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Structural Performance of Precast Non-Load Bearing Wall Panels with Recycled Concrete Aggregate and Perlite

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ABSTRACT

The scarcity of natural sand in wall construction poses a significant challenge, prompting a novel solution in this study: wall panels using Recycled Concrete Aggregates (RCA) and perlite. The lack of existing literature on such panels underscores the study's importance. Panels of varying thicknesses (75 mm, 100 mm, and 125 mm) are prepared with a 1:4 concrete mix, with the aggregate portion consisting of 40% sand, 40% RCA, and 20% perlite. For control purposes, additional wall panels are prepared using natural sand as the aggregate. Subsequently, all panels undergo compressive tests to evaluate their structural performance, including crack analysis. Comprehensive analyses, encompassing load, stress, and strain, yield Young's Modulus and Poisson's Ratio. Strain gauges and acoustic emissions enhance data precision. Maximum loads of 936.51 kN are observed on 125 mm panels. Findings reveal variations in compressive strength, with control panels surpassing the proposed ones. Wall panel thickness proves pivotal, influencing both strength and crack visibility. Notably, the 100 mm panel performs optimally, displaying minimal percentage differences in compressive strength compared to the control. This research offers invaluable insights into alternative aggregate-infused wall panels' structural behaviour, enriched by verification through an AE analysis.

Keywords: Recycled concrete aggregates; perlite; wall panels; compressive tests; structural performance

INTRODUCTION

A wall serves various purposes, including dividing spaces for privacy and security, acting as a sound barrier, and providing defence against hazards. This research focuses on precast wall panels, which are concrete panels manufactured using the Industrialised Building System (IBS). IBS reduces accidents and construction time (Rubio-Romero et al. 2014) by completing potentially hazardous tasks in factories, ensuring consistent quality (Rahim et al. 2012).

Despite the benefits of precast walls, their construction relies heavily on natural resources. This study aims to replace natural fine aggregates with Recycled Concrete Aggregate (RCA) and perlite to promote sustainability. However, experimental testing and data analysis are essential to evaluating the structural performance, considering the varying strengths associated with different thickness of wall panels. The use of RCA and perlite was extensively investigated by Md Nor et al. (2024). It was found that the use of these two materials influences the strength of the structure. The study identifies a research gap concerning the impact of RCA on wall panels under Uniformly Distributed Load (UDL) loading. Existing studies lack comprehensive analyses addressing defined research objectives, emphasizing the need for further research.

Acoustic Emission (AE) is a non-destructive testing method that detects real-time structural issues like cracks by capturing stress-induced acoustic signals (Zhang et al. 2022; Noorsuhada 2016). Its advantages include continuous monitoring, early damage detection, and precise localization of issues. AE is effective for assessing concrete wall panels, offering sensitivity to subtle changes, and contributing to enhanced structural performance.

The scarcity of natural fine aggregate (Chung et al. 2023) and the challenges associated with the proposed substitution underscore the urgency for a detailed investigation into potential shortcomings. Justifying these shortcomings is essential to ensure that the sustainable solution aligns with both sustainability goals and structural integrity requirements. The main objectives of the study include analyzing the structural performance of precast wall panels with RCA and perlite under compression tests.

METHODOLOGY

The methodology summary for this research study is illustrated in Figure 1. The study employed a systematic approach to evaluate the characteristics of concrete with varying material compositions. Concrete samples were prepared with different proportions of sand, recycled concrete aggregate (RCA), and perlite. The raw ingredients, including sand, water, ordinary Portland cement (OPC), perlite, and RCA, were carefully prepared to ensure consistent starting conditions. Three wall panel samples were created with varying compositions: a control sample with 100% sand and 0% RCA, a sample with 40% sand, 40% RCA, and 20% perlite, and a sample with 100% sand and 0% perlite. These sample compositions allowed for the assessment of the impact of using RCA and perlite as partial replacements for conventional sand and cement. After the mixing stage, the fresh concrete samples were tested using a flowability test to evaluate their workability and ease of placement. The hardened concrete samples then underwent a curing process, followed by compressive strength testing. Additionally, AE monitoring was conducted, with sensors placed on the wall panel samples to observe their performance during the curing process.

All materials utilized in the study were meticulously prepared with a mixed design ratio of 1:4. This encompassed RCA, natural fine aggregates (sand), perlite, OPC, water, and superplasticizer. The RCA production involved splitting concrete cubes, crushing them into small sizes, and sieving for the desired aggregate. The study used 40% RCA in wall panels, equivalent to 21.115 kg, 28.153 kg, and 35.192 kg for 75 mm, 100 mm, and 125 mm thickness, respectively. Natural fine aggregates (sand) comprised 40% of the total weight in the control panels. Water (63.756 kg) initiated the hydration process in cement, and 20% perlite reduced concrete weight while maintaining strength. OPC (98.09 kg) served as the binding agent, and superplasticizer enhanced workability and strength. Detailed preparation of materials is shown in Table 1.

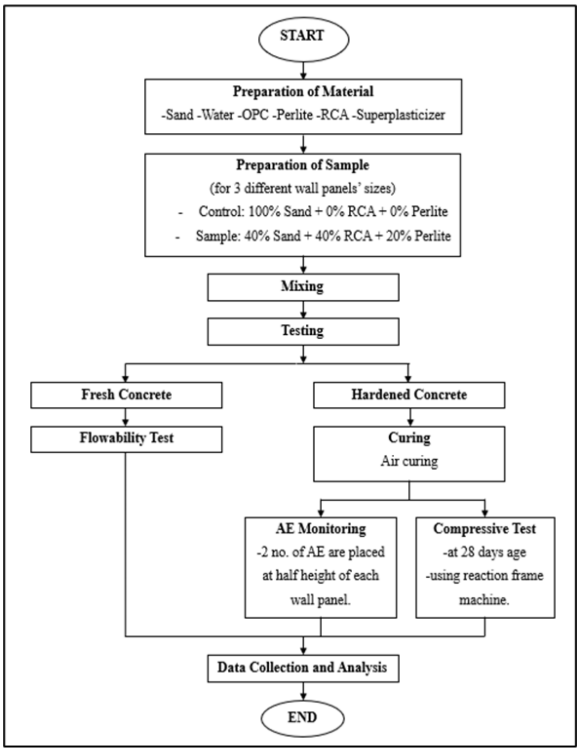

FIGURE 1. Flowchart for Methodology

The materials, which included natural fine aggregate and its substitute, were first mixed in a concrete mixer. Once the aggregates were fully blended, the cement was added to the mixer along with those aggregates. Water and superplasticizer were then added to the mixture to complete it. The superplasticizer was added to the concrete mix with the goal of increasing the fluidity of the concrete without adding more water, increasing the strength of the mortar, and reducing shrinkage and cracking (Li et al. 2023). Promptly following the mixing process, flowability tests were administered to assess the workability of the concrete.

Utilizing the remaining fresh concrete, six wall panels were cast in aluminium formwork. After a 24-hour hardening period, the formwork was removed, paving the way for compressive tests conducted after 28 days of air curing. The deliberate choice of air curing over water curing stemmed from its economic advantages, offering gradual drying that nurtured superior long-term hydration and strength (Naderi et al. 2009). This measured approach minimized surface flaws and cracks, culminating in a denser concrete surface. Furthermore, the extended drying time provided an opportunity for the superplasticizer to uniformly permeate the concrete matrix, potentially elevating long-term durability.

The pre-test setup involved precise measures, including marking midpoints and attaching strain gauges (SG) both laterally and axially as shown in Figure 3 (b). For securing the steel washer at the panel front, two specific positions at each wall panel's midpoint were carefully marked and affixed using 3-second glue for durable adhesion. To aid crack detection during compression tests, a uniform layer of white paint was applied. Two AE sensors were strategically placed at the half height of the wall panels as shown in Figure 3 (a), utilizing Dow Corning high vacuum grease for optimal contact (Farnam et al. 2015), enabling the detection of sound waves during stress or cracking.

The compression tests were executed using reaction frame machines equipped with hydraulic actuators as shown in Figure 2, ensuring a robust evaluation of the compressive strength of the wall panels. A laser is activated at the wall panel's corner for early visual detection of its behavior. Misalignment signals wall deformation. AE signals provided real-time monitoring (Zhang et al. 2022) of panel behavior, enabling the early detection of deformation and crack initiation.

FIGURE 2. Compression test using reaction frame machine.

TABLE 1. Detailed preparation of wall panels

Wall Designation	RCA (kg)	Sand (kg)	Cement (kg)	Perlite (kg)	Water (kg)	Superplasticizer (kg)
S1MP-1	21.115	21.786	12.401	0.671	8.060	0.124
S1CP-1	-	53.235	12.121	-	7.879	0.121
S2MP-1	28.163	29.047	16.535	0.894	10.747	0.166
S2CP-1	-	70.980	16.162	-	10.505	0.162
S3MP-1	35.192	36.310	20.669	1.117	13.434	0.206
S3CP-1	-	88.725	20.202	-	13.131	0.202
Total (kg)	84.470	300.083	98.090	2.682	63.756	0.981

Post-laboratory work, the study progressed to finite element analysis using Abaqus software. The stress-strain graphs from the experimental tests facilitated the derivation of Young's modulus, while lateral strain-axial strain graphs provided the Poisson's ratio (Oliveira et al. 2021). These experimentally obtained values were then inserted into Abaqus for simulation analysis.

Abaqus generated its Young's modulus values, allowing for a comprehensive comparison with the experimentally derived values. This meticulous process of experimental testing, coupled with finite element analysis, provided a holistic evaluation of the structural behavior and performance (Awan & Shaikh 2021) of the precast wall panels. The results not only contribute valuable insights to the understanding of construction materials but also offer a reliable validation of the computational model, ensuring its accuracy in predicting material performance and structural integrity under varying conditions. However, data related to the experimental work were presented in this paper.

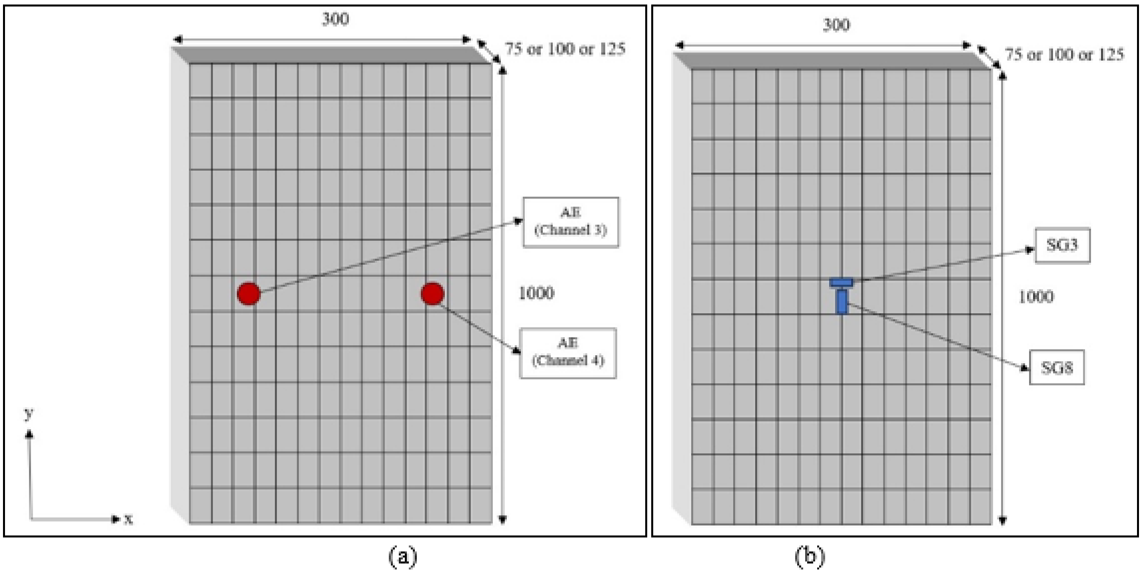

FIGURE 3. Schematic diagram of wall panel: (a) front view; (b) rear view.

RESULTS AND DISCUSSION

COMPRESSIVE STRENGTH

The compressive test results for wall panels as shown in Table 3 reveal several significant findings. Across the samples tested, a notable variation in the applied load is observed, ranging from 432.84 kN to 1051.28 kN. This variation suggests differing levels of structural integrity or load-bearing capacity among the panels under compressive forces. While the area of the panels is not provided for all samples, it remains a crucial factor affecting the calculation of compressive strength, as larger surface areas may distribute load differently, ultimately impacting overall strength. Regarding compressive strength, measurements range from 19.237 MPa to 28.034 MPa, indicating varying abilities of the panels to withstand compression without failure. Moreover, the percentage difference between the control and sample panels, although relatively small in the provided data, sheds light on the effectiveness of novel materials like RCA and perlite. Positive differences suggest improvements in compressive strength compared to the control, while negative differences indicate potential decreases. Overall, these findings hint at the promising potential of utilizing RCA and perlite in wall panel construction, but further research is warranted to validate these initial results and assess long-term durability and sustainability.

CRACK OF WALL PANELS UNDER COMPRESSION TEST

Crack localization in structural elements is crucial for assessing the integrity of materials. The process involves plotting energy graphs on both the x and y axes, with values derived from sound waves detected by AE sensors.

In this study, each wall panel is equipped with two AEs, namely Channel 3 on the left and Channel 4 on the right, both positioned at half the height of the panels. However, examination of the data reveals that S1MP-1, S2CP-1, and S2MP-1 exhibit readings from only one AE as shown in the graphs in Table 3, suggesting malfunction or damage to the other sensor.

Additionally, it can be seen from Figure 3 that S2CP-1, S2MP-1, and S3CP-1 show limited readings compared to other panels, indicating potential detachment of AEs due to cracks at their placement locations. Despite the challenges, the experiment continues, focusing on achieving the highest compressive strength. It is notable that the recorded AE signals, which are supposed to capture real-time data up to 0.5m (Zhang et al. 2022), mostly gather around the middle of the wall panels. This discrepancy may be attributed to the faintness of sound signals associated with cracks occurring at the top or bottom corners of the panels, leading to failure to record the readings accurately.

TABLE 3. Compressive strength of wall panels

	Load (kN)	Area (m^2)	Compressive Strength (MPa)	% difference between control and sample
S1CP-1	544.66	0.0225	24.207	0.205
S1MP-1	432.84		19.237	
S2CP-1	687.96	0.03	22.932	0.007
S2MP-1	682.875		22.763	
S3CP-1	1051.28	0.0375	28.034	0.109
S3MP-1	936.51		24.974	

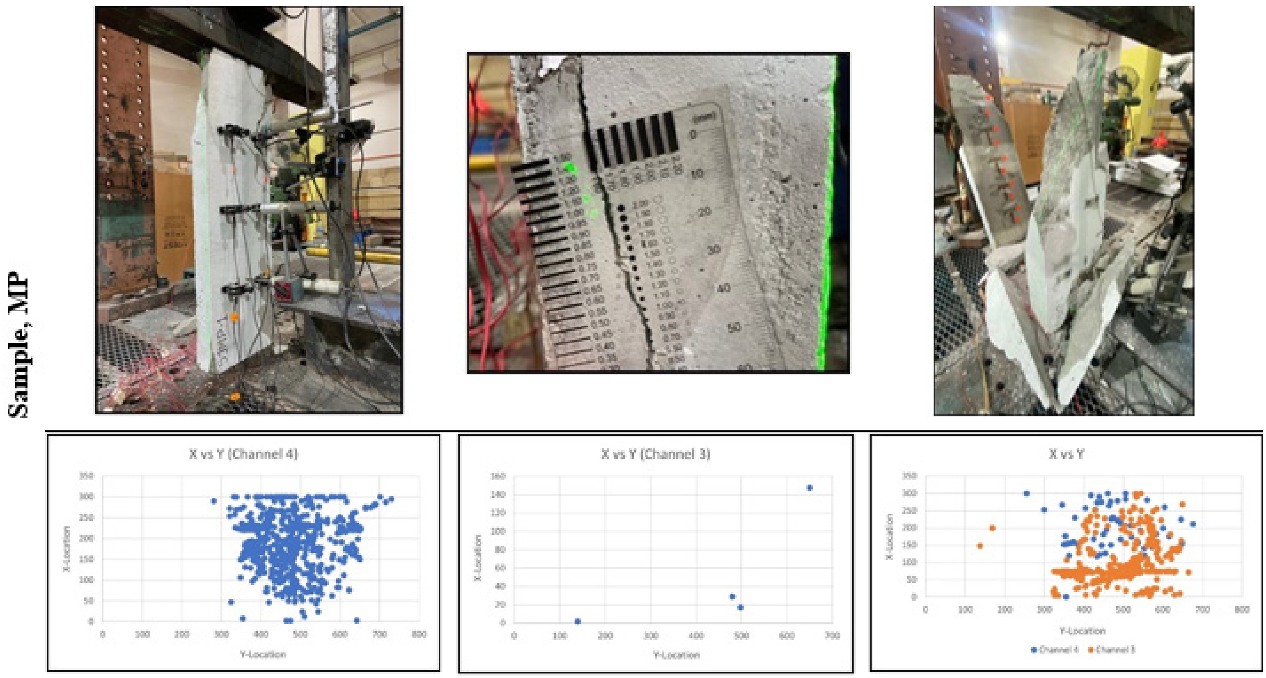

FIGURE 4. Comparison Between Visual Observation and AE Signals

ACOUSTIC EMISSION ANALYSIS

The analysis of cumulative energy versus time graphs for all wall panels reveals a clear correlation between the increasing cumulative energy and the progression of activity within the panels. The growing pattern in cumulative energy clearly signals the development of cracks, contributing to the generation of an acoustic signal (Li et al. 2023). This escalating activity is indicative of the cracks intensifying over time, eventually culminating in the failure of the wall panels at their respective maximum loads. Even in cases where panels exhibit malfunctioning AE with only a few readings, such as S2CP-1, S2MP-1, and S3CP-1, the noticeable increase in cumulative energy supports the idea that cracks are getting bigger. In the case of S3MP-1, even though Channel 3 captures more readings than Channel 4, it remains evident that both channels show a proportional increase in cumulative energy over time.

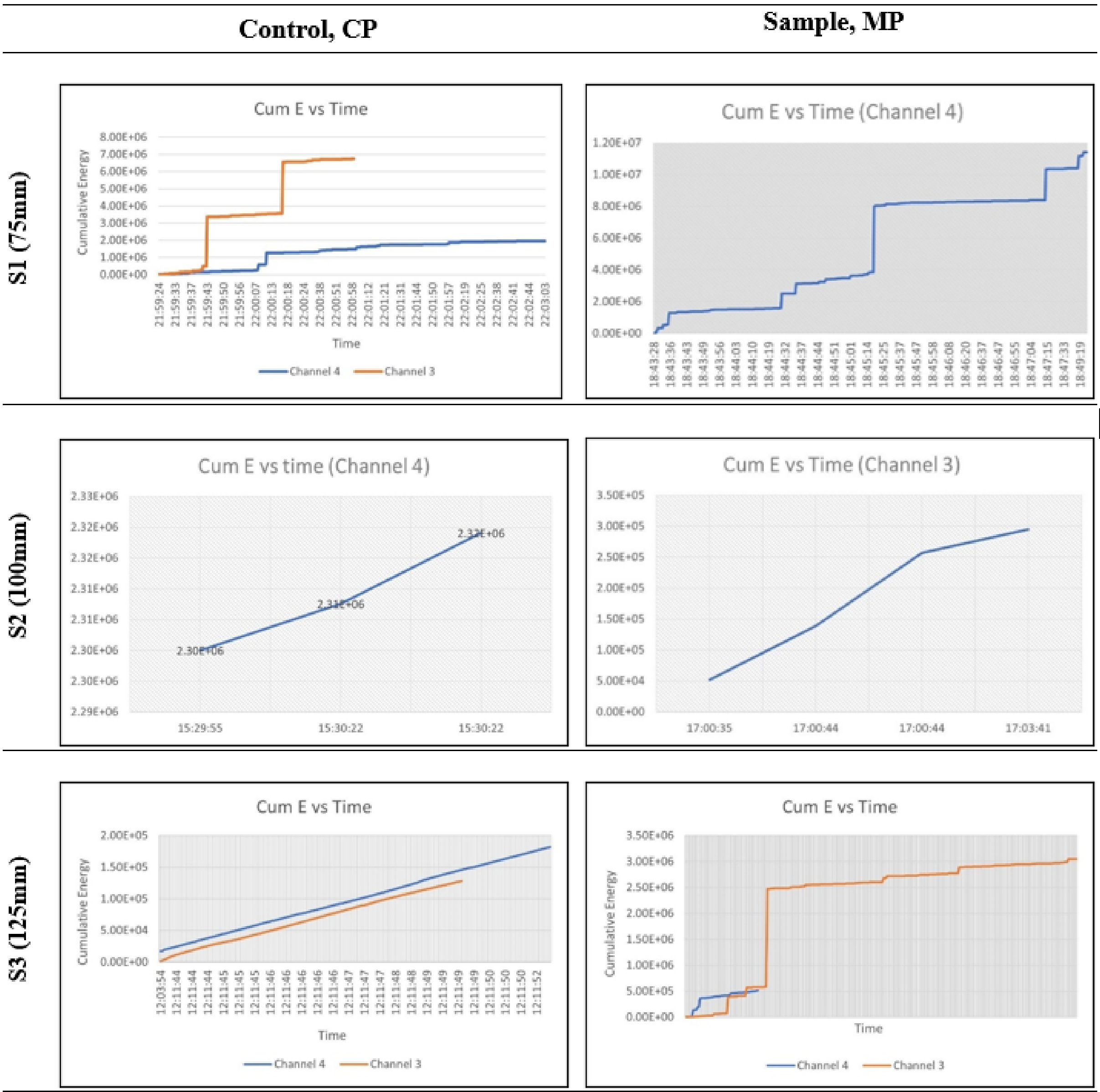

FIGURE 5. Cumulative energy with respect to time for all wall panels

CONCLUSION

The performance of the proposed wall panels, which incorporate RCA and perlite, has been thoroughly evaluated in terms of compressive strength and crack behaviour. The findings revealed variations in the compressive strength of the wall panels, with the control panels exhibiting greater strength compared to the proposed panels. The observed cracks on the wall panels were further scrutinised during the experiment. It was noted that the choice of wall panel thickness significantly influenced both compressive strength and crack visibility, with thicker sections displaying more visible cracks while maintaining superior load-bearing capabilities. Notably, the wall panel with a thickness of 100 mm emerged as the optimal performer, demonstrating a minimal percentage difference in compressive strength compared to the control panel.

Additionally, the visual crack observations during the experiment were confirmed through AE analysis, which involved an in-depth examination of energy patterns. This study contributes valuable insights into the structural behaviour of the proposed wall panels, particularly those incorporating alternative aggregates. The experimental results, verified using AE techniques, provide a comprehensive understanding of the panels' performance and crack characteristics. The combined use of these verification methods enhances the reliability and credibility of the study's outcomes.

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DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Awan, A. B., & Shaikh, F. U. A. 2021. Structural behaviour of tyre-bale sandwich wall under axial load. *Structures* 31: 792–804. https://doi.org/10.1016/j.istruc.2021.02.037

Chung, S. Y., Oh, S. E., Jo, S. S., Lehmann, C., Won, J., & Elrahman, M. A. 2023. Microstructural investigation of mortars incorporating cockle shell and waste fishing net. *Case Studies in Construction Materials* 18. https://doi.org/10.1016/j.cscm.2022.e01719

Farnam, Y., Geiker, M. R., Bentz, D., & Weiss, J. 2015. Acoustic emission waveform characterization of crack origin and mode in fractured and ASR damaged concrete. *Cement and Concrete Composites* 60: 135–145. https://doi.org/10.1016/j.cemconcomp.2015.04.008

Li, H., Hu, Y., Li, L., & Xu, D. 2023. Influence of backing layer on the non-metallic encapsulated acoustic emission sensor for concrete monitoring. *Case Studies in Construction Materials* 19. https://doi.org/10.1016/j.cscm.2023.e02416

Li, L., Dabarera, A., & Dao, V. 2023. Assessment of cracking risk of concrete due to restrained strain based on zero-stress temperature and cracking temperature. *Construction and Building Materials* 383. https://doi.org/10.1016/j.conbuildmat.2023.131381.

Md Nor, N., Md Hassan, A.S., Mohd Habibullah Hassan, N.H.H., Mat Saliah, S.N., Ruslan, A.K., Jamaludin, A.H., Fauzi, M.A. & Aziz, N.A. 2024. Analysing the influence of recycled concrete aggregate and expanded perlite on mortar performance. Jurnal Kejuruteraan 36(4): 1423–1435.

Naderi, M., Sheibani, R., & Shayanfar, M. A. 2009. Comparison of different curing effects on concrete strength. In 3rd *International Conference on Concrete & Development* 28: 507-516.

Noorsuhada M.N. 2016. An overview on fatigue damage assessment of reinforced concrete structures with the aid of acoustic emission technique. *Construction and Building Materials* 112: 429 – 439.

Oliveira, R. G., Rodrigues, J. P. C., Miguel Pereira, J., Lourenço, P. B., & Lopes, R. F. R. 2021. Experimental and numerical analysis on the structural fire behaviour of three-cell hollowed concrete masonry walls. *Engineering Structures* 228. https://doi.org/10.1016/j.engstruct.2020.111439

Rahim, A. A., Hamid, Z. A., Zen, I. Hj., Ismail, Z., & Kamar, K. A. M. (2012). Adaptable Housing of Precast Panel System in Malaysia. Procedia - Social and Behavioral Sciences, 50, 369–382. https://doi.org/10.1016/j.sbspro.2012.08.042

Rubio-Romero, J. C., Suárez-Cebador, M., & Abad, J. (2014). Modeling injury rates as a function of industrialized versus on-site construction techniques. Accident Analysis and Prevention, 66, 8–14. https://doi.org/10.1016/j.aap.2014.01.005

Zhang, R., Yan, X., & Guo, L. (2022). Deep learning-based classification of damage-induced acoustic emission signals in UHPC. Construction and Building Materials, 356. https://doi.org/10.1016/j.conbuildmat.2022.129285