EFFECT OF CURING METHOD ON COMPRESSIVE STRENGTH OF MORTAR CONTAINING TIN TAILING AS FINE AGGREGATE REPLACEMENT

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Abstract- Sand mining leads to various environmental issues due to the extensive use of sand in cement mortar production. Concurrently, tin tailing (TT), a mining industry byproduct, accumulate rapidly and contribute to environmental pollution when disposed of in dumping sites. This study explores the sustainable recycling of TT by partially replacing fine aggregates in mortar and examines the influence of curing methods on the compressive strength of TT-incorporated mortar. Mortar specimens with varying TT replacement levels (0–100%) were cured under two conditions: air curing and water curing, and tested at 7, 28, 60, 90, and 180 days. Results demonstrate that water curing significantly improves compressive strength compared to air curing, attributed to enhanced hydration. An optimal TT replacement of 20% was identified, providing the highest strength under both curing regimes, while higher TT contents led to strength reductions due to altered microstructure and moisture behavior. These findings underscore the importance of curing techniques in optimizing the mechanical performance of TT- based mortars and support the environmentally responsible reuse of mining waste, reducing reliance on natural sand and promoting sustainable construction practices.

Keywords- Compressive Strength, Curing Regimes, Mortar, Tin Tailing

1 Introduction

Mortar is one of the oldest and most fundamental construction materials, widely used globally to bind bricks and blocks in various structures. It is composed of fine aggregates, cement, and water, which harden to form a durable composite [1]. The rapid urbanization and infrastructure development in the 21st century have significantly increased the demand for mortar, making it one of the most commonly used cement-based materials in construction [2]. However, the extensive use of mortar has raised environmental concerns, primarily due to the excessive extraction of natural sand, a key ingredient in mortar production. Sand mining can lead to severe ecological issues such as riverbank erosion, habitat destruction, and increased risk to local communities. Consequently, there is an urgent need to identify sustainable alternatives that can reduce reliance on natural sand without compromising the mechanical performance of mortar [3].

Malaysia's Construction Industry Development Board (CIDB) and Public Works Department (PWD) have launched the Malaysian Carbon Reduction and Environmental Sustainability (MyCREST) [4] initiative, which aims to mitigate the environmental impact of the built environment through carbon emission reduction and holistic life cycle management (CIDB, 2020) [4]. One promising approach aligned with these sustainability goals is the incorporation of industrial byproducts as recycled materials in mortar production, which helps conserve natural resources and reduce waste disposal [5], [6] and [7].

Tin tailing is a waste product generated from tin mining activities, is accumulating rapidly and poses environmental pollution risks when disposed of in dumping sites. Utilizing TT as a partial replacement for fine aggregate in mortar can provide a dual benefit: reducing environmental pollution caused by mining waste and minimizing the depletion of natural sand resources. This study investigates the potential of TT as a sustainable alternative fine aggregate in mortar, contributing to eco-friendly construction practices and supporting Malaysia's commitment to environmental sustainability. The curing regime significantly impacts the performance of cement-based materials, including mortar and concrete [8]. Proper curing ensures adequate hydration of cement, which directly influences the development of compressive strength [9] [10].

2 Research Methodology

2.1 Materials and Mortar Mix Proportion

The mortar specimens for this study were formulated using Ordinary Portland Cement (OPC), natural sand, water, and TT as a partial fine aggregate replacement. The ordinary Portland cement, was procured from a local supplier and complies with the specifications outlined in BS EN 197-1 [11] . The fine aggregates were subjected to particle size classification using a sieve shaker, with only particles passing the 1.18 mm sieve and retained on the 150 µm sieve selected for incorporation into the mortar mix to ensure appropriate gradation. Tap water was employed throughout the experimental procedures The TT used in this investigation was collected from a tin mining site located in West Malaysia, serving as a sustainable alternative fine aggregate source. Figure 1 shows the raw materials used in the mortar mix preparation.

Figure 1: Raw materials used

The control mortar mix (TT-0) was formulated using standard materials: cement, water, and sand. For the mortar incorporating TT, five different replacement levels of fine aggregate with TT were prepared, specifically at 20%, 40%, 60%, 80%, and 100%, designated as TT-20, TT-40, TT-60, TT-80, and TT-100, respectively. The water-to-cement ratio was consistently maintained at 0.65 across all mixes. The target compressive strength for these mortar formulations was set at 20 MPa. The detailed proportions are shown in Table 1.

Table 1 Mix Proportion (kg/m^3)

Mixes	Cement (kg)	Water (kg)	Sand (kg)	TT (kg)
TT-0	240	156	600	0
TT-20	240	156	480	120
TT-40	240	156	360	240
TT-60	240	156	240	360
TT-80	240	156	120	480
TT-100	240	156	0	600

2.2 Testing

A compressive strength test was performed to evaluate the maximum load and compressive capacity of the hardened cement mortar. In this study, the test was conducted on mortar cubes following the ASTM C109-21 (2021) standard [12]. A compression testing machine was used to determine the optimum mortar mix design incorporating TT as a partial replacement for sand. Six mortar mixes with varying TT replacement levels, 0% (control), 20%, 40%, 60%, 80%, and 100% were prepared and subjected to both air curing and water curing regimes. A total of 180 cubes, each measuring 50 x 50 x 50 mm, were cast and tested at curing ages of 7, 28, 60, 90, and 180 days, with three specimens per mix at each age. The compressive strength of the mortar cube samples was measured using a compression testing machine, depicted in Figure 2(a). The specimens were carefully placed between the loading plates, as shown in Figure 2(b), and a uniform load at a rate of 140 kg/cm² per minute until failure occurred. The compressive strength was calculated by dividing the failure load by the cross-sectional area of the specimen, formula shown in Equation (1).

$$F_m = \frac{P}{A} \qquad (1)$$

Where,

F_m= compressive strength, (N/mm2)

P = maximum indicated load, (N)

A = surface area of specimen, (mm2)

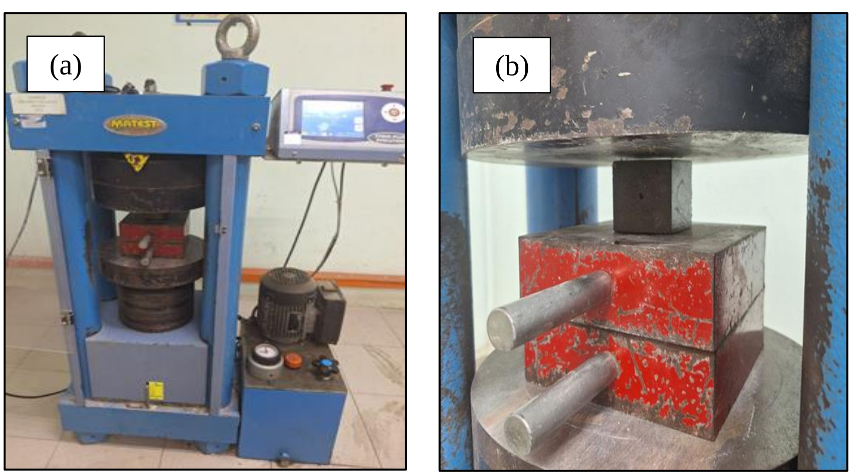

Figure 2: Compressive strength test of mortar cube samples

3 Results

3.1 Compressive strength

The compressive strength results for the control mortar and mortar specimens incorporating TT as a partial fine aggregate replacement at various curing intervals (7, 28, 60, 90, and 180 days) under both water and air curing conditions are presented in Figures 3 and 4, respectively. The mortar mix containing 20% TT subjected to water curing exhibited the highest compressive strength of 30.47 MPa at 28 days (matured period), surpassing the control mix, which recorded 28.33 MPa, as well as all other replacement levels. This trend persisted throughout the entire curing duration. Similarly, air-cured specimens with 20% TT replacement achieved the highest compressive strength of 27.58 MPa at 28 days, outperforming other mixtures. Consistent with findings by Zhao et al. [13], these results indicate a progressive increase in compressive strength with curing age, reflecting ongoing hydration and matrix densification.

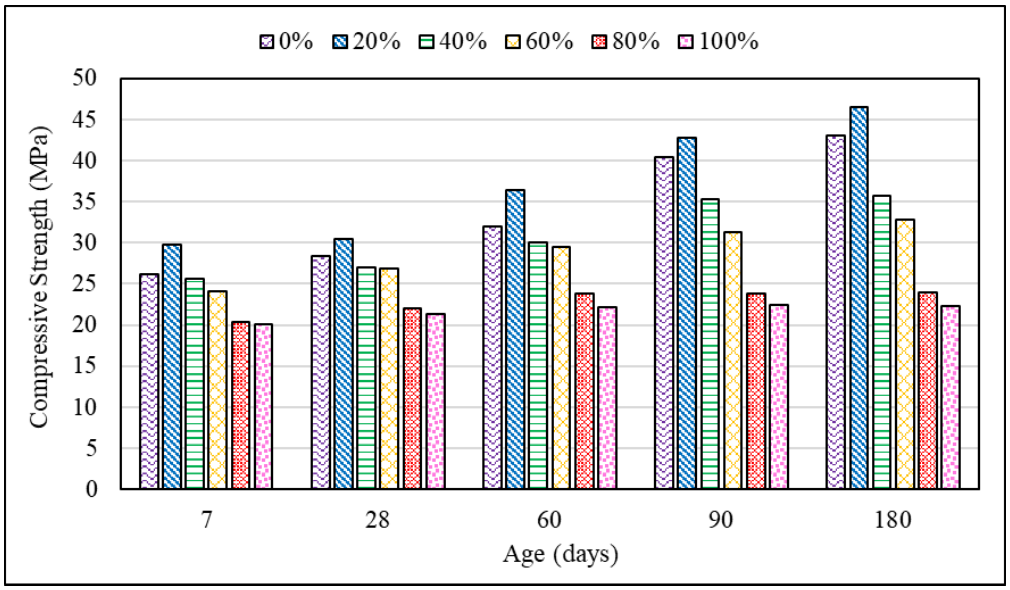

Figure 3: Tin tailing mortar compressive strength result – water curing

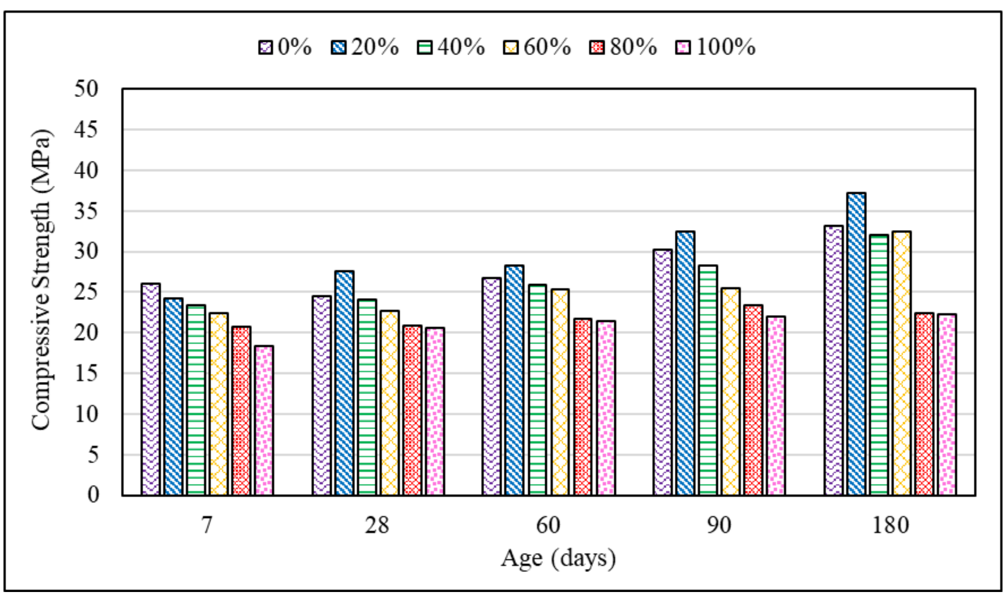

Figure 4: Tin tailing mortar compressive strength result – air curing

The incorporation of TT significantly influences strength development across all mixtures. A 20% TT replacement optimally enhances compressive strength under both water and air curing regimes. This improvement is attributed to increased packing density and reduced void content within the mortar matrix, as supported by Cai [14], and Essam et al. [15] who reported that moderate replacement levels of alternative materials or industrial wastes improve mechanical performance by optimizing particle packing. However, at higher TT replacement levels (40%, 60%, 80%, and 100%), the compressive strength of water-cured specimens at 28 days declined progressively to 27.02 MPa, 26.86 MPa, 22.06 MPa, and 21.30 MPa, respectively. Correspondingly, air-cured specimens with these replacement levels exhibited lower strength values of 24.15 MPa, 22.67 MPa, 20.89 MPa, and 20.61 MPa, respectively, all inferior to their water-cured counterparts. These observations align with previous studies by Hasan et al. [16] and Vo et al [17], which reported that excessive substitution of fine aggregates with waste materials adversely affects mortar strength.

Regarding the effect of curing methods on specimen performance, water-cured samples consistently exhibited superior compressive strength throughout the curing period. Specifically, the 20% TT water-cured mix attained a compressive strength of 46.43 MPa at 180 days, significantly exceeding the 37.21 MPa recorded by the corresponding air-cured specimen. The enhanced strength development under water curing is attributed to the sustained availability of moisture, which facilitates continuous hydration and the formation of calcium silicate hydrate (C-S-H) gel, thereby densifying and strengthening the mortar matrix. In contrast, air curing restricts hydration due to limited moisture availability, resulting in comparatively lower strength gains [18].

3.2 Interaction Between Curing Age and Tin Tailing Percentages on Mortar's Compressive Strength Using Response Surface Methodology (RSM)

The Response Surface Methodology (RSM) was employed to examine the influence of curing time (days) and TT percentage (%) on the compressive strength (MPa) of mortar. Statistical analysis of the model's significance level ($p < 0.05$) confirmed its reliability, while an adjusted R^2 value close to 1 indicated strong model accuracy and predictive capability [19], [20].

3.2.1 Water Curing

The compressive strength of water-cured mortar was accurately predicted using a two-factor interaction (2FI) regression model. The model showed a good fit, confirmed by ANOVA results with an R^2 of 0.9000, a predicted R^2 of 0.8267, and a p-value of 0.0271 as can be seen in Table 2. These statistics indicate a strong relationship between curing time, TT percentage, and compressive strength.

Table 2 P-value and model summary statistic for compressive strength of mortar cured in water

Source	p-value	Std. Dev	R^2	Adjusted R^2	Predicted R^2	remark
Linear	0.0002	3.52	0.8228	0.7874	0.6485	
2FI	0.0271	2.79	0.9	0.8667	0.8267	Suggested
Quadratic	0.1089	2.3	0.9469	0.909	0.7434	
Cubic	0.0943	1.21	0.9937	0.9749	-0.2437	

Figure 5 displays 3D and 2D response surface plots that demonstrate how curing time and TT percentage interact. The 3D plot shows that compressive strength increases with longer curing times but decreases as TT content rises. The 2D contour plots support this, highlighting higher compressive strength in water-cured samples with longer curing and lower TT levels, shown by the red and orange areas.

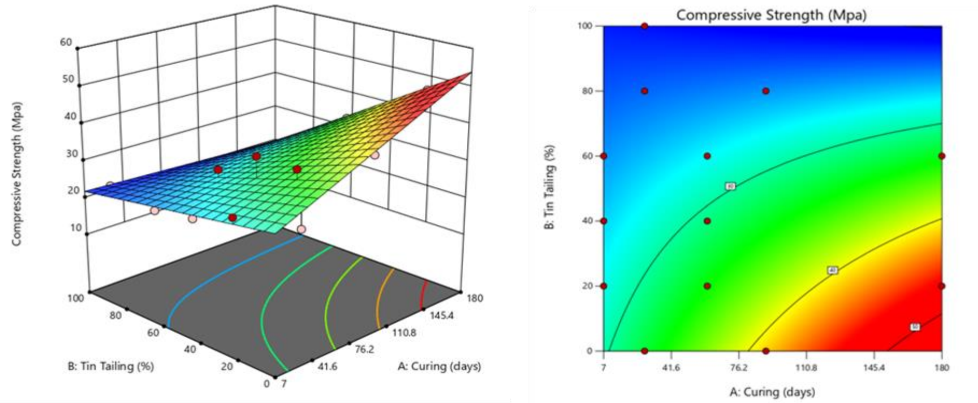

Figure 5:3D and 2D response surface plots of compressive strength indicating effects of curing days and percentage of TT for water curing

3.2.2 Air Curing

The compressive strength of air-cured mortar was modelled using a quadratic regression, which demonstrated a strong fit with an R^2 of 0.9846, a predicted R^2 of 0.9066, and a p-value of 0.0359, as shown in Table 3. These results confirm the significant effect of the studied factors.

Table 3 P-value and model summary statistic for compressive strength of mortar cured in air

Source	**p-value**	**Std. Dev**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**remark**
Linear	< 0.0001	1.26	0.9428	0.9314	0.8906	
2FI	0.0789	1.11	0.9602	0.9469	0.9051	
Quadratic	0.0359	0.7829	0.9846	0.9736	0.9066	Suggested
Cubic	0.0833	0.3936	0.9983	0.9933	0.9199	

Similar to water-cured mortar, air-cured samples showed increased compressive strength with longer curing times, while higher TT content led to reduced strength. However, as illustrated in Figure 7, air-cured mortar generally exhibited lower compressive strength compared to water-cured samples.

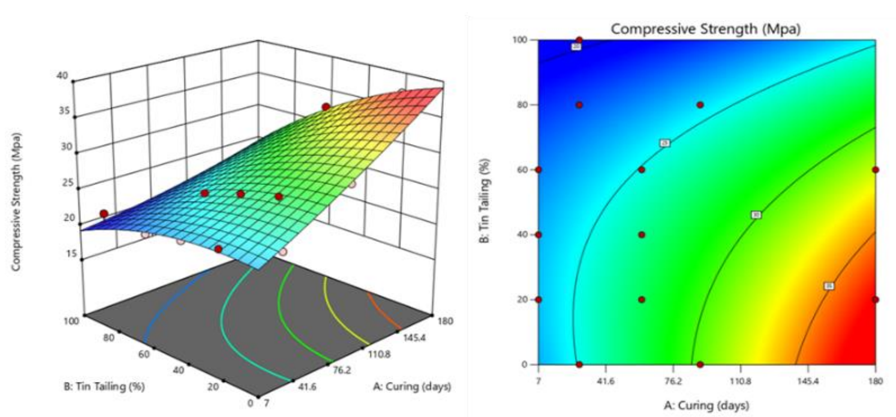

Figure 6: 3D and 2D response surface plots of compressive strength indicating effects of curing days and percentage of TT for air curing

4 Practical Implementation

The findings of this study provide valuable guidance for the practical use of TT as a partial replacement for fine aggregate in mortar, emphasizing the critical role of curing methods on compressive strength development.

5 Conclusion

This study confirms that the curing method significantly affects the compressive strength of mortar when tin tailing (TT) is used as a fine aggregate replacement. Water curing consistently yields higher compressive strength than air curing, attributed to enhanced cement hydration and a more compact microstructure. Notably, a 20% replacement level of TT was identified as optimal, providing substantial improvements in mechanical performance. Additionally, utilizing TT supports sustainable construction by recycling mining waste and reducing the demand for natural river sand, thereby helping to protect river ecosystems and prevent erosion. To further advance the practical application of TT-modified mortar, future research should investigate its long-term durability properties such as shrinkage, creep, and resistance to chemical attack, as well as its behaviour under fire conditions. These efforts will help establish a comprehensive understanding of TT mortar's performance in diverse construction scenarios.

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References

[1] A. Surahyo, *Concrete Construction: Practical Problems and Solutions*. Springer International Publishing, 2019. doi: 10.1007/978-3-030-10510-5.

[2] Biernacki, J. J., Bullard, J. W., Sant, G., Brown, K., Glasser, F. P., Jones, S., & Prater, T., "Cements in the 21 st century: Challenges, perspectives, and opportunities," *Journal of the American Ceramic Society*, vol. 100, no. 7, pp. 2746–2773, Jul. 2017, doi: 10.1111/jace.14948.

[3] M. Singh and R. Siddique, "Effect of coal bottom ash as partial replacement of sand on properties of concrete," *Resour Conserv Recycl*, vol. 72, pp. 20–32, 2013, doi: https://doi.org/10.1016/j.resconrec.2012.12.006.

[4] *CIDB. (2020). MyCREST. Construction Industry Development Board (CIDB).*

[5] B. Manjunath, C. M. Ouellet-Plamondon, B. B. Das, and C. Bhojaraju, "Potential utilization of regional cashew nutshell ash wastes as a cementitious replacement on the performance and environmental impact of eco-friendly mortar," *Journal of Building Engineering*, vol. 66, p. 105941, 2023, doi: https://doi.org/10.1016/j.jobe.2023.105941.

[6] S. Sakir, S. N. Raman, M. Safiuddin, A. B. M. Amrul Kaish, and A. A. Mutalib, "Utilization of by-products and wastes as supplementary cementitious materials in structural mortar for sustainable construction," *Sustainability (Switzerland)*, vol. 12, no. 9, 2020, doi: 10.3390/su12093888.

[7] Z. Zhang, X. Liu, R. Hu, C. Liang, Y. Zhang, and Z. Ma, "Mechanical behavior of sustainable engineered cementitious composites with construction waste powder as binder and sand replacement," *Constr Build Mater*, vol. 404, p. 133185, 2023, doi: https://doi.org/10.1016/j.conbuildmat.2023.133185.

[8] D. Xu, J. Tang, X. Hu, C. Yu. F. Hang, S. Sun, W. Deng and J. Liu, "The influence of curing regimes on hydration, microstructure and compressive strength of ultra-high performance concrete: A review," *Journal of Building Engineering*, vol. 76, p. 107401, Oct. 2023, doi: 10.1016/J.JOBE.2023.107401.

[9] A. I. Muhammad, D. Shashivendra, U. Abhishek, S. I. Umar, S.U. Salihu, Z.I. Idris and A.I Ibrahim, "A Review on the Curing of Concrete using Different Methods," *International Journal of Mechanical and Civil Engineering*, vol. 7, no. 2, pp. 15–25, Sep. 2024, doi: 10.52589/IJMCE-4ENVMZOX.

[10] B. O. Orogbade, E. A. Adetoro, and G. M. Amusan, "The evaluation of the effects of different curing methods on concrete," *Scientia Africana*, vol. 23, no. 3, pp. 115–126, Sep. 2024, doi: 10.4314/sa.v23i3.11.

[11] "BS EN 197-1. (2000). Cement —Part 1: Composition, specifications and conformity criteria for common cements. In British Standard."

[12] ASTM C109, "ASTM C109 / C109M - 20b. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens)," 2020.

[13] Z. Xu, Z. Zhu, Y. Zhao, Z. Guo, G. Chen, C. Liu, J. Gao and X. Chen, "Production of sustainable plastering mortar containing waste clay brick aggregates," *Case Studies in Construction Materials*, vol. 16, p. e01120, 2022, doi: https://doi.org/10.1016/j.cscm.2022.e01120.

[14] Q. X. Xiong, L. yu Tong, Z. Zhang, C. Shi, and Q. feng Liu, "A new analytical method to predict permeability properties of cementitious mortars: The impacts of pore structure evolutions and relative humidity variations," *Cem Concr Compos*, vol. 137, Mar. 2023, doi: 10.1016/j.cemconcomp.2022.104912.

[15] A. Essam, S. A. Mostafa, M. Khan, and A. M. Tahwia, "Modified particle packing approach for optimizing waste marble powder as a cement substitute in high-performance concrete," *Constr Build Mater*, vol. 409, p. 133845, Dec. 2023, doi: 10.1016/j.conbuildmat.2023.133845.

[16] K. Hasan, M. Rahaman, M. Ali, M. Urmi, N. Farisha, M. Islam, T. Nahar and F. Yahaya, "A comprehensive review of the application of waste tire rubber in concrete/mortar as fine aggregate replacement," *Architecture, Structures and Construction*, vol. 4, no. 1, pp. 91–111, Mar. 2024, doi: 10.1007/s44150-023-00102-y.

[17] D.-H. Vo, T.-M. Ngo, N.-L. Phan, K.-D. T. Thi, and T. T. H. Truong, "A Study of Characteristics of the Mortar Produced from Waste Ceramic as a Fine Aggregate Replacement," in *2023 8th International Scientific Conference on Applying New Technology in Green Buildings (ATiGB)*, IEEE, Nov. 2023, pp. 217–220. doi: 10.1109/ATiGB59969.2023.10364478.

[18] Z. Hussain, W. Ansari, M. Akbar, A. Azam, Z. Lin, A. Yosri and W. Shaaban, "Microstructural and mechanical assessment of sulfate-resisting cement concrete over portland cement incorporating sea water and sea sand," *Case Studies in Construction Materials*, vol. 21, Dec. 2024, doi: 10.1016/j.cscm.2024.e03689.

[19] M. I. Ejimofor, I. G. Ezemagu, and M. C. Menkiti, "RSM and ANN-GA modeling of colloidal particles removal from paint wastewater via coagulation method using modified Aguleri montmorillonite clay," *Current Research in Green and Sustainable Chemistry*, vol. 4, Jan. 2021, doi: 10.1016/j.crgsc.2021.100164.

[20] C. Onyutha, "From R-squared to coefficient of model accuracy for assessing "goodness-of-fits"," May 04, 2020. doi: 10.5194/gmd-2020-51.