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Influence of plastic waste addition on mechanical properties of cement mortars: An experimental study

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Abstract

With the increasing need for sustainable construction materials and to cope with plastic waste management, a lot of research has been undertaken on the recycling of plastics in cementitious composites. An experimental investigation was performed in the current study to study the effect of adding ground polyvinyl chloride (PVC) waste particles on physical, mechanical and thermal properties of cement mortars. Fifteen series of mortar mixtures were made with four plastic contents (5%, 10%, 15% and 20% by cement weight) and three water-to-cement (w/c) ratios (0.35, 0.40 and 0.45). Workability, density, thermal conductivity and flexural and compressive strength were investigated by comprehensive tests in compliance with the applicable ASTM standards. The results obtained showed that plastic admixture induced a significant reduction in mortar density (up to 4.5%) and thermal conductivity (11%), representing its applicability as an artificial lightweight material. It was shown that workability was more affected by plastic dosage amount and w/c ratio according to the flow table test results, whereas moderate amounts of plasticizer enhanced workability. It was also found that the mechanical performance followed nonlinear behavior, where the flexural strength increased by approximately 43% and compressive strength up to 59% with a 5% plastic content achieved; thereafter, both performances decreased at higher concentrations due to the lack of strong interfacial bonding with particles and higher porosity. The findings demonstrate that the controlled incorporation of plastic waste at low dosages is mechanically feasible and effective, identifying 5-10% addition as the optimal range for improving mortar performance without compromising strength.

Keywords

Recycled plastic waste, Cement mortar, Compressive strength, Flexural strength, Thermal conductivity, Workability

1. Introduction

The worldwide building industry is one of the most significant users of resources and energy and, by extension, one of the world's largest sources of waste and greenhouse gases. Cement-derived materials (e.g., mortar and concrete) are essential building blocks of modern society, although their production is extremely resource-intensive as it contributes to 8% of global anthropogenic CO₂ emissions through limestone calcination and energy consumption during the clinker preparation (Al-Luhybi et al., 2025; Ali et al., 2023; Andrew, 2018; Ibrahim et al., 2024; Özbayrak et al., 2024). Researchers and engineers have looked for creative ways to lessen the environmental impact of cementitious composites as sustainability becomes a top concern for the built environment. One such approach involves incorporating additives, such as recycled waste materials and industrial by-products, into concrete mixtures (Al-Sulayvani & Al-Talabani, 2015; Qader et al., 2024; Thomas & Gupta, 2016; Torgal & Jalali, 2011).

In the wide spectrum of waste, plastic waste has become a great concern plaguing mankind in the 21st century. Over 350 million tons of plastic are made each year, a large amount which is landfilled or left in the environment, where it will remain for centuries (Fediuk et al., 2023; Geyer et al., 2017). Poorly managed plastic waste results in soil and water pollution, damages ecosystems, and endangers human health due to microplastic ingestion from food chains (Ghaidan et al., 2025; Kareem et al., 2025; Qader et al., 2025; Rochman et al., 2013). Such utilization of plastic wastes in construction materials provides a two-fold advantage: an environmentally sound waste management route and the possibility to impart or improve properties of cement-based composites (Kaewpikul et al., 2025; Merlo et al., 2020; Rao et al., 2025; Rocha et al., 2025).

The addition of recycled plastic particles to cement mortar has been extensively studied as an innovative strategy for sustainability and reduction of product density. Previous investigations revealed that the substitution of natural aggregates by polyethylene terephthalate (PET) or polyvinyl chloride (PVC) particles could decrease the density of mortars, yielding lightweight composites for non-structural and insulating purposes (Al-Luhybi & Qader, 2021; Albano et al., 2009; Saikia & De Brito, 2012). It has been reported by other workers that the incorporation of plastic can enhance impact resistance, toughness and thermal insulation properties but often at the expense of a decrease in compressive or flexural strength (Gu & Ozbakkaloglu, 2016; Mohammed et al., 2019).

Moreover, Al-Luhybi and Qader (2021) studied the possibility of using PET fibers made with recycled plastic bottles as a green agent for Ordinary Portland Cement (OPC)-based concrete. Their findings indicated that the addition of PET fibers increased compressive and flexural strengths in the case of low contents, but reduced workability and tensile strength. However, good quality concrete was obtained, and a strong relationship between UPV and compressive strength was observed, indicating the possibility of producing eco-friendly concrete with recycled PET fibers. Recently, Qader et al. (2025) studied the addition of plastic fibers, walnut shells and tire rubber fibers in cement mortar. In the case of mix with 1% waste content, walnut shells and tire rubber increased compressive strength (8.7%, 4.9%) and flexural strength (11.1%, 8.9%), while all wastes decreased workability and tensile strength. The performance was systematically reduced by the plastic fibers, noting that certain waste can be used to improve concrete and sustainability.

The strength and toughness properties of the plastic-modified mortar are influenced by a number of factors: type, size, shape and content of plastic particles as well as water-to-cement ratio (w/c) ratio and presence of admixtures. Siddique et al. (2008) have revealed that when adding 10% of plastic particles in comparison to cement weight, density decreases and ductility increases, however at a cost of less loss in compressive strength. In the same way, Hussein et al. (2017) found that fine PVC powder served to improve the thermal and acoustical characteristics of cement mortars, indicating possible use in high-performance building shells. Nevertheless, too much plastic content would result in poor bond performance, higher porosity and decrease the load carrying capacity, so it is necessary to optimize mixture design (Albano et al., 2009; Ismail & Al-Hashmi, 2008).

The purpose of this study, therefore, is to contribute to the body of knowledge on sustainable construction materials by experimentally investigating the influence of ground plastic waste addition on the physical and mechanical properties of cement mortars. It is important to note that the objective of this research is to report on how changes in plastic contents (5-20 wt% of cement) and water/cement ratios (0.35, 0.40 and 0.45) affect the density, workability, flexural strength, compressive strength and thermal conductivities of these innovative concrete materials. The study also aims to explore the best combination percentages as well as a trade-off between mechanical properties and environmentally friendly aspects following this investigation. The results are valuable for the design of lightweight, durable and sustainable cement-based materials applicable to the future construction industry.

1.1 Research significance

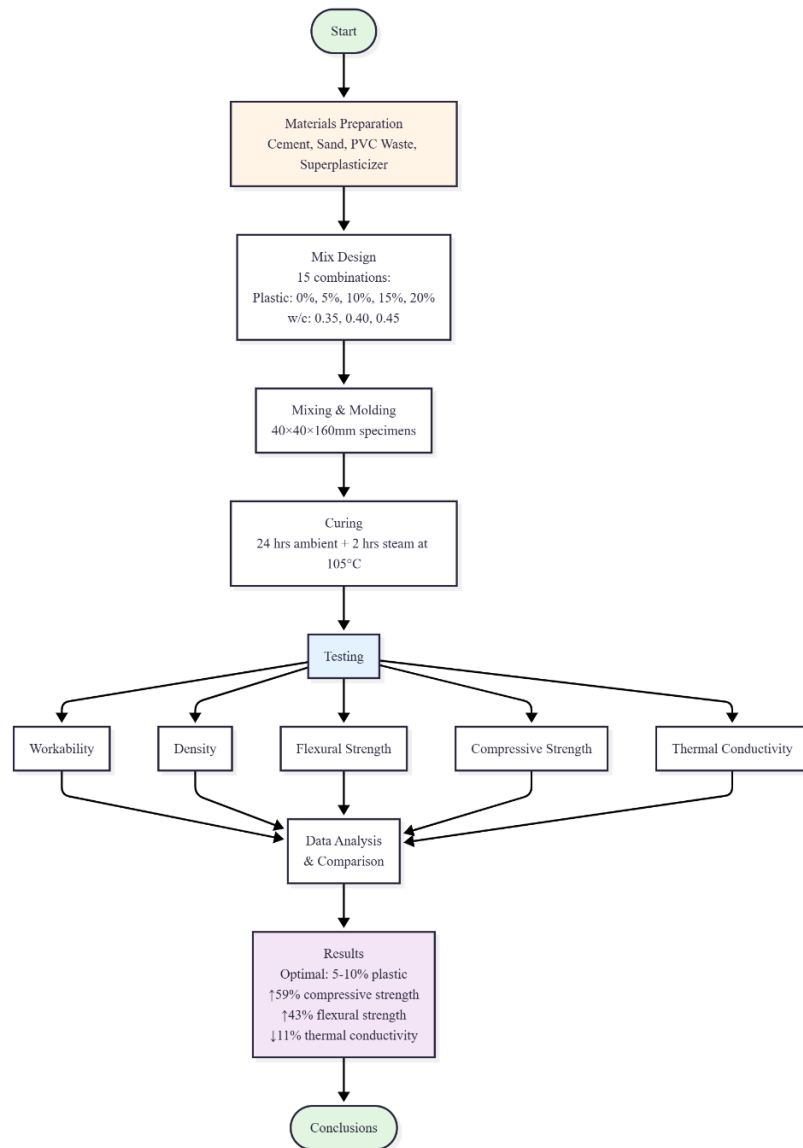


Fig.1 Research methodology flowchart for the present study.

The significance of this work is due to the dual-solution approach for sustainable construction, in terms of plastic waste management and building resource efficiency. The manufacture of conventional cement mortar is based primarily on non-renewable natural resources and contributes largely to global CO₂ emissions; meanwhile, the increasing disposal rate of non-biodegradable PVC waste brings about great ecological risks and public health problems. The present investigation makes the new contribution by pinpointing a certain "synergy zone" (5%-10% content) where fine PVC particles (Sieve No. 200) serve as a kind of high-elasticity micro-reinforcement phase rather than just occupying active volume. By disputing the traditional "strength-loss paradigm" of plastic additives, this work shows that ground PVC could even improve compressive and flexural strengths by as high as 59% and 43%, respectively, at low dosages while showing improved thermal insulation function. The results of this study can serve as a scalable architecture for the circular economy and provide engineers with an immediate strategy to design functional, environmentally friendly mortars without compromising on structural performance for the sake of sustainability. The methodology flowchart for the current experimental study is illustrated in Figure 1.

2. Materials and methods

2.1 Materials

Cement and sand

OPC, conforming to the specifications of ASTM C150 (ASTM-C150/C150M, 2024), was utilized as the primary binder throughout this investigation. The specific gravity, fineness modulus, and water absorption of the sand utilized in this study were 2.68, 3.02, and 1%, respectively. Dry quantities of sand were employed for each mixture. The sieve analysis of the employed sand is displayed in Figure 2.

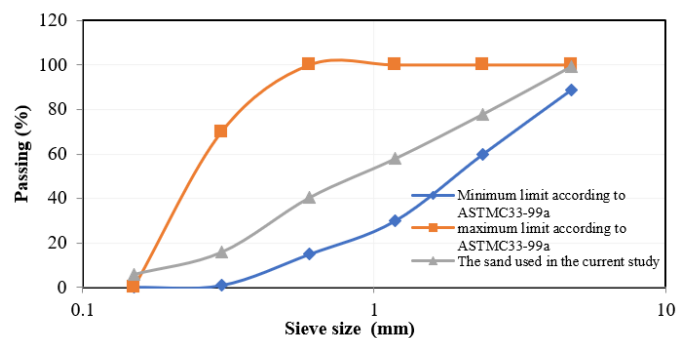


Fig.2 Grading of sand used in this research.

Plastic waste

Recycled plastic particles were adopted as the major additive in this study. The plastic waste was collected from trashed PVC pipes obtained from an industrial unit, shown in Figure 3. The collected material was then cleaned, mechanically shredded, and ground into fine particles under a high-speed rotary grinder provided with horizontal rotating and vertical rotating blades, as shown in Figures 4 and 5, respectively. The ground plastic was sieved using sieve No. 200 to achieve a particle size distribution suitable for cement mortar applications, ensuring homogeneity and consistent dispersion in the mixture. PVC was selected because of its easy availability, low cost, and good mechanical and thermal performance as a lightweight aggregate (Gu & Ozbakkaloglu, 2016; Hussein et al., 2017).

The PVC waste was grounded to pass through sieve No. 200 and become fine like a powder. This size was chosen in order that the plastic micro-fills in the cementitious matrix, filling micro-voids and increases

density of ITZ (Interfacial Transition Zone) at low levels of addition. The fine gradation can contribute to even distribution of the elastic plastic phase and thus lead to a phenomenon of micro-reinforcement effect that fills into micro-cracks and enhances ductility of the mortar.



Fig.3 Raw PVC pipes.



Fig.4 Plastic grinding machine.



Fig.5 PVC plastic after grinding process.

Superplasticizer

A third-generation polycarboxylate-based superplasticizer (ViscoCrete®-1681, 2022) was added to enhance the workability of the cement mortars without increasing water demand. The dosage was fixed at 2% by cement weight, in accordance with manufacturer recommendations and previous studies (Mohammed et al., 2019). The admixture conforms to ASTM C494/C494M (ASTM-C494/C494M, 2020) requirements for high-range water-reducing admixtures.

2.2 Mixture proportions

Fifteen mortar mixes were formulated with different proportions of recycled plastic as well as varying w/c ratios. Specifically, plastic was used as an additive in four percentages, 5%, 10%, 15%, and 20% by weight of the cement. Concerning the influence of water content on the physical and mechanical characteristics of mortar, three w/c ratios of 0.35, 0.40, and 0.45 were utilized. The 1:2.75 cement-to-sand ratio was used for all mixtures. Each mortar sample contained 500 g of cement and 1375 g of sand. The total water volume differed depending on the w/c ratio used in proportion, and the superplasticizer was added at a constant quantity. To achieve statistical reliability, three samples of each mix were cast and tested for mechanical and physical properties. The measurements were repeated and the results averaged. Table 1 outlines the mixed proportions.

Table 1. Mix proportions and plastic content.

Mix ID	Cement	Sand	Plastic (%)	Plastic (g)	w/c	Water (g)
1	500	1375	0	0		
2	500	1375	5	25		
3	500	1375	10	50	0.35	225
4	500	1375	15	75		
5	500	1375	20	100		
6	500	1375	0	0		
7	500	1375	5	25		
8	500	1375	10	50	0.4	250
9	500	1375	15	75		
10	500	1375	20	100		
11	500	1375	0	0		
12	500	1375	5	25		
13	500	1375	10	50	0.45	275
14	500	1375	15	75		
15	500	1375	20	100		

2.3 Specimen preparation

The mortar specimens were prepared according to ASTM C109/C109M (ASTM-C109/C109M, 2020) for the determination of compressive strength of hydraulic cement mortars. The dry materials (cement, sand, and plastic) were mixed in a laboratory mechanical mixer (ASTM C305 (ASTM-C305, 2020)) at low speed (90 rpm) for 30 s. Water and superplasticizer were then slowly added until complete mixing was achieved for 60 s. The mixer was stopped for the initial hydration to begin stage (90 s) and then switched on again at high velocity (185 rpm) for 60 seconds, allowing for a homogeneous paste.

The fresh mortar was filled into 40 × 40 × 160 mm triple gang steel molds in two layers, with each layer being compacted with a tamper using 25 strokes to release entrapped air. The faces of the hatchways were smoothed with steel-trowel. After 24 h of ambient setting the specimens were demolded and steam-cured at 105 °C for 2 hours in a controlled oven (Figure 6) to promote hydration and simulate the mechanical properties development after 28 days.



Fig.6 Steam oven device.

2.4 Testing procedures

Flow table test

Workability was determined by the flow table test according to ASTM C230/C230M (ASTM-C230/C230M, 2021). The mortar was poured into a truncated cone mold resting on a flow table that fell 25 times in 15 s. The maximum diameters of final cell spread were obtained and the data shown as percent increments with respect to the base diameter. This test offered a comprehension of the effects of plasticizer content and w/c ratio on flow ability and cohesion of mortar.

Density measurement

The density of hardened mortars was measured in accordance with ASTM C642 (ASTM-C642, 2022). Specimens were oven-dried to a constant weight, and the volume was obtained through geometric computation. Density is the ratio between dry mass and volume, illustrating the lightening potential of plasticized mortar.

Flexural strength test

The three-point bending test was conducted to measure the flexural strength following an ASTM C348 (ASTM-C348, 2021) specification as depicted in Figure 7. The load was placed at the midspan of the prism until failure, and flexural strength was evaluated from the peak load and dimensions of the specimen. This test assessed the effect of plastic on the tensile and ductility behavior of mortar.



Fig.7 Flexural strength test machine.

Compressive strength test

The compressive strength of the broken halves from flexural test was measured as per ASTM C109/C109M (ASTM-C109/C109M, 2020). The specimens were loaded by a hydraulic press with a constant loading rate at the capacity of 250 kN until failure (see Figure 8). Compressive strength was obtained by dividing the maximum load by specimen's cross section. This test provided a measure of the load bearing ability of plastic-modified mortar and facilitated comparison with control mixes.



Fig.8 Compressive strength test machine.

Thermal conductivity test

Thermal conductivity measurements were performed using a custom-built guarded hot plate apparatus. The test setup consisted of insulated sides, a heating plate, and copper plates to ensure uniform heat distribution. The relationship between density and thermal conductivity was analyzed using the empirical equation proposed by ACI (1986):

$$K = 0.072e^{0.00125p} \quad (1)$$

where K is the thermal conductivity (W/m·K) and p is the dry density (kg/m³). This test provided insights into the potential of plastic-modified mortars for thermal insulation applications.

2.5 Experimental design and analysis

Two main parameters that affect the behavior of cement mortar (plastic content and w/c) were selected to establish the experimental program of the current study. Three samples of each mix were cast and tested for mechanical and physical properties to achieve statistical reliability. The measurements were repeated and averaged; also, the standard deviations for variability. Quantification of enhancements or impairments to the performance-based activities was measured with control mixes.

3. Results and discussion

3.1 Density of plastic-modified mortar

The addition of recycled plastic particles to cement mortars had caused a consistent drop in density values with respect to control specimens. As reported in Figure 9, the density decreased from a value of 2109.38 kg/m³ (no plastic, w/c: 0.35) to around 2013.67 kg/m³ at 15% content of plastic, and this means an increase equal to about 4.5%. This phenomenon is ascribed to the decrease in specific gravity of PVC particles with respect to natural sand, and greater inter-particle porosity caused by the irregular shape of plastic products (Albano et al., 2009; Gu & Ozbakkaloglu, 2016). Although excessive density reduction may compromise mechanical integrity, this property can be beneficial in producing lightweight mortars suitable for non-structural elements, insulation panels, and prefabricated components.

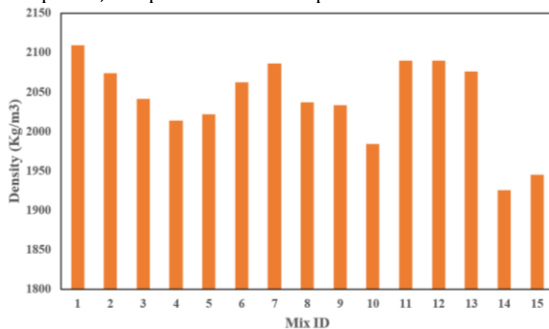


Fig.9 Density of samples with and without plastic waste.

3.2 Workability and flow properties

Workability, determined by the flow table test (ASTM-C230/C230M, 2021), showed a non-linear behavior with the increase in plastic content (see Figure 10). For w/c = 0.35 mixes, the flow percentage decreased from 55% (control) to 47.5% when adding 5-10% plastic, demonstrating that cohesion and internal friction weakened due to light particles causing interference of cement matrix continuity. Only one transition was observed at 15% plastic (77.5%), but it probably resulted from a localized lubrication effect and diminished particle interlock effect. At low percentages of plastics (5-10%), the irregular shape and rough surface texture of the ground PVC particles develop a greater internal friction and a higher mechanical interlock between mortar components. This interrupts the continuity of the cement paste thus causing a decrease in flow as initially observed. At higher plastic contents (15%), however, there is a crossover, and the hydrophobic character of the plastic starts to take control. As plastic does not absorb water, it releases more 'free water' in the matrix to lubricate which-together with possible dilution of solid particle contact-suddenly increases the flow percentage. In higher w/c ratios (0.40, and 0.45) the flowability improved very much up to 160% in optimal plastic by 10%. This suggests that workability can be optimized by carefully balancing plastic dosage with water content and admixture use.

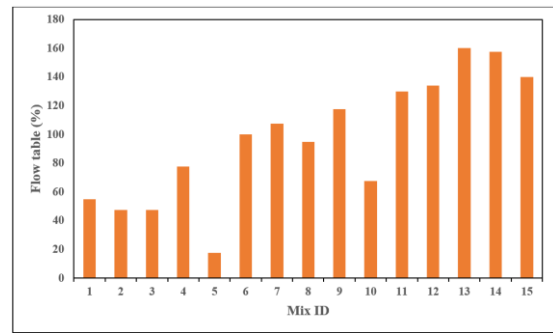


Fig.10 Percentage of flow table for the mortar specimens.

3.3 Thermal conductivity

Thermal conductivity values showed a reduction with an increase of plastic content, which implies toward the insulating capacity of plastic-modified mortars as presented in Figures 11 and 12. When w/c ratio = 0.35, the thermal conductivity reduced from 1.006 W/m·K for the control mix to 0.892 W/m·K at plastic content of 15% — decreasing by ~11%. Drop in values is mostly related to the poor thermal conductivity of PVC and higher air void content, which breaks a path for heat transfer in between the matrix (Hussein et al., 2017). These findings suggest that incorporating waste plastics can contribute to energy-efficient building materials, particularly for thermal insulation applications.

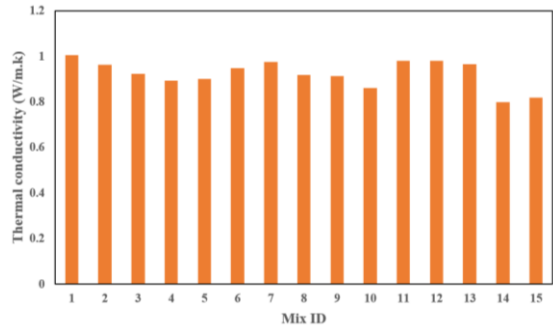


Fig.11 Thermal conductivity of mortar specimens.

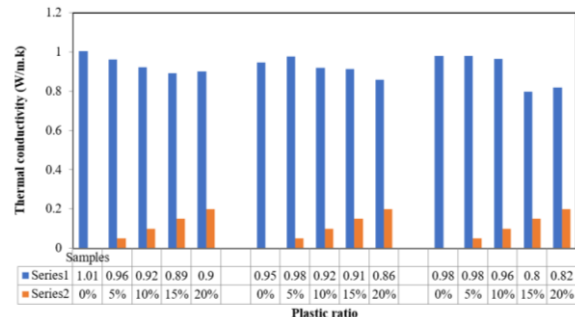


Fig.12 Thermal conductivity results.

3.4 Flexural strength

The impact of plastic addition on the flexural strength strongly depended on the volume and w/c ratio. At w/c = 0.35, as indicated from Table 2 and Figures 13-15 there was an impressive increase in the flexural strength from 5.88 MPa (control) to 8.40 MPa at plastic % an increment of about 43%. Continued improvements were recorded as plastic content was increased to the 20% level, beyond which strength trends dropped slightly, but still above that of the control mix up to 15%. At w/c = 0.40, the maximum flexural strength (8.12 MPa) was also obtained with 5% plastic, following a similar trend. At w/c = 0.45, however, flexural strength decreased with plastic incorporation, indicating that at high water contents, matrix cohesion and bond strength decrease.

The enhanced improvement of flexural properties at a lower content of plastic is attributed to the improved crack-bridging and energy-absorbing ability offered by an elastic phase of plastic particles, which suppresses their cracking as well as raises ductility. Moreover, the plastic within the surface layer may cause generations to of a micro-reinforcement effect, distribute stress and lead to a delay in failure initiation. But when the plastic content is higher than a critical value, usually more than 10%, the interaction between polymer and cement paste will be decreased due to the hydrophobicity of polymers, resulting in an increasing porosity and inefficient load transfer. The present findings reaffirm that 5% plastic content represents an optimal balance between ductility enhancement and matrix integrity. At lower contents (5%) the

ground PVC particles behave as a micro-reinforcement phase. These particles bridge micro-cracks at the onset of load due to their higher elasticity than the relatively brittle cement matrix. At levels higher than 10%-15%, beyond the hydrophobic characteristic of PVC particles become predominant, resulting in a weak ITZ and a high porosity, which explains the subsequent reduction of strength.

Table 2. Flexural strength values for mortar specimens.

Mix ID	Mix composition	Tensile strength (MPa)
1	0% Plastic - 0.35 w/c	5.88
2	5% Plastic - 0.35 w/c	8.40
3	10% Plastic - 0.35 w/c	8.26
4	15% Plastic - 0.35 w/c	8.12
5	20% Plastic - 0.35 w/c	6.16
6	0% Plastic - 0.40 w/c	5.04
7	5% Plastic - 0.40 w/c	8.12
8	10% Plastic - 0.40 w/c	7.84
9	15% Plastic - 0.40 w/c	7.56
10	20% Plastic - 0.40 w/c	7.28
11	0% Plastic - 0.045 w/c	7.56
12	5% Plastic - 0.045 w/c	7.00
13	10% Plastic - 0.045 w/c	7.31
14	15% Plastic - 0.045 w/c	7.42
15	20% Plastic - 0.045 w/c	7.11

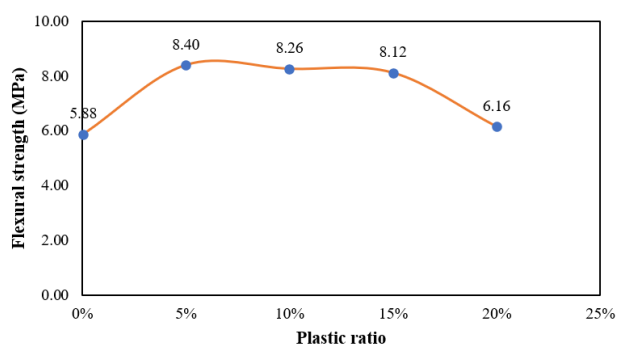


Fig. 13 Flexural strength versus plastic waste ratios with w/c = 0.35.

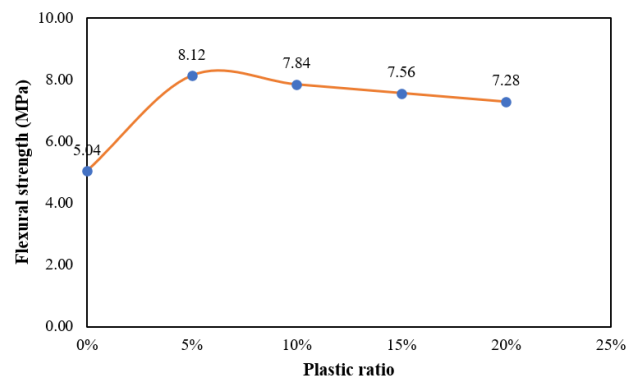


Fig. 14 Flexural strength versus plastic waste ratios with w/c = 0.4.

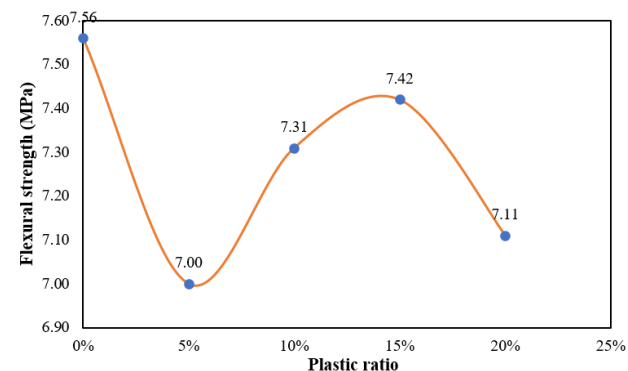


Fig. 15 Flexural strength versus plastic waste ratios with w/c = 0.45.

The strength response of the flexural strength test was quantified by normalization of the measured strengths to their theoretical control mixes (0% plastic) for each w/c ratio. With w/c = 0.35, a 5% plastic addition value also led to an increase in flexural strength from 5.88 MPa to 8.40 MPa (approximately +43%). The mixes containing 10% and 15% plastic elicited somewhat lower values (8.26 MPa, 8.12 MPa), which

however were still higher than the control level before another sharp decrease at 20% plastic (6.16 MPa). This behavior reflects a consistent non-linear (parabolic shape) character of the relation between flexural strength and plastic amount.

Similar quantitative trends were noted at w/c = 0.40, with the maximum flexural strength (8.12 MPa) obtained also at 5% plastic contrasting against the control mix case (61% higher than the control mix [5.04 MPa]). At doses above this level, flexural strength showed a gradual reduction with rising plastic content. For w/c = 0.45, the trend of strength reduction was not very evident however the fact that no further improvement is obtained by adding more plastic at higher plastic contents confirms that excessive addition is detrimental to flexural behavior for high water content.

Based on these quantitative trends, an optimal flexural strength threshold can be identified at approximately 5% plastic content, while addition levels exceeding 10-15% mark the onset of strength deterioration due to increased porosity and weakened interfacial bonding.

3.5 Compressive strength

Compressive strength followed the same patterns as flexural strength but with more expanded differences, as shown in Table 3 and Figures 16-18. Compressive strength at w/c ratio of 0.35 increased from a control value of 70.88 MPa to 112.75 MPa at 5% plastic, exhibiting an impressive increment of about 59%. This strengthening is more likely to be attributed to the better internal stress distribution due to the increase of plastic particles and denser microstructure, preventing crack propagation by filling voids and weakening localization. But the strength decreased with the increase of plastic content and fell to 87.26 MPa in 20%.

Table 3. Compressive strength values for mortar specimens.

Mix ID	Mix composition	Compressive strength (MPa)
1	0% Plastic - 0.35 w/c	70.88
2	5% Plastic - 0.35 w/c	112.75
3	10% Plastic - 0.35 w/c	105.7
4	15% Plastic - 0.35 w/c	88.7
5	20% Plastic - 0.35 w/c	87.255
6	0% Plastic - 0.40 w/c	59.23
7	5% Plastic - 0.40 w/c	93.06
8	10% Plastic - 0.40 w/c	84.065
9	15% Plastic - 0.40 w/c	79.16
10	20% Plastic - 0.40 w/c	64.03
11	0% Plastic - 0.045 w/c	55.955
12	5% Plastic - 0.045 w/c	80.245
13	10% Plastic - 0.045 w/c	83.88
14	15% Plastic - 0.045 w/c	62.235
15	20% Plastic - 0.045 w/c	52.65

The optimum content by weight was the same as that found for w/c = 0.40, 5%, and it produced a maximum compressive strength (93.06 MPa), being 57% greater than for the control (59.23 MPa). For w/c = 0.45, the highest compressive strength (83.88 MPa) at 10% plastic is slightly higher than that at the optimal dose because of the availability of more matrix porosity and less paste-plastic interaction at lower doses.

The analysis emphasizes an important conclusion: when the plastic content is low (i.e., 5-10%), it increases the compressive strength by densifying the matrix and also increasing its resistance to cracking, but excessive inclusion (>15%) of this material results in interfacial weaknesses and internal defects that will negate this advantage. Moreover, the observed sensitivity to the w/c ratio indicates that to be able to achieve optimal mechanical performance when using plastic waste in powder form, attention must be given to water content. The peak compressive strength at low dosages (5%) is likely due to the fine plastic particles acting as a physical filler, densifying the matrix and reducing the volume of large capillary pores, which leads to a more uniform internal stress distribution. Studies by Al-Luhybi and Qader (2021) and Qader et al. (2025) similarly found that low contents of recycled plastic fibers or other waste materials (1%-5%) can improve mechanical properties before detrimental effects occur at higher concentrations.

Relative strength change against control mixes was analyzed to quantify the relationship of plastic material with compressive strength. At w/c = 0.35, the improvement in compressive strength was significant and the control compressive strength of 70.88 MPa enhanced to 112.75 MPa for plasticity of 5% which is approximately 59%. Higher plastic content led to the reduction of strength to 105.70 MPa (10%), 88.70 MPa (15%) and 87.26 MPa (20%), which proved that the relationship between strength and plastic content was nonlinear with initial ascending stage and followed by a decline stage.

At w/c = 0.40, the same general tendency was observed in terms of quantitative behavior with a maximum compressive strength (93.06/59.23 MPa) at 5% plastic, i.e., by approximately 57% higher than the control mix. At w/c = 0.45, the highest strength was achieved with 10%

plastic (83.88 MPa) and a lower maximum increase in strength resulted due to higher porosity of the matrix at a high-water content.

These findings provide the critical added threshold. Plastic contents of 5-10% result in noticeable strength improvements whereas those above 15% always cause a reduction in strength. Hence, in terms of mechanical performance for quantitative dosage, 5% plastic is the most suitable amount that offers a maximum compressive strength at all of studied w/c ratios.

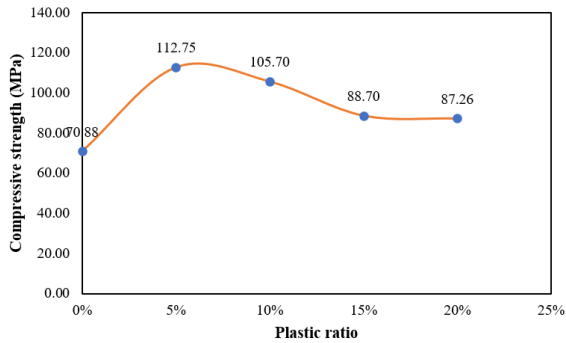


Fig. 16 Compressive strength versus plastic waste ratios with w/c = 0.35.

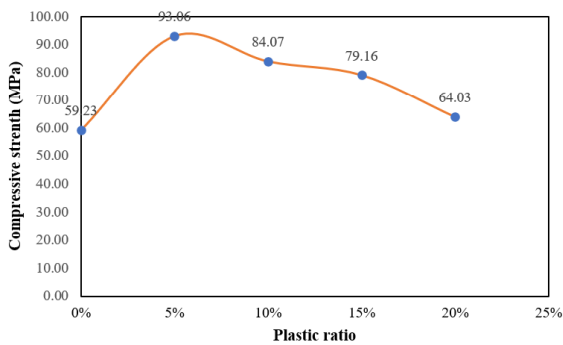


Fig. 17 Compressive strength versus plastic waste ratios with w/c = 0.4.

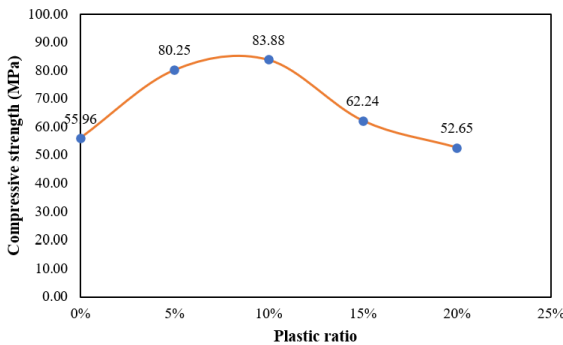


Fig. 18 Compressive strength versus plastic waste ratios with w/c = 0.45.

3.6 Combined interpretation of mechanical response

The flexural and compressive strength trends obtained from the experimental work are consistent, peaking for both at 5% plastic content before decreasing to maximum mass additions. The same response is indicative of the fact that at lower dosages (5-10%), the PVC ground particles serve well as both physical filler and micromechanical reinforcing phase. Under compression, the particles pack densify the matrix and redistribute internal stresses more uniformly, contributing to a remarkable 59% enhancement in strength. It is running in parallel to flexure, where the elasticity of the PVC particles allows for a crack-bridging mechanism that increases the energy absorption per unit volume of mortar (by 43%) until failure occurs.

However, above the 10% level, the mechanical behavior is controlled by the hydrophobic character of PVC and an increase in porosity of ITZ. This causes both mechanisms strength reduction, since the loosening bond of the plastic to cement paste now becomes prevalent for both loading situations. This dual behavior of the polymer confirms that maximum mechanical synergy was achieved at a 5% addition level, where the beneficial effects coming from particle elasticity and from filling are more attractive than the adverse ones due to plastic hydrophobicity.

Under compression, a larger w/c ratio (0.45) resulting in more porous and less bonded cement matrix is formed. With the addition of plastic, which is hydrophobic, ITZ becomes even more debilitated. Under high compressive loads, these cumulative weaknesses lead to rapid crack propagation through the porous matrix and the weak ITZ, resulting in the observed sharp decline in load-bearing capacity.

On the other hand, flexural strength depends on material performance in postponing crack initiation and reducing its measurement during cracking process. With w/c 0.45, the significantly higher ductility that is introduced by ground PVC particles partly offsets the weaknesses of the matrix. As the porosity of the matrix increases, however, the bridging behavior of elastic plastic particles on micro-cracks is maintained. This redistribution of tensile stresses leads to the absence of unpredictable reduction measured previously in compression, and brings stability recorded in flexural values for various plastic contents.

4. Conclusions

This study experimentally investigated the influence of adding ground recycled PVC plastic waste to the cement mortars and evaluated its influence on physical, mechanical, and thermal properties under different w/c ratios. Based on a comprehensive analysis of the experimental results and their comparison with published literature, the following conclusions can be drawn:

1. **Optimal Mechanical Synergy (Novelty):** In contrast to several studies that have consistently shown a decrease in strength with plastic addition; this study demonstrates a critical threshold (5-10% plastic content) at which mechanical performance is markedly improved. In this interval, the fine size PVC is a physical filler from which densifies the matrix acting also as micro-reinforcement phase that links cracks and increases the energy dissipation.
2. **Functional Lightweighting & Insulation:** The use of PVC waste effectively reduces mortar density and thermal conductivity, establishing these composites as viable materials for energy-efficient, non-structural building components such as insulation panels and prefabricated elements.
3. **Density reduction and lightweight properties:** The inclusion of PVC-based plastic particles led to a measurable reduction in the density of cement mortars, decreasing by up to ~4.5% compared with the control mix. This reduction is primarily attributed to the lower specific gravity of plastic and the introduction of micro-voids within the matrix. Such lightweight composites are advantageous for non-structural elements, thermal insulation panels, and prefabricated building components.
4. **Workability sensitivity to plastic content:** Flow table results revealed that the addition of plastic modifies the rheological behavior of fresh mortar. Low plastic content reduced workability slightly due to particle irregularity and increased internal friction, while higher dosages improved flowability, particularly at elevated w/c ratios. These findings highlight the need for careful proportioning to balance workability with mechanical performance.
5. **Enhanced thermal insulation:** Thermal conductivity decreased with increasing plastic content, achieving reductions of up to ~11%. This is attributed to the low thermal conductivity of plastic and the increased air-void structure, demonstrating the potential for developing energy-efficient construction materials.
6. **Flexural performance optimization:** Flexural strength improved significantly at lower plastic dosages, with a peak strength of 8.40 MPa (~43% higher than the control) achieved at 5% plastic and 0.35 w/c. The enhancement is attributed to the crack-bridging effect and stress redistribution provided by plastic inclusions. However, strength declined beyond 10-15% plastic due to poor bonding and increased porosity.
7. **Compressive strength enhancement at low dosage:** The most notable result of this study was the substantial increase in compressive strength — up to ~59% above the control — achieved with 5% plastic content at 0.35 w/c. Beyond this dosage, strength decreased progressively, indicating an optimum plastic content range between 5-10% for structural applications. This aligns well with previous studies, which also reported mechanical performance peaks within similar ranges.
8. **Limitations:** Main limitation of this material is the PVC hydrophobic character that also results in a weakened ITZ and higher porosity when beyond 15% dosages resulting subsequent decrease of load bearing capacity. Furthermore, the performance improvement is quite sensitive to w/c ratio, thus requiring careful water control during mixing.

The practical implications of this research are that both the construction and environmental industries can benefit from a technical process to manufacture sustainable functional building material. The measured increases in permeability and porosity and decreases in density thermal conductivity show that PVC-modified mortars would be especially

suitable for non-structural applications (for example, insulation panels or light prefabricated cladding) with the demand of reducing structural dead weight. Beyond that, the finding that low contents (5-10%) of finely ground PVC have a very important positive influence on mechanical performance, also opens an economical way for manufacturers to achieve better quality mortar avoiding incomplete use of cement. This study provides a practical useful guidance enabling, site engineers and ready-mix plants take maximum advantage of the ACAs devised by establishing the real "tipping point" related to plastic content overshadowing the common occurrence of strength reduction with higher addition percentages. At the end of the day, by upcycling low-cost industrial PVC waste into a performance-enhancing additive, this work provides economic incentives for circular economy practices that diminish environmental stress from plastic landfilling and contributes to global green infrastructure ambitions.

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