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Spent Epoxy Molding Compound as Cement Replacement in Lightweight Concrete

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Abstract

The increasing demand for sustainable development in the construction industry has spurred interest in utilizing industrial waste materials. This study investigates the potential of incorporating EMC as a partial replacement in concrete, aiming to reduce cement usage by partially replacing it with EMC to enhance environmental sustainability. The main objective of this research is to evaluate the effects of different EMC replacement ratio (0%, 2.5, 5% and 7.5%) on the mechanical properties and workability of concrete. The methodology involves preparing concrete mixes with varying proportions of EMC as a partial replacement for cement. Standard tests were conducted to assess the concrete's workability, as well as its mechanical properties through compressive strength, water adsorption, thermal conductivity and density tests at 7 and 28 days of curing. Based on mechanical, durability, density, and thermal performance 2.5% EMC replacement was determined to be the optimal EMC-to-cement ratio for LPUC. This mix demonstrated a balanced performance, with compressive strength similar to the control mix, along with the advantages of reduced density and enhanced durability. The anticipated strength development trend was observed at both 7 and 28 days of curing, in accordance with BS EN 12390-3, indicating that low EMC replacement does not significantly interfere with the cementitious bonding or hydration process.

1 Introduction

The increasing demand for sustainable infrastructure has accelerated the search for environmentally responsible materials in construction. Conventional concrete production heavily relies on Portland cement, a major contributor to global CO_2 emissions and natural resource depletion [1].

Encapsulation of the chips in electronic devices to protect against mechanical, environmental and chemical attack is a common use of EMC which are typically made from epoxy resin. Among all the components of an electronic package, EMC is most exposed to the atmosphere and thus undergoes aging [2]. The application in industrial molding takes the form of compressed solid powder pellets that are subsequently heated into liquid and molded to encapsulate or packaging in semiconductor or electronic device.

PU consists of two main liquid components, polyol and isocyanate, each serving a specific function in the formation of PU foam. Polyol acts as the base material that contributes to the flexibility, density, and overall structure of the foam, while isocyanate functions as the reactive agent that initiates polymerization [3]. When these two components are mixed, a chemical reaction occurs that forms long-chain polyurethane polymers, accompanied by gas generation that causes the mixture to expand and create a foam structure.

This study focuses on evaluating the performance of LPUC using spent EMC as a cement replacement through its physical, mechanical, and thermal properties. The physical properties of LPUC were determined by measuring density and water absorption, while material characterization was conducted using Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), and Fourier Transform Infrared Spectroscopy (FTIR). The mechanical performance of LPUC was assessed through a compressive strength test, whereas its thermal performance was evaluated using a thermal conductivity test. All experimental results were systematically tabulated and presented in graphical form for analysis and discussion, allowing the calculated data to be analyzed to determine the overall performance of the LPUC.

2 Material Preparation and Performance of LPUC

The main raw material used in this research was spent EMC sourced from ST Microelectronics Sdn. Bhd., located in Muar, Johor, Malaysia, which was mechanically ground into powder form using a high-speed grinder (FW400A) and sieved to obtain consistent particle sizes of 425 µm, before being subjected to a silica dioxide (SiO_2) extraction process through pyrolysis in a muffle furnace (Lindberg/Blue M Moldatherm Box Furnaces) at a temperature of 500 °C for 3 minutes. Subsequently, the material was analyzed for the characterization of the LPUC. The EMC was subjected to particle analysis using SEM, EDX, and FTIR.

The PU mixture consists of two main liquid components, polyol and isocyanate. When these two chemicals are combined, they react to form PU foam. The total amount of PU foam added into the concrete mixture is 15% of the cement weight, which corresponds to 992.3 g. This total weight represents the combined mass of both components and is therefore divided equally, resulting in 496 g of isocyanate and 496 g.

The design focuses on producing lightweight material by partially replacing cement with EMC while incorporating polyurethane foam into the mixture. Each batch of mix design was prepared to cast three cubes for every physical, mechanical and thermal properties. The performance of LPUC was determined through its physical, mechanical, and thermal properties, including compressive strength (BS EN 12390-3), water absorption (BS 1881-122) and density, and thermal conductivity using the single plate method.

2.1 Experimental Design

The mix design proportions were based on the total weight of concrete, with varying EMC replacement ratios of 0% (Control), 2.5% (Mix 1), 5% (Mix 2), and 7.5% (Mix 3). In these mixes, EMC was incorporated as a partial replacement material, while the contents of cement, silica fume, fine aggregate, PU resin (PU A + PU B), hardener, and water were adjusted accordingly to maintain consistent overall mix proportions and ensure comparable workability and performance across all mixtures.

Table 1 *Mix Design Proportion of the LPUC*

Materials	Control	Mix 1 (ratio 2.5%)	Mix 2 (ratio 5%)	Mix 3 (ratio 7.5%)
Cement (g)	735.00	678.05	661.5	711.11
EMC (g)	0	16.55	33.1	49.61
Silica Fume (g)	36.75	33.90	33.075	35.55
Fine Aggregate (g)	2572.5	2373.18	2315.3	2488.89
PU Resin (PU A + PU B)	1102.5	1017.075	992.3	1066.67
Hardener (g)	22.05	20.34	19.8	21.33
Water (g)	441.00	406.83	396.9	426.67

2.1.1 Compressive Strength Performance

The BS EN 12390-3 standard was adopted to determine the compressive strength of the concrete specimens. The tests were conducted at the end of each curing period, specifically on the 7th and 28th days after the specimens were submerged in water. Compressive strength measurements were carried out using a Universal Compressive Testing Machine. The compressive strength formula was calculated using Eq. 1 below:

$$fc = \frac{F}{Ac} \tag{1}$$

2.1.2 Water Adsorption and Density

The water absorption of each specimen is calculated by measuring the increase in mass after immersion in water, expressed as a percentage of the dry mass. This standardized procedure, as outlined in BS 1881-122,

helps assess the quality and long- term performance of concrete by evaluating its ability to resist water ingress. Water absorption testing in LPUC lightweight concrete is closely tied to density, pore structure, and mix composition. The density of LPUC samples is calculated as the mass of the test specimen divided by its volume, with three samples tested for each mixture and the average value considered as the final density. The water adsorption and density were calculated using Eq. 2 and Eq. 3 below:

$$\text{Water Adsorbtion (\%)} = \frac{\text{Ws} - \text{Wd}}{\text{Wd}} \times 100 \tag{2}$$

$$\text{Density } (\boldsymbol{\rho}) = \frac{\text{M}}{\text{V}} \tag{3}$$

2.1.3 Thermal conductivity

Thermal conductivity of concrete with varying ratios of EMC was evaluated after 7 and 28 days of curing using the OLTEQ Thermal Conductivity of Building Materials apparatus (Model: HE110). The test was conducted to determine the heat-transfer (single plate method) efficiency of each LPUC mix. Thermal conductivity were calculated using Eq. 4 below:

$$\text{k} = \frac{\text{Heat Transfer Rate, q} \times \text{Thickness, m}}{\text{Area, A}(\text{m}^2) \times \textit{Temperature Difference, } (°C)} \tag{4}$$

3 Result and Discussion

3.1 SEM Analysis

Fig. 3(a) shows the SEM microstructure of EMC before extraction. The surface appears thick, dense, and highly agglomerated, with large, irregular clusters observed. These features indicate that the fine particles are strongly bonded within the epoxy resin matrix, resulting in a compact surface with very few visible voids or micro-cracks. The microstructure is mainly dominated by a carbon-rich epoxy resin that acts as a continuous phase, binding the silica-based filler particles together [4]. The EMC with a particle size of 450 µm shows a relatively coarse and uneven structure, with large agglomerates formed due to strong interactions between the resin and fillers.

After the grinding process Fig. 3(b), the SEM microstructure of EMC shows clear changes in surface morphology. The surface becomes rougher, less agglomerated, and more porous, with visible particle boundaries and micro-voids. The removal of resin exposes the inorganic fillers, especially silica particles, which appear more angular and clearly separated [5]. The particle structure after extraction is finer and more fragmented, indicating that the loss of resin weakens the bonding and breaks larger agglomerates into smaller particles.

Overall, the analysis of SEM proves that extraction process changes the microstructure of the EMC size 450 µm greatly. Prior to extraction, EMC has the morphology of a resin-dominated, compact and aggregated structure with rough clusters of particles held together by epoxy resin. The material that extracted to a filler-controlled structure mixed is more porous, agglomerates less, and more silica particles are exposed [6]. These microstructural developments are predicted to have effects on the physical, mechanical as well as thermal behavior of EMC when with the concrete, specifically the interaction between particles, bonding and internal structure.

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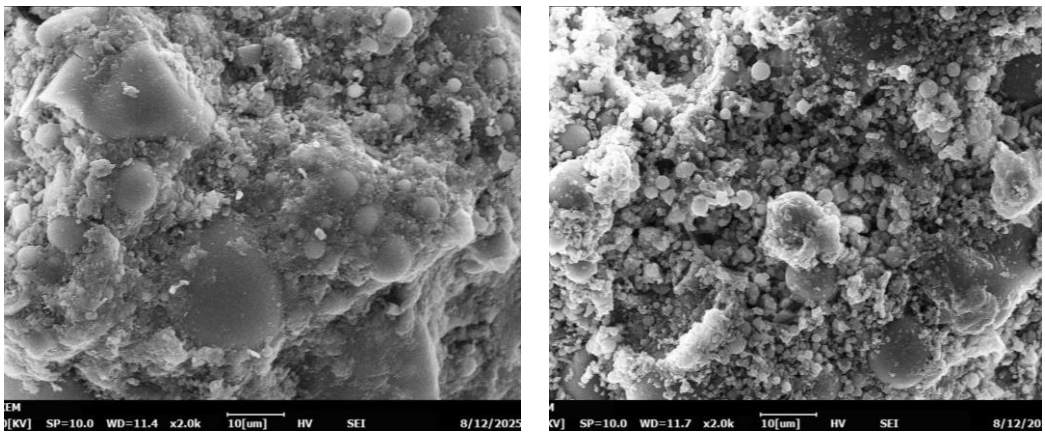


(a) **(b)**

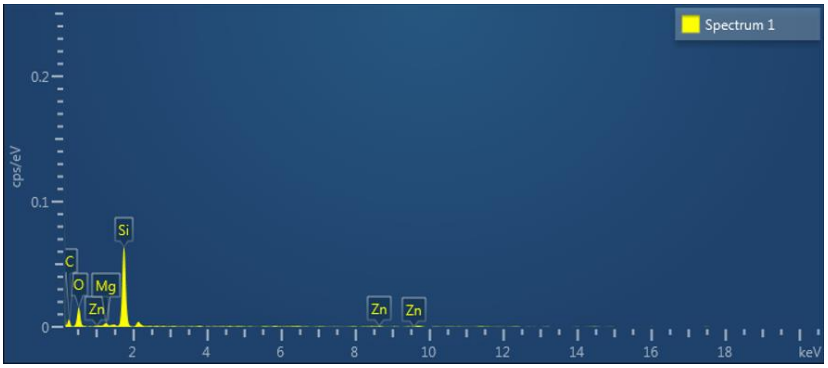
Fig. 1 *SEM microstructure of EMC before (a) and after extraction (b)*

3.2 EDX Analysis

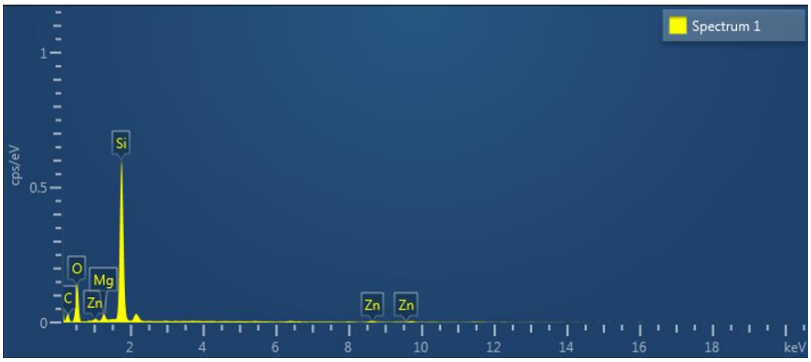
The EDX spectra for both conditions indicate the presence of silicon (Si), carbon (C), magnesium (Mg), and zinc (Zn). The EDX analysis of the EMC samples reveals significant differences in elemental composition Fig. 2 before and after extraction. Prior to extraction, the EMC contained a higher proportion of carbon C, 41.56% and lower silicon Si, 20.98% and oxygen O, 35.51% content. Other elements such as Mg and Zn were present in minor amounts 0.93% and 0.24%. This composition suggests that the unextracted EMC had a carbon-rich epoxy resin matrix surrounding inorganic fillers like silica and minor metallic elements.

After extraction, the EDX results show a decrease in carbon content from 41.56% to 37.63%, along with an increase in silicon from 20.98% to 28.20% and oxygen from 35.51% to 41.57%. These changes indicate the partial removal of organic epoxy resin and a higher presence of silica-based inorganic material. Magnesium and zinc were detected in small amounts and are considered impurity elements, as their contents are low and not part of the main EMC matrix [7]. Overall, the reduction in carbon and increase in oxygen confirm that the extraction process effectively reduced the resin content and enriched the inorganic phases.

C and O were the dominant elements, while Si, Mg, and Zn were also detected. After extraction, C decreased, whereas O and Si increased, indicating partial removal of the organic epoxy resin and enrichment of the inorganic phase. The increase in Si highlights the higher silica content, important for the material's structure and properties [8]. Mg and Zn were present in small amounts and are considered impurities. Overall, the extraction process reduced organic content and concentrated the Si- and O-rich phases in the EMC.



(a)



(b)

Fig. 2 *EDX analysis of SEM EMC before (a) and after extraction (b)*

3.3 FTIR Analysis

The FTIR analysis was conducted to focusing the existence of the components of the Silica Oxide (SiO2) and the presence of inorganic fillers that were left after the extraction process, and to determine any chemical alterations caused by the extraction process. In both transmittance and absorbance mode, the spectral was measured, to allow a complete analysis of the molecular structure of the extracted EMC .

The FTIR transmittance spectrum of the EMC shows several characteristic absorption bands that indicate the functional groups present in the material. A broad reduction in transmittance observed in the region of approximately 3200–3600 cm^{-1} is associated with O–H stretching vibrations, which may arise from hydroxyl groups in the epoxy resin or absorbed moisture. Peaks around 2920–2850 cm^{-1} correspond to aliphatic C–H stretching, confirming the presence of organic polymer chains [9]. Additionally, a distinct decrease in transmittance near 1600 cm^{-1} can

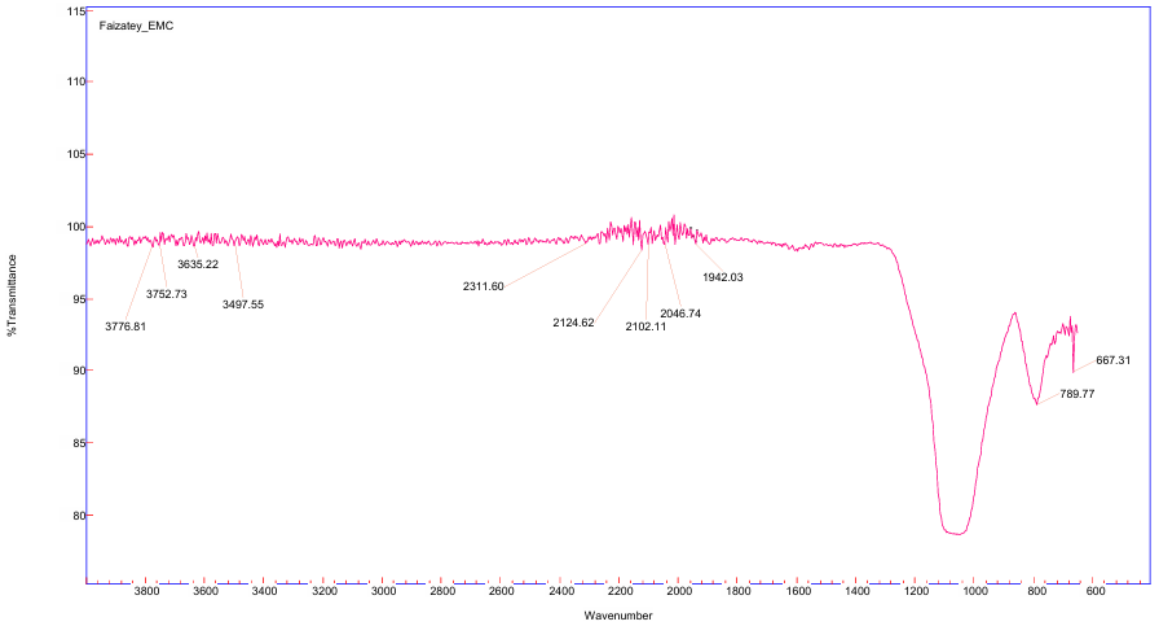


Fig. 3 *FTIR spectrum of EMC Transmittance*

3.4 Water Adsorption and Density test

The water absorption test was conducted to evaluate the pore structure of the composite, as higher water absorption indicates greater porosity. Fig. 4 shows the water absorption results. After 7 days of curing, the

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control specimen showed the highest water absorption (18.10%), indicating a more porous internal structure due to incomplete hydration at early curing ages, which allows water to easily penetrate through capillary voids [11]. In contrast, mixes containing EMC and PU exhibited reduced water absorption, particularly Mix 2 (5% EMC) and Mix 3 (7.5% EMC), with Mix 3 recording the lowest value (4.42%), demonstrating effective refinement. After 28 days of curing, all mixes showed lower water absorption as hydration progressed and pores were filled; however, the EMC-modified mixes still recorded significantly lower values, with Mix 3 showing the lowest average absorption (6.85%). This reduction is attributed to the continued formation of hydration products that fill pores over time [12], as well as the complete curing of epoxy resin, which integrates with the cement matrix to form a dense polymer–cement network.

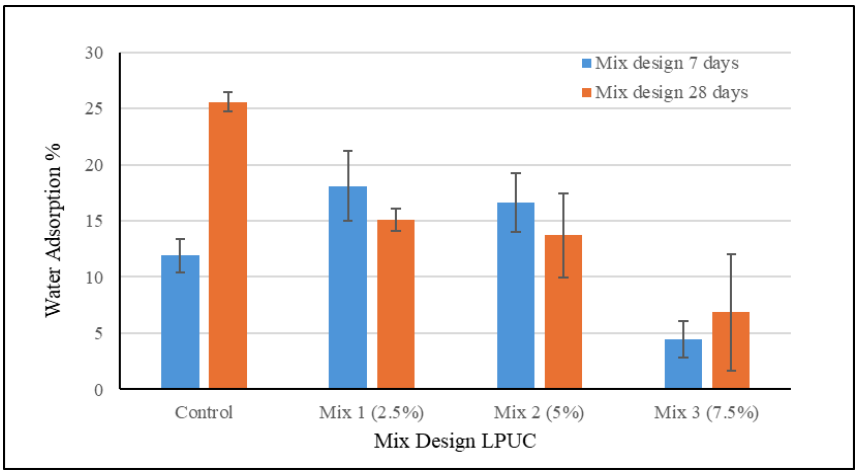

Fig. 4 *Water adsorption results at different percentages of EMC-LPUC*

The density of LPUC was determined using cube specimens to ensure consistent results. The specimens were oven-dried to a constant mass, and their dry weights were recorded. Density was calculated by dividing the dry weight by the specimen volume, and the average value was used to represent each mix design. Density is an important parameter as it influences the compressive strength, thermal conductivity, and water absorption of LPUC [13], and the results provide a basic reference for evaluating and comparing the performance of different mix designs. Fig. 5 shows the density result at different percentages of EMC-LPUC.

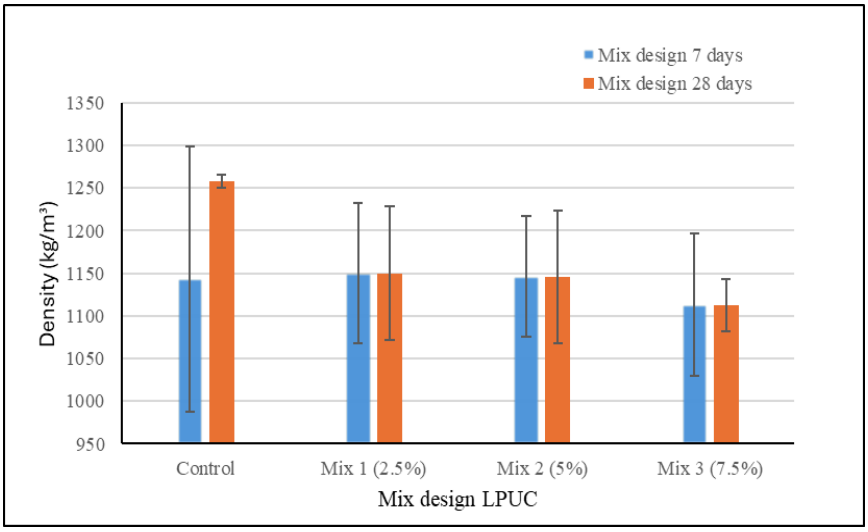

Fig. 5 *EMC density results at different percentages of EMC-LPUC*

3.5 Compressive Strength test

A total of 24 LPUC specimens were tested to evaluate the compressive strength, with 12 specimens tested at 7 days and the remaining 12 specimens tested at 28 days of curing. The compressive strength test was conducted in accordance with BS EN 12390-3 using a compression testing machine. During the test, each specimen was subjected to a controlled loading condition until the peak force was reached, ensuring consistent and reliable results for comparison between different curing ages.

The compressive strength results at Fig 6 shows the LPUC specimens show clear differences in performance with varying EMC contents at 7 and 28 days of curing. At 7 days, mix 1 (2.5% EMC) recorded the highest peak force, followed by the control mix, while mix 2 (5%) and mix 3 (7.5%) showed lower strength values, with Mix 3 performing the weakest. This indicates that higher EMC contents tend to reduce early-age strength. Based on BS EN 12390-3, the control mix and Mix 1 followed the expected strength development trend for concrete, which typically gains significant strength within the first 28 days of curing. The reduction in compressive strength observed in Mix 2 and Mix 3 is attributed to the increased replacement of cement and other essential materials by EMC, which weakens the cementitious bonding. These findings emphasize the importance of optimizing the EMC replacement level to maintain adequate compressive strength and structural performance in LPUC (BS EN 12390-3).

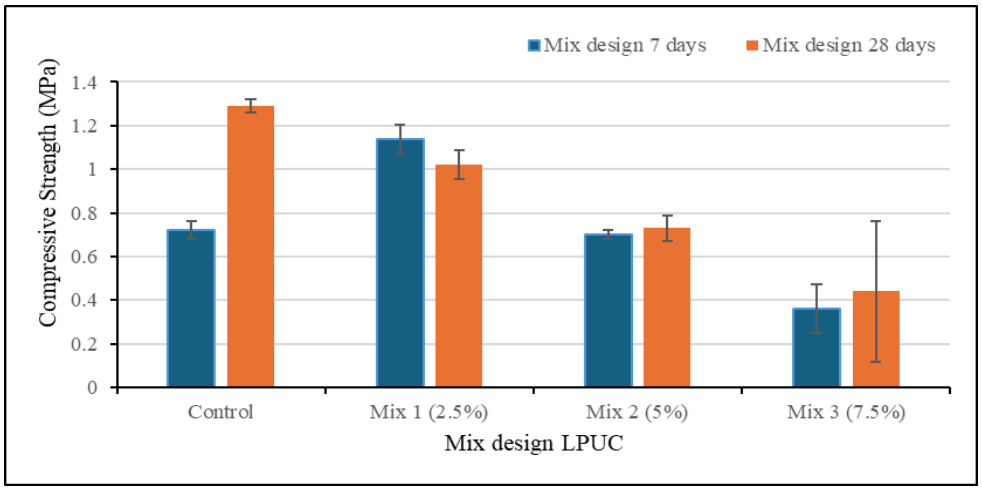

Fig. 6 *EMC Compressive strength results at different percentages of EMC-LPUC*

3.6 Thermal Conductivity test

Fig. 7 shows that as the temperature gradient increased, the thermal conductivity slightly decreased, especially in mixes containing added components such as PU, silica fume, and EMC, indicating higher resistance to heat transfer [14]. Mix 1 recorded a thermal conductivity of 0.076 W/m·°C at 7 days, which was lower than the control mix, likely due to the influence of the polyurethane mixture and the anisotropic behavior of silica fume and EMC on heat transfer [15]. The cool plate temperatures for the 7-day samples ranged from 28.4°C to 28.6°C, showing minimal variation and consistent testing conditions, as thermal measurements are temperature-dependent and commonly standardized at 300 K for comparison [15]. Overall, the findings indicate that the incorporation of polyurethane and silica fume influences the thermal properties of the concrete.

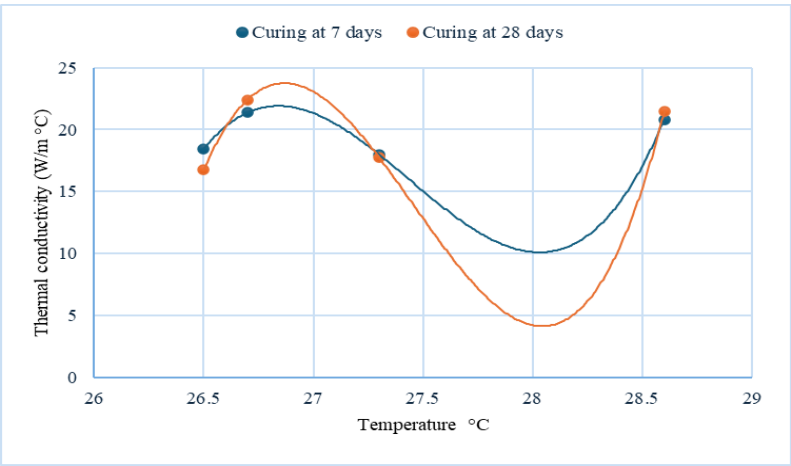

Fig. 7 *Thermal conductivity vs temperature at curing age 28 and 7 days*

4 Conclusions

Based on the results of the elemental analysis, the first objective of this study was to extract and characterize SiO2 from spent EMC using the pyrolysis method successfully achieved. The extracted EMC shows a relatively high Si content, with a weight percentage of 28.20% and an atomic percentage of 16.95%, accompanied by a dominant O presence. This composition strongly indicates the existence of silica SiO2 as a major constituent after the pyrolysis process. The findings confirm that the pyrolysis method is effective in recovering silica-rich material from spent EMC.

According to the mechanical, durability, density, and thermal performance, Mix 1 with 2.5% EMC replacement is determined to be the best EMC-to-cement ratio of LPUC. This combination was obtained with a balanced performance in that it has similar compressive strength to the control mix and has the advantage of low density and enhanced durability properties. The same case obtained at 7 and 28 days of curing whereby Mix 1 took the anticipated strength development trend in reference to BS EN 12390-3 meaning that low EMC replacement does not substantially interfere with the cementitious bonding or hydration process.

The second objective in this research is to identify the optimum EMC to cement ratio that desirable mechanical and durability behaviours in LPUC has been accomplished successfully as it gave the best overall balance between strength, durability and lightweight properties. This combination not only retained compressive strength to the control specimen, but also obeyed the expected strength build with curing age, but also had lower density, better thermal insulation, and lesser water adsorption than the control mix. Thus, the EMC-to-cement ratios of 2.5% are found to be the most effective mix to meet the desired mechanical and durability of the polyurethane-based lightweight concrete.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhammad Faqhrul Haiqal, Hasnida Harun;* ***data collection:*** *Muhammad Faqhrul Haiqal;* ***analysis and interpretation of results:*** *Muhammad Faqhrul Haiqal, Hasnida Harun;* ***draft manuscript preparation:*** *Muhammad Faqhrul Haiqal, Hasnida Harun. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Felipe Arbeláez Pérez, O., Senior Arrieta, V., Hernán Gómez Ospina, J., Herrera Herrera, S., Ferney Rodríguez Rojas, C., & María Santis Navarro, A. (2024). Carbon dioxide emissions from traditional and modified concrete. A review. Environmental Development, 52, 101036. **https://doi.org/10.1016/J.ENVDEV.2024.101036**

[2] Inamdar, A., Gromala, P., Prisacaru, A., Kabakchiev, A., Yang, Y., & Han, B. (2022). EMC Oxidation Under High-Temperature Aging. In Reliability of Organic Compounds in Microelectronics and Optoelectronics: From Physics-of-Failure to Physics-of-Degradation (pp. 53–80). Springer International Publishing. **https://doi.org/10.1007/978-3-030-81576-9_3**

[3] Lim, C. C. N. D., Ong, M. J. H., Wu, M., Lee, C. L. K., & Choong, P. Sen. (2024). Emerging Trends in Nonisocyanate Polyurethane Foams: A Review. ACS Engineering Au, 4(6), 493–518. **https://doi.org/10.1021/acsengineeringau.4c00026**

[4] Wang, X., Xia, Y.-F., Liu, J.-H., & Li, Z.-W. (2015). Study on the fabrication and properties of CB@SiO2-BaTiO3-epoxy composite. *Rengong Jingti Xuebao/Journal of Synthetic Crystals*. https://doi.org/DOI:10.1007/s10854-016-6283-6

[5] Ramalho, A., Vale Antunes, P., De Braga Carvalho, M. D., Gil, H., & Rocha, J. (2006). Mechanical properties of particle reinforced resin composites. Materials Science Forum, 514–516(PART 1), 619–623. https://doi.org/10.4028/www.scientific.net/msf.514-516.619

[6] Han, K., Zhou, J., Li, Q., Shen, J., Qi, Y., Yao, X., & Chen, W. (2020). Effect of filler structure on the dielectric and thermal properties of SiO2/PTFE composites. Journal of Materials Science: Materials in Electronics, 31(12), 9196–9202. https://doi.org/10.1007/s10854-020-03449-w
[7] Kammerer, C., Kulkarni, N., Warmack, R., & Sohn, Y. (2014). Al and Zn impurity diffusion in binary and ternary magnesium solid-solutions. Magnesium Technology, 407–411. https://doi.org/10.1002/9781118888179.ch76
[8] Zhigachev, A. O., Rodaev, V. V., Umrikhin, A. V., & Golovin, Y. I. (2019). The effect of silica content on microstructure and mechanical properties of calcia-stabilized tetragonal zirconia polycrystalline ceramic. Ceramics International, 45(1), 627–633. https://doi.org/10.1016/j.ceramint.2018.09.220
[9] Francis, B. (2021). Water Absorption Studies in Epoxy Nanocomposites. In Epoxy Composites: Fabrication, Characterization and Applications (pp. 241–258). wiley. https://doi.org/10.1002/9783527824083.ch9
[10] Mao, Q., Bian, L., & Huang, M. (2011). Study of the visible light curing of vinyl ester resins using in situ Raman spectroscopy. Journal of Polymer Research, 18(6), 1751–1756. https://doi.org/10.1007/s10965-011-9581-y
[11] Givi, A. N., Rashid, S. A., Aziz, F. N. A., & Salleh, M. A. M. (2010). Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete. Construction and Building Materials, 24(11), 2145–2150. https://doi.org/10.1016/J.CONBUILDMAT.2010.04.045
[12] Zhang, S., Fan, Y., Huang, J., & Shah, S. P. (2021). Effect of nano-metakaolinite clay on the performance of cement-based materials at early curing age. Construction and Building Materials, 291, 123107. https://doi.org/10.1016/J.CONBUILDMAT.2021.123107
[13] C., S., Y., W., & M., R. (2005). Properties of fiber-reinforced lightweight concrete. American Concrete Institute, ACI Special Publication. https://www.scopus.com/pages/publications/63049096776?
[14] Zhang, E., Yao, Y., Gao, T., Kang, D., Wu, J., & Dai, J. (2019). The effect of external temperature gradients on thermal conductivity in non-equilibrium molecular dynamics simulations: From nanowires to bulk Si. Journal of Chemical Physics, 151(6). https://doi.org/10.1063/1.5107485
[15] Hamada Fakra, D. A., Alfonso José, B. R., Murad, N. M., & Gatina, J. C. (2020). A new affordable and quick experimental device for measuring the thermo-optical properties of translucent construction materials. Journal of Building Engineering, 32, 101708. https://doi.org/10.1016/J.JOBE.2020.101708