International Conference on Mechanical System Engineering and Technology Applications
(ICoMSETA) 2024, pp. X – XX

ORIGINAL ARTICLE

The Characteristics of Tensile Splitting and Compressive Strength at Elevated Temperature 1000 °C Characteristics of Foamed Concrete Containing Semiconductor Epoxy Molding Component Resin Waste (SEMR-FC)

Siti Aminah Mansor[1], Noraini Marsi[1,2*], Izzati Abdul Manaf [1], Efil Yusrianto[1,3], Jamaluddin Johar[4], Hock Chee Low[4] and Hafizuddin Hakim Shariff [5]

[1]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Campus KM 1, Jln Panchor, 86400 Pagoh, Johor, MALAYSIA.
[2]Advanced Manufacturing and Material Centre (AMMC), Integrated Engineering, UTHM, Parit Raja, 86400 MALAYSIA
[3]Universitas Islam Negeri Imam Bonjol Padang, Jl. Prof. Mahmud Yunus Lubuk Lintah, Padang, 25153 Sumatera Barat, INDONESIA.
[4]STMicroelectronics Sdn Bhd, Industrial Area Muar, 84007 Muar, Johor, MALAYSIA
[5]Kim Hoe Thye Industries Sdn. Bhd., No.99, Lot 143, Jalan Air Manis, Bukit Mor, 84150 Parit Jawa, Johor, Muar, MALAYSIA.

* mnoraini@uthm.edu.my

Abstract. Foamed concrete is a low-density concrete that is highly air-entrained with more air per volume using materials such as sand, cement, and foam. Foamed concrete can be applied in various shapes as required. The statistical condition of foamed concrete, which is a free-flowing liquid, allows the foamed concrete to take place and shape accordingly. Epoxy resin is a type of thermoset polymer with a highly connected, crosslinked structure. Thermoset epoxy is known to contain high stiffness and strength. In this study, research was done by adding semiconductor epoxy resin waste as fine aggregate to produce non-loading bearings. The semiconductor epoxy resin waste was obtained from ST Microelectronics SDN BHD and was ground until the particle size was less than 0.6mm. The preparation of samples involved the grinding process of the Semiconductor Epoxy Mold Component Resin Waste and the mixing process of different percentages of RW at 0, 5, 10, 15, 20, 25, and 30% with the constant percentages of cement, quartz sand, water, and foam. Tests were carried out on the mix design, which involves compressive strength before and after elevated temperature (1000°C for 4 hours), tensile splitting strength, density and porosity. The results indicated that adding 10% semiconductor epoxy resin waste yielded the highest compressive strength of 9.88 MPa at 28 days and tensile splitting strength of 5.95 MPa, with the mixture achieving the targeted density of 900 kg/m3 in dry state. This research demonstrates the viability of using semiconductor epoxy resin waste in foamed concrete, providing a sustainable solution for waste management in construction.

1.0 Introduction

The growing consumer population and the increase in non-degradable waste products have created a significant waste disposal problem, posing both economic and environmental challenges [1]. As a result, there is a global trend toward waste recovery and utilizing waste as raw materials in the construction sector. The rapid rise in the global population, driven by urbanization, has increased the demand for building materials. This demand depletes natural resources and raises the cost of building materials. Engineers face the challenge of addressing this sustainability issue by exploring more compact and custom-made brick components that meet building standards while promoting low-cost and environmentally sustainable masonry systems.

Foamed concrete, also known as lightweight or cellular concrete, is a cementitious material containing at least 20% mechanically entrained foam by volume in the mortar mix. Typically produced with a density ranging from 500 to 1600 kg/m^3, it is valued for its self-leveling ability, high insulation properties, filling ability, fire-resistant characteristics, and cost-effectiveness [2], [3]. Hashem Moniri et al. 2019 [4] emphasize the characteristics of foamed concrete, also known as foam crate, cellular lightweight concrete (CLC), or reduced density concrete, which is notable for its lightweight nature but lower strength compared to standard concrete. This type of concrete, made from fine aggregate, cement, water, and a foaming agent, is versatile in its applications, including structural, partition, insulation, and filling uses. Foamed concrete blocks, composed of cement, fine sand, water, and foam bubbles, are particularly suitable for block manufacturing. The research also notes the increasing interest in lightweight concrete blocks for wall construction, especially as wall panels, due to their enhanced thermal insulation properties.[4]

Foamed concrete is produced by adding a foaming agent to a cement slurry. Once the foaming agent is fully foamed, it is thoroughly mixed with the cement slurry to create foamed concrete. This method produces a material with several key advantages, including rapid construction speed and low density, making it an efficient and lightweight solution for various construction applications [5], [6]. The utilization of waste materials in the manufacturing of foamed concrete has been extensively researched worldwide. This sustainable development approach by the construction industry aims to reduce landfill waste and pollution. The extensive use of thermoset resins, especially epoxy resins, in the coatings industry leads to significant waste due to their irreversible cross-linked structure, posing recycling challenges and environmental concerns [7]. The prevalent use of epoxy resins, which dominate 70% of the thermoset market for their thermal stability, chemical resistance, and flexibility, results in over 60% of this waste. Past research has demonstrated the use of polymer resin as an additive and replacement material in the construction industry [8], [9], [10] yet few studies have focused on recycling epoxy resin due to the challenges in remelting it for the curing process. Consequently, the industry often resorts to landfill disposal. [11]

Epoxy molding compounds, primarily used in packaging, incorporate various additives to enhance molding workability and optimize product properties, further complicating waste management[12], [13]. According to the Inamdar et al. (2021) paper, epoxy resin molding compounds are the most commonly utilized composite material for semiconductor encapsulation because they contain a polymer-based matrix, inorganic filler particles, and additional additives designed to improve their properties [14]. Epoxy resins, renowned for their high stiffness and strength, chemical resistance, dielectric properties, corrosion resistance, low shrinkage during curing, and excellent thermal features, are the most extensively studied class of thermosetting resins and are crucial for a variety of engineering applications [15]. The global annual production of epoxy resins reached 3 million tons, valued at over 25 billion dollars in 2017. However, despite a worldwide resin production of approximately 130 million tons, only 21% is recycled, with significant disparities among resin types [16]. Resin waste generally sees a 32% recycling rate, while epoxy resin lags at just 11%. In 2018, the Malaysian branch of STMicroelectronics generated about 3.3% of the country's 1140 tons per day of resin waste. The production of epoxy composites is estimated to be at least 4 million tons by 2030 which shows an increment due to demand in the future [17].To mitigate high transportation costs, some organizations crush resin waste for construction use, adopting this approach as a sustainable solution.

2.0 Literature Review

Epoxy resin offers several advantages, including high bonding strength, excellent dimensional stability, superior chemical resistance, high mechanical strength, exceptional electrical insulation, and strong resistance to radiation [18]. Epoxy resin, commonly used as a polymer matrix in advanced composite packages, provides numerous benefits including excellent mechanical properties, electrical characteristics, chemical resistance, and environmental durability, and is often reinforced with glass fibers and fly ash in various forms [19], [20].

Shrivastava & Shrivastava (2020) [19] conducted a study to advance the application of polymer concrete by comparing it with conventional concrete through the incorporation of various resins and fibers. Utilizing IS10262:2009 mix design for M25 grade concrete, the study assessed the impact of 3% and 5% resin, as well as 0.5% and 1% glass fiber on the compressive, flexural, and tensile strengths of polymer concrete. The findings demonstrated that both epoxy resin and glass fiber substantially enhanced these strengths, with optimal results observed at 28 days and significant gains in strength by day 7. The research also highlighted the benefits of increased resin content and fly ash addition, which improved workability and reduced voids. Cakir et al. (2021) [21] also found that incorporating resin polymers into concrete significantly enhances its mechanical properties and durability, surpassing those of traditional Ordinary Portland Cement (OPC) concrete. The addition of resin improves compressive, flexural, and split tensile strengths, making polymer concrete suitable for structural applications and capable of withstanding higher impact forces without cracking.

Salari F et al. (2023) [22] they investigated the use of palm oil clinker (POC) and palm oil clinker powder (POCP), including thermally activated POCP (TPOCP), as replacements for sand and cement in lightweight foamed concrete. The study evaluated the compressive strength of concrete with varying percentages of POC (0%, 25%, 50%, 75%, 100%) and POCP/TPOCP (0%, 10%, 20%, 30%) using Type I Ordinary Portland Cement at densities of 1300 g/m^3 and 1500 g/m^3. The study found that reducing the size of fine aggregates to smaller than 0.6 mm significantly increases compressive strength, with the highest strength observed at 90 days—76% and 52.35% greater than that of aggregates smaller than 4.75 mm and 2.36 mm, respectively. This improvement is due to the uniform pore distribution achieved with smaller aggregates, while larger aggregates create irregular, larger pores that decrease strength.

Gencel et al. (2022) [23] findings also align where the study demonstrated that using smaller fine aggregates in concrete enhances compressive strength by minimizing air void size, which improves load-bearing capacity. Properly sized fine aggregates prevent the formation of larger voids, optimizing the balance between foam and aggregate for increased strength and durability. Experimental studies confirm that the mechanical properties of foam concrete, including compressive strength, are significantly influenced by the aggregate-to-foam ratio, with smaller aggregates contributing positively.

Addressing the identified research gap in the literature, it has been observed that smaller particle sizes enhance the compressive strength of concrete. This study investigates the physical and mechanical properties of SMERW from municipal solid waste as an additional material, mixed with sand, in the production of Foamed Concrete Based on Semiconductor Epoxy Molding Component Resin Waste (FC-SEMRW). This research aims to contribute to sustainable construction practices while reducing the amount of glass in landfills.

3.0 Material and Methodology

3.1. Fabrication process for FC-SEMRW Foamed Concrete

This study investigates the use of semiconductor epoxy molding component resin waste (SEMRW) as an additive in concrete mixtures. SEMRW, obtained from STMicroelectronics Sdn Bhd, Muar, Johor. The SEMRW was ground into a fine powder with particle sizes less than 0.6 mm using a Los Angeles Grinding Machine. The foaming agent utilized in this study was a synthetic foaming agent from DIGITAL STORE Village in Johor, mixed with water at a ratio of 1:30 using an Allefix Electric Mixer to produce pre-formed foam. The raw materials for this study include cement of Holcim's Pozzolanic Cement CEM IV/B (V) 32.5 R, quartz sand, SEMRW, foaming agent, and water, which were meticulously prepared and stored before production. Quartz sand and SEMRW were sieved to meet specific particle size requirements per British Standard BS 410. Seven different FC-SEMRW compositions were created by mixing various percentages of SEMRW from 0% to 30% with consistent volumes of cement, quartz sand, foam, and water, as shown in Figure 1 and Table 1.

Table 1: Composition of materials ratio for producing FC-SEMRW

Mix ID	Resin waste (kg)	Cement (kg)	Quartz sand (kg)	Water (kg)	Foaming Agent (kg)	Water for Foam Making (kg)
FC- SEMRW 0%	0.0	500.0	300.0	200.0	3.0	90.0
FC- SEMRW 5%	15.0	500.0	300.0	200.0	3.0	90.0
FC- SEMRW 10%	30.0	500.0	300.0	200.0	3.0	90.0
FC- SEMRW 15%	45.0	500.0	300.0	200.0	3.0	90.0
FC- SEMRW 20%	60.0	500.0	300.0	200.0	3.0	90.0
FC- SEMRW 25%	75.0	500.0	300.0	200.0	3.0	90.0
FC- SEMRW 30%	90.0	500.0	300.0	200.0	3.0	90.0

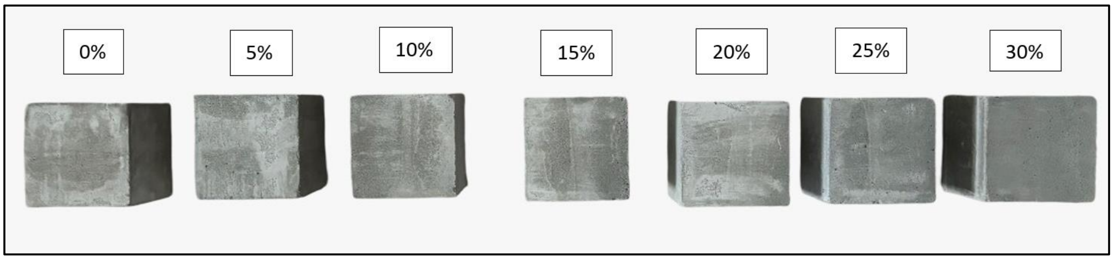

Fig.1 Sample of FC-SEMRW with different compositions of SEMRW

The process of producing mortar slurry and foam for FC-SEMRW involves precisely maintaining ingredient proportions to achieve the desired consistency. Following Hameed and Hamada's (2020) procedure, dry raw materials (cement and sand for the control sample) are mixed with water to form the mortar slurry [24]. For FC-SEMRW samples, semiconductor epoxy resin waste (SEMRW) is added to the dry mix before introducing water as shown in Figure 2(a). After a 2-minute blending process, the mortar slurry was prepared. The stable foam was then generated using Allefix's Electric Mixer for 4 minutes as shown in figure 2(b) and subsequently introduced into the mortar slurry to create the FC-SEMRW slurry as depicted in Figure 2 (c). This mixture was further blended with the electric mixer for 2 minutes to ensure uniformity and the absence of residual white foam on the slurry surface, as depicted in Figure 2(d), maintaining a minimal speed of 133 rpm to prevent foam disruption. Concrete samples were moulded to dimensions of 100mm×100mm×100mm for compressive and tensile splitting strength tests. Each sample's density was measured in the fresh state, and then cured at room temperature for 24 hours. Post-hardening, the samples were submerged in water until the 7th and 28th days for further testing. Figure 2 shows the process involved in producing FC-SEMRW.

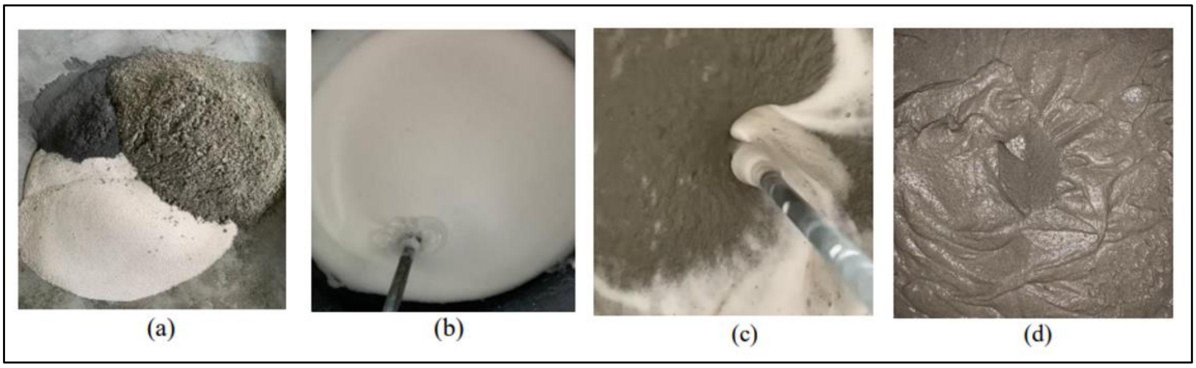

Fig 2. FC-SEMRW mixing process (a) mixing Cement, sand, and water to form dry mortar; (b) production of foam; (c) adding pre-formed foam into mortar slurry and (d) mixture of FC-SEMRW slurry

4.0 Result and Discussion

4.1. Density and Porosity

The results from Figure 3 showed a direct relationship between the SEMRW percentage and the physical properties of the samples. As the SEMRW percentage increased, the density of the samples also increased, while their porosity decreased. This trend was most pronounced in the FC-SEMRW 30% samples, which had the highest density of 941 g/m^3, followed by FC-SEMRW 25%, FC-SEMRW 20%, FC-SEMRW 15% FC-SEMRW 10%, FC-SEMRW 5% and FC-SEMRW 0% having the lowest density. The increase in SEMRW percentage led to a higher total mass of material, thereby increasing the density of the foamed concrete samples. In this research, SEMRW acts as filler material to quartz sand. Therefore, when the percentage of SEMRW added increased in the FC-SEMRW, the total mass of fine aggregates used also increased, which increased the density of each FC-SEMRW samples.

Figure 3 illustrates that as the percentage of SEMRW increased, the density of the samples also increased, while porosity decreased. The lowest density recorded was 0.851 g/cm^3 for FC-SEMRW at 0%, which corresponded to the highest porosity of 82.9%, and had the most voids, resulting in the highest porosity compared to other samples. The existence of more voids may cause pores to merge, resulting in larger, more linked pores. Conversely, the highest density was 0.941 g/cm^3 for FC-SEMRW at 30%, which had the lowest porosity of 62.9%. This increase in density can be attributed to the fine SEMRW particles filling the voids and refining the pore structure. Such improvements in packing density and pore structure are likely to enhance the strength of FC-SEMRW. The observed decrease in porosity suggests that higher SEMRW percentages lead to better water resistance due to the reduction in voids. Therefore, it can be concluded that the finer SEMRW particles, when used as fillers, do not yield improved properties at low density and high porosity. The existence of more voids may cause pores to merge, resulting in larger, more linked pores. The fine SEMRW enhanced the microstructure by filling pores and increasing particle packing, resulting in a denser and less permeable aggregate-paste interface zone (ITZ). This uniform distribution and regular shape of voids contributed to the decreased trend in permeability. These findings align with those of Khan et al. (2020).[25]

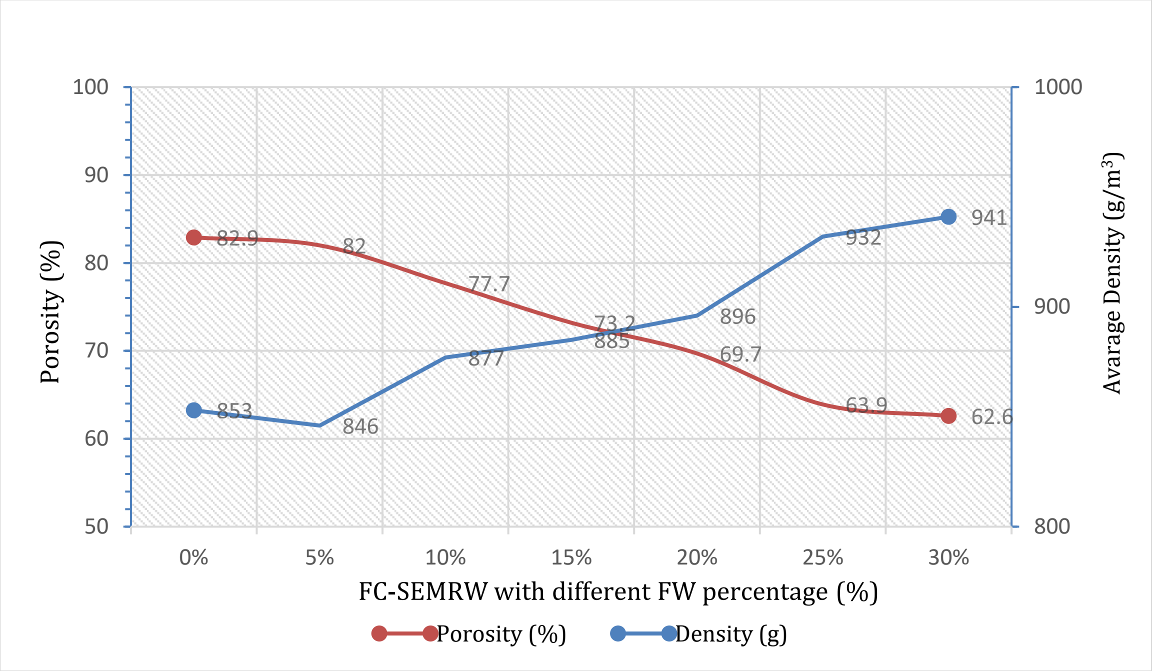

Fig 3. Average density and porosity results at different percentages of FC-SEMRW

4.2. *Compressive Strength Test Before and After Elevated Temperature.*

4.2.1. *Compressive Strength Test Before Elevated Temperature.*

Figure 3 shows the overall average results of the compressive strength for all specimens at the age of 7th and 28th days of tests before and after elevated temperature. FC-SEMRW with a 10% proportion exhibited the highest compressive strength at 7 days with 8.49 MPa, followed by FC-SEMRW 15%, 20%, 30%, 5%, 0%, and 25%. Similarly, at 28 days, FC-SEMRW 10% demonstrated the highest compressive strength with 9.88 MPa, followed by FC-SEMRW 15%, 20%, 5%, 25%, and 0%. The compressive strength of hardened concrete generally increases with curing time. Notably, foamed concrete incorporating 10% semiconductor epoxy resin waste (SEMRW) as a filler demonstrated the highest compressive strength. This composition outperformed the reference foamed concrete without SEMRW filler, indicating that SEMRW enhances compressive strength. This proves that SEMRW improves the strength as it has greater bonding strength.

The average compressive strength increased with higher ratios of FC-SEMRW up to 10%, after which it decreased. The highest compressive strength was achieved by FC-SEMRW with 10% SEMRW, likely due to the strong cohesion of matrix bonding. This is also agreed by Khan et al., (2019).[26] The highest bond strength was achieved at a 10% SEMRW concentration, showing a 2.9-fold strength enhancement compared to 0% SEMRW. This improvement is likely due to the increased effectiveness of load transfer and enhanced ductility in the modified epoxy layer at this concentration. The incorporation of SEMRW into FC beyond an optimal level of 15% leads to a reduction in compressive strength due to insufficient cementitious matrix formation. As SEMRW content increases, it diminishes the available space for cement paste, resulting in inadequate hydration and bonding, which compromises structural integrity. Additionally, higher SEMRW levels contribute to increased porosity within the FC-SEMRW mixture, as excess particles create voids that the cement paste fails to adequately fill, further weakening the material. This increased porosity, along with reduced contact area between SEMRW and cement paste, results in weaker interfacial bonding, negatively affecting stress transfer and load distribution, ultimately leading to diminished compressive strength.[27], [28]

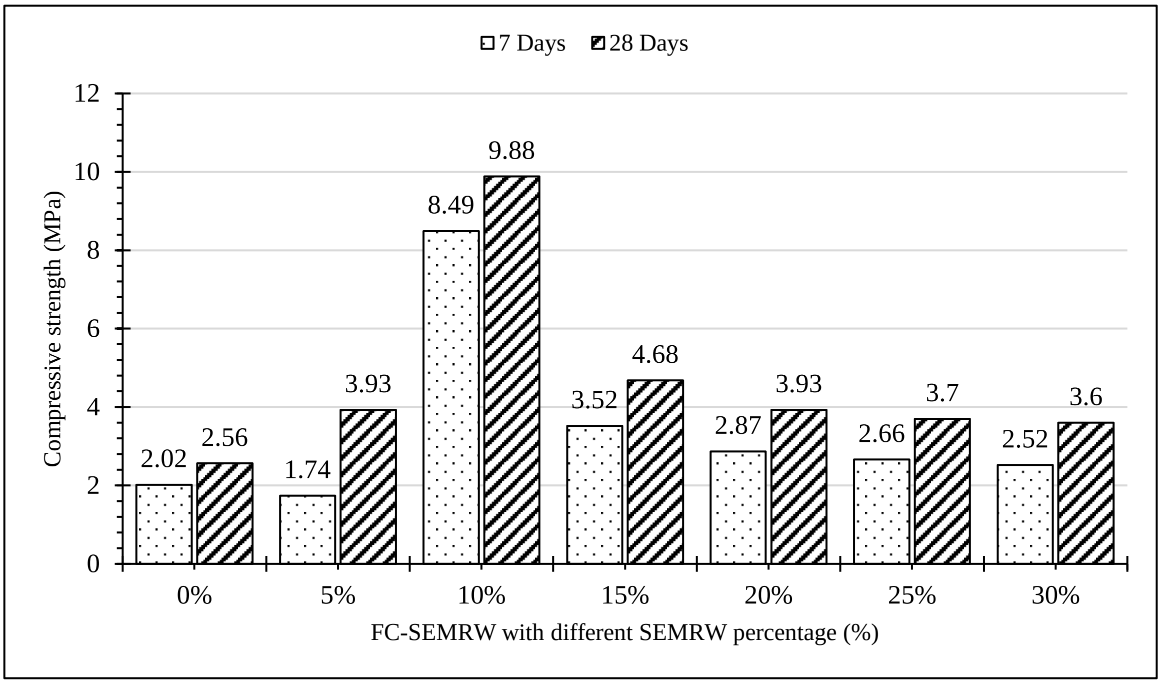

Fig 3. Compressive strength test at the age of 7 and 28 days before elevated temperature.

4.3. Compressive Strength Test After Elevated Temperature.

Figure 4 shows the data of the compressive strength test at the age of 28 days after an elevated temperature of 1000 °C for 4 hours. 10% of SEMRW composition shows the highest compressive strength value after elevated temperature with 0.59MPa while 0% of SEMRW composition obtained the lowest compressive strength with 0.11Mpa. The highest compressive strength before and after exposure to elevated temperatures was observed in FC-SEMRW with 10% composition. This was followed by FC-SEMRW compositions of 15%, 20%, 30%, 25%, 5%, and 0%, respectively. Notably, FC-SEMRW 10% demonstrated the highest resistance to compressive strength before and after being subjected to 1000 °C for 4 hours, while FC-SEMRW 0% exhibited the lowest. A drastic drop in bond strength was observed at 1000 °C compared to the compressive strength before elevated temperature.

The bond strength of SEMRW decreased with exposure to elevated temperature. Under elevated temperatures, SEMRW softened and flowed within the microstructure, partially filling the pores. This process resulted in a denser structure with higher microhardness post-exposure. The reduction in strength of FC-SEMRW at elevated temperatures can be attributed to several factors, including heat incompatibility between the mix and aggregates, the buildup of internal pressure from water evaporation during heating, and chemical changes within the mix. Micro-cracks arise from the release of both physically and chemically bound water, dehydration of the cement matrix, alterations in mineral phase transformations, and differing thermal expansion coefficients between aggregates and cement stone. The dehydration of FC-SEMRW, along with the combined effects of concrete dehydration and the formation of micro-cracks within its internal structure, are critical factors influencing the results of strength tests on concrete exposed to high temperatures. This finding aligns with the observations of Hemraj et al. (2023) [29].

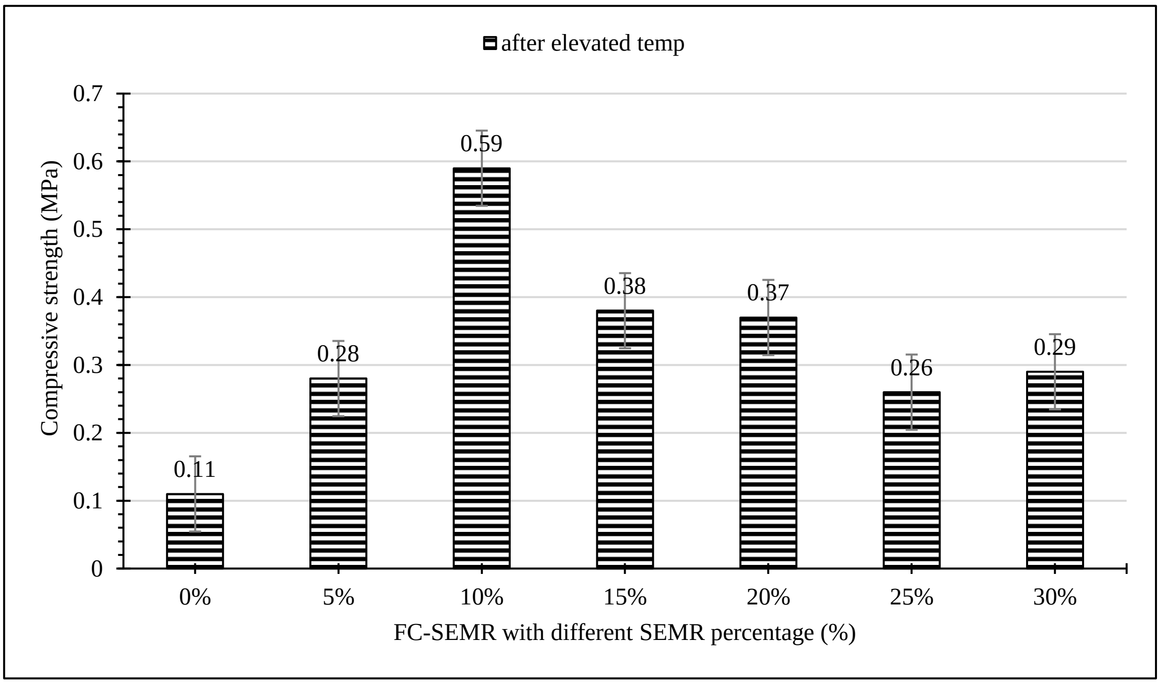

Fig 4. Compressive strength test at the age of 28 days after elevated temperature.

4.4. Tensile Splitting Strength Test

This study investigates the tensile splitting strength of cylinder samples, 100mm in diameter and 200mm in height, through tests conducted using a compressive machine. The research findings depicted in Figure 5 illustrate the tensile splitting strength outcomes after 7 and 28 days. Notably, the highest values were observed in FC-SEMRW 10%, recording 3.06MPa at 7 days and 5.95MPa at 28 days. The lowest tensile splitting strength was 0% of FC-SEMRW recording only 1.5 MPa. Subsequent concentrations of SEMRW filler in FC-SEMRW showed a trend of increasing tensile splitting strength until reaching 10% SEMRW, after which a decline ensued until 30% of FC-SEMRW. FC- SEMRW 10% achieved the highest tensile splitting strength even when its density was higher than 0%, 5%, 15%, 20%, 25% and 30%. This result corresponded with Hameed and Hamada (2020).

The FC-SEMRW 10% demonstrated higher tensile splitting strength due to its optimal composition ratio of concrete, which balanced cementitious materials, aggregates, and water, leading to a more homogeneous microstructure with dense and uniform particle distribution. This improved microstructure enhanced the interfacial bonding between the cement paste and SEMRW, resulting in increased tensile splitting strength. Furthermore, the use of smaller SEMRW particles than quartz sand in this study also led to a uniform distribution of fine particles and voids, which facilitated even load distribution, allowing the samples to withstand larger tensile forces.

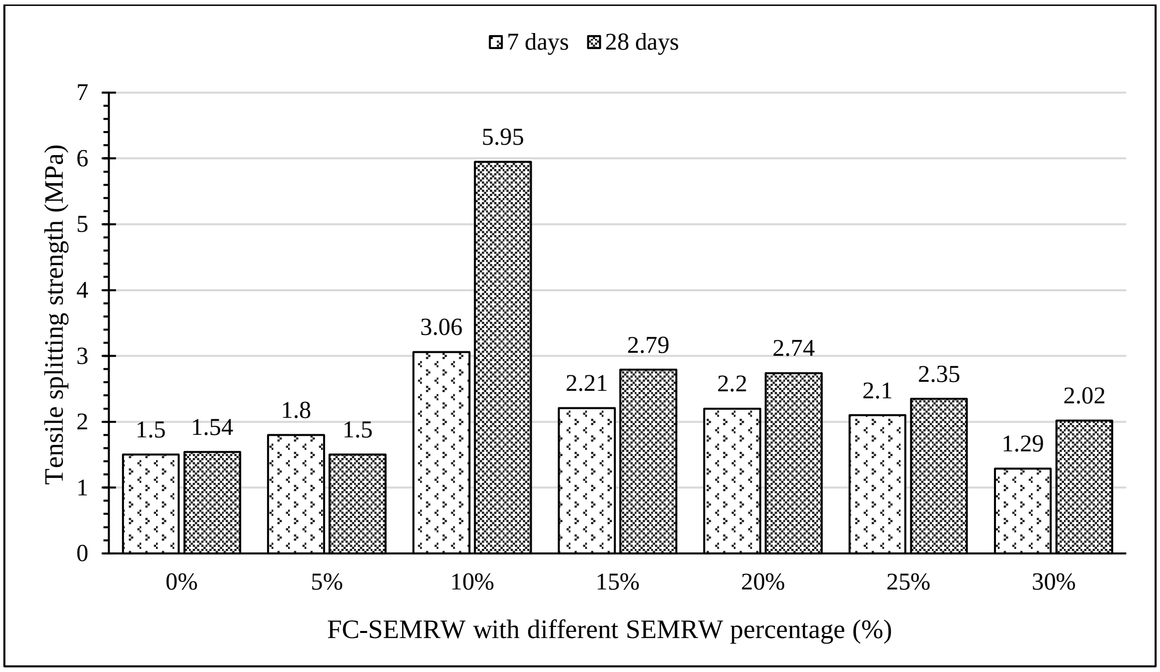

Fig 5. Tensile splitting strength results at different percentages of FC-SEMRW

5.0 Conclusion

This study aims to utilize waste materials and additives to create lightweight foamed concrete with a key emphasis on optimizing workability for construction purposes. The research concludes that a 10% composition ratio of Semiconductor epoxy moulding component resin waste (SEMRW) yields the highest performance, with compressive strength reaching 9.88MPa and tensile splitting strength reaching 5.95MPa, alongside appropriate density and porosity values compared to other samples. These results indicate the potential of SEMRW in various applications within foamed concrete, offering environmental benefits and contributing to sustainability in the construction sector.

References

[1] S. Elbialy, “Compressive Strength Evaluation of Cured Cement Mortar including Rubber, Foam, Plastic, and Paper Wastes as Partial Replacement with Sand,” *Journal of Sustainable Cities and Built Environment*, vol. 01, no. 01, Jan. 2023, doi: 10.58757/jscbe.cseccmir.002.

[2] M. Abd Elrahman, P. Sikora, S. Y. Chung, and D. Stephan, “The performance of ultra-lightweight foamed concrete incorporating nanosilica,” *Archives of Civil and Mechanical Engineering*, vol. 21, no. 2, May 2021, doi: 10.1007/s43452-021-00234-2.

[3] M. Kozłowski and M. Kadela, “Mechanical Characterization of Lightweight Foamed Concrete,” *Advances in Materials Science and Engineering*, vol. 2018, 2018, doi: 10.1155/2018/6801258.

[4] S. N. HashemMoniri and F. Usman, “Characteristics of Lightweight Foamed Concrete Brick Mixed with Fly Ash,” *International Journal of Civil Engineering*, vol. 6, no. 3, pp. 22–28, Mar. 2019, doi: 10.14445/23488352/ijce-v6i3p103.

[5] Z. Cao *et al.*, “Experimental study on the effect of basalt fiber reinforced expanded polystyrene foams on the compressive strength of lightweight concrete,” *AIP Adv*, vol. 14, no. 3, Mar. 2024, doi: 10.1063/5.0193756.

[6] Schumacher Katrin, Saßmannshausen Nils, Pritzel cHristian, and Trettin Reinhard, “Lightweight aggregate concrete with an open structure and a porous matrix with an improved ratio of compressive strength to dry density”.

[7] W. C. Huang, C. M. Hsu, and C. F. Yang, “Recycling and refurbishing of epoxy packaging mold ports and plungers,” *Inventions*, vol. 1, no. 2, Jun. 2016, doi: 10.3390/inventions1020011.

[8] A. D. K.-T. Lam *et al.*, *Information and Innovation for Modern Technology : proceedings of the 2017 IEEE International Conference on Information, Communication and Engineering (IEEE-ICICE 2017), Xiamen, Fujian, P.R. China, November 17-20, 2017*.

[9] “Effects of waste rubber powder and resin content on the free shrinkage of”.

[10] S. Y. Lee and T. H. M. Le, “Feasibility of Sustainable Asphalt Concrete Materials Utilizing Waste Plastic Aggregate, Epoxy Resin, and Magnesium-Based Additive,” *Polymers (Basel)*, vol. 15, no. 15, Aug. 2023, doi: 10.3390/polym15153293.

[11] M. Kazemi, S. Faisal Kabir, and E. H. Fini, “State of the art in recycling waste thermoplastics and thermosets and their applications in construction,” Nov. 01, 2021, *Elsevier B.V.* doi: 10.1016/j.resconrec.2021.105776.

[12] L. Brunnbauer *et al.*, “Classification of epoxy molding compounds by Tandem LA-ICP-MS/LIBS to enhance the reliability of electronic devices,” *Spectrochim Acta Part B At Spectrosc*, vol. 207, Sep. 2023, doi: 10.1016/j.sab.2023.106739.

[13] IJI M., “Recycling of epoxy resin compounds for moulding electronic components.”

[14] A. Inamdar, Y. H. Yang, A. Prisacaru, P. Gromala, and B. Han, “High temperature aging of epoxy-based molding compound and its effect on mechanical behavior of molded electronic package,” *Polym Degrad Stab*, vol. 188, Jun. 2021, doi: 10.1016/j.polymdegradstab.2021.109572.

[15] A. Kausar, “Role of Thermosetting Polymer in Structural Composite,” *Issue 1 Kausar A. American Journal of Polymer Science & Engineering*, vol. 5, pp. 1–12, 2017, [Online]. Available: http://www.ivyunion.orghttp://www.ivyunion.org/index.php/ajpse/http://www.ivyunion.org

[16] D. H. Kim, A. Yu, and M. Goh, “Oxidative chemical depolymerization of thermoset epoxy resin for green recycling,” *Journal of Industrial and Engineering Chemistry*, vol. 96, pp. 76–81, Apr. 2021, doi: 10.1016/j.jiec.2021.01.047.

[17] E. Morici and N. T. Dintcheva, “Recycling of Thermoset Materials and Thermoset-Based Composites: Challenge and Opportunity,” Oct. 01, 2022, *MDPI*. doi: 10.3390/polym14194153.

[18] K. Jin, H. Luo, Z. Wang, H. Wang, and J. Tao, “Composition optimization of a high-performance epoxy resin based on molecular dynamics and machine learning,” *Mater Des*, vol. 194, Sep. 2020, doi: 10.1016/j.matdes.2020.108932.

[19] M. A. Shrivastava and P. L. P. Shrivastava, “A STUDY ON FLY ASH-BASED POLYMER CONCRETE WITH EPOXY RESIN & GLASS FIBER: A BRIEF REVIEW,” *© 2020 IJRTI* |, vol. 5, no. 10, 2020, [Online]. Available: www.ijrti.org

[20] A. Firda and A. Saggaff, “ARTIFICIAL AGGREGATE USING POLYMER EPOXY RESIN AND FLY ASH.” [Online]. Available: https://www.researchgate.net/publication/368506999

[21] F. Cakir, A. Karimi, A. Ulu, and M. Gundogdu, “Effects of resins on mechanical performance of polymer concrete,” *Gradjevinar*, vol. 73, no. 10, pp. 995–1006, 2021, doi: 10.14256/JCE.3187.2021.

[22] F. Salari *et al.*, “PERFORMANCE EVALUATION OF PALM OIL CLINKER AS CEMENT AND SAND REPLACEMENT MATERIALS IN FOAMED CONCRETE,” *Journal of Civil Engineering and Management*, vol. 29, no. 8, pp. 691–713, Oct. 2023, doi: 10.3846/jcem.2023.19785.

[23] O. Gencel, T. Bilir, Z. Bademler, and T. Ozbakkaloglu, “A Detailed Review on Foam Concrete Composites: Ingredients, Properties, and Microstructure,” Jun. 01, 2022, *MDPI*. doi: 10.3390/app12115752.

[24] Hansika H., Nanayakkara A., and IEEE Sri Lanka Section, *Investigation on Properties of Cellular Lightweight Concrete Blocks with Bottom Ash*. 2019.

[25] M. N. N. Khan, A. K. Saha, and P. K. Sarker, "Reuse of waste glass as a supplementary binder and aggregate for sustainable cement-based construction materials: A review," Mar. 01, 2020, *Elsevier Ltd*. doi: 10.1016/j.jobe.2019.101052.

[26] Khan S. Qasim, Sheikh m. naez, mccarthy timonthy J., Robati Mehdi, and Allen Mark, "Experimental investigation on foam concrete without and with recycled glass powder: a sustainable solution for future construction".

[27] I. A. Manaf *et al.*, "Compressive strength, sound absorption coefficient (SAC) and water absorption analysis of HDPE plastic waste reinforced polystyrene and Portland cement for lightweight concrete (LWC)," in *Journal of Physics: Conference Series*, IOP Publishing Ltd, Oct. 2021. doi: 10.1088/1742-6596/2051/1/012043.

[28] I. A. Manaf, N. Marsi, H. H. Shariff, and N. Kassim, "Influence of Recycled Glass Ceramic Waste on Physical and Mechanical Properties of Foamed Concrete," *International Journal of Integrated Engineering*, vol. 14, no. 8, pp. 55–66, 2022, doi: 10.30880/ijie.2022.14.08.008.

[29] H. Kumavat, "Experimental study on behavior of normal strength concrete influenced by elevated temperatures."

Acknowledgments

The authors would like to thank the Ministry of Higher Education Malaysia for supporting this research under the Fundamental Research Grant Scheme (FRGS)(FRGS/1/2021/STG08/UTHM/03/1) kod K397, partially sponsored by Universiti Tun Hussein Onn Malaysia kod K397. The research was supported by the GPPS Grant Vot. Q569. The author also acknowledges the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), and Kim Hoe Thye Industries Sdn Bhd for the equipment and technical assistance. The authors are grateful for the fruitful discussions and input UTHM staff brought to the project