



Research Article

Utilization of expired cement and aged roof tile powder in the production of sustainable geopolymer: Mechanical and physical properties

Serdal Ünal^a , Mehmet Canbaz^{a,*} 

^a Department of Civil Engineering, Eskişehir Osmangazi University, 26480 Eskişehir, Türkiye

ABSTRACT

This study deals with the production of geopolymer mortar in order to promote the recycling of waste materials as sustainable building materials. The use of waste materials such as expired cement and aged roof tiles powders in cementitious systems is of great importance in terms of increasing environmental sustainability and reducing industrial waste. Recycling these materials and using them as alternative binders contributes to more environmentally friendly and economical concrete and mortar production by reducing natural resource consumption. Expired cement and aged roof tile powder were used as binder materials and mortar specimens were produced by activating these materials with alkalis such as NaOH and Na₂SiO₃ at different ratios. Within the scope of the experimental studies, mechanical and physical properties such as unit weight, ultrasonic pulse velocity, compressive strength and bending strength were investigated in detail. The results showed that the expired cement specimens performed better especially in unit weight, ultrasonic pulse velocity and compressive strength tests, while the roof tile powder had superior properties in terms of bending strength. It was also found that the specimens activated with sodium hydroxide (NaOH) exhibited generally higher strength and performance than those activated with sodium silicate (Na₂SiO₃). These findings prove that waste materials such as both expired cement and roof tile powder can be valuable alternatives in the construction industry in terms of sustainability and waste management and reveal the potential of using these materials in geopolymer mortar production.

Citation: Ünal S, Canbaz M (2025). Utilization of expired cement and aged roof tile powder in the production of sustainable geopolymer: Mechanical and physical properties. *Challenge Journal of Structural Mechanics*, 11(2), 82–88.

ARTICLE INFO

Article history:

Received – January 17, 2025
Revision requested – February 14, 2025
Revision received – February 28, 2025
Accepted – March 3, 2025

Keywords:

Geopolymer
Expired cement
Aged roof tile powder
Alkali activation



This is an open access article distributed under the CC BY licence.

© 2025 by the Authors.

1. Introduction

Today, rapid urbanisation and industrialisation are increasing the consumption of natural resources and leading to the generation of large amounts of waste. The rapid expansion of the construction sector driven by population growth has presented humankind with unprecedented challenges, primarily due to the significant increase in waste production (Bulut 2024; Şamdan et al. 2024; Shaheen et al. 2024). The recycling and reuse of waste materials is of great importance, both in terms of

reducing pollution and conserving natural resources. This approach also plays a crucial role in the building materials industry for a sustainable future (Marrucci et al. 2025). Carbon emissions and energy consumption caused by cement production are among the most important issues in terms of environmental sustainability (Wuyts et al. 2025). The release of greenhouse gases, such as carbon dioxide, contributes to global warming—a major environmental issue that exacerbates disposal problems (Güney and Yıldız 2024). Therefore, the use of waste materials as alternative building materials sup-

* Corresponding author. Tel.: +90-222-239-3750 ; E-mail address: mcanbaz@ogu.edu.tr (M. Canbaz)

Nomenclature

σ_b	Bending strength
σ_c	Compressive strength
A	Area
b	Length
h	Height
l	Distance between supports
M	Mass
P	Load
UPV	Ultrasonic pulse velocity
UW	Unit weight
V	Volume

ports the goals of the circular economy by providing both environmental and economic benefits (Farshadfar et al. 2025). In addition, the use of waste components in building materials not only reduces environmental impact, but also supports economic sustainability by reducing material costs (Menegaki and Damigos 2018). Cement production in particular is a significant contributor to global greenhouse gas emissions due to high energy consumption and carbon emissions, and the use of alternative binding materials has the potential to minimize these negative impacts (Kajaste and Hurme 2016). In addition, the integration of waste materials into the construction sector promotes the use of industrial waste by providing innovative solutions to waste management problems (Ghaffar et al. 2020). Recent studies show that geopolymers and other alternative binder systems have a lower carbon footprint compared to conventional cement and provide adequate strength properties (Neupane 2022; Singh and Middendorf 2020). Such innovative approaches are becoming increasingly important in both academic research and industrial applications in the development of sustainable building materials.

Geopolymer mortars and concretes have become an important area of research in recent years as environmentally friendly and sustainable building materials. Developed as an alternative to traditional Portland cement, these materials have the potential to reduce natural resource consumption and carbon footprint (Chen et al. 2025). Geopolymer materials consist of silica and aluminium containing materials activated by alkaline acti-

vators and are characterised by high mechanical strength, low water permeability and chemical resistance. These properties enable geopolymers to find a wide range of applications in the construction industry (Bulińska et al. 2025). However, the type of binders and activation methods used in the production of geopolymers play a critical role in the performance of the final product (Milad 2025). Geopolymer mortar is a sustainable alternative to conventional cement, offering durability and resistance to chemical attack. It has practical applications in infrastructure rehabilitation, precast elements, fire-resistant coatings, and 3D printing. However, challenges related to scalability, long-term performance, and standardization must be addressed for widespread adoption. Future research in this area will focus on optimising production methods, improving durability and developing regulatory frameworks for successful implementation.

This study investigated the potential of using expired cement and aged roof tile powder as binders in the production of geopolymer mortars. Specimens of expired cement and aged roof tile are shown in Fig. 1. The mechanical and physical properties of mortar specimens activated with alkalis such as NaOH and Na₂SiO₃ at different ratios were tested. The originality of this study stems from its comprehensive evaluation of the potential of using expired cement and aged tile powder as alternative binders in geopolymer mortar production. While materials such as fly ash, blast-furnace slag, and metakaolin have generally been investigated as geopolymer binders in the literature, this study analyzed in detail the effect of recyclable materials such as waste cement and tile powder on geopolymer performance. In this respect, the research provides a new perspective in the field of sustainable building materials. As a result of the experimental studies, it was observed that the use of old cement and tile powder significantly affected the strength properties of geopolymer mortars. Our study contributes to the use of more sustainable materials in the construction industry by revealing the recycling potential of waste materials such as expired cement and tile powder. In particular, the improvement in performance of the NaOH activated specimens highlights the effectiveness of this method. The results obtained are an important step towards the sustainable use of waste materials in the construction sector.



Fig. 1. Expired cement and aged roof tile.

2. Experimental study

2.1. Materials

In this study, expired cement and aged roof tile powder were used as binders and Na_2SiO_3 and NaOH solutions were used as alkali activators in the production of geopolymer mortars. The chemical properties of the materials used are given below.

- Binder: Expired cement and tile powder were used as binders in the study. CEM I 42.5R cement produced by

ÇİMSA (Eskişehir, Türkiye) was used. The mechanical, physical and chemical properties of the cement used are shown in Table 1, while the properties of the waste tiles used in the experiment are given in Table 2.

- Water: Eskişehir city mains water was used in mortar production. The chemical analysis of the water used is given in Table 3.
- Alkalis: NaOH and Na_2SiO_3 were used to activate the waste materials. The chemical properties of the materials used are given in Tables 4 and 5.

Table 1. Properties of cement.

Cement (CEM I 42.5 R)	Specific gravity	Fineness (cm^2/g)	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SO ₃	Na ₂ O	K ₂ O	MgO
			(%)							
	3.11	0-3	63.62	19.23	5.44	3.48	2.17	0.68	0.55	0.88

Table 2. Properties of aged roof tile.

Specific gravity	Density (kg/m^3)	Water absorption (wt%)	Abrasion (Los Angeles) (%)
0.925	1904	11.56	82

Table 3. Properties of water.

Water	pH	SO ₄	Ca	Mg	Cl	Na	K
	(kg/dm^3)						
	7.27	45	21.10	12.20	9.82	8.30	3.00

Table 4. Properties of NaOH .

NaOH	Na ₂ CO ₃	NaCl	Fe
≥98.0	≤0.4	≤0.05	≤0.001

Table 5. Properties of Na_2SiO_3 .

Na ₂ O	SiO ₂	Density (kg/dm^3)	Module
8.57	26.73	1.316	2.87

2.2. Method and tests

In the production phase, the materials that we have defined as waste (expired cement and roof tile powder) were ground in the shaft mill as the first step. After the grinding process was completed, the materials were sieved through a 150 micron sieve. In the production of geopolymer mortars, mortars were produced with only NaOH as alkali activator, with $\text{NaOH}/\text{Na}_2\text{SiO}_3$ solution in the ratio of 1:2, and with only Na_2SiO_3 . During the production phase, a 12 M NaOH solution was prepared approximately 26 hours in advance. As the dissolution of NaOH in water is a highly exothermic reaction that releases significant heat, the solution was left to cool to ambient temperature for about 2 hours (İpek and Ekmen

2022). Consequently, the NaOH solution was prepared approximately 2 hours prior to mixing with the Na_2SiO_3 solution. The alkali activator solution was then prepared by combining predetermined amounts of NaOH and Na_2SiO_3 solutions approximately 24 hours before being utilized in the production of geopolymer mortar. The production process began by mixing the binders with the alkali activator solution in a mixing pan for 3 minutes to produce geopolymer paste. Once the paste was formed, sand was gradually added to the mixer, and the mixture was stirred for an additional 3 minutes to complete the mixing process. A flowchart illustrating the entire production sequence, from the initial preparation of the NaOH solution to the completion of the manufacturing process, is shown in Fig. 2.

Mortar specimens produced were tested for unit weight, ultrasonic pulse velocity, bending and compressive strength. Ultrasonic pulse test was used to determine the effect of placement and structural voids that may occur in the geopolymer specimen, unit weight was calculated since weight is important in applications, compression and bending test methods were used to determine the mechanical properties. Unit weight was calculated using equation $UW=M/V$, ultrasonic pulse velocity using equation $UPV=L/T$, compressive strength using equation $\sigma_c=P/A$ and bending strength using equation $\sigma_b=1.5 \cdot (Pl)/(bh^2)$. Fig. 3 shows the equipment and tools used in the experiments.

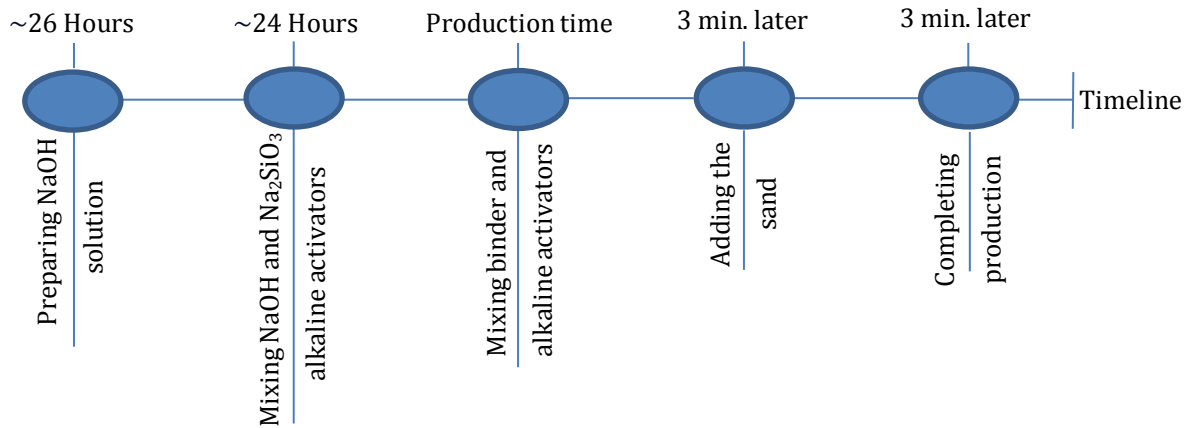


Fig. 2. Timeline of geopolymer mortar production.



Fig. 3. Test equipment to determine physical and mechanical properties.

3. Results and Discussion

3.1. Unit weight analysis

Fig. 4 shows the unit weight analysis results of the specimens containing expired cement and aged roof tile powder binders with different alkali activators. When analysing Fig. 4, it can be seen that the mortar specimens with expired cement binder have higher unit weight values than the specimens with aged roof tile powder binder. This can be explained by the fact that the unit weight of cement is higher than the unit weight of roof tile powder. While the highest density of 1.8 g/cm^3 was obtained from the specimens with expired cement binder, the highest density of 1.52 g/cm^3 was obtained from the specimens with roof tile powder. This may also indicate that there are fewer micro voids in the structures of the specimens with expired cement. When analysed according to the content of alkali activators, mortar specimens containing only Na_2SiO_3 achieved the highest unit weight value in both binder types. In the specimens containing old cement, the unit weight of the specimens containing Na_2SiO_3 was 10% higher than that of the specimens containing NaOH . In the mortar specimens with aged roof tile powder binder, the unit weight of the specimens containing Na_2SiO_3 was 9% higher than the specimens containing NaOH .

3.2. Ultrasonic pulse velocity analysis

Fig. 5 shows the results of the ultrasonic pulse velocity analysis of the specimens containing expired cement and aged roof tile powder binders with different alkali activators. When analysing Fig. 5, the highest ultrasonic pulse velocity of 4.47 km/sec was obtained in the specimens with expired cement binder, while the highest ultrasonic pulse velocity value of 3.73 km/sec was obtained in the aged roof tile powder specimens. It was found that the mortar specimens with expired cement binder had higher ultrasonic pulse velocity values than the aged roof tile powder binder specimens. The expired cement geopolymer mortar specimens have higher unit weight values compared to the aged roof tile powder binder mortars and therefore have fewer voids in their structure. A lower void ratio results in a high ultrasonic pulse velocity. When the alkali activators were analysed according to their content, mortar specimens containing only Na_2SiO_3 reached the highest value of the ultrasonic pulse velocity in both binder types. In the specimens containing expired cement, the unit weight of the specimens containing Na_2SiO_3 was 13% higher than that of the specimens containing NaOH . In the mortar specimens with tile powder binder, the unit weight of the specimens containing Na_2SiO_3 was 14% higher than the specimens containing NaOH .

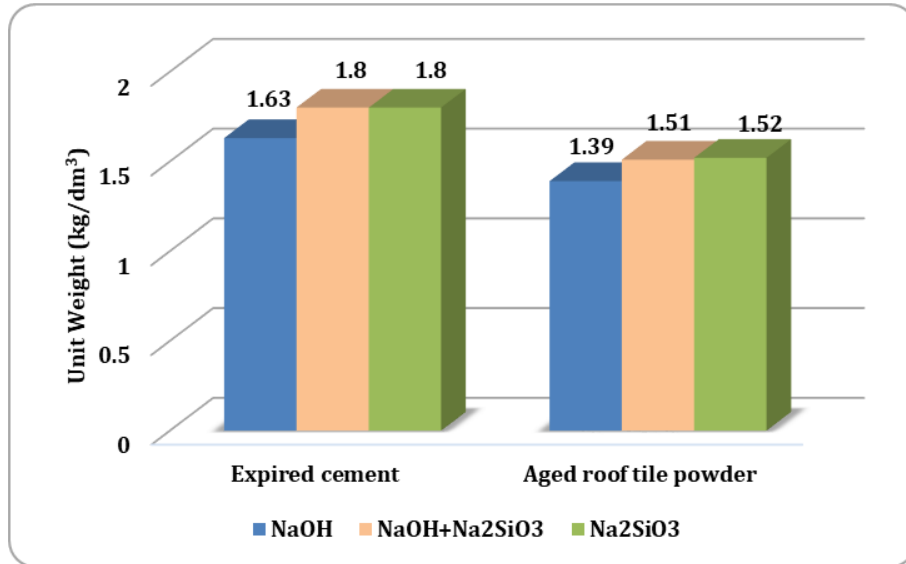


Fig. 4. Unit weight analysis results of the specimens.

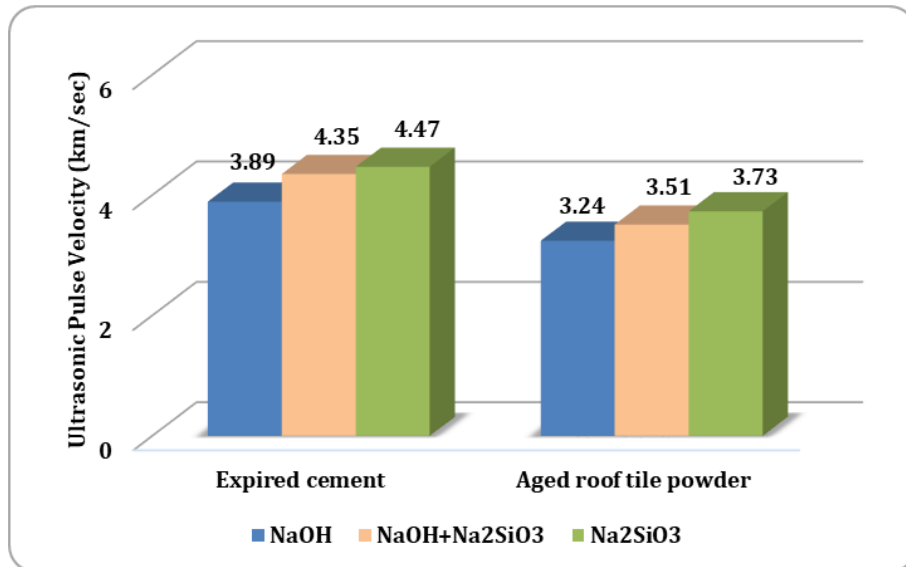


Fig. 5. Ultrasonic pulse velocity analysis result of the specimens.

3.3. Bending strength test

Fig. 6 shows the bending strength test results of the geopolymer mortar specimens. It can be clearly seen from Fig. 6 that the use of expired cement as a binder gives higher bending strength results than the use of tile powder. Similar results have been obtained in the literature depending on the material ratio and production method (Naenudon et al. 2022). The use of Na₂SiO₃ as an alkali activator in expired cement gave 8% higher bending strength results than the use of NaOH. In geopolymer mortar specimens using tile powder as a binder, the use of Na₂SiO₃ resulted in 9% higher bending strength than the use of NaOH.

3.4. Compressive strength test

Fig. 7 shows the compressive strength test results of the geopolymer mortar specimens. In Fig. 7, as with the

bending strength results, it is clearly seen that the use of expired cement as a binder result in higher compressive strengths than the use of roof tile powder. Similar results have been obtained in the literature depending on the material ratio and production method (Mahmoodi et al. 2020, 2021; Usha et al. 2016).

It can be seen that the higher unit weight and filling ratio in the expired cement specimens have a direct effect on the higher compressive strength results. The highest compressive strength value of 18.78 was obtained from the expired cement specimens, while the highest compressive strength value of 14.77 was obtained from the aged roof tile powder specimens. When Na₂SiO₃ was used as an alkali activator in expired cement, the compressive strength results were 9% higher than NaOH. In geopolymer mortar specimens using aged roof tile powder as a binder, the compressive strength was 4% higher when Na₂SiO₃ was used than when NaOH was used.

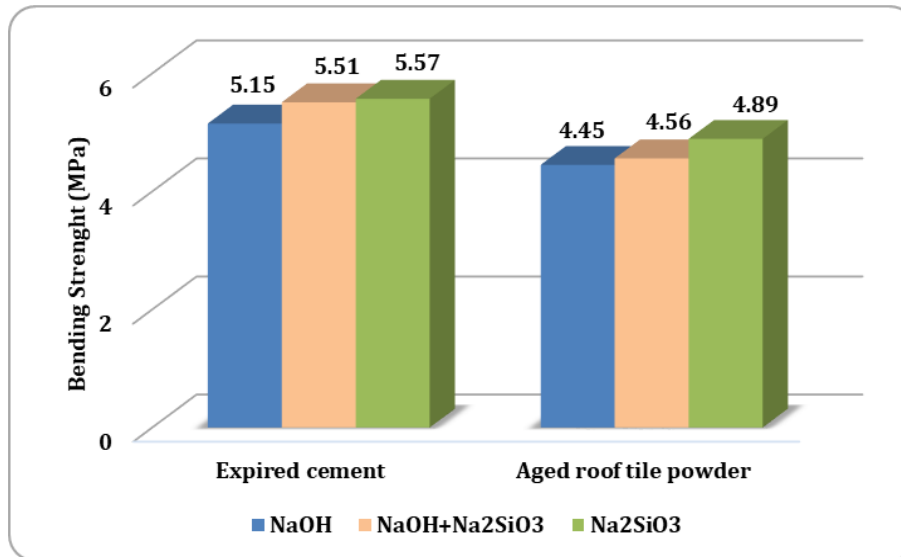


Fig. 6. Bending strength test results of the specimens.

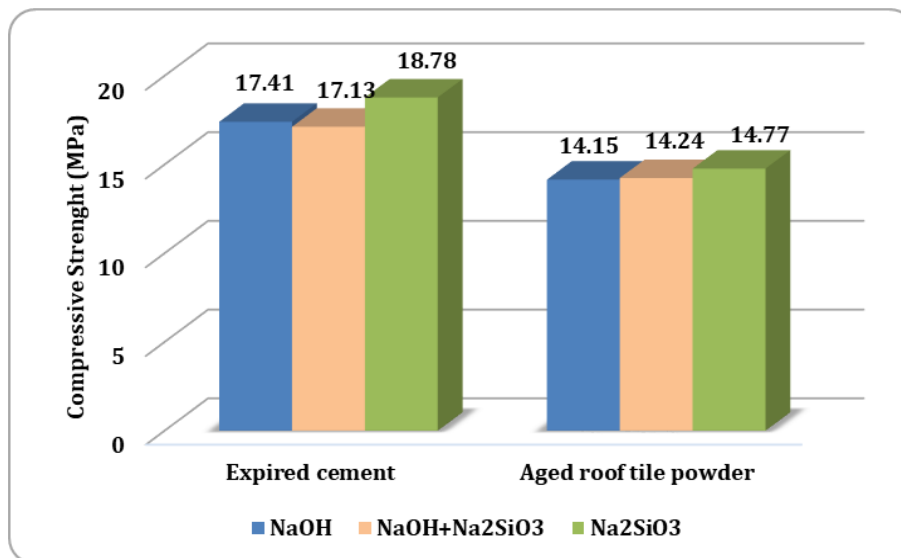


Fig. 7. Compressive strength test results of the specimens.

Recycling expired cement and aged roof tile powder into construction products as geopolymers offers significant environmental and economic benefits. This process reduces natural resource consumption by up to 30% by utilizing waste materials, while increasing environmental sustainability by reducing carbon emissions by up to 60% and energy consumption by 50% compared to cement production. In addition, it provides cost savings of up to 25% in the construction sector with its low raw material cost, while the up to 50% longer life of geopolymer-based building elements reduces maintenance and repair costs. The development of geopolymer technology with such waste materials offers a sustainable alternative in both environmental and economic terms.

4. Conclusions

As a result of the tests and analyses performed on geopolymer mortars containing waste binder, the following results were obtained:

- The geopolymers produced using expired cement had significantly higher unit weight and ultrasonic pulse velocity values compared to the specimens using aged roof tiles powder as a binder. Unit weight of 1.8 g/cm³ and an ultrasonic pulse velocity of 4.47 km/sec have been obtained. These results are particularly important for the use of expired cement in the production of sustainable materials.
- Geopolymers produced using expired cement had significantly higher compressive and bending strength values compared to the specimens using aged roof tiles powder as binder. 18.78 MPa compressive strength value and 5.57 MPa bending strength were obtained. These results showed that geopolymer with high compressive and bending strength can be produced with waste materials.
- The use of Na₂SiO₃ alone as an alkaline activator showed better results in all experiments than the use of NaOH-Na₂SiO₃ and NaOH alone. In general, it was found that high mechanical and physical properties were obtained with the use of these activators.

In this study, it is shown that expired cement and aged roof tile powder can be used effectively in geopolymer mortar production. While it is recommended to use Na_2SiO_3 as an alkali activator, it can be used with waste binder to provide the required mechanical and physical properties. For future studies, it is recommended to investigate the effect of different curing conditions on these materials, develop hybrid binder systems with different waste materials and investigate their long-term durability performance. Thus, more efficient use of recycled binders in geopolymer systems can be achieved.

Acknowledgements

None declared.

Funding

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Author Contributions

All of the authors made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; were involved in drafting the manuscript or revising it critically for important intellectual content; and gave final approval of the version to be published.

Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

REFERENCES

- Bulińska S, Sujak A, Pyzalski M (2025). Sustainable management of photovoltaic waste through recycling and material use in the construction industry. *Materials*, 18(2), 284.
- Bulut HA (2024). A different approach for green concrete production: Determination of the effect of e-waste and waste rubber powder on durability properties of concrete. *Challenge Journal of Concrete Research Letters*, 15(3), 69-81.
- Chen Y, Zou C, Yeo JS, Lin J, Tan TH, Mo KH (2025). Valorization of high-volume crushed waste glass as fine aggregate in foamed geopolymer. *Case Studies in Construction Materials*, e04202.
- Farshadfar Z, Khajavi SH, Mucha T, Tanskanen K (2025). Machine learning-based automated waste sorting in the construction industry: A comparative competitiveness case study. *Waste Management*, 194, 77-87.
- İpek S, Ekmen Ş (2022). Investigation of recycling of building materials as sand in the production of geopolymer mortar. *Adiyaman University Journal of Engineering Sciences*, 9(17), 404-419.
- Ghaffar SH, Burman M, Braimah N (2020). Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. *Journal of Cleaner Production*, 244, 118710.
- Güney B, Yıldız S (2024). Optimization of mechanical properties in lime-based composites using the Taguchi method. *Challenge Journal of Structural Mechanics*, 10(3), 109-115.
- Kajaste R, Hurme M (2016). Cement industry greenhouse gas emissions—management options and abatement cost. *Journal of Cleaner Production*, 112, 4041-4052.
- Mahmoodi O, Siad H, Lachemi M, Dadsetan S, Sahmaran M (2020). Development of ceramic tile waste geopolymer binders based on pre-targeted chemical ratios and ambient curing. *Construction and Building Materials*, 258, 120297.
- Mahmoodi O, Siad H, Lachemi M, Dadsetan S, Sahmaran M. (2021). Development of optimized binary ceramic tile and concrete wastes geopolymer binders for in-situ applications. *Journal of Building Engineering*, 43, 102906.
- Marrucci L, Daddi T, Iraldo F (2025). Boosting circular economy solutions in the construction sector using a life cycle assessment. *Journal of Industrial Ecology*, 29(2), 473-485.
- Menegaki M, Damigos D (2018). A review on current situation and challenges of construction and demolition waste management. *Current Opinion in Green and Sustainable Chemistry*, 13, 8-15.
- Milad A (2025). Recycled and upcycled materials in contemporary architecture and civil engineering: Their applications, benefits, and challenges. *Cleaner Waste Systems*, 10, 100203.
- Naenudon S, Vilaivong A, Zaetang Y, Tangchirapat W, Wongs A, Sata V, Chindaprasit P (2022). High flexural strength lightweight fly ash geopolymer mortar containing waste fiber cement. *Case Studies in Construction Materials*, 16, e01121.
- Neupane K (2022). Evaluation of environmental sustainability of one-part geopolymer binder concrete. *Cleaner Materials*, 6, 100138.
- Shaheen YBI, Etman ZA, Mohamed AAF (2024). Structural behavior of ferrocement beams with circular openings. *Challenge Journal of Structural Mechanics*, 10(4), 116-137.
- Singh NB, Middendorf B (2020). Geopolymers as an alternative to Portland cement: An overview. *Construction and Building Materials*, 237, 117455.
- Şamdan F, Çelikyürek İ, Canbaz M (2024). Determination of waste crushed baked clay aggregate concrete with granular composite material preparations. *Challenge Journal of Concrete Research Letters*, 15(4), 112-119.
- Usha S, Nair DG, Vishnudas S (2016). Feasibility study of geopolymer binder from terracotta roof tile waste. *Procedia Technology*, 25, 186-193.
- Wuyts W, Strøm-Andersen N, Khatri S, Eriksen A, Jørgensen PF, Øvergaard A, Nore K (2025). SirkTRE's evolution or circulation?: Diverse pathways of circular systemic solutions for a Net-Zero timber-built environment. In: Kioumarsis, M., Shafei, B. (eds) *The 1st International Conference on Net-Zero Built Environment. NTZR 2024. Lecture Notes in Civil Engineering*, vol 237. Springer, Cham.