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PRODUCTION OF MORTAR INCORPORATING WASTE PLASTER OF PARIS AND WASTE TILES

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ABSTRACT

This study focuses on evaluating the compressive strength, water absorption, and acid resistance of mortar incorporating waste Plaster of Paris (POP) and waste tiles (WT). The physical properties of POP and WT were assessed through consistency, setting time, sieve analysis, and bulk density tests. The hardened properties investigated include compressive strength, water absorption, and acid resistance of the mortar specimens. Waste tiles were manually crushed using a hammer and sieved through a 4.75 mm sieve. Mortar mixes were prepared with 5% and 10% POP as partial replacements for cement, and 0%, 25%, 50%, 75%, and 100% WT as replacements for fine aggregate, using a water-to-cement (w/c) ratio of 0.45. Mortar cubes of 50 × 50 × 50 mm were cast and cured in water for 3, 7, 28, and 56 days. Water absorption tests were conducted at 7, 28, and 56 days, while acid resistance tests were performed by immersing specimens in 5% dilute sulfuric acid after curing for 28 days and evaluating their performance at 7, 28, and 56 days. The results showed that the highest compressive strength of 23.41 N/mm² was achieved at 56 days for mortar with 5% POP and 25% WT replacement. The lowest compressive strength, 13.43 N/mm², was observed at 3 days for mortar with 0% POP and 100% WT replacement. Specimens exposed to acid exhibited lower compressive strengths than those cured in water. Water absorption results indicated that mortar with 5% POP absorbed more water than those with 0% and 10% POP, and absorption decreased with curing age. Residual compressive strength after acid exposure decreased across all replacement levels, along with noticeable weight loss. However, the control mix (0% POP) maintained the highest residual compressive strength after 56 days of acid immersion compared to other POP replacement levels.

Keywords: Mortar, POP, Waste Tiles, Setting Time, Compressive Strength, Water Absorption, Acid Resistance Attack.

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1.0 INTRODUCTION

The global construction industry is increasingly shifting its focus toward sustainable development and the efficient use of resources, driven by the pressing need to address environmental degradation, reduce carbon emissions, and minimize construction waste. As urbanization accelerates, so does the demand for construction materials, resulting in the generation of significant quantities of construction and demolition (C&D) waste. Among these, waste Plaster of Paris (POP) and waste ceramic tiles (WT) represent a substantial portion that often ends up in landfills, posing environmental and health hazards. The integration of such waste materials into new construction applications offers a promising route for achieving resource conservation, cost reduction, and environmental sustainability (Mat, 2016).

Mortar is an essential component in construction, commonly used for binding masonry units such as bricks, stones, and concrete blocks. It serves as a key structural and aesthetic element, contributing to the strength, durability, and integrity of masonry structures. Traditional mortar is composed of cement, fine aggregates (usually sand), and water. However, the production of Portland cement a primary constituent of mortar is energy-intensive and contributes significantly to global CO_2 emissions. Consequently, there is a growing interest in developing alternative cementitious materials and aggregate replacements to enhance the environmental performance of mortar without compromising its mechanical and durability properties.

The durability of mortar is a critical performance indicator that encompasses its resistance to environmental stressors such as moisture ingress, chemical attack, and mechanical wear. Factors such as mix design, curing regime, and exposure conditions play a decisive role in influencing mortar's long-term behavior. Acidic environments, in particular, pose a major threat to cement-based materials, as they can induce leaching of calcium hydroxide, leading to structural deterioration. As such, exploring the acid resistance and water absorption behavior of modified mortar formulations is essential for their deployment in aggressive service conditions (Folk & Valastro, 1979; Ogork & Ayuba, 2014).

Plaster of Paris (POP), chemically known as calcium sulfate hemihydrate ($CaSO_4 \cdot ½H_2O$), is derived by heating gypsum at temperatures between 128°C and 150°C. It has been widely used in construction for plastering, casting, and molding applications due to its excellent workability and quick-setting properties. However, significant quantities of waste POP are generated during construction activities, particularly in interior finishing, mold preparation, and renovation works. This waste is typically non-biodegradable and poses disposal challenges. Studies have indicated that finely ground POP, when rehydrated, sets into an interlocking mass of gypsum crystals, which can potentially be leveraged in cementitious matrices to enhance workability, reduce setting time, and improve early strength development (Ghosal & Moulik, 2015; Prasad, Hanitha, & Anil, 2016).

On the other hand, waste tiles, primarily composed of ceramic or porcelain, are often discarded during demolition, remodeling, or tile cutting processes. These materials exhibit high compressive strength, low water permeability, and resistance to chemical attack, making them suitable candidates for partial or full replacement of natural fine aggregates in mortar. The recycling of ceramic waste not only diverts waste from landfills but also reduces the depletion of natural sand resources, aligning with principles of circular economy and green construction (Ferrara, Ozyurt, & Di Prisco, 2011).

The synergistic use of waste POP and waste tiles in mortar formulations offers a dual advantage: it allows for the beneficial reuse of industrial and construction waste, and it provides an opportunity to modify the microstructure and performance characteristics of

mortar. When appropriately proportioned, these materials can contribute to enhanced mechanical properties, reduced permeability, and improved chemical resistance, thereby extending the service life of mortar in challenging environments (United States Gypsum Company, 2000).

Previous studies have investigated the use of waste POP and ceramic tile powder in concrete and mortar applications. Paris, Roessler, Ferraro, DeFord & Townsend (2601) reported improvements in workability, compressive strength, and flexural strength with partial replacement of cement by waste POP. Similarly, Weyer et al. (2015) demonstrated that incorporating ceramic waste into mortar resulted in higher compressive strength and lower water absorption, supporting its viability for sustainable construction. These findings underscore the potential of waste-based materials as functional additives in cementitious systems.

Despite growing interest, limited comprehensive studies have focused on the combined effect of waste POP and waste tiles in mortar, particularly in relation to durability under acidic conditions and long-term water absorption behavior. This study, therefore, aims to fill this research gap by evaluating the compressive strength, water absorption, and acid resistance of mortar specimens modified with varying percentages of waste POP (5% and 10%) and waste tile aggregate (0% to 100%).

2. MATERIALS AND METHOD

2.1 Cement and aggregate

In this study, Ordinary Portland Cement (OPC) conforming to ASTM C150 (2012) standards was used as the primary binder. The cement used was classified as CEM I with compressive strength of 42.5 MPa, indicating its high early and standard compressive strength. The specific gravity of the cement was determined to be 3.15, which is consistent with values typical of Portland cement and essential for accurate mix proportioning.

To enhance the workability of the mortar mixtures without increasing the water-to-cement (w/c) ratio, a superplasticizer conforming to ASTM C494 (2013) was incorporated. This admixture plays a critical role in improving flow characteristics, ensuring better compaction and uniform distribution of materials, particularly when incorporating fine particles such as Plaster of Paris and waste tiles, which may otherwise affect the rheology of the mix.

2.2 Fine Aggregate

The fine aggregate used in this study was naturally occurring river sand, locally sourced and air-dried before use. River sand is a preferred material for mortar due to its rounded particle shape, clean surface texture, and low organic impurities, all of which contribute positively to workability and bonding in cement-based materials.

The bulk density of the sand was determined to be 1651 kg/m^3, which falls within the acceptable range for mortar production. This property directly influences the volume yield, cement demand, and overall weight of the mortar.

A sieve analysis was conducted to determine the particle size distribution of the fine aggregate, and the results are presented in Figure 1. The sand exhibited a fineness modulus (FM) of 2.60, which falls within the recommended range of 2.3 to 3.0 as specified by BS EN 13139 (2013). This indicates a well-graded sand with a balanced distribution of fine and coarse particles, which is ideal for mortar production. A fineness modulus within this range suggests that the sand will not demand excessive water for workability, thereby minimizing the risk of segregation or bleeding and ensuring a cohesive and durable mortar mix.

The selection of this particular fine aggregate was based on its compliance with grading requirements, availability, and performance characteristics, making it suitable for use in mortars incorporating waste Plaster of Paris and ceramic tile waste as replacement materials.

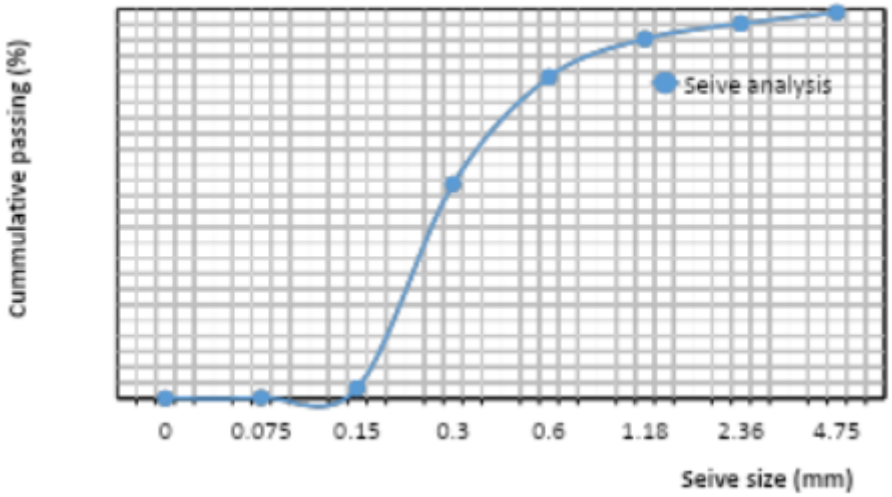


Figure 1: Particle size distribution for fine aggregate

2.3 Waste Tiles

Waste tiles (WT) refer to discarded, damaged, or surplus ceramic and porcelain tiles obtained from construction, renovation, or tile manufacturing processes. These tiles are typically unsuitable for their original application due to breakage, outdated designs, or excess stock, and thus contribute significantly to construction and demolition (C&D) waste (Deshmukh, 2018; Jayraj, 2013). Utilizing such waste material in mortar production not only helps reduce the environmental burden associated with landfill disposal but also supports sustainable construction practices.

In this study, waste tiles were sourced locally from construction and demolition sites at negligible cost. The collected tiles were manually broken into smaller fragments using a hammer, as illustrated in Figure 2. These fragments were then passed through a 2.36 mm sieve to ensure particle sizes were comparable to those of natural river sand, making them suitable for use as fine aggregate replacements.

The particle size distribution of the sieved waste tile aggregate was analyzed and is presented in Figure 3. The distribution indicated that the WT aggregate meets the medium-grade quality requirements of BS EN 13139 (2013) for fine aggregates used in mortar. Furthermore, the fineness modulus of the WT was determined to be 3.72, which suggests a coarser grading. While slightly above the commonly recommended range of 2.3–3.0, the grading remains within acceptable limits for mortar production and is expected to influence both workability and strength development.

The physical properties of the processed waste tile aggregate were evaluated and are summarized as follows:

- Specific Gravity: 3.10
- Relative Density: 1.75 g/cm³
- Water Absorption Rate: 15%

These characteristics reveal that the waste tile possesses a relatively high specific gravity, which can contribute positively to the mechanical strength of the mortar. However, the water

absorption rate of 15% is significantly higher than that of natural river sand, which may require adjustments to the mix water content or the incorporation of chemical admixtures to maintain proper workability and prevent premature drying.

Overall, the physical and grading characteristics of the WT indicate its potential as a viable substitute for natural sand in mortar, especially when used in conjunction with plaster of Paris (POP) as a cement replacement.



Figure 2: Waste tile

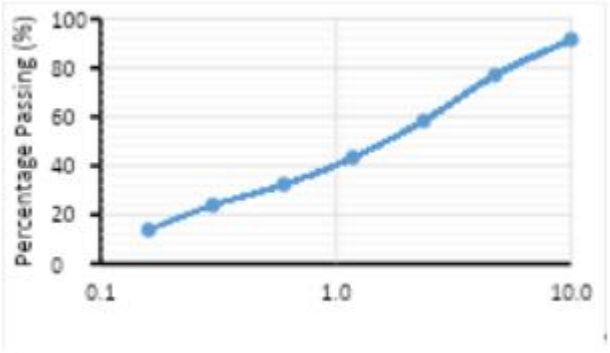


Figure 3: Sieve analysis curve of broken tiles

2.4 Plaster of Paris

The waste POP used in this study was sourced from discarded ceiling boards and ornamental moldings recovered from construction and renovation sites. The material was first air-dried to remove moisture, then manually crushed and pulverized into a fine powder using a mechanical grinder as shown in Figure 4. The resulting powder was passed through a 75-micron sieve to ensure uniform fineness suitable for use as a cement substitute.

The POP was chemically composed of calcium sulfate hemihydrate ($CaSO_4 \cdot \frac{1}{2}H_2O$), which reacts with water to form gypsum ($CaSO_4 \cdot 2H_2O$) during setting. The setting behavior of POP allows it to bind quickly, contributing to early strength development in mortar. However, its use in excess can result in volumetric instability and strength reduction, which necessitates careful dosage control. In this study, waste POP was incorporated at 5% and 10% replacement levels by weight of cement to assess its influence on workability, strength, and durability.

The initial and final setting times, standard consistency, and bulk density of the waste POP were determined.



Figure 4: Sample specimen of waste POP

3. Mix proportion of mortar, casting and testing

The mix proportions for the mortar specimens were prepared in accordance with BS EN 998-2 (2003), which provides specifications for masonry mortars. A manual mixing (hand mixing) approach was employed throughout the process to ensure consistency and replicate practical site conditions. The mixes were designed to achieve a target mean compressive strength of 15 N/mm² at 28 days.

A nominal mix ratio of 1:6 (cement to fine aggregate by weight) was used for all mortar compositions. The water-to-cement (w/c) ratio was maintained at 0.45, which aligns with standard recommendations for mortar workability and strength balance. To assess the effect of waste materials on the performance of mortar, two types of substitutions were incorporated:

- Waste Plaster of Paris (POP) was used to replace Ordinary Portland Cement (OPC) at 5% and 10% replacement levels by weight.
- Waste Tiles (WT) were used to replace natural river sand at 0%, 25%, 50%, 75%, and 100% replacement levels by weight.

This resulted in a matrix of different mix combinations, covering various POP and WT replacement scenarios. For each mix, 50 mm × 50 mm × 50 mm cube specimens were cast using steel molds. The fresh mortar was compacted and leveled to avoid air voids, and specimens were demolded after 24 hours and subsequently cured in clean water for 3, 7, 28 and 56 days to evaluate the progression of strength and durability.

A summary of the mix combinations is provided in Table 1, detailing the exact replacement levels of POP and WT for each batch.

Table 1: Mix proportion for the mortar specimens

Percentage Replacement (%)	**Sand (g)**	**Waste Tiles (g)**	**Cement (g)**	**5% POP (g)**	**10% POP (g)**	**Cement (g)**	**Water (g)**
							0.45
0	3420	0	513	0	0	513	231
25	2565	855	462	25.65	51.3	410	231
50	1710	1710	462	25.65	51.3	410	231
75	855	2565	462	25.65	51.3	410	231
100	0	3420	462	25.65	51.3	410	231

4.0 EXPERIMENTAL WORK

4.1 Consistency and Setting Time Test of OPC and POP

The standard consistency and setting time tests were conducted for both Ordinary Portland Cement (OPC) and waste Plaster of Paris (POP) to determine their water demand and hydration characteristics in accordance with BS EN 196 - 3 (2016). The set-up of the apparatus is shown in Figure 5.



Figure 5: Testing of consistency and initial setting time

4.2 Compressive Strength Test

Compressive strength was conducted in accordance with ASTM C270 -14a (2014), using a calibrated compression testing machine as shown in Figure 6 to evaluate the load-bearing capacity of the mortar cubes at each curing age.



Figure 6: Compressive strength machine

4.3 Water absorption test of Mortar specimens

Water absorption test was performed in line with ASTM C642 (2012), to assess the porosity and permeability characteristics of the mortar, which influence its durability and service life. Three specimens of 50x50x50 mm cubes were used at the ages of 7, 28 and 56 days of curing. The specimens were oven dried at 105° C for 72 hours. They were then allowed to cool in an air tight vessel for 24 hours. The specimens were weighed and immediately immersed in water tank for 30 minutes. The specimens were then weighed and water absorption was calculated as an increase in weight expressed in percentage of the mass of the dry specimen as shown in eqn. 1.

W=Ww-WdWd x 100% ..... [eqn. 1]

Where:

W = Percentage of water absorption
W_w = Weight of specimen wet
W_d = Weight of specimen dry

4.4 Acid attack test

Samples were immersed in 5% dilute sulfuric acid (H_2SO_4) solution and tested at 7, 28, and 56 days to simulate aggressive environmental conditions. Post-immersion compressive strength and mass loss were recorded to determine the resistance of the mortar mixes to chemical attack. Prior to immersion, the cube specimens were dried under laboratory condition for 48 hours and weighed as referenced. Visual observations of acid attack on specimens as shown in Figure 7.



Figure 7: Acid attack on mortar specimen

5.0 RESULTS AND DISCUSSION

5.1 Consistency and Setting of Binder Material

The results of the consistency and setting time tests for binders containing 0%, 5%, 10% and 100% plaster of Paris (POP) are presented in Table 2. The findings reveal notable variations in the setting behavior with the incorporation of POP into the cement matrix.

It was observed that the initial and final setting times decreased as the percentage of POP increased. Specifically, mixtures with 5% and 100% POP showed shorter setting times compared to the control mix with 100% OPC. This trend suggests that the inclusion of POP, especially at higher percentages, accelerates the setting process, which may be attributed to the rapid rehydration and crystallization behavior of POP during mixing.

Although this appears to contradict earlier findings by Ganesan (2008), which suggested that POP increases the setting time of pastes, the apparent discrepancy may be due to differences in particle fineness and specific surface area. POP with finer particle sizes tends to exhibit faster reactivity, leading to earlier setting. This reinforces the understanding that the setting behavior of hydraulic binders like POP is highly dependent on their particle size distribution and surface characteristics.

Furthermore, the reduction in final setting time for mixes containing POP can be attributed to the low rate of continued hydration and the formation of a dense gypsum matrix, which promotes quicker stiffening of the paste. The early setting nature of POP is beneficial in certain construction applications where rapid setting is desirable; however, it must be carefully balanced to prevent premature stiffening that could affect workability.

Overall, the results suggest that partial replacement of cement with POP modifies the setting characteristics of mortar, and this effect becomes more pronounced with increasing POP content. The data emphasize the importance of optimizing the replacement percentage based on the desired application, ensuring sufficient working time without compromising the early strength development.

Table 4.1: Consistency and setting time

Description proportion	Consistency (%)	Initial settings time (min)	Final settings time (min)
Control (0%)	35	40	250
5% POP + 95% OPC	38	25	30
10%POP +90% OPC	42	52	30
100% POP	50	10	30

4.5 Compressive strength of mortar

The compressive strength of mortar samples incorporating varying proportions of waste Plaster of Paris (POP) and waste tiles (WT) was evaluated at curing periods of 7, 28, and 56 days. Figures 8, 9, and 10 illustrate the average compressive strength values for 0%, 5%, and 10% POP replacements, respectively, across different WT replacement levels (0%, 25%, 50%, 75%, and 100%).

The results revealed that the compressive strength of mortar increased with the inclusion of 5% POP and 25% WT, exceeding the control mix at 56 days of curing. Specifically, the mortar mix with 25% WT and 5% POP recorded the highest compressive strength of 23.41 MPa, compared to 23.36 MPa for the control mix—representing a modest 0.2% increase in strength. Although the gain appears marginal, it is significant considering the inclusion of waste materials.

This increase in strength may be attributed to several factors:

- Finer particle size of POP, which contributes to improved packing density by filling micro voids within the matrix, thereby optimizing the pore structure and reducing porosity.
- The angular texture and rough surface of the crushed waste tiles likely enhanced the mechanical bond between the aggregate and the cementitious paste.

Similar behavior has been reported by Uchechukwu and Ezekiel (2014) in concrete containing iron ore tailings and Hou (2014) in studies involving ceramic waste aggregates.

Trend analysis across POP and WT variations indicates that 5% POP mixtures showed performance improvements, increasing the POP content to 10% resulted in lower compressive strengths, particularly at higher WT replacement levels. The strength dropped consistently beyond the 25% WT threshold, suggesting a dilution effect of the binder due to excessive substitution of cement and fine aggregate. This is in line with findings from Goyal, Singh, Hussain, and Singh (2015), who observed similar strength reductions in concrete when iron ore tailings replaced natural sand in large quantities.

The compressive strength across all samples ranged between 13.45 MPa and 23.41 MPa. The lowest strength was observed for the 100% WT / 5% POP mix, while the 25% WT / 5% POP mix yielded the highest strength. Notably, both the 5% and 10% POP replacement samples with 25% WT surpassed the design target strength of 15 MPa at 56 days, achieving 23.41 MPa and 22.34 MPa, respectively. These results demonstrate the potential for partial

replacement of cement and sand with sustainable alternatives, without compromising structural performance. The observed increase in strength may be partially attributed to the pozzolanic reaction facilitated by the presence of reactive silica in the waste tiles. This reaction contributes to additional calcium silicate hydrate (C-S-H) formation, which enhances the microstructure and strength of the mortar over time. Similar findings were reported by Jamil, Kaish, Raman, and Zain (2013), where the incorporation of reactive silica-rich materials improved the mechanical performance of cementitious composites.

The increase in curing time led to a progressive increase in compressive strength for all mix combinations. This trend highlights the importance of hydration and continued pozzolanic activity over time. The improvement in mechanical performance at 56 days, particularly in mixes containing 5% POP and 25% WT, underscores the synergistic effect of extended curing on mortar development.

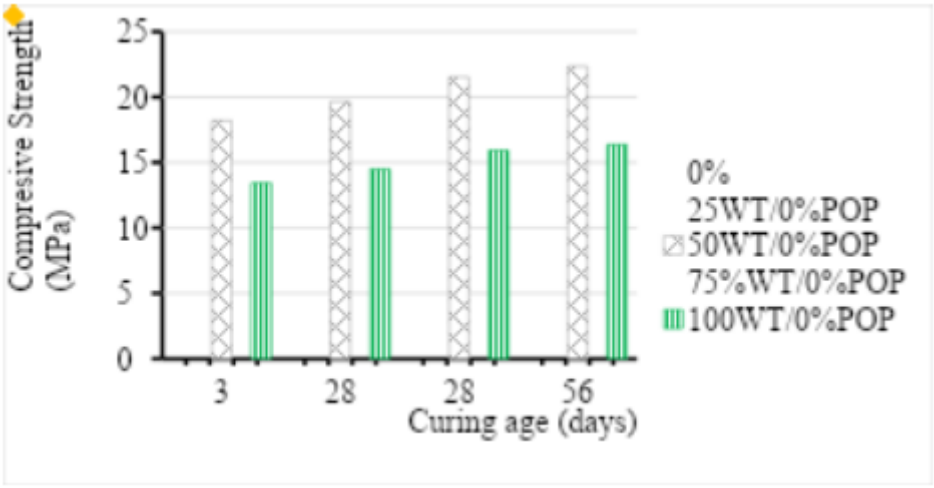


Figure 8: Compressive strength of 0% POP

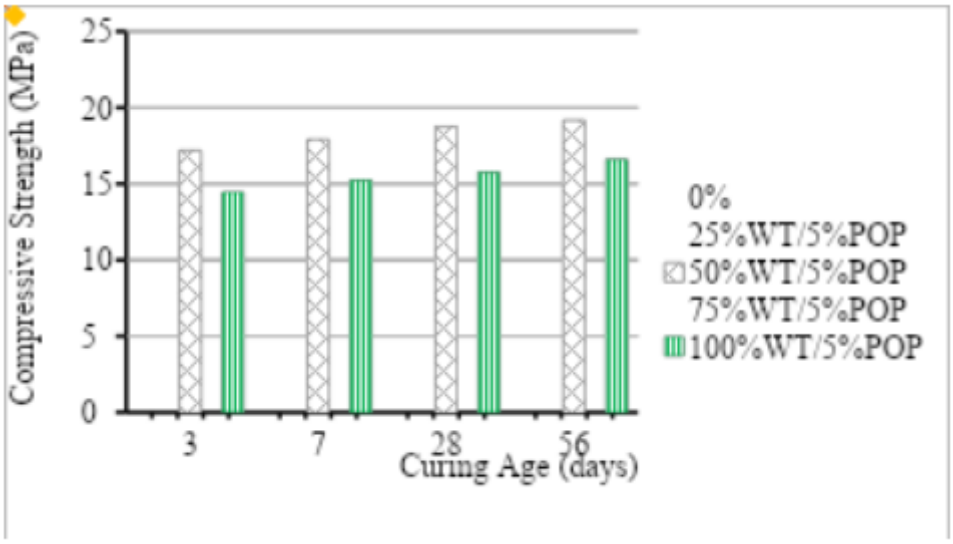


Figure 9: Result of Compressive Strength of 5% POP

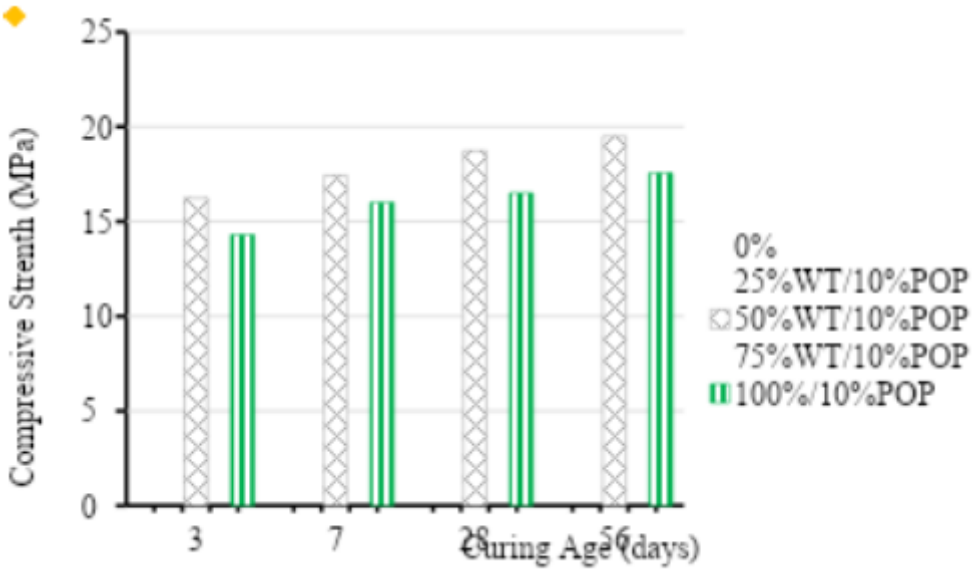


Figure 10: Result of Compressive strength of 10% POP

4.6 Water absorption of mortar

The results of the water absorption tests conducted on mortar specimens containing 0%, 5%, and 10% Plaster of Paris (POP) at 7, 28, and 56 days of curing are presented in Figures 11, 12, and 13, respectively. The test data indicate a general trend of reduced water absorption with increased curing duration across all mix compositions, reflecting the continued hydration and densification of the mortar matrix over time.

As shown in Figure 11, the control mix (0% POP and 0% WT) exhibited the lowest water absorption across all curing ages, highlighting the relatively impermeable nature of standard mortar. In contrast, mortar specimens incorporating Waste Tiles (WT) demonstrated higher water absorption rates, particularly at earlier ages. This increase can be attributed to the porous nature and surface texture of ceramic waste materials, which tend to retain more water compared to natural aggregates.

Figures 12 and 13 reveal that the inclusion of 5% and 10% POP in combination with varying levels of WT further increased the water absorption at early curing stages. However, a notable decline in absorption was observed as the specimens matured to 56 days. This progressive reduction is likely due to the refinement of pore structure resulting from ongoing hydration and the filler effect of fine POP particles, which effectively occupy micro voids within the matrix. Additionally, the pozzolanic activity of POP may contribute to the formation of secondary hydration products, further reducing porosity and permeability.

The behavior observed aligns with the findings of Yu, Zhang, and Mu (2012), who reported that finer binder materials, such as POP, enhance grain packing and reduce pore connectivity. Similarly, Correia, de Brito, and Pereira (2006) noted that the use of ceramic waste as coarse aggregate led to increased water absorption in concrete mixes due to the intrinsic porosity of the ceramic material.

Despite the variations, all mortar mixes tested in this study remained within the acceptable limit of 20% water absorption by weight, as recommended by Rajput (2006) for building applications. However, it is important to note, as Chan and Sun (2013) have emphasized, that

excessive water absorption can negatively impact the durability and long-term performance of cement-based materials by facilitating the ingress of harmful substances.

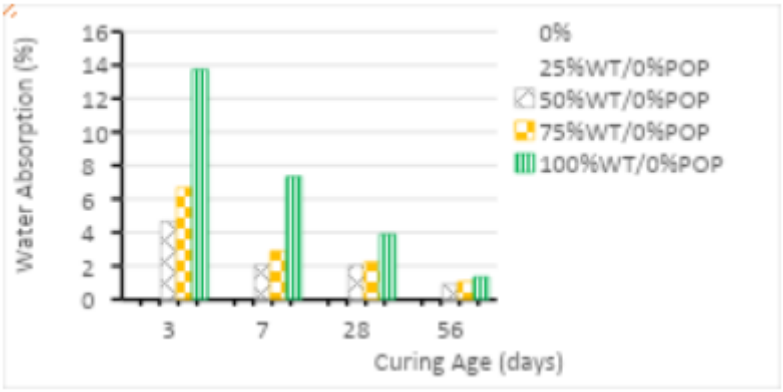


Figure 11: Results of water absorption of mortar specimens at 0% POP

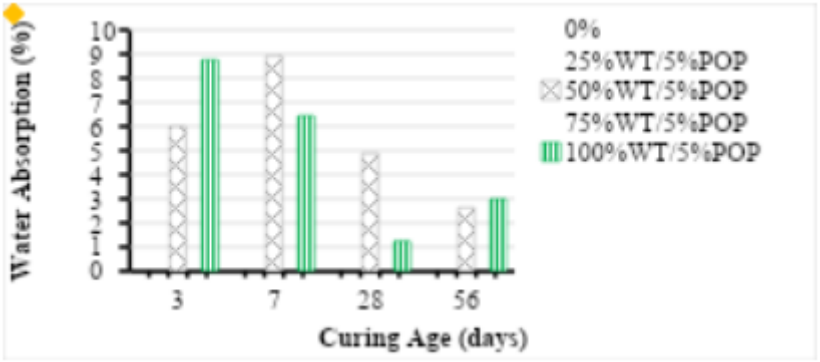


Figure 12: Results of water absorption of mortar specimens at 5% POP

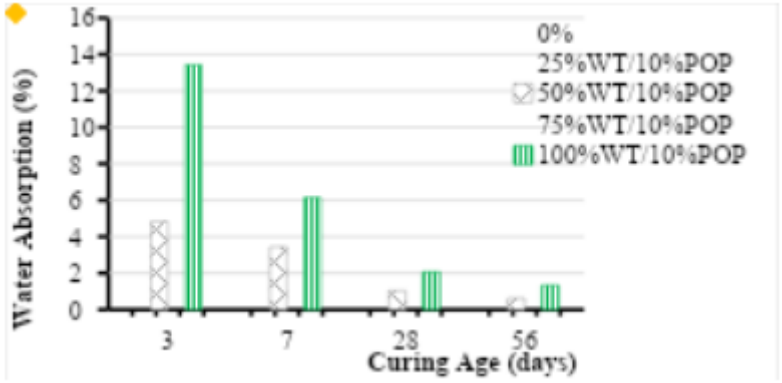


Figure 13**:** Results of water absorption of mortar specimens at 10% POP

4.7 Resistance to Acid Attack

This section presents the performance of mortar specimens incorporating Waste Tiles (WT) and Plaster of Paris (POP) when subjected to an acidic environment. Two key parameters were evaluated to assess acid resistance: residual compressive strength and weight loss. The aim was to expose the specimens to chemically aggressive conditions, simulating real-life environmental challenges such as acid rain or industrial exposure.

4.7.1 Residual Compressive Strength due to Acid Attack

The residual compressive strength results of mortar samples exposed to an acidic medium (H_2SO_4 solution) are shown in Figures 14, 15, and 16, corresponding to 0%, 5%, and 10% POP replacement levels with varying WT contents.

At early exposure durations (7 and 28 days), specimens containing 50% WT demonstrated higher residual compressive strength compared to both the control and other mix combinations. This suggests that partial replacement with WT can enhance acid resistance in the short term, possibly due to the densification of the matrix and the filler effect provided by finely crushed ceramic particles. The angular texture and lower solubility of WT aggregates may contribute to a more compact and chemically resistant matrix.

However, at 56 days of immersion, the control specimens (without POP and WT) exhibited the highest residual compressive strength, indicating superior long-term resistance to acid attack. This could be attributed to the extended hydration process and the formation of stable calcium silicate hydrate (C–S–H) phases due to continuous curing in potable water before acid exposure. The control mix likely benefited from a more robust microstructure less prone to acid degradation.

In contrast, the residual compressive strength of specimens with 100% WT and 5% or 10% POP decreased significantly after prolonged exposure. At 56 days, these mixes showed a reduction in compressive strength of 58.99% and 59.18%, respectively, relative to the control. This pronounced decline suggests that excessive inclusion of POP and WT compromises the acid resistance of the mortar. The potential reasons include: Increased porosity from higher POP content, which may accelerate acid ingress, Leaching of calcium compounds in acidic environments, which weakens the matrix; and Low durability of POP in aggressive media, as POP is known for rapid setting but poor resistance to chemical attack.

These findings are consistent with the observations of Pushpalatha, Vaishali, and Sudarsana (2022), who reported significant strength reductions in concrete mixes exposed to acids when supplementary cementitious materials with lower chemical stability were used.

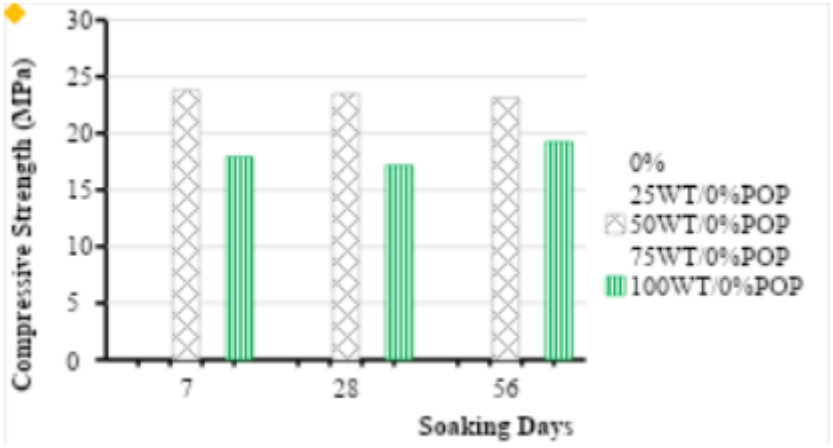


Figure 14: Results of Sulphuric acid attack of control mortar specimens (0%)

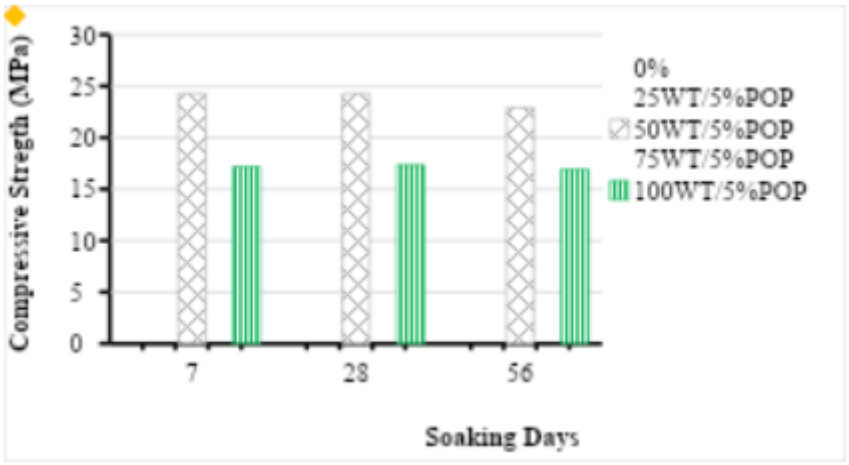


Figure 15: Results of Sulphuric acid attack mortar specimens at 5% POP

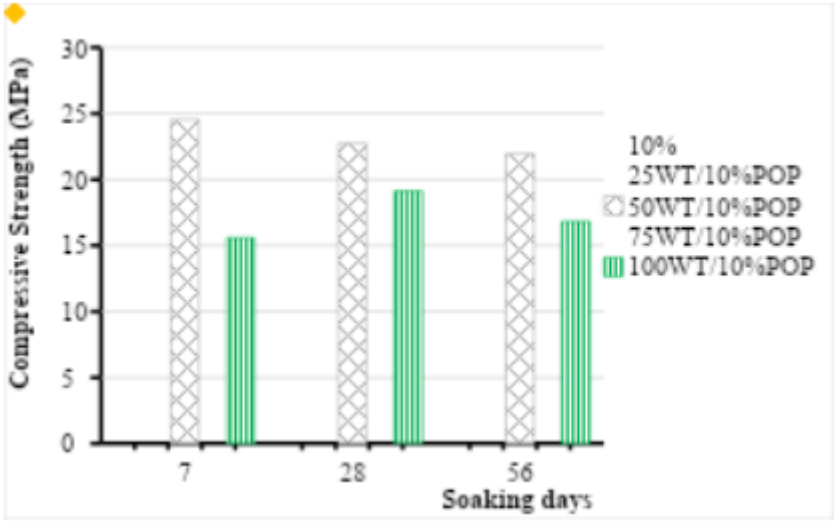


Figure 16: Results of Sulphuric acid attack mortar specimens at 10% POP

4.7.2 Weight loss of mortar specimens exposed to sulphuric acid

The results of the weight loss analysis of mortar specimens exposed to a 5% sulfuric acid (H_2SO_4) solution are presented graphically in Figures 17, 18, and 19. The weight loss was monitored at various curing ages (7, 28, and 56 days) for specimens with different proportions of waste tiles (WT) and plaster of Paris (POP).

At 0% WT replacement, no clear or consistent trend in weight change was observed across the different POP replacement levels (0%, 5%, and 10%). This indicates that POP alone does not significantly influence the acid resistance of mortar in terms of weight retention or loss at this level of WT substitution.

However, at 25% WT replacement, the weight of the specimens increased progressively with the duration of acid exposure across all POP percentages. This increase may be attributed to the absorption of acid solution into the matrix due to microstructural porosity, particularly in early stages of exposure. The phenomenon suggests that WT particles at this proportion may contribute to capillary suction effects that retain moisture from the acidic environment.

At 50% WT replacement, a more distinct trend emerged. For specimens with 0% POP, weight increased initially up to 28 days and then remained relatively constant. In contrast,

specimens containing POP showed an initial increase (at 7 days), followed by a decrease in weight by 56 days. This weight reduction is likely the result of the acid reacting with calcium hydroxide in the hydrated cement matrix to form calcium sulfate (gypsum), which is soft, white, and soluble. The formation of gypsum causes leaching and disintegration of the binder matrix, leading to material loss and surface deterioration, as supported by (Bakharev, Sanjayan, & Cheng, 2003).

At 75% WT replacement, the weight behavior was somewhat variable. For specimens with 0% POP, weight decreased at 7 days, then increased as immersion duration progressed to 56 days. For 5% POP, the weight reduced initially, increased at 28 days, and then stabilized up to 56 days. In contrast, with 10% POP, the specimens gained weight at 7 days, remained unchanged at 28 days, and experienced weight loss at 56 days. These trends indicate the complex interaction between POP, WT, and the acid solution. POP, being fine and highly reactive, might have initially filled pores and slowed degradation, but over time, its lower durability under acidic conditions may have contributed to mass loss.

At 100% WT replacement, the weight change pattern was inconsistent. For specimens with 0% and 10% POP, the weight decreased initially at 7 days, followed by a gradual increase up to 56 days. This may be due to the highly porous nature of 100% WT mortar absorbing acid solution in later stages. However, for 5% POP, the weight change was non-linear—decreasing at 7 days, increasing at 28 days, and decreasing again at 56 days. This irregularity suggests that the combination of 5% POP and 100% WT does not offer a predictable response to acid exposure and may be less chemically stable.

In summary, the weight loss analysis demonstrates that the durability of mortar under acidic conditions deteriorates with increasing WT and POP content beyond certain thresholds. While low levels of replacement may slightly enhance resistance due to densification and filler effects, higher replacements lead to increased permeability and acid ingress, accelerating degradation. These findings align with earlier studies and emphasize the need for optimized proportions to balance performance and sustainability.

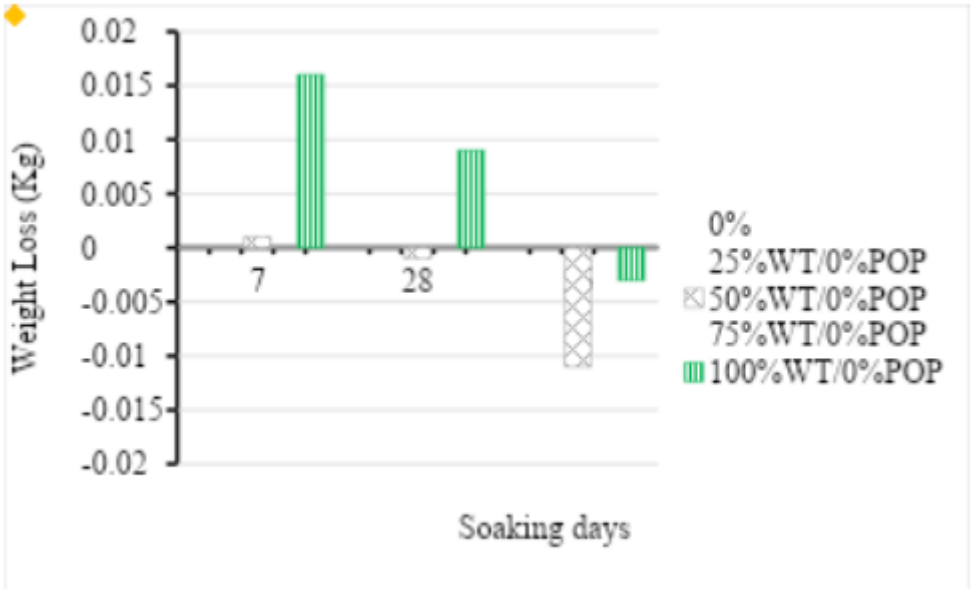


Figure 17: Result of Weight loss of sulphuric acid attack of control mortar specimens (0%)

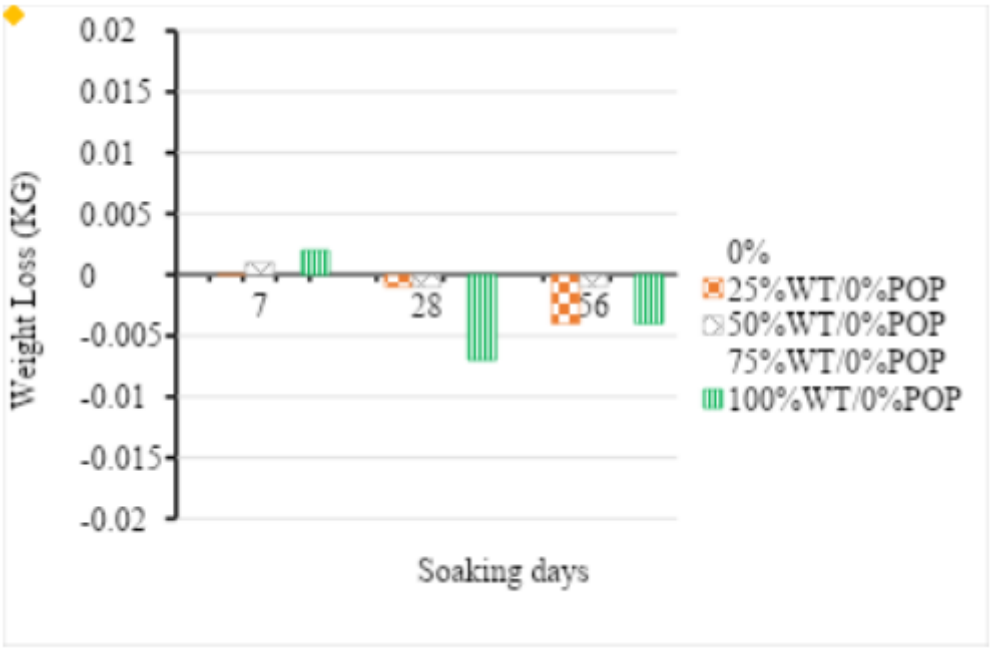


Figure 18: Result of Weight loss of sulphuric acid attack of mortar specimens at 5% POP

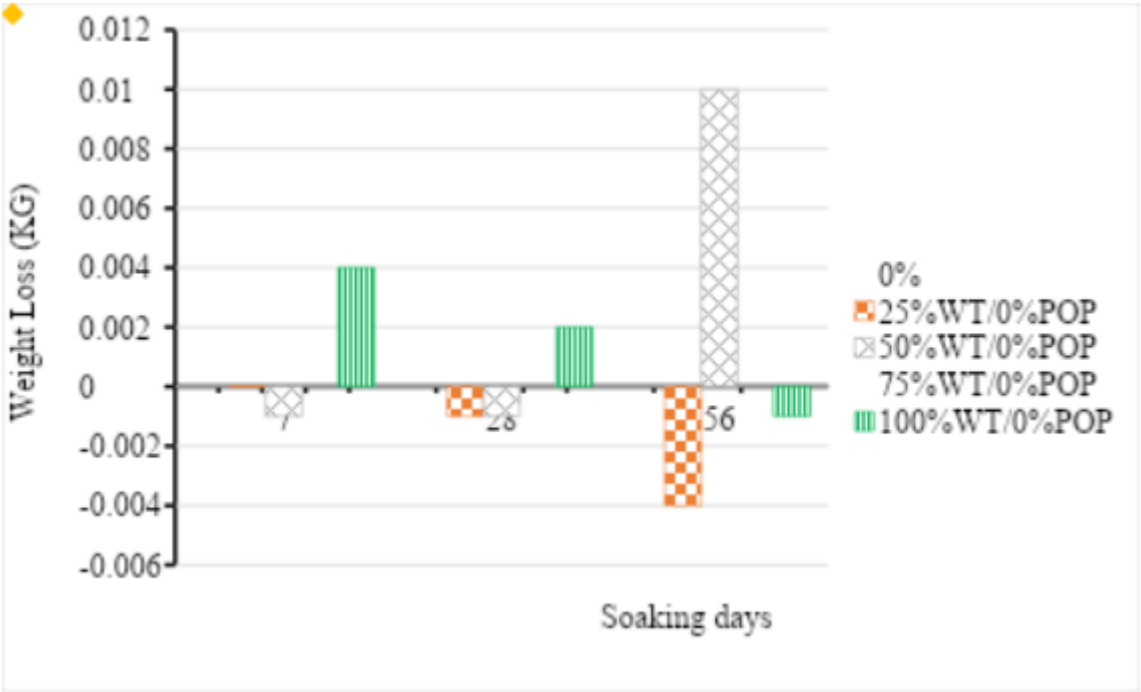


Figure 19: Result of Weight loss of sulphuric acid attack of mortar specimens at 10% POP

5.0 Conclusion:

Based on the findings of this research, the following conclusions can be drawn:

1. The results revealed that increasing the percentage of Plaster of Paris (POP) in the mortar mix generally led to a reduction in compressive strength. However, a partial increase in strength was observed at certain waste tile (WT) replacement levels as the curing age progressed, particularly at 5% and 10% POP replacements. The optimum strength was achieved with 25% WT and 5% POP at 56 days of curing.

2. Mortar specimens containing 5% POP exhibited higher water absorption compared to the control mix. However, the water absorption of all specimens decreased with increasing curing age, indicating continued hydration and pore refinement.
3. The weight loss results indicated that specimens exposed to 5% sulfuric acid solution showed varying degrees of degradation over 7, 28, and 56 days of immersion. At 28 days, the highest weight loss was recorded for the mix containing 5% POP and 75% WT (0.016 kg), followed by the 0% POP and 100% WT mix with a similar weight loss at 7 days. The lowest weight loss (-0.16 kg) was recorded for the control specimen, suggesting better acid resistance.
4. A general decline in residual compressive strength was observed in all specimens after acid exposure. Notably, specimens with 5% and 10% POP combined with 100% WT showed significant strength reductions of 58.99% and 59.18%, respectively, when compared to the control at 56 days of immersion. This highlights the vulnerability of high WT/POP mixtures to aggressive acidic environments.

6.0 Recommendations:

1. Further durability studies such as alkali–aggregate reaction, sorptivity, and chloride ion penetration tests should be conducted to evaluate long-term performance under different environmental conditions.
2. Additional chemical resistance tests, such as sulfate attack, should be performed to better understand the effects of POP and waste tiles on the durability and integrity of mortar specimens.

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