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UTILIZATION OF CONCRETE WASTE AS A CEMENT REPLACEMENT: INFLUENCE OF CALCINATION ON REACTIVITY AND PERFORMANCE

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Abstract: Concrete waste is one of the major components of construction and demolition wastes, as well as a material that must be removed in an environmentally safe manner. With the inclusion of concrete waste as a minor additional constituent, the popularity of its utilization has gained importance. This study utilizes concrete waste with replacement ratios of 20%, 40%, and 60%, in both calcined and non-calcined forms. Two different calcination temperatures were applied to see the effect of calcination temperatures. Results show that as the replacement ratio of non-calcined concrete waste increases, mechanical performance decreases. However, calcination enhances the reactivity of concrete waste, and at an optimum replacement ratio of 20%, the compressive strength is higher than that of the reference specimen. After freeze-thaw cycles, specimens with 20% calcined concrete waste exhibit lower compressive strength losses compared to the reference specimen. Regarding the mass losses after freeze-thaw cycles, 20% concrete waste calcined at 950 °C have better performance than reference specimen. This study shows that with a 20% replacement ratio, calcined concrete waste can be used as a cement replacement material.

Keywords: Concrete waste, Calcination, Freeze-thaw, Strength loss, Electrical resistance

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1. Introduction

Cement production plays a major role in environmental degradation, primarily due to its high consumption of natural resources and energy (Sari et al., 2020), as well as its contribution to nearly 7% of global CO_2 emissions (Neupane, 2022). To mitigate these negative impacts, the use of blended cements is encouraged under the TS EN 197-1 standard, incorporating materials such as fly ash (FA), blast furnace slag (BFS), natural pozzolans (NP), limestone, and silica fume (SF) to reduce clinker content. Although some of these are industrial byproducts and others are naturally occurring, they are well-known for their positive effects on mechanical and durability performance when used in cement blends.

More recently, even concrete waste (CW) has emerged as a viable component in blended cement formulations, in line with sustainability goals, as its generation rate continues to rise each year. The renovation of existing structures, as well as unfortunate events such as earthquakes and wars, are among the primary causes behind the accumulation of large volumes of CW. With the growing emphasis on sustainability and the circular economy, researchers have increasingly focused on the reuse of waste materials, including CW and other construction and demolition wastes (CDW). If not properly managed, the disposal of concrete waste can result in soil and groundwater contamination; furthermore, its bulky and inert nature contributes to land occupation and long-term environmental degradation (Maaze and Shrivastava, 2023). In this context, TS EN 197-6 permits the use of CW in cement blends at rates of up to 35%. However, despite this allowance, due to its highly crystalline structure—primarily composed of portlandite, calcite, and quartz—20% is generally recommended as the upper limit for replacement (Maaze and Shrivastava, 2023).

One of the most effective methods to compensate for the low reactivity caused by CW's crystalline structure is thermal activation. Studies report that CW becomes denser around 400 °C, while 800 °C is frequently cited as the optimum calcination temperature (Zhang et al., 2022). However, Xu et al. (2021) identified 750 °C as the optimal treatment temperature—among 550, 650, 750, 850, and 950 °C—based on maximum compressive strength results. In another study, 800 °C combined with a 10% replacement ratio was determined to be the most effective combination (Kim and Ubysz, 2024). According to Wu et al. (2021) CW treated between 600 and 800 °C exhibited the best performance at a 30% replacement level.

Although strength development with thermally activated CW has been reported, the durability performance of mortars incorporating CW remains less explored. Therefore, this study investigates not only the compressive strength development of mortars containing 20%, 40%, and 60% CW, but also evaluates their durability. In this context, mass and strength losses were measured after freeze–thaw cycling. Additionally, electrical resistance tests were conducted to assess the microstructural changes of the mortars.

2. Materials and Methods

This study evaluates both thermally treated and untreated concrete waste (CW) as a cement replacement material by assessing mechanical and durability performance.

2.1 Concrete Waste

Concrete waste obtained from a demolition site was first crushed in a jaw crusher with a 1 mm gap and then ground in a ball mill. The waste was obtained through selective demolition and consisted solely of concrete, without any impurities such as brick, gypsum, or other constituents. Previous studies revealed that the optimum grinding time is 60 minutes; otherwise, shorter grinding results in insufficient fineness, while longer grinding causes agglomeration (Zhao et al., 2020) and an increase in particle size. CW was thermally treated in a muffle furnace at temperatures of 750 °C and 950 °C for 2 hours.

2.2 Specimen Preparation and Method

Concrete waste replacement ratios were determined as 20%, 40% and 60%. The water-to-binder ratio was set to 0.6 due to the higher water demand of concrete waste. Although the water-to-binder ratio was kept constant at 0.6 in all mixtures, workability was still sufficient even at the 60% replacement level. This is attributed to the relatively high w/b ratio, which compensated for the increased water demand of CW. The specimens, whose mix proportions are shown in Table 1, were mixed in a laboratory mixer with a 5-liter capacity. The amounts of water and aggregate were 240 g and 1200 g, respectively, and were kept constant for all specimens. When ingredients were placed in the mixer, firstly dry ingredients were mixed for 60 s, then water was added and mixed for 60 s, after that the mortar inside the chamber was turned over manually using a mini shovel and finally, a further 60 seconds of mixing was performed. The produced specimens were cast in 40×40×160 mm prismatic molds and in cubic molds with an edge length of 50 mm, in two layers, each compacted using a 16 mm diameter rod. For each specimen group, six prismatic and three cubic specimens were produced (Figure 1) and placed in a curing environment with 95% relative humidity and a temperature of 23 °C. For each test type, three specimens were evaluated, and the reported values represent the mean results. Standard deviations were calculated and presented as error bars in the corresponding figures. In addition, the coefficient of variation was calculated for each group and found to be within an acceptable range (3–6%), confirming the reliability and reproducibility of the results.

Figure 1. Prismatic and cubic specimens.

Mechanical properties were evaluated on the 7th and 28th days. Flexural strength tests were performed on 40×40×160 mm prismatic specimens, and compressive strength was determined on the remaining halves after flexural testing. F–T resistance was assessed based on mass loss, strength loss, and changes in electrical resistance (ER) after the F–T cycles. The F–T procedure was conducted in accordance with TS EN 12390-9 "Testing hardened concrete – Part 9: Freeze–thaw resistance – Scaling". During testing, specimens were checked daily in the F–T cabinet. On the 10th day, when two specimens cracked and split at mid-span, the F–T process was terminated.

Table 1. Specimen constituents

ID	Cement (gr)	Concrete Waste	
		Amount (gr)	Treatment Temperature (°C)
Ref	400	-	-
C20	320	80	-
C40	240	160	-
C60	160	240	-
C20-750	320	80	750
C40-750	240	160	750
C60-750	160	240	750
C20-950	320	80	950
C40-950	240	160	950
C60-950	160	240	950

Electrical resistance measurements were carried out on 50 mm cubic mortar specimens using a two-electrode method. Before testing, all samples were saturated by immersing them in water for 24 hours, followed by gently wiping the surface with a damp cloth. Measurements were taken at room temperature after the

F–T cycles, both on reference specimens and those subjected to F–T. While mass and strength losses were evaluated using prismatic specimens, ER changes were determined on the cubic ones. The F–T-exposed samples were compared to specimens cured under identical conditions until the end of the F–T period. An image of the electrical resistance measurement setup is presented in Figure 2.

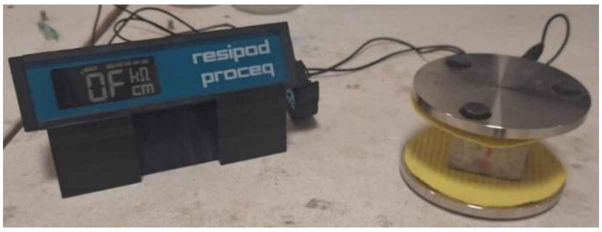

Figure 2. Image of the electrical resistance measurement setup.

3. Results and Discussion

3.1 Compressive and flexural strength

Flexural and compressive strength results at 7 and 28 days are presented in Figure 3. Since the C60 and C60-750 specimens failed easily without any measurable flexural strength on the bending device, their flexural strength values are reported as zero. Considering the flexural strength results, specimens with non-calcined concrete waste (C20, C40, and C60) exhibit lower flexural strengths compared to the reference specimen. However, when the concrete waste was calcined, an improvement in mechanical properties was observed. For instance, C20-750 exhibited flexural strengths of 4.6 and 7.1 MPa at 7 and 28 days, respectively, whereas C20 showed 4.3 and 6.3 MPa. C20-950 exhibited a similar performance in terms of flexural strength, with values of 4.9 and 5.2 MPa. At a 40% replacement ratio, a calcination temperature of 750 °C provided better performance than non-calcined CW, with C40-750 showing flexural strengths of 4.0 and 6.3 MPa at 7 and 28 days—higher than those of C40 (3.6 and 5.0 MPa). However, further increasing the calcination temperature resulted in a decrease in flexural strength for specimens containing 40% calcined CW.

Compressive strength results clearly reveal the effects of CW replacement level and calcination temperature. Non-calcined CW caused a reduction in compressive strength compared to the reference specimens. Moreover, as the replacement ratio increased, compressive strength further decreased. In contrast, calcined CW led to significant improvements. For example, C20-750 exhibited compressive strengths of 24.7 and 36.6 MPa at 7 and 28 days, respectively. When the calcination temperature increased to 950 °C, compressive strengths further increased to 32.2 and 41.9 MPa—the highest values among all specimens at the 20% replacement ratio.

Regardless of calcination, specimens with 60% CW replacement exhibited the lowest strength values. This is likely due to the high water absorption capacity of CW. As the replacement level increases, so does water demand. CW typically consists of aged aggregates surrounded by a residual cement matrix, which makes its water absorption higher than that of natural aggregates. Another contributing factor to the reduction in mechanical properties at 60% replacement is the dilution effect caused by the reduced cement content (Lothenbach et al., 2008).

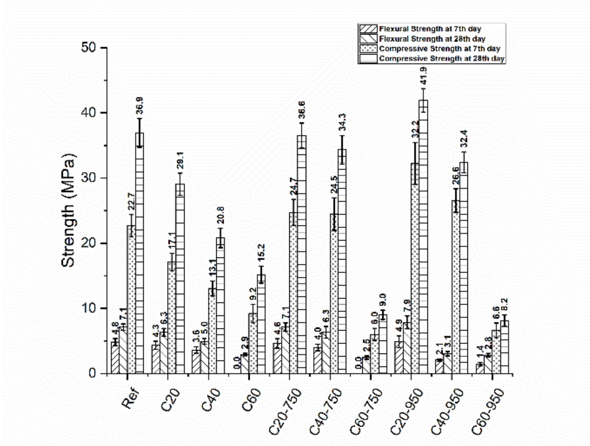

Figure 3. Flexural and compressive strength results at 7 and 28 days.

When considering specimens with 60% calcined CW, an additional factor is the quicklime content. Calcination temperatures above 600 °C lead to the formation of CaO (quicklime), and higher temperatures result in increased quicklime content. Although the water-to-binder ratio was set at 0.6, which is relatively high, hydration of quicklime requires additional water. Therefore, specimens with 60% calcined CW likely suffered from insufficient water for proper hydration of the cementitious matrix. Furthermore, an increased calcium-to-silica ratio may result in highly alkaline calcium silicates with lower strength (Mao and Ai, 2023).

Overall, the results indicate that calcination of CW significantly enhances both flexural and compressive strengths, particularly at lower replacement levels (20%). In contrast, higher replacement levels (60%) consistently lead to reduced mechanical performance, regardless of the calcination temperature. The improvement in mechanical properties with calcined CW can be attributed to the increased pozzolanic reactivity and improved particle packing after thermal treatment. However, excessive replacement ratios result in higher water demand and reduced binder content, leading to strength reductions.

3.2 Electrical resistance and mass changes

Electrical resistance results are presented in Figure 4. The results are expressed in kΩ·cm to normalize for specimen geometry and dimensions. Considering the electrical resistance (ER) results before the F–T procedure, the specimens generally exhibited lower resistance as their mechanical strength decreased. For example, while the Ref specimen showed 43.7 kΩ·cm, the

C20, C40, and C60 specimens exhibited 38.6, 37.2, and 35.2 kΩ·cm, respectively —consistent with the decreasing strength trend. This is attributed to the fact that lower strength is typically associated with higher pore volume (Cosoli et al., 2020). One of the main reasons for the parallel trend between strength and ER is that a porous structure negatively impacts both. The presence of interconnected pores facilitates water conductivity, thereby reducing both strength and electrical resistance. However, ER is not only influenced by the pore structure but also by factors such as mineral admixtures, water-to-cement ratio, moisture content, and aggregate type (Mathew and Vishnudas, 2025). Among the C20-750, C40-750, and C60-750 specimens, C60-750—despite its very low strength—exhibited the highest ER values. This is attributed to the filler effect of CW, which becomes dominant at such high replacement levels. Although 60% CW is unlikely to contribute significantly through pozzolanic activity, it may reduce total pore volume and clog the interconnected pore structure, thereby increasing ER (Cosoli et al., 2020). This finding indicates that electrical resistance is not solely governed by mechanical strength. In the case of C60-750, the relatively fine calcined CW particles likely acted as a filler, partially blocking interconnected pores and reducing ion mobility. As a result, even though the cementitious matrix was mechanically weak, the reduced pore connectivity contributed to higher electrical resistance values. A similar pattern is observed in the ER results of C20-950, C40-950, and C60-950, where C40-950 shows higher ER than C20-950, even though it has lower strength. In this case, the 40% CW likely acted as a filler material that blocked capillary pores and increased ER. However, C60-950 exhibited the lowest ER value among all calcined CW specimens. During mixing, CW calcined at 950 °C released a significant amount of heat, and C60-950 specimens experienced extensive cracking as a result. These cracks disrupted the matrix continuity and negated the filler effect, causing a drastic reduction in ER.

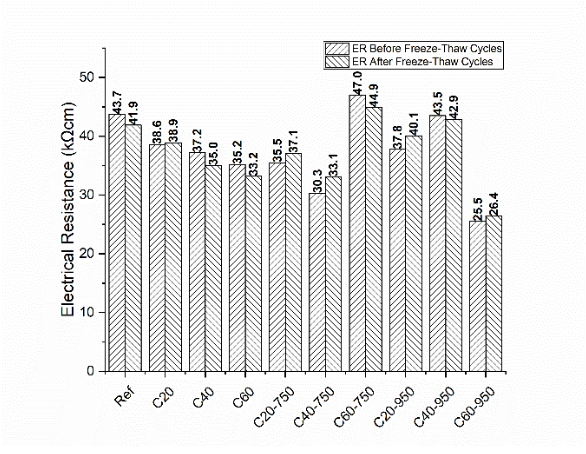

Figure 4. Electrical resistance results of specimens before and after freeze-thaw cycles.

In general, ER after F–T exposure showed a decreasing trend with decreasing compressive strength, in line with increased microcracking and enhanced pore connectivity. However, some exceptions were observed in the C20, C20-750, C40-750, C20-950, and C60-950 specimens. This behavior may be explained by the filler effect of calcined CW, which may have contributed to clogging interconnected pores or reducing effective ionic pathways. Additionally, partially saturated cracks formed during F–T cycling could have altered ER measurement results. Similar trends and anomalies have been reported in the literature (Chen et al., 2023), indicating that ER behavior post–F–T is not solely determined by mechanical deterioration, but also by changes in pore structure and moisture distribution. Furthermore, Dvoynikov et al. (2026) noted that temperature fluctuations can cause water evaporation, which may lead to inverse effects on electrical resistivity (ER), occasionally leading to increased ER values after F–T cycles.

Figure 5 presents the average mass changes of the specimens after F–T cycles. While the Ref specimen had a mass loss of 0.66%, both C20 and C40 showed nearly identical losses of 0.67%. However, when the replacement ratio increased to 60%, the C60 specimen exhibited a mass loss of 1.06%. Similarly, specimens incorporating calcined CW showed a comparable pattern: C60-750 and C60-950 had mass losses of 0.92% and 1.65%, respectively, representing the highest mass losses among the specimens treated at 750 °C and 950 °C, respectively. This can be attributed to the use of 60% CW, which results in a more permeable structure with a reduced volume of hydrated cement matrix, leading to lower durability under F–T conditions. In contrast, C20-950, which achieved the highest strength among all specimens, exhibited the lowest mass loss (0.57%). As expected, increased mechanical performance generally translates into enhanced F–T durability (Atasham ul Haq et al., 2025). Although C20-950 was the only specimen that outperformed the Ref specimen in terms of mass loss, other specimens such as C20, C40, C20-750, and C40-750 also exhibited values close to that of the Ref specimen (0.67%, 0.67%, 0.71%, and 0.69%, respectively). Whether calcined or not, a 20% CW replacement appears to offer favorable F–T durability in terms of mass loss.

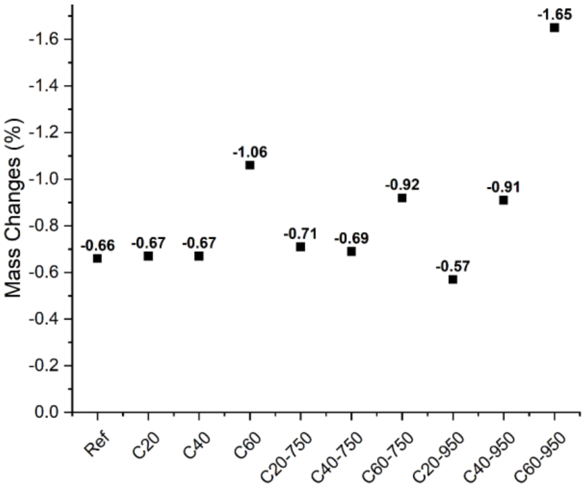

Figure 5. Mean mass changes of specimens after freeze-thaw cycles.

3.3 Flexural and compressive strength losses

After a 28-day curing period, the specimens were subjected to 10 freeze–thaw (F–T) cycles, and then tested to determine their flexural and compressive strengths, as well as to evaluate the corresponding strength losses. Flexural and compressive strength results, along with percentage losses, are presented in Figure 6. Damage caused by freeze–thaw exposure is primarily governed by two factors. First, the specimen must have sufficient tensile strength to resist the internal pressure from water freezing within capillary pores. Second, the pore structure plays a crucial role in determining F–T resistance. Generally, as a specimen's strength and compactness increase, so does its resistance to F–T damage. However, in some cases, specimens with a high volume of capillary pores—and consequently lower strength—may exhibit unexpectedly high F–T resistance due to the availability of pore volume that can accommodate freezing-induced expansion. This phenomenon is evident in the current study. For instance, while the Ref specimen experienced a 45.6% loss in flexural strength, the losses for C20, C40, and C60 were 38.7%, 37.8%, and 30.9%, respectively—demonstrating a decreasing trend in strength loss as initial flexural strength decreases.

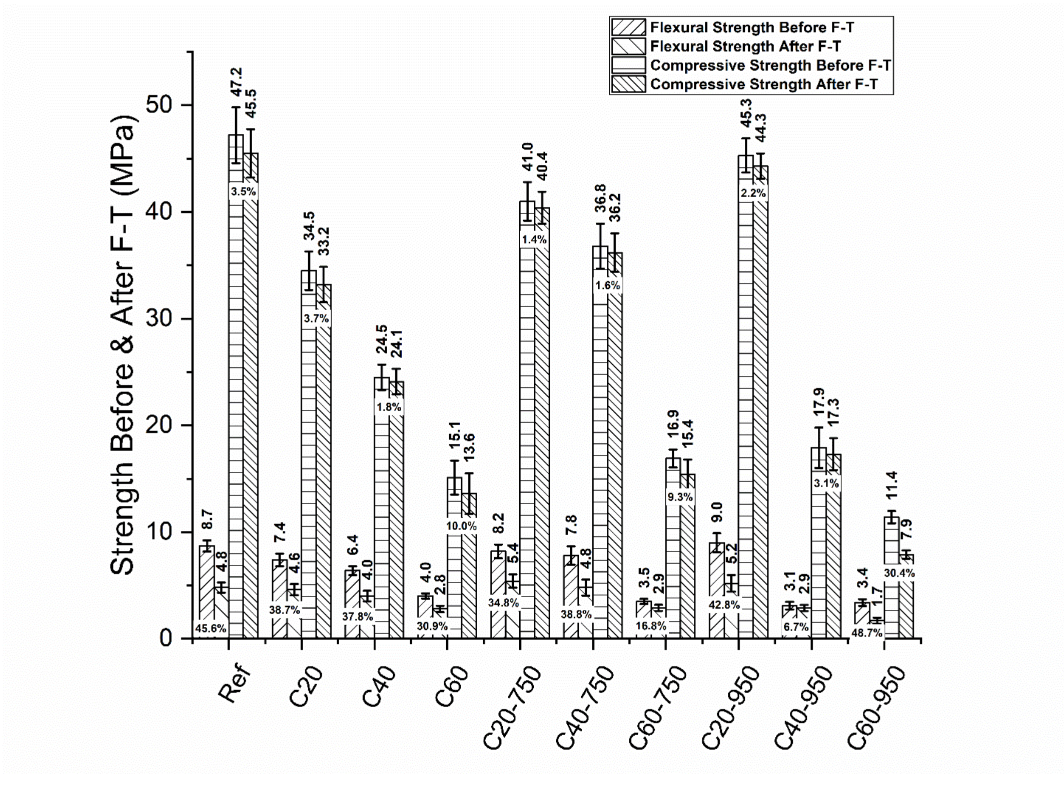

Figure 6. Flexural and compressive strength results and strength losses of specimens.

On the other hand, compressive strength was less affected by F–T cycles. The Ref specimen showed a compressive strength loss of only 3.5%, and C20 exhibited a similar loss of 3.7%. C40 had the lowest loss at 1.8%. However, when the replacement ratio increased to 60%, the compressive strength loss rose to 10.0% in C60. A similar increase in strength loss was observed in specimens with 60% calcined concrete waste (CW), especially at higher replacement levels. This trend is attributed to the more permeable structure of high-CW specimens, particularly when calcined. Calcined CW contains CaO (quicklime), which hydrates during mixing. This exothermic reaction consumes water and releases heat, accelerating water loss and leading to the formation of voids within the cement matrix. Moreover, the reduced cement content in these mixtures results in a dilution effect, further weakening the matrix. Interestingly, the C60 specimen exhibited a lower flexural strength loss (30.9%) than the Ref specimen (45.6%), indicating better resistance to surface cracking under F–T conditions. However, its significantly higher compressive strength loss (10.0%) suggests internal structural degradation. This seemingly contradictory behavior can be explained by the different failure mechanisms associated with flexural and compressive strength. While flexural strength is more sensitive to surface-level microcracking—and may benefit from increased pore volume that buffers internal pressure—compressive strength is largely dependent on the integrity and compactness of the bulk matrix. Indeed, previous studies have shown that flexural strength tends to be more vulnerable to F–T degradation than compressive strength (Solatiyan et al., 2015). High replacement levels of cement with calcined CW result in fewer hydration products, reducing the internal load-bearing capacity. Additionally, the hydration of residual CaO creates localized voids due to rapid water consumption and heat generation, further contributing to compressive strength loss. Therefore, the improved flexural performance observed in high-CW specimens does not necessarily imply enhanced overall durability or structural performance under F–T exposure.

4. Conclusion

This study investigated the use of calcined and non-calcined concrete waste (CW) as a pozzolanic material in cementitious mortars. Based on the findings, the following conclusions can be drawn:

- A limited amount of CW can be effectively used as a cement replacement material, provided that the performance of the binder system is adequately controlled.
- Calcination significantly increases the reactivity of CW, leading to improved mechanical performance in mortars incorporating calcined CW.
- A 20% replacement level of calcined CW was identified as the optimum ratio, resulting in higher mechanical strength than both the reference and non-calcined CW specimens.
- Excessive use of calcined CW (e.g., 60%) led to substantial reductions in mechanical strength due to increased water demand, the dilution effect, and internal void formation caused by quicklime hydration.
- In terms of durability, incorporating 20% calcined CW enhanced freeze–thaw resistance, while 40% could still be considered acceptable with moderate mass loss and ER degradation.
- Electrical resistance results highlighted the filler effect of CW, especially at higher replacement levels, contributing to reduced pore connectivity and increased microstructural resistance in some cases.

In practical terms, the calcination of CW requires additional energy input. However, this demand can be significantly reduced by integrating the process with existing high-temperature industrial operations. For example, waste heat from cement kilns, steel plants, or other thermal processes could be utilized for CW calcination. Such strategies would minimize the environmental and economic costs while enhancing the industrial feasibility of using calcined CW as a sustainable cement replacement material.

Based on these results, it is recommended that future studies consider adjusting the water-to-cement (or water-to-binder) ratio to account for the presence of reactive CaO in calcined CW. Furthermore, optimizing curing regimes and investigating long-term durability under different environmental exposures would provide valuable insights for the broader application of CW in sustainable construction materials. These findings support the feasibility of incorporating thermally treated concrete waste into binder systems, offering a promising approach for both resource conservation and improved material performance.

In addition, extended durability tests such as sulfate resistance, chloride penetration, or carbonation should be considered in future studies to provide a more comprehensive understanding of the long-term performance of mortars incorporating calcined CW.

Author Contributions

The percentages of the author contributions are presented below. The author reviewed and approved the final version of the manuscript.

	H.U.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

References

Atasham ul Haq M, Wang P, Wang Y, Cui H, Tahir M, Gong F, Li W. 2025. Optimization and utilization of air-entrained recycled brick aggregate concrete under freeze-thaw environment. Case Stud Constr Mater, 23: e04941.

Chen H, Xu N, Jiang P, Jiang L. 2023. Study on the effect of freeze–thaw action on the electrical conductivity and sensing properties of graphene-based cement composites. Materials (Basel), 16(2): 855.

Cosoli G, Mobili A, Tittarelli F, Revel G, Chiariotti P. 2020. Electrical resistivity and electrical impedance measurement in mortar and concrete elements: a systematic review. Appl Sci (Basel), 10(24): 1-43.

Dvoynikov MV, Kopteva AI, Romanova NA, Yurtaev SL, Gromov DA. 2026. Influence of thermal cycling on cement sheath integrity in permafrost conditions. Int J Eng, 39(1): 148-158.

Kim J, Ubysz A. 2024. Thermal activation of multi-recycled concrete powder as supplementary cementitious material for repeated and waste-free recycling. J Build Eng, 98: 111169.

Lothenbach B, Le Saout G, Gallucci E, Scrivener K. 2008. Influence of limestone on the hydration of Portland cements. Cem Concr Res, 38(6): 848-860.

Maaze MR, Shrivastava S. 2023. Development of framework in the selection and reuse of concrete waste and brick waste powder as pozzolanic material in cement concrete application using analytical hierarchy process technique. Constr Build Mater, 393: 132056.

Mao F, Ai H. 2023. A study on the hydrothermal synthesis of calcium silicate products by calcination of full-component waste concrete. Sustainability (Basel), 15(23): 16341.

Mathew J, Vishnudas S. 2025. Application of adaptive neuro fuzzy inference system for contemplating the factors affecting electrical resistivity of concrete. Innov Infrastruct Solut, 10(4): 141.

Neupane K. 2022. Evaluation of environmental sustainability of one-part geopolymer binder concrete. Clean Mater, 6(2): 100138.

Sari B, Geyik ŞY, Keskinkan O. 2020. Çimento üretim sektöründe ISO 14001 çevre yönetim sisteminin enerji kazanımı ve iklim değişikliği üzerine etkilerinin incelenmesi. Cukurova Univ J Fac Eng Archit, 35(4): 847-858.

Solatiyan E, Asadi M, Bozorgmehrasl M. 2015. Investigating the effect of freeze-thaw cycles on strength properties of concrete pavements in cold climates. Indian J Fundam Appl Life Sci, 5(S2): 2421-2428.

Wu H, Xu J, Yang D, Ma Z. 2021. Utilizing thermal activation treatment to improve the properties of waste cementitious powder and its newmade cementitious materials. J Clean Prod, 322: 129074.

Xu J, Kang A, Wu Z, Gong Y, Xiao P. 2021. The effect of mechanical-thermal synergistic activation on the mechanical properties and microstructure of recycled powder geopolymer. J Clean Prod, 327: 129477.

Zhang D, Zhang S, Huang B, Yang Q, Li J. 2022. Comparison of mechanical, chemical, and thermal activation methods on the utilisation of recycled concrete powder from construction and demolition waste. J Build Eng, 61: 105295.

Zhao Y, Gao J, Liu C, Chen X, Xu Z. 2020. The particle-size effect of waste clay brick powder on its pozzolanic activity and properties of blended cement. J Clean Prod, 242: 118521.