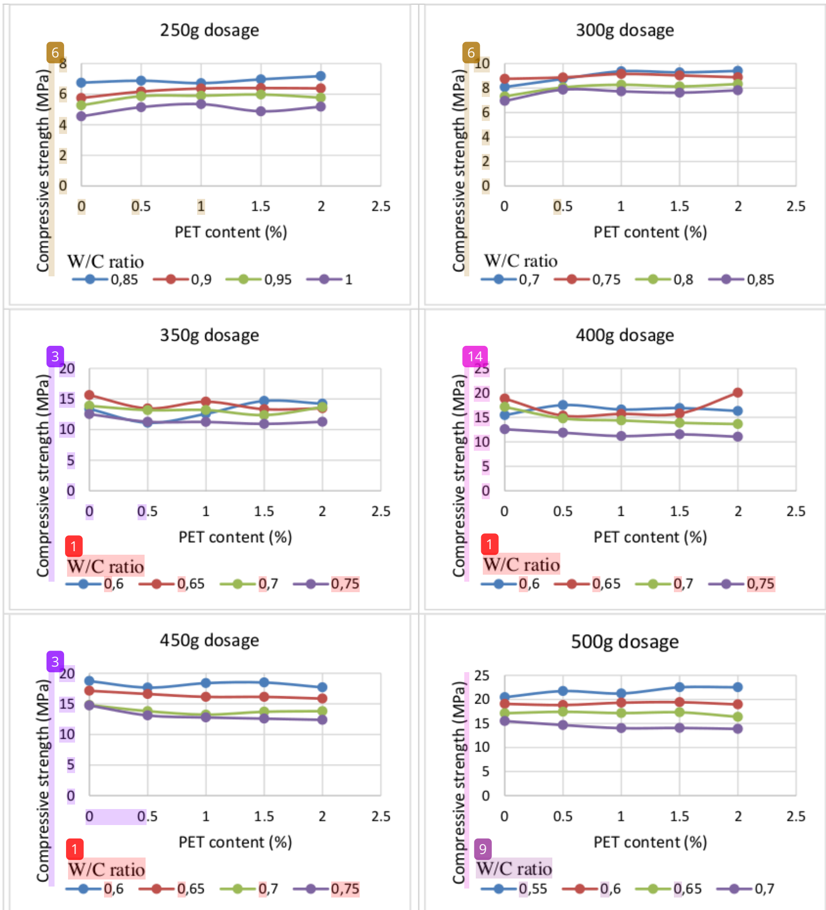


Figure 6: Compressive Strength at 7 Days curves

- **Dosage 250**
    - The optimal water-to-cement (W/C) ratio for maximum compressive strength is 0.85.
    - A PET fiber content of 2% yields the highest strength.

- The peak compressive strength for this dosage (7.18 MPa) was recorded at a W/C ratio of 0.85 with 2% PET incorporation.

- **Dosage 300**
  - The W/C ratio of 0.7 generally produced the highest strengths, except for the control mortar and the 0.5% PET mix, which achieved their maxima at 0.75.
  - The best strength outcomes corresponded to PET contents of 1% and 1.5%. The control mortar exhibited two peak values among the four tested.
  - The maximum strength for dosage 300 (9.40 MPa) was observed at a W/C ratio of 0.7 and 2% PET content.

- **Dosage 350**
  - The W/C ratio of 0.65 resulted in superior strength values overall, with the exception of the 1.5% and 2% PET mixes, which peaked at a 0.6 ratio.
  - Control mortars demonstrated higher compressive strengths in most cases, except for one. Incorporation of 1% PET led to results differing by up to 1.5 MPa.
  - The optimal strength (15.63 MPa) was achieved with the control mortar at a 0.65 W/C ratio. The subsequent highest value, differing by 0.59 MPa, corresponded to a 0.6 W/C ratio with 1.5% PET.

- **Dosage 400**
  - The best compressive strengths were generally observed at a W/C ratio of 0.6, except for two instances where 0.65 provided higher values.
  - The PET content yielding the highest strength was 2% for the first two water dosages and 0% for the latter two.
  - The maximum strength (20.03 MPa) was attained at a 0.65 W/C ratio with 2% PET.

- **Dosage 450**
  - A W/C ratio of 0.6 produced the highest strengths.
  - Control mortars outperformed PET-modified mixes in most cases, except one. The incorporation of 1% PET resulted in a maximum strength difference of 1.5 MPa.
  - The peak compressive strength (19.18 MPa) was recorded for the control mortar at 0.6 W/C ratio, with strength reductions due to PET addition remaining below 2%.

- **Dosage 500**
  - The W/C ratio of 0.55 showed the most favorable strength results.
  - The substitution rate of 1.5% PET provided superior strength compared to the control mortar, except at a 0.7 W/C ratio.
  - The highest compressive strength (22.83 MPa) was achieved at 0.55 W/C ratio with 1.5% PET.

The W/C ratios were maintained following PET incorporation to ensure formulation consistency. Given the reduced sand content in these mortars, PET-containing mixes required less water to achieve optimal strength values, attributable to the hydrophobic nature of PET fibers. This phenomenon explains the observed shift in strength trends under both flexural and compressive loading.

For instance, while control mortars (0% PET) exhibit strength increases followed by declines with increasing W/C ratio, PET-modified mortars generally show decreasing strength with rising W/C ratio.

To correct for this shift, formulation adjustments should have been made by proportionally reducing water to compensate for the substituted sand volume.

CONCLUSION

The results of this study substantiate the potential application of polyethylene terephthalate (PET) waste fibers as a partial replacement for sand in mortar formulations. Although PET addition slightly influences the fresh mortar density, it markedly affects properties such as water absorption and mechanical performance. Increased water absorption, correlated with higher PET content, is attributed to elevated internal porosity, consistent with prior literature. This increase may negatively impact long-term durability unless mitigated by optimized mix design.

Regarding mechanical performance, compressive strengths improved with PET contents of 1%, 1.5%, and 2%, sometimes exceeding those of control mortars, despite a general reduction in flexural strength.

In summary, controlled PET fiber incorporation offers a promising valorization pathway for plastic waste, delivering acceptable mechanical performance and compatibility with conventional mortar production methods.

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