IMPACT OF USING RECYCLED POLYSTYRENE FOAM IN PLACE OF NATURAL COARSE AGGREGATE ON CONCRETE PERFORMANCE

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Abstract - The extensive use of conventional concrete intensifies environmental degradation through high natural aggregate consumption and carbon emissions. Concurrently, polystyrene waste remains a persistent yet underutilized pollutant. This study examines recycled polystyrene foam (RPS) as a partial replacement for coarse aggregate (0–40 vol.%) in concrete, focusing on fresh, mechanical, durability, and thermal properties. Increasing RPS content improved workability and reduced density but led to significant strength and durability losses. However, mixtures with up to 20% RPS maintained compressive strength above 17 MPa and acceptable ultrasonic pulse velocity, while thermal conductivity decreased markedly (62.4%), enhancing insulation. These findings suggest RPS incorporation can yield sustainable, lightweight, and energy-efficient concretes suitable for non-structural applications, advancing both waste valorization and environmental performance.

Keywords - Recycled polystyrene foam; lightweight concrete; thermal conductivity; compressive strength; durability; aggregate replacement

1. Introduction

The production of conventional concrete exerts significant pressure on natural resources and contributes to global environmental issues due to its heavy reliance on non-renewable materials such as crushed stone and sand. At the same time, increasing amounts of plastic waste, particularly expanded polystyrene (EPS) foam, continue to accumulate in landfills and oceans, where their non-biodegradable nature poses long-term ecological risks [1]. Among these, EPS packaging waste remains one of the most voluminous and persistent forms of solid waste worldwide, yet it is rarely recycled into structural materials.

In parallel with the global pursuit of sustainable construction practices, the reuse of waste materials in cementitious systems has emerged as a promising solution to reduce the carbon footprint, material consumption, and overall environmental burden of the construction industry [2]. Recycled polystyrene foam (RPS) offers several attractive properties for integration into concrete, including its low density, low thermal conductivity, and widespread availability. However, its use as a direct replacement for coarse aggregate is limited due to its poor mechanical performance, weak bond with the cement matrix, and its potential to introduce excessive porosity.

The increasing incorporation of RPS into cement-based composites reflects a dual aim of minimizing environmental waste and enhancing the thermal efficiency of construction materials. Dissanayake et al. [3] performed an embodied energy comparison and showed that concrete wall panels containing EPS offer a marked reduction in energy consumption over conventional brickwork, highlighting their potential in low-impact building systems. In a more recent study, Abu-Melha [4] introduced a multifunctional approach by embedding luminescent nanoparticles into polystyrene-based concrete, demonstrating its suitability for smart and decorative applications. Assaad et al. [5] evaluated the structural feasibility of sandwich panels incorporating EPS and reported that adequate mechanical strength can be retained through appropriate mix calibration. Similarly, Olofinnade et al. [6] utilized a blend of polystyrene and polyethylene waste to produce lightweight concrete, noting significant weight reduction but also a decrease in strength performance. Mohammed and Aayeel [7] focused on EPS in reinforced concrete beams and confirmed that such materials can be used effectively in flexural elements when reinforcement is correctly designed. Gregorova et al. [8] explored various recycled plastic types, including polystyrene, in lightweight concrete production, affirming their application potential in structural and semi-structural uses. Navarro et al. [9] combined EPS with alkali-activated silicon-manganese slag in masonry mortars and observed improved thermal insulation, suggesting compatibility with alternative binder systems. Leão et al. [10] investigated the use of EPS as a substitute for sand in rendering mortars and found substantial decreases in thermal conductivity, paired with overall density reduction. More recently, studies have introduced innovative methods to enhance foam-based concrete performance. Xue-Sen et al. [11] developed a high-performance foam concrete by incorporating hydrophobic foam, improving its strength and chemical resistance while reducing water absorption. Joseph et al. [12] examined hybrid natural fiber composites for concrete strengthening, achieving significant improvements in compressive strength and ductility. Additionally, Wu et al. [13] modified EPS particles for foam geopolymer systems, resulting in a 41.76% increase in compressive strength and reduced thermal conductivity, making it suitable for high-strength, lightweight construction.

Previous studies have primarily focused on the use of EPS beads or crushed foam in lightweight concrete, often targeting non-structural applications or decorative elements. Yet there remains a lack of comprehensive understanding regarding the quantitative impact of RPS replacement on the integrated performance of concrete, including mechanical strength, ultrasonic properties, moisture durability, and thermal insulation. In particular, the simultaneous analysis of compressive strength, surface resistivity, water absorption, and thermal conductivity within a single matrix has not been systematically addressed.

This study aims to fill this gap by evaluating the effects of replacing 0 – 40 vol.% of coarse aggregate with RPS on key performance parameters of concrete. The investigation includes fresh properties (slump and unit weight), compressive strength (CS) development, ultrasonic pulse velocity (UPV), water absorption (WA), surface electrical resistivity (SER), and thermal conductivity (TC). The outcomes provide new insights into the performance trade-offs and potential benefits of RPS as an eco-efficient aggregate replacement, offering practical implications for the development of lightweight and thermally enhanced concrete products for non-structural and energy-conscious applications.

2. Materials and experimental works

2.1. Materials

Grade-40 cement of Nghi Son branch conforming to ASTM C150/C150M-24 [14] Type I with a specific gravity of 3.12 was used as the binder in all concrete mixtures. The fine aggregate consisted of natural river sand with a fineness modulus of 2.87, a specific gravity of 2.62, and water absorption of 1.1%, meeting the requirements of ASTM C33/C33M-18 [15]. Crushed stone was used as the coarse aggregate, with a maximum nominal size of 9.5 mm, a density of 2.69 g/cm^3, and water absorption of 0.8%.

Figure 1. *RPS used for making concrete*

EPS foam is widely used in Vietnam, particularly in thermal insulation and packaging, with its production increasing due to technological advancements. While determining the exact amount of EPS waste produced is challenging, the material's growing popularity presents a significant opportunity for recycling. The use of RPS in this study not only offers a cost-effective solution but also contributes to environmental sustainability by reducing the impact of EPS waste. The RPS (see Figure 1) used in this study was obtained from post-consumer packaging waste. It was manually shredded and ground into irregular particles to simulate coarse aggregate dimensions. The RPS particles were lightweight (bulk density ~50 kg/m^3), non-absorbent, and hydrophobic in nature.

Sikament R4 superplasticizer (SP) with a density of 1.15 g/cm^3 was used to ensure the desired workability of fresh concrete. Local tap water was used for mixing and curing concrete.

2.2. Mixture proportions

Five concrete mixtures (see Table 1) were prepared with a constant water-to-cement ratio of 0.35. The only variable was the replacement of coarse aggregate (crushed stone) with RPS at replacement levels of 0%, 10%, 20%, 30%, and 40% by volume. The corresponding mixes were labeled RPS00, RPS10, RPS20, RPS30, and RPS40, respectively. As the RPS content increased, the volume of crushed stone was proportionally reduced while the total aggregate volume remained constant. A fixed SP dosage of 1.5% by weight of cement was used in all mixtures.

Table 1. *Mixture proportions of concrete (Unit: kg)*

Mix.	Cement	Sand	Stone	RPS	Water	SP
RPS00	514	865	807	0.00	180	7.7
RPS10	514	865	726	0.87	180	7.7
RPS20	514	865	646	1.74	180	7.7
RPS30	514	865	565	2.61	180	7.7
RPS40	514	865	484	3.48	180	7.7

2.3. Sample preparation and test methods

All concrete mixtures were prepared in a laboratory pan mixer following ASTM C192/C192M-13 [16]. Dry materials including cement, sand, stone, and RPS were blended for 1 min, after which water and SP were added gradually and mixed for an additional 2 min. The fresh mixture was immediately tested for slump and unit weight (UW) using the. The remaining fresh concrete was then cast into molds appropriate for each test as summarized in Table 2, covered to prevent evaporation, and de-molded after 24 hours. All specimens were cured in lime-saturated water at 23 ± 2 °C until testing. All tests were performed on three specimens per mix, and the average results were used for analysis.

Table 2. *Test methods used to evaluate concrete's performance*

Test name	Age (day)	Sample size (mm)	Reference
Slump	Right after mixing	-	ASTM C143/C143M-20 [17]
UW			ASTM C138/C138M-23 [18]
CS	3, 7, 14, 28, 56	Ø100×200	ASTM C39/C39M-23 [19]
UPV			ASTM C597-22 [20]
WA	28		ASTM C1585-20 [21]
SER	28		ASTM C1876-19 [22]
TC	28		Huynh et al. [23]

3. Result and discussion

3.1. Fresh concrete properties

The fresh concrete properties were strongly influenced by the incorporation of RPS as a substitute for coarse aggregate, particularly in terms of workability (measured by slump) and UW. As shown in Table 3, the slump value increased markedly with each increment of RPS content. The reference mix without RPS (RPS00) exhibited a low slump of 1.5 cm, indicative of a relatively stiff, low-workability mixture typically associated with conventional dense coarse aggregates. When 10% of the stone was replaced by RPS (RPS10), the slump increased to 3.5 cm, a 133% increase, and continued to rise with higher replacement levels: 6.5 cm at RPS20, 16.5 cm at RPS30, and peaking at 19.0 cm for RPS40. This pronounced gain in slump is primarily attributed to the non-absorbent, low-density, and smooth surface texture of the RPS particles, which reduces inter-particle friction and internal resistance to flow. In addition, the lower mechanical interlock between particles reduces the energy required for deformation under gravity, thus promoting higher slump values. The reduced angularity and absorption behavior of RPS further contribute to a more fluid and easily compacted fresh mix.

Table 3. *Slump and unit weight of fresh concrete mixtures*

Mix.	RPS (%)	Slump (cm)	Fresh UW (kg/m^3)	UW reduction (%)
RPS00	0	1.5	2348	0
RPS10	10	3.5	2182	-7.1
RPS20	20	6.5	2092	-10.9
RPS30	30	16.5	1981	-15.6
RPS40	40	19.0	1920	-18.2

Concurrently, the UW of the fresh concrete exhibited a consistent and significant decline with increasing RPS content. The control mix (RPS00) had a fresh UW of 2348 kg/m^3, which gradually decreased to 2182 kg/m^3 (−7.1%) in RPS10, 2092 kg/m^3 (−10.9%) in RPS20, 1981 kg/m^3 (−15.6%) in RPS30, and 1920 kg/m^3 (−18.2%) in RPS40. These reductions correlate directly with the low specific gravity of RPS (~50 kg/m^3) compared to that of natural crushed stone (~2690 kg/m^3), resulting in a lighter mixture per unit volume. Furthermore, the incorporation of RPS tends to increase air entrainment due to its hydrophobic nature and the presence of microvoids around the lightweight particles, further contributing to decreased UW.

These findings are consistent with prior research [5], which noted similar trends in lightweight concrete incorporating EPS and other polymeric aggregates. The dual effect observed here-a sharp increase in workability and a concurrent decrease in UW-suggests that RPS-modified concrete could be particularly advantageous for non-structural applications, such as lightweight panels, insulation layers, or precast elements, where reduced dead load and thermal benefits are prioritized over compressive strength. However, the magnitude of the slump gain, particularly in RPS30 and RPS40, may raise concerns regarding segregation and stability, warranting careful evaluation of mix cohesion and admixture compatibility.

3.2. Compressive strength

The CS of concrete decreased progressively with increasing levels of RPS replacement, as shown in Figure 2. At 3 days, the reference mix (RPS00) achieved an early strength of 20.59 MPa, while mixes containing 10%, 20%, 30%, and 40% RPS recorded significantly lower values of 12.70 MPa, 9.27 MPa, 9.05 MPa, and 8.34 MPa, respectively. These correspond to reductions of 38.3% (RPS10), 55.0% (RPS20), 56.0% (RPS30), and 59.5% (RPS40) compared to the control. The CS loss continued across all ages, though the differences became slightly less severe with time. At 28 days, CS reached 31.14 MPa for RPS00, while RPS10 and RPS20 attained 20.04 MPa (−35.6%) and 17.48 MPa (−43.9%), respectively. For higher RPS contents, the reductions were more dramatic: RPS30 yielded 14.13 MPa (−54.6%) and RPS40 only 10.57 MPa (−66.0%). At 56 days, although continued hydration led to strength gains in all mixes, the RPS40 mix still exhibited a 56.8% reduction compared to the control (34.93 MPa vs. 15.10 MPa).

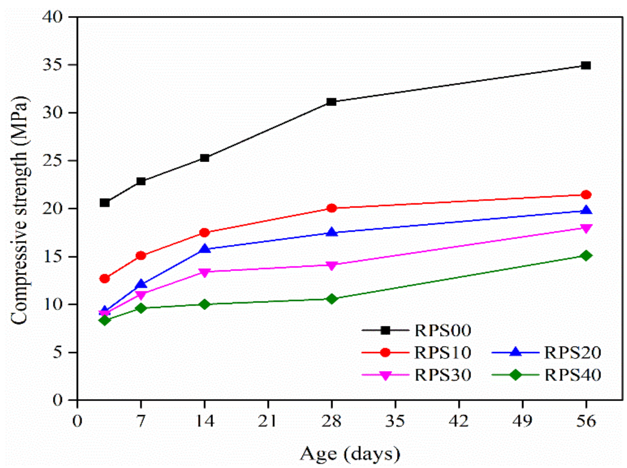

Figure 2. *CS development of concrete*

The progressive decline in CS with increasing RPS content can be attributed to several interrelated mechanisms. First, the low stiffness, low strength, and highly porous nature of RPS particles weaken the load-bearing skeleton of the concrete. Unlike crushed stone, which contributes directly to the concrete's structural integrity, RPS offers minimal resistance under compression and introduces more deformable zones within the matrix. Second, the poor interfacial bond between the hydrophobic surface of RPS and the cement paste leads to weak interfacial transition zones, resulting in localized stress concentrations and early microcrack formation under load. Third, the increased air content and internal voids associated with lightweight aggregates reduce the effective cross-sectional area resisting compression, further decreasing CS.

Despite these reductions, it is important to note that mixes with up to 20% RPS still achieved 28-day CS above 17 MPa, making them potentially suitable for non-structural or semi-structural applications where low density and thermal performance are prioritized over mechanical strength. Furthermore, the consistent strength gains between 28 and 56 days across all mixes-up to 42.9% in RPS40-suggest that long-term pozzolanic or filler effects of fine particles may partially offset early-age strength losses. These findings are consistent with prior studies on lightweight concrete incorporating EPS [4], which also observed significant strength reductions with increasing EPS or foam content. Ultimately, while replacing coarse aggregate with RPS reduces CS, it offers significant potential for lightweight, thermally-insulating concretes in applications. This material is especially useful in non-load-bearing walls, partition panels, roof insulation, and thermal insulating facades, thanks to its lightweight nature and excellent thermal properties. These applications can contribute to energy-efficient and sustainable building practices, making RPS-based concrete an effective solution for lightweight construction with enhanced insulation performance.

3.3. Ultrasonic pulse velocity

As shown in Figure 3, the UPV results demonstrate a consistent decline with increasing RPS content at all ages, reflecting the progressive loss in material compactness and continuity due to the introduction of lightweight, low-density aggregates. At 3 days, the control mix (RPS00) recorded a UPV of 4158 m/s, while RPS10, RPS20, RPS30, and RPS40 exhibited 3948 m/s, 3745 m/s, 3629 m/s, and 3366 m/s, respectively. These values represent early-age reductions of 5.0% (RPS10) to 19.0% (RPS40), relative to the control. The trend persisted at later ages, though UPV values increased overall due to continued hydration and matrix densification. By 28 days, the control mix reached 4758 m/s, and the RPS mixes recorded 4544 m/s (RPS10), 4444 m/s (RPS20), 4292 m/s (RPS30), and 3839 m/s (RPS40)-marking reductions of 4.5%, 6.6%, 9.8%, and 19.3%, respectively. At 56 days, the highest UPV was observed in RPS00 at 4905 m/s, while the lowest occurred in RPS40 at 4065 m/s, a substantial 17.1% reduction. These values indicate that although RPS concrete continues to hydrate and develop internal structure, its overall sonic conductivity is compromised by the inclusion of polystyrene, which is non-load-bearing, acoustically inert, and discontinuous in nature.

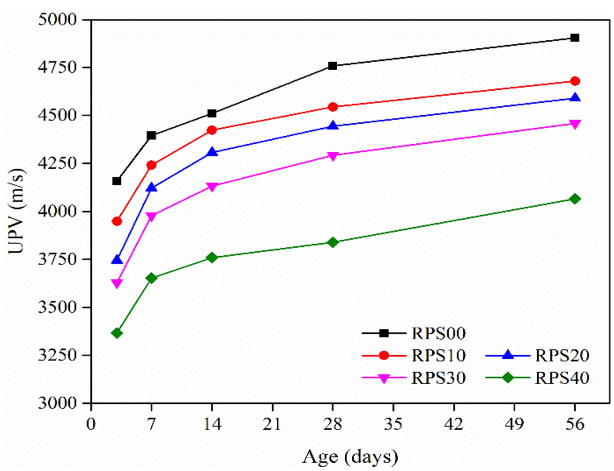

Figure 3. *UPV of concrete*

Mechanistically, the lower UPV in RPS-modified mixes is attributed to three main factors: (1) the lower density and stiffness of RPS particles compared to natural aggregates; (2) the increased entrapped air content and microvoids, which reduce the effective medium for wave transmission; and (3) the weaker bond strength at the paste–RPS interface, which creates micro-discontinuities that scatter and slow down ultrasonic waves. These effects cumulatively degrade the velocity of pulse transmission, serving as an indirect measure of reduced compactness and increased porosity.

Figure 4 presents the relationship between UPV and CS of concrete at 7, 28, and 56 days, modeled through quadratic regression. In all cases, a strong positive correlation is evident, with coefficients of determination (R^2) of 0.88, 0.95, and 0.98 for 7, 28, and 56 days, respectively. These high R^2 values indicate that UPV is a reliable non-destructive indicator of CS evolution in RPS-modified concrete, especially at later ages.

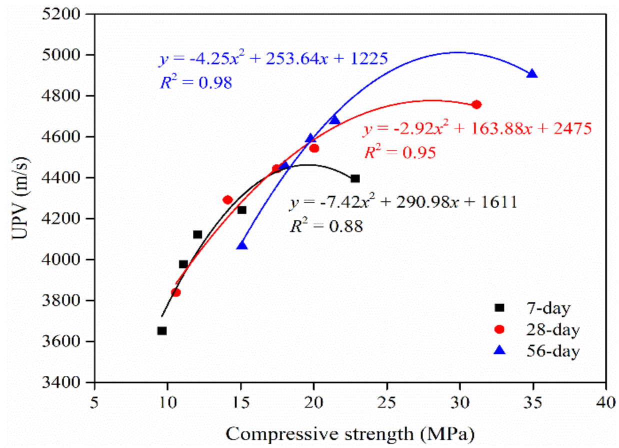

Figure 4. *Correlation between UPV and CS of concrete*

The strength–UPV relationship exhibits a non-linear trend, reflecting how early gains in strength contribute significantly to UPV, while later increases in strength are associated with diminishing gains in wave velocity. This is particularly evident in the flattening of the 56-day curve, where CS continues to rise, but UPV tends to plateau. The regression equation for 56 days, $y = -4.25x^2 + 253.64x + 1225$ ($R^2 = 0.98$), confirms that the correlation tightens with hydration maturity, likely due to microstructural densification and reduced porosity stabilizing wave transmission pathways.

Comparatively, the 7-day curve, $y = -7.42x^2 + 290.98x + 1611$ ($R^2 = 0.88$), has a steeper slope and a lower R^2, suggesting more variability due to immature microstructure, higher moisture content, and unstable interfacial transition zones formation. At 28 days, the curve $y = -2.92x^2 + 163.88x + 2475$ ($R^2 = 0.95$) represents an intermediate behavior, balancing hydration development and pore refinement. These patterns underscore that UPV becomes a more accurate predictor of strength as concrete ages and heterogeneity diminishes. Overall, this figure validates UPV as a practical and non-destructive tool for estimating CS in lightweight concrete systems incorporating recycled polystyrene. The strong correlations, particularly at 56 days, suggest that UPV could serve as a quality control metric in real-time applications where destructive testing is impractical.

3.4. Water absorption

Figure 5 illustrates the influence of RPS content on the WA capacity of concrete. A gradual increase in absorption is observed as the RPS replacement level increases from 0% to 40%, indicating that the incorporation of RPS negatively affects the concrete's resistance to water ingress. The control mix (0% RPS) exhibited the lowest absorption value of 2.32%, while mixtures containing 10%, 20%, 30%, and 40% RPS recorded absorption values of 2.38%, 2.43%, 2.59%, and 3.12%, respectively. The increase becomes more pronounced beyond 20% replacement. At 40% RPS, WA rose by 34.5% relative to the control.

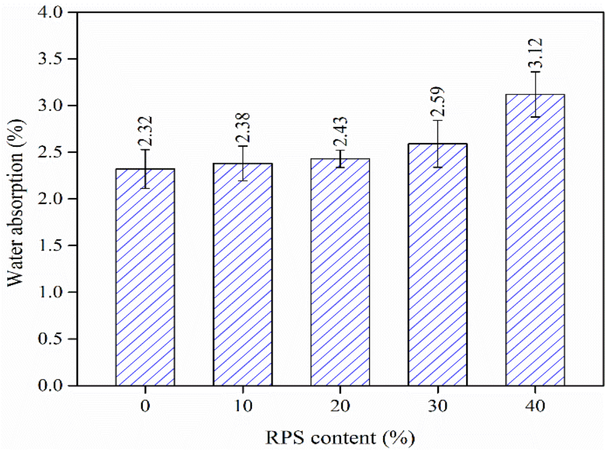

Figure 5. *WA of concrete*

The rising trend can be attributed primarily to the inherent characteristics of RPS particles, which are lightweight, hydrophobic, and poorly bonded to the cement matrix. These particles do not contribute to water-blocking or compaction but instead create interfacial voids and microchannels that facilitate capillary suction. Moreover, their low stiffness and irregular surface geometry further hinder tight packing and allow for more entrapped air and discontinuities. These factors collectively increase the effective porosity and connectivity of the pore network, making it easier for water to be absorbed into the concrete over time. Interestingly, the increase in absorption at lower RPS levels (10–20%) was relatively modest (<5%), suggesting that small dosages may still retain acceptable durability performance. However, once the RPS content exceeds 20%, the effect becomes increasingly significant, reflecting a threshold where the negative impacts on pore structure outweigh the benefits of density reduction. These findings are in agreement with prior studies [10], which reported that the substitution of conventional aggregates with lightweight polymers typically leads to higher permeability and moisture absorption unless mitigated by surface treatments or densification strategies.

3.5. Surface electrical resistivity

Figure 6 shows the variation of SER with increasing RPS content.

SER is a critical indicator of a concrete's ability to resist ionic penetration, closely related to its pore connectivity and, consequently, its durability against chloride ingress and corrosion risk. The reference mix (RPS00) exhibited the highest SER value of 43 kΩ·cm, while the inclusion of RPS progressively reduced this value to 37, 35, 34, and 32 kΩ·cm for RPS10 through RPS40, respectively. These represent relative decreases of 14.0% (RPS10), 18.6% (RPS20), 20.9% (RPS30), and 25.6% (RPS40) compared to the control. The reduction in SER with higher RPS content can be attributed to the increase in pore connectivity and moisture pathways caused by the incorporation of low-density, poorly bonded RPS particles. Unlike traditional stone aggregates that contribute to a denser microstructure, RPS introduces interfacial gaps and entrained air, both of which reduce the concrete's resistivity by facilitating ionic mobility. Moreover, the lack of cementitious reaction or filler contribution from polystyrene further limits the matrix refinement, leaving the pore system relatively unblocked and conductive to moisture and chloride transport.

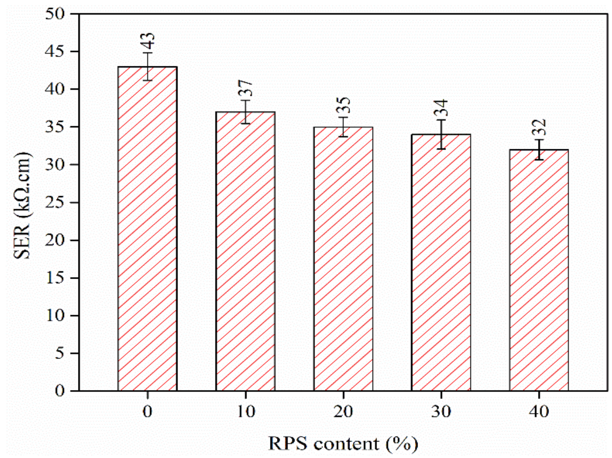

Figure 6. *SER of concrete*

In light of the observed increase in WA (Figure 5) and decrease in SER (Figure 6) at higher RPS levels, which may suggest long-term durability concerns, potential mitigation strategies will be explored in future stages of this research. These strategies may include the use of coatings, hybrid additives, and supplementary cementitious materials to improve the durability and performance of RPS-based concrete. Future studies will also assess how these properties evolve over time to better understand the long-term performance of concrete with recycled polystyrene foam.

3.6. Thermal conductivity

The influence of RPS on the TC of concrete is presented in Figure 7. A clear and substantial reduction in TC is observed with increasing RPS content, highlighting the material's potential as a thermal insulating component. The control mix (RPS00) exhibited the highest TC at 2.270 W/m·K, characteristic of conventional normal-weight concrete. Upon replacing 10% of the coarse aggregate with RPS, TC dropped to 1.727 W/m·K, representing a 23.9% reduction, while further replacements led to even lower values: 1.398 W/m·K (−38.4%), 1.299 W/m·K (−42.8%), and 0.853 W/m·K (−62.4%) for RPS20, RPS30, and RPS40, respectively. This significant decline in TC is attributed to the intrinsically low TC of RPS (~0.03 W/m·K), which is several orders of magnitude lower than that of mineral aggregates. Additionally, the inclusion of RPS introduces more air voids and discontinuities into the concrete matrix, both of which disrupt heat transfer pathways. Since air is a poor thermal conductor, these voids act as barriers to conductive heat flow, thereby enhancing the insulation capacity of the material. The sharp drop between RPS30 and RPS40 suggests a threshold effect, where the material transitions from structural to more insulating behavior.

Interestingly, the TC trend correlates inversely with UW and CS, reinforcing that RPS replacement leads to a lighter but thermally superior material. However, as indicated by rising WA and decreasing SER values, this improvement in thermal performance comes with trade-offs in moisture durability and microstructural compactness. Nonetheless, the TC value of 0.853 W/m·K in RPS40 is comparable to insulating lightweight concretes, demonstrating the feasibility of RPS-based concrete in applications such as non-load-bearing walls, infill blocks, and energy-efficient facades.

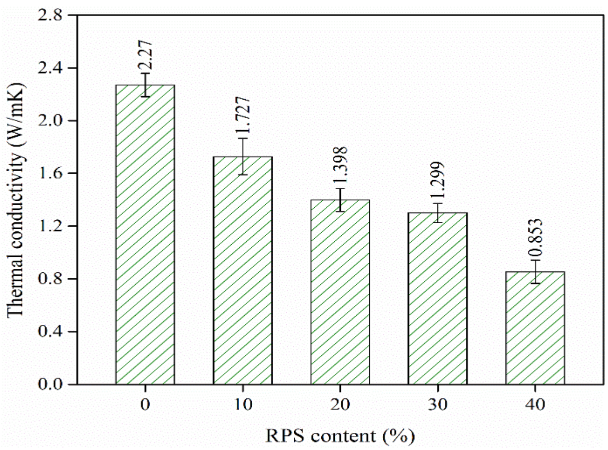

Figure 7. *TC of concrete*

Figure 8 presents the interrelationship between WA, SER, and TC of concrete containing RPS. Both SER and TC exhibit strong non-linear inverse relationships with WA, modeled using quadratic regression functions. The coefficient of determination (R^2 = 0.95 for SER and R^2 = 0.89 for TC) indicates that WA is a robust predictor of both electrical and thermal behavior in lightweight concrete containing RPS.

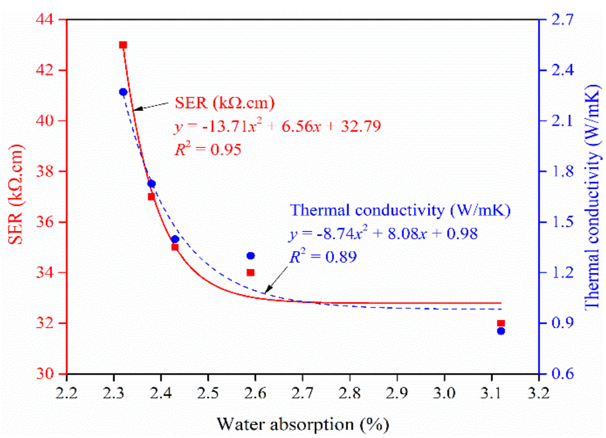

Figure 8. *Correlation among WA, SER, and TC of concrete*

As WA increases from around 2.32% to 3.12%, SER declines from around 43 to 32 kΩ·cm, highlighting a 25.6% drop in SER. This trend is described by the equation y (SER) = $-13.71x^2 + 6.56x + 32.79$ and reflects the enhanced ionic mobility through the increasingly porous and moisture-permeable concrete matrix induced by the RPS particles. As more hydrophobic and loosely bonded RPS replaces traditional aggregate, interfacial voids and capillary pores increase, leading to greater moisture ingress and reduced resistance to ion flow, especially under saturated or chloride-rich conditions.

Simultaneously, TC decreases from around 2.270 to 0.853 W/m·K, or a 62.4% reduction, in response to rising WA. The TC trend follows the regression: y (TC) = $-8.74x^2 + 8.08x + 0.98$, which supports the notion that WA not only influences durability-related properties but also directly correlates with the microstructural discontinuities and void content that govern heat flow. In lightweight concretes, the presence of air-filled voids (introduced by RPS) interrupts the heat conduction pathways, thereby significantly lowering TC even as the concrete becomes more permeable to water. This dual-trend analysis reveals a critical design insight: while increasing RPS content improves thermal insulation, it simultaneously leads to compromised moisture resistance and reduced electrical resistivity. These trade-offs necessitate careful balancing based on the intended application, e.g., thermal-insulating blocks in non-exposed environments may benefit greatly, while moisture-sensitive or chloride-prone applications may require hybrid strategies (e.g., SCMs, hydrophobic admixtures, surface sealers).

4. Conclusion

This investigation evaluated the influence of RPS as a replacement for coarse aggregate on the fresh, mechanical, durability, and thermal performance of concrete. The experimental findings allow the following quantitative conclusions to be drawn:

- The increase in RPS content improved workability substantially, with the slump rising from 1.5 cm in the control mix to 19.0 cm at 40% RPS, while fresh UW decreased from 2348 kg/m³ to 1920 kg/m³, reflecting an 18.2 % reduction. These changes suggest good potential for lightweight concrete production.

- CS declined as RPS content increased. At 28 days, strength dropped from 31.14 MPa in the control to 10.57 MPa at 40% RPS, amounting to a 66.0% reduction. Nevertheless, mixtures containing up to 20% RPS still achieved strengths exceeding 17 MPa, which may be suitable for non-structural applications. Whereas, UPV values also showed a downward trend, decreasing from 4758 m/s to 3839 m/s at 28 days. Despite the reduction, all mixes maintained UPV above 3500 m/s, indicating an acceptable level of internal quality for lightweight concrete.

- Durability-related indicators showed moderate impacts. WA increased from 2.32 to 3.12 % as RPS increased, while SER decreased from 43 to 32 kΩ·cm. These trends reflect higher porosity and reduced resistance to ionic penetration, particularly at higher replacement levels.

- TC benefited most from RPS inclusion. Values decreased from 2.270 W/m·K in the control to 0.853 W/m·K at 40% RPS, yielding a 62.4% reduction. This significant improvement in insulation performance supports the use of RPS concrete in thermally efficient building components.

- Strong correlations were found between WA and both SER and TC, with R^2 values of 0.95 and 0.89, respectively. These relationships confirm that moisture-related porosity governs both durability and thermal behavior in RPS concrete systems.

In summary, the use of RPS offers a promising route for producing lightweight and thermally enhanced concrete. While reductions in strength and resistivity occur, the material remains suitable for non-structural and insulating applications when properly proportioned and designed.

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