International Journal of
Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 25 (June 2026) PP. 388-407

International Journal of Innovation and Industrial Revolution (IJIREV)
eISSN: 2637-0972

INTERNATIONAL JOURNAL OF
INNOVATION AND
INDUSTRIAL REVOLUTION
(IJIREV)
www.gaexcellence.com/ijirev

GLOBAL ACADEMIC EXCELLENCE

DENSITY AND COMPRESSIVE STRENGTH OF LIGHTWEIGHT CONCRETE CONTAINING HYBRID FIBRE REINFORCEMENT

Izzat Anuar[1], Muhammad Assyahmizi Mohd Yunus[2]*, Ahmad Faisol Yusof[3], Mohd Zikri Mohd Zaki[4]

[1]Department of Built Environment Studies and Technology, Faculty of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610 Seri Iskandar, Perak, Malaysia
✉ izzat731@uitm.edu.my https://orcid.org/0009-0000-7913-2492

[2]Department of Built Environment Studies and Technology, Faculty of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610 Seri Iskandar, Perak, Malaysia
✉ assyahmizi@uitm.edu.my https://orcid.org/0009-0009-0968-1862

[3]Department of Built Environment Studies and Technology, Faculty of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610 Seri Iskandar, Perak, Malaysia
✉ ahmad860@uitm.edu.my https://orcid.org/0000-0002-3595-9989

[4]Department of Built Environment Studies and Technology, Faculty of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610 Seri Iskandar, Perak, Malaysia
✉ zikri203@uitm.edu.my https://orcid.org/0009-0007-0042-1920

*Corresponding Author

Article Info:

Article history:
Received date: 30.04.2026
Revised date: 17.05.2026
Accepted date: 21.06.2026
Published date: 30.06.2026

To cite this document:

Anuar, I., Yunus, M. A. M., Yusof, A. F., & Zaki, M. Z. M. (2026). Density And Compressive Strength of Lightweight Concrete Containing Hybrid Fibre Reinforcement. *International*

Abstract:

Lightweight concrete (LWC) has advantages of lower self-weight and better thermal efficiency, yet its limited mechanical performance restricts its broader use in structural fields. This study attempts to investigate the effect of hybrid micro-synthetic fibre reinforcement on physical and mechanical properties of LWC, namely density and compressive strength under open-air curing conditions. Control (no fibre), single-fibre (0.5% PP and 0.5% nylon) and hybrid-fibre mixes were prepared by adding polypropylene (PP) and nylon fibres at total volume fractions of 0.20%, 0.25% and 0.30%, respectively, while maintaining a constant 1:1 ratio of PP to nylon. The findings showed that the insertion of hybrid fibres resulted in a modest increase in the density of LWC because of improved packing of the matrix and reduction of air voids. Moreover, the compressive strength showed a remarkable improvement compared to the control and single-fibre mixes, with the best performance obtained at 0.20% and 0.30% hybrid fibre contents. The synergistic interaction of PP and nylon fibres increased stress transfer, crack-bridging capability and microstructural

Journal of Innovation and Industrial Revolution, 8(25), 388-407.

stability, providing evidence of the potential of hybrid fibre-reinforced LWC as a sustainable material for semi-structural applications.

DOI: 10.35631/IJIREV.825024

Keyword:

Compressive Strength, Density, Hybrid Fibre, Lightweight Concrete, Structural

Introduction

Green building methods have been slowly accepted in Malaysia, with a focus on sustainable materials and sophisticated construction technology (Effendi Amran et al., 2019; Liu et al., 2021). The building industry is important for economic growth but has a large negative impact on the environment. Environmental repercussions arise throughout each stage of construction, operation and destruction, resulting in pollution, waste production and pressure on infrastructure. The building industry has been gradually moving towards sustainable practices and environmental damage remediation to reduce these impacts (Mahyuddin et al., 2024). Lightweight concrete (LWC), especially lightweight foamed concrete (LFC), has garnered significant interest in the Malaysian building sector owing to its lower self-weight, ease of handling, cost-effectiveness, and thermal insulation features (Alshannag et al., 2023; Lu, 2023).

LWC promotes energy-efficient architecture by decreasing structural dead loads, which decreases foundation cost and improves construction efficiency (Mousa et al., 2018). These characteristics make LWC a suitable material for sustainable and semi-structural applications. However, LWC is usually characterised by lower compressive strength and higher brittleness than normal-weight concrete (NWC), which limits its use in structural and semi-structural members (Anuar et al., 2025; Guler, 2018; Shahpari et al., 2022). The porous properties result in greater water absorption and decreased durability, while the higher water/binder ratios affect the workability and cause segregation (Liu et al., 2021). Moreover, the brittleness of LWC increases with the increase of compressive strength, which leads to the decrease of tensile and flexural strength (Kaplan et al., 2021). Hence, the development of improved LWC systems with both lightweight characteristics and enough mechanical performance is still a problem in sustainable building.

To overcome these limitations, fibre reinforcement has been successfully used as a modification technique. Fibres help to reduce cracking, increase tensile strength and enhance post-cracking performance. Man-made fibres such as polypropylene (PP) and nylon are widely used because of their low density, chemical resistance and thermal stability. When included into LWC, these fibres may bridge microcracks, improve the adhesion between the cement matrix and aggregates and reduce the internal porosity, thereby increasing the mechanical strength of the material (Effendi Amran et al., 2019; Jhatial et al., 2018). Furthermore, increasing the microstructure and transport properties of LWC, such as permeability, diffusivity, and moisture migration, is vital to ensure long-term durability and effectiveness (Azzmi et al., 2025). The use of polymeric materials or synthetic fibres may also greatly reduce permeability and enhance resistance to environmental degradation, thereby improving the overall structural integrity of LWC.

Recent studies have shown that hybrid fibre reinforcement, which is a combination of several fibre types, may achieve synergistic advantages by using the specific physical and mechanical characteristics of each fibre type (Liu et al., 2021). For instance, PP fibres, apart from having lower modulus and density, also provide better toughness and fracture control, while nylon fibres, because of their higher tensile strength and elasticity, assist in load distribution and increase ductility. The tuning of hybrid fibre volume fractions in LWC is yet insufficiently researched, notably in the widely used open-air curing conditions in the local sector. The aim of this study is to evaluate the effect of hybrid microsynthetic fibres on the physical and mechanical characteristics of LWC, especially density and compressive strength. The experimental programme included control mixtures (fibre-free), single-fibre mixes with 0.5% PP or nylon and hybrid-fibre mixes with volume fractions of 0.20%, 0.25% and 0.30% in a constant 1:1 PP-to-nylon ratio. The findings are anticipated to define the optimum dose of hybrid fibres to enhance the compressive strength without compromising the lightweight qualities, thereby enabling the development of more efficient and sustainable LWC for semi-structural applications.

Classification of Lightweight Concrete

Chen & Liu (2005) report that the density of LWC ranges from 1400 to 2000 kg/m³. Nensok et al. (2021) stated that LWC possesses a density range of 400-1900 kg/m³, corroborated by prior research from Elshahawi et al. (2021). Structural LWC is classified by a density range of 800 to 1900 kg/m³, while ultra-light foamed concrete (ULFC) is defined by a density range of 400 to 800 kg/m³. The density of NWC varies between 2300 and 2400 kg/m³ (Uysal et al., 2004). The generally recognised definition of LWC is concrete with a density under 2,000 kg/m³ (Guler, 2018; Mousa et al., 2018). The density of LWC is stipulated to range from 800 to 2000 kg/m³, as per the EN 206-1 standard. The specified compressive strength and density for this study are 800-1350 kg/m³, with a range of 7-14 MPa for medium-density hybrid fibre-reinforced LWC, as per Chaipanich & Chindaprasirt (2015).

The construction industry can improve the mechanical quality and longevity of building materials by employing accessible fibres. Khan & Ali (2016) that using fibres in LWC could improve its mechanical characteristics, durability, ductility, performance, and energy absorption capacity. This addition does not significantly affect the material's workability. Mousa et al. (2018) assert that adding fibres to LWC significantly improves the mechanical characteristics and durability of the resulting product. The integration of diverse fibres into concrete, particularly lightweight mixtures, can alleviate this constraint by enhancing the material's energy absorption capability after matrix breakdowns (Mydin, 2022). Navilesh J (2017), classifies fibres into two separate categories, as presented in Table 1.

Table 1: The Two Categorizations of Fibres

No	Categorizations of Fibres
1	Fibres whose moduli are lower than the cement matrix, such as cellulose, nylon, polypropylene, etc.
2	Fibres with higher moduli than cement, such as asbestos, glass, steel, etc.

Source: (Navilesh J, 2017)

Shahpari et al. (2022) establish that different fibres enhance the brittleness of high-strength LFCs, suggesting that all fibres augment ductility, toughness, and tensile strength when applied at optimal dosages. The use of hybrid fibres of varying sizes and proportions synergistically enhances the brittleness of LFC compared to a single fibre type.

Influence of Hybrid Fibres on Fresh Concrete Properties

The heightened utilisation of high-strength concrete (HSC) and the environmental and economic advantages of LWC have sparked renewed interest in employing fibres to mitigate brittle failure. However, more research is needed, even though the benefits in this field are clear. Such an issue is due to the range of quality and options within each fibre type and the variety of sources for lightweight aggregates (LWA) extraction. No single fibre type can offer comprehensive support in terms of strength, ductility, and durability. The efficient application of diverse techniques to incorporate various types and dimensions of fibre in LWC has enhanced several material properties (Alshannag et al., 2023; Seydmoradi et al., 2024). Consequently, hybrid fibre-reinforced LWC employs microfibres to span micro-cracks, enhancing initial cracking strength and diminishing shrinkage. Macrofibres additionally mitigate macrocracks and enhance toughness and post-cracking performance (Alshannag et al., 2023).

The fibre-bridging technique, along with type, shape, volume %, and tensile strength, influences the enhancement of LWC performance, as noted by (Liao et al., 2024; Nematzadeh et al., 2021). Parameters reliant on concrete, such as fibre type, diameter, shape, aspect ratio, tensile strength, elastic modulus, dosage, bonding, and chemical compatibility with the cement matrix, along with mixture proportioning, compressive strength, and density, influence the toughness and crack resistance of LFC, according to Lee & Yang (2023). This study categorises synthetic fibres based on diameter. Fibres measuring less than 0.3 mm are classified as microsynthetic, whereas those over 0.3 mm are categorised as macrosynthetic (ACI Committee 544. & American Concrete Institute., 2008). Microsynthetic fibres control microcracks, while macrosynthetics may influence macrocracks and structural fractures.

Hedjazi & Castillo (2020) indicated that numerous studies have been conducted on the advantages and disadvantages of type I: steel fibre-reinforced concrete (SFRC). Glass fibre-reinforced concrete (GFRC) represents the second category. The third type of LWC, synthetic LWC, was evaluated, and nylon fibre-reinforced concrete (NFRC) was selected. The results indicate that including a suitable type and amount of fibre in LWC may significantly diminish shrinkage cracks, enhance compressive strength, improve impact and shatter resistance, and promote homogeneity. The study found a satisfactory correlation between fibre volume percentage and fibre tensile strength with the splitting and flexural strengths of LWC. Peng et al. (2025) assert that the unit weight of new LWC is influenced by the specific gravity of the fibres and their content. These variables could potentially impact the pulse velocity of LFC specimens. According to Amizah & Jusoh (2017) based on their reference Qian and Stroeven (2000), an analysis was conducted on the mechanical properties of LFC reinforced with hybrid fibres. The strands consisted of micro-synthetic PP and other steel filaments. The study revealed that the incorporation of 6 mm-long steel fibres enhanced the compressive strength of LWC more significantly than its tensile strength. The post-cracking strength of the hybrid fibre matrix was primarily enhanced by the incorporation of longer steel fibres (30 mm and 40 mm). Sivanantham et al. (2022) investigated the mechanical properties of HSC reinforced with 30 mm steel fibres and 6–20 mm non-metallic fibres. Their investigation indicated that steel and PP fibres surpassed all other hybrid fibre combinations in every evaluated category. In comparison to NWC, HSC's use of steel and synthetic fibres enhanced many mechanical properties, including compressive strength, strain at peak stress, ultimate strain, and toughness index.

Bulk Density

LWA are extensively used in the production of LWC because of their markedly decreased bulk density, which results in less dead load and enhanced thermal and acoustic properties (Aslam et al., 2024). NWC generally possesses a density of 2300–2400 kg/m³, while LWC can vary from 300 to 1840 kg/m³ depending on its design and use (Chinnu et al., 2021). LFC, a variant of LWC that includes a foaming agent, is classified by density for structural appropriateness. The air-dry density is often approximately 80 kg/m³ less than the wet density (Lamond & Pielert, 2006). The study categorised LFC applications from 300 to 1800 kg/m³ into four density-based categories, as stated by Abdulameer (2015) based on his reading from Liew (2005), as shown in Table 2.

Table 2: LFC Applications According to Density

Density (kg/m³)	Applications
300-600	Thermal insulation (roofs and floors), cavity wall fill, general sound and heat insulation.
600-900	Roofing slabs, floors for stables/poultry farms, internal partition panels, cool room walls/roofs.
900-1200	Structural and non-structural blocks/panels for external walls, industrial soundproofing.
1200-1800	Medium-weight blocks and slabs, reinforced/precast walls and floor panels.

Source: (Abdulameer, 2015)

Compressive Strength

Compressive strength is a standard statistic for evaluating the quality of a construction project. “Capacity” refers to a material’s ability to support a load without reducing particle size. Halvaei et al. (2016) discovered that incorporating natural fibres such as jute, hemp, pineapple, basalt, sisal, and banana into concrete improves its mechanical properties and reduces crack propagation. Ramkumar et al. (2020) evaluated the mechanical properties and durability of hybrid fibre concrete incorporating PP, sisal, and banana fibres. The study revealed that compressive strength increased by 24.3% and 14.9% relative to control after 7 and 28 days of curing with 1.5% PP fibre and 0.5% sisal fibre, respectively. Similarly, Ammari et al. (2020) reported that hybrid fibres significantly increased the compressive strength of concrete. Excessive fibres (exceeding 1%) may increase porosity (density is not significantly enhanced) and may induce microcracks that compromise cement integrity. Incorporating fibres in LWC seems to enhance compressive strength to an optimal degree. Ammari stated that 30 kg/m³ of fibre yields optimal compressive strength.

According to Chaipanich & Chindaprasirt (2015), LWC is often 393ategorized based on its density and associated compressive strength to identify appropriate functional applications in the building industry. Table 3 delineates the conventional classification of LWC types.

Table 3: Classification of LWC by Density and Compressive Strength

Type of LWC	Density Range (kg/m³)	Compressive Strength Range (MPa)	Typical Application
Low-density	300-800	0.7-2	Non-structural uses such as insulation and void filling.
Medium-density	800-1350	7-14	Semi-structural elements such as walls and partition panels.
Structural	1350-1920	17-63	Load-bearing structural components.

Source: (Chaipanich & Chindaprasirt, 2015)

Methodology

This chapter outlines the experimental program and laboratory procedures established to achieve the research objective of creating hybrid fibre-reinforced LWC for semi-structural applications. The attributes of the constituent materials are initially analysed, with an emphasis on the geometry and qualities of PP and nylon fibres. Comprehensive details about the LWC mix design, fibre incorporation methods, mixing sequence, open-air curing protocol, and specimen preparation are included. This chapter defines the test methodologies and performance standards employed to assess the mechanical properties of hybrid fibre-reinforced LWC, ensuring a thorough examination of all aspects of the experimental approach.

Experimental Program Design

All experimental test procedures in this work were performed in full accordance with relevant British Standards, unless specified otherwise. Density and compressive strength are included as the main performance indicators in this study since these properties are important to evaluate the suitability of LWC for semi-structural applications. Optimised ratios of micro-synthetic PP and nylon fibres were used in the hybrid LWC mixes to achieve the targeted lightweight density range and increase the compressive strength. This study uses a strategy that is divided into numerous important stages, shown in the flowchart in Figure 1.

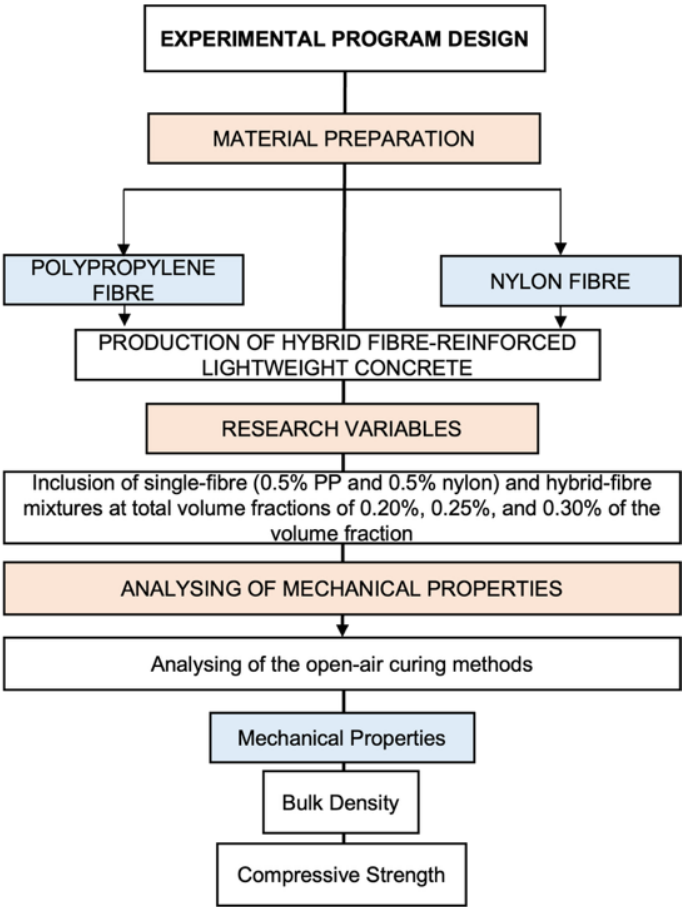

Figure 1: Flowchart of the Methodology

Source: (Anuar et al., 2026)

The selection of PP and nylon fibres was based on their known compatibility with LWC and their synergistic reinforcing characteristics in hybrid systems, respectively. PP fibres are efficient in controlling plastic shrinkage and reducing early microcracks owing to their hydrophobic and crack-bridging properties (Blazy et al. 2021), whereas nylon fibres offer higher tensile strength and better bonding with the matrix due to their moisture absorption capacity (Ahmad et al., 2021). These characteristics are essential for improved compressive load transmission and minimum void nucleation inside LWC. In this investigation, the hybrid fibre volume fractions used were 0.20%, 0.25% and 0.30% with the ratio of PP and nylon at 1:1 to maintain balanced reinforcement and workability. This dosage range was chosen based on preliminary mixing assessments to minimise fibre agglomeration and excessive porosity, which might negatively influence density. Open-air curing conditions were also used to imitate genuine building settings where water curing may not be practical. This curing process allows for the evaluation of real performance properties, especially the density stability and compressive strength development of LWC. The purpose of this hybrid fibre approach is to improve the physical and mechanical properties of LWC by improving the matrix compaction, stress distribution and microstructural integrity.

Materials

The main binder 394tilized in this investigation was Ordinary Portland Cement (OPC) in compliance with BS 12:1991 (ASTM Type 1). The fine aggregate was premium natural river sand to ensure the combination of uniformity and consistency. The mixing water was supplied from a municipal supply nearby, and it was found to comply with the requirements for concrete production. The LWC was 395tilized395ed using a protein-based foaming agent (PM-2) (Figure 2) that was locally 395tilized395ed to ensure accessibility and repeatability. The foaming compound was diluted with water as 1:30 and aerated to produce a stable foam with a density of 65 to 68 kg/m³. The foam was a fundamental step in the development of the air-void structure of the LWC that allowed the low density required and the stability of the mixture. This study used micro-synthetic fibres made of PP and nylon. Both fibre types were chosen for their synergistic properties, PP fibres for fracture resistance and hydrophobic stability, and nylon fibres for enhanced tensile strength and ductility. The fibres were included in the LWC matrix as single-fibre and hybrid-fibre systems to assess their impact on the density and compressive strength of the material during open-air curing conditions. Table 4 and Figure 3 summarise the physical and mechanical parameters of all constituent materials, while Figure 4 depicts the appearance and shape of the micro-synthetic fibres 395tilized in the experimental programme.

Table 4: Develop Appropriate Mix-Concrete Design and Mixing Procedure

No.	Constituent of Materials	Description
1	Cement	Ordinary Portland Cement (OPC) which complies with BS 12: 1991
2	Fine Natural Aggregate	River sand max. size 2.36 mm
3	Water	Plain water
4	Foaming Agent	Diluted in water at a ratio of 1:30. Density of 65 - 68 kg/m³
5	Fibre	Multi-Filament (PP) length 12 mm and Nylon Fibres. Length 6 mm

Source: (Anuar et al., 2026)

Figure 2: Protein Based Foaming Agent (PM-2)

Source: (Anuar et al., 2026)

Figure 3: All Constituent Materials

Source: (Anuar et al., 2026)

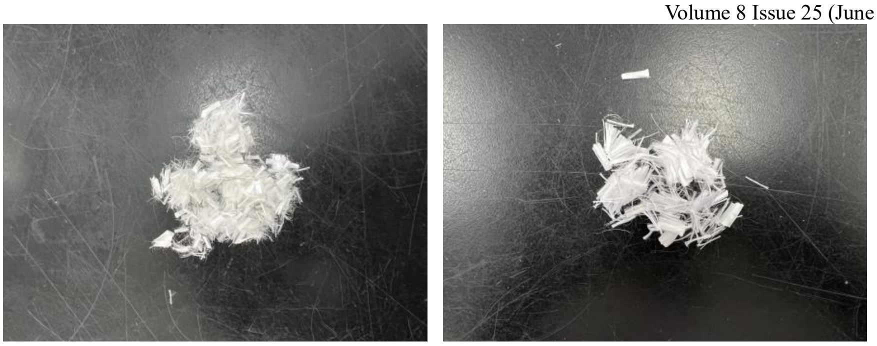

Figure 4: Micro-synthetic Fibres Nylon (Left) and PP (Right)

Source: (Anuar et al., 2026)

Mixture Proportions and Specimen Preparation

This study aimed to produce and evaluate hybrid fibre-reinforced LWC specimens capable of attaining a wet density of 1450 kg/m³. The main aim was to examine the influence of PP and nylon fibres on the mechanical and durability characteristics of LWC with hybrid fibres during the curing process. Furthermore, six separate experimental groups were established by a design incorporating two varying volume fractions. A group that received no fibres functioned as a control mixture to evaluate the performance of the other groups. Table 5 presents the details of mixing proportion design. Figure 5 illustrates that the sample preparation technique adheres to the stipulations established by the British Standard.

Table 5: Details of Mixing Proportion

Specimen	**Design Density (kg/m³)**	**Cement (kg/m³)**	**Sand (kg/m³)**	**Water (kg/m³)**	**Foam (kg/m³)**	**Volume Fraction of Fibre (%)**	
						PP fibre	**Nylon fibre**
Control Mix	1450	583.62	583.62	262.63	46.69	-	-
Single PP Fibre						0.50	-
Single Nylon Fibre						-	0.50
Hybrid Fibres 1						0.30	0.20
Hybrid Fibres 2						0.25	0.25
Hybrid Fibres 3						0.20	0.30

Source: (Anuar et al., 2026)

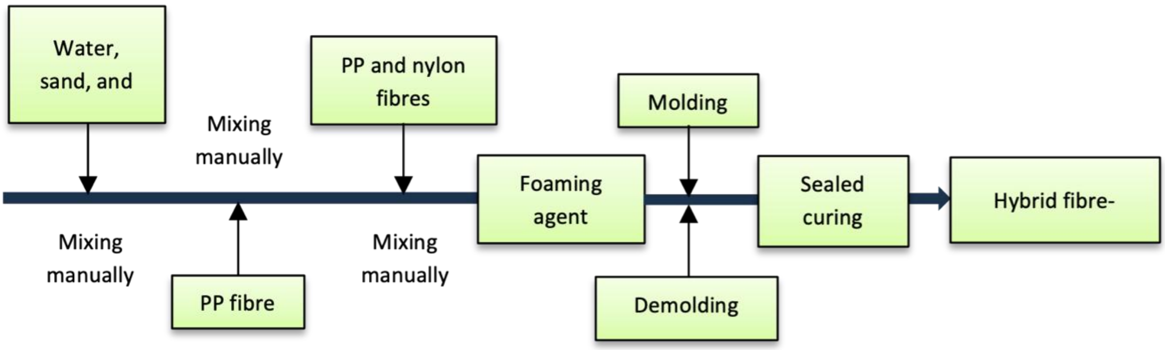

Figure 5: The Sample Preparation

Source: (Anuar et al., 2026)

Bulk Density

The volume of the hardened LWC specimens was ascertained using the Buoyancy Balance and water displacement method, as per BS 1881-114 (1983), as shown in Figure 6. The density of the LWC specimens was thereafter computed utilising the relevant equations, Equation 1 and Equation 2.

$$V = \frac{ma - mw}{Pw} \tag{1}$$

and

$$P = \frac{ma}{v} \tag{2}$$

Where V is the volume of the specimen, in m³, ma is the mass of the specimen in air, in kg, mw is the apparent mass of the immersed specimen, in kg, and Pw is the density of water, at 20 °C, taken as 998 kg/m³.

Figure 6: Bouyance Balance

Source: (Anuar et al., 2026)

Compressive Strength Test

Compressive strength is a primary indicator of the hardened characteristics of LWC, as it is easily assessed and immediately affects other mechanical properties, including flexural and tensile strength. This test was conducted to evaluate the ability of LWC to resist axial force without failure. The main cause of structural cracking in concrete is the onset and propagation of cracks. The compressive strength test was performed on 100 mm cube specimens under uniaxial stress in accordance with BS EN 12390-3 (2009). The test was performed using a universal testing device GT-7001-LCU with a maximum load capacity of 50 kN (see Figure 7). The load was increased at a constant rate of 3.0 N/sec till failure. For the compressive strength values, the average of three specimens was taken at 7, 21 and 28 days of open-air curing to ensure the data dependability. The compressive strength of the specimens was obtained from Equation 3 as the ratio of the maximum applied force to the cross-sectional area of the cube.

$$f_c = \frac{F}{A} \tag{3}$$

Where f_c is the is the compressive strength, in megapascals (N/mm²), F is the maximum load at failure, in newtons, and A is the cross-sectional area of the specimen on which the compressive force acts, calculated from the designated size of the specimen.

Figure 7: Compressive Strength Test

Source: (Anuar et al., 2026)

Result and Discussion

This section elucidates and analyses the experimental results for the bulk density and compressive strength of LWC with hybrid fibre reinforcement. The investigation examines the impact of incorporating PP and nylon fibres, both individually and in hybrid combinations, on the physical and mechanical properties of LWC during open-air curing conditions. Five mix designs were analysed (as shown in Figure 8): the control mix, devoid of fibres; single-fibre mixes incorporating PP and nylon fibres with fibre volume fractions of 0.50% separately; and three hybrid-fibre mixes with total fibre volume fractions of 0.20%, 0.25%, and 0.30%, retaining a 1:1 ratio of PP to nylon. The results aim to clarify the relationship between fibre content, density, and compressive strength to determine the optimal hybrid fibre dosage for enhancing the semi-structural efficiency and performance of LWC.

Figure 8: Mix Design Specimens

Source: (Anuar et al., 2026)

Bulk Density

Table 6 and Figure 9 show the average bulk density values of the three specimens evaluated at each curing age (7, 21 and 28 days) for all LWC compositions with varying fibre volume percentages under open-air curing circumstances. The measured bulk densities ranged from 1210 to 1765 kg/m^3. The bulk density was improved by the introduction of fibre compared to the control mix, with most fibre-reinforced concrete mixtures being in the density range typically associated with semi-structural LWC (800 - 1350 kg/m^3), as proposed by Chaipanich & Chindaprasirt (2015). Figure 10 shows the bulk density testing equipment and the specimen measuring process used to determine the density of the LWC specimens.

Table 6: Bulk Density of Hybrid Fibre-Reinforced LWC

Specimen	Density (kg/m^3)		
	7	**21**	**28**
Control Mix	1210	1258	1259
Single PP Fibre	1545	1549	1543
Single Nylon Fibre	1468	1470	1472
Hybrid Fibres 1	1539	1544	1558
Hybrid Fibres 2	1539	1371	1369
Hybrid Fibres 3	1703	1726	1765

Source: (Anuar et al., 2026)

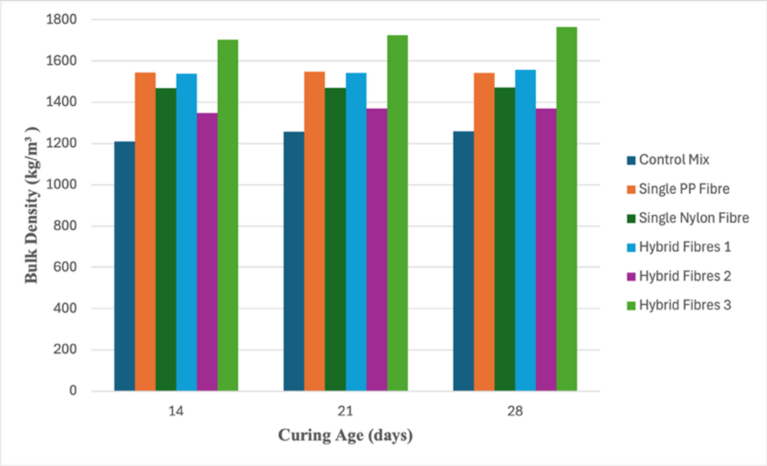

Figure 9: Development of Bulk Densities

Source: (Anuar et al., 2026)

Figure 10: Density Measurement of Control Mix (Left) and Hybrid Fibres 3 (Right) Specimens After 28 Days

Source: (Anuar et al., 2026)

Hybrid Fibres 3 had the greatest bulk density of 1703 kg/m³ at 7 days, which is an increase of almost 41% compared to the Control Mix. A similar trend was also found at 21 and 28 days when Hybrid Fibres 3 recorded the greatest densities of 1726 kg/m³ and 1765 kg/m³, respectively, which represented an increase of around 33% and 26%, respectively, compared to the Control Mix. The single-fibre combinations using PP or nylon also showed greater density values than the Control Mix, although the benefits were not as evident as in the hybrid fibre mixtures. On the other hand, Hybrid Fibres 2 showed considerably lower values of density than Hybrid Fibres 3 throughout the curing time but still greater than the Control Mix. This data indicates that the increase in the dosage of fibre or the change in the fibre combination did not necessarily lead to additional improvements in bulk density, which might be attributed to changes in fibre dispersion within the cement matrix.

The steady rise in bulk density with curing age seen in all the mixes is consistent with the continuous hydration of the cementitious matrix in an open-air curing environment, leading to hardened concrete that becomes increasingly denser. Additionally, the greater densities from hybrid fibre combinations, especially Hybrid Fibres 3, imply that the dual usage of PP and nylon microfibres had better physical performance than single-fibre reinforcement. To conclude, the findings proved that hybrid fibre reinforcement, namely Hybrid Fibres 3, significantly boosted the bulk density of LWC under open-air curing conditions. Contrary to earlier investigations mainly considering single-fibre reinforcement or controlled curing circumstances, the current work illustrates the efficiency of hybrid PP–nylon microfibre reinforcement under actual open-air curing conditions. The hybrid fibre combinations acquired better bulk density, suggesting their potential appropriateness for semi-structural and non-load bearing LWC applications where lower self-weight and enhanced dimensional stability are sought.

Compressive Strength

Table 7 and Figure 11 show the compressive strength progression of the LWC mixes cured in open air at 7, 21 and 28 days. The table displays the average compressive strength values derived from three specimens tested at each curing age for all evaluated specimens with differing fibre volume fractions under open-air curing circumstances. All specimens exhibited compressive strength values surpassing the standard range for semi-structural LWC (7 – 14

MPa) as delineated by Chaipanich & Chindaprasirt (2015), signifying a shift towards structural-grade LWC with densities over 1350 kg/m³.

Table 7: Compressive Strength of Hybrid Fibre-Reinforced LWC

Specimen	Compressive Strength (MPa)		
	7	21	28
Control Mix	2.10	2.85	2.00
Single PP Fibre	8.90	10.15	10.60
Single Nylon Fibre	5.10	5.45	6.65
Hybrid Fibres 1	6.70	7.95	8.05
Hybrid Fibres 2	3.05	3.35	3.70
Hybrid Fibres 3	8.90	9.60	10.00

Source: (Anuar et al., 2026)

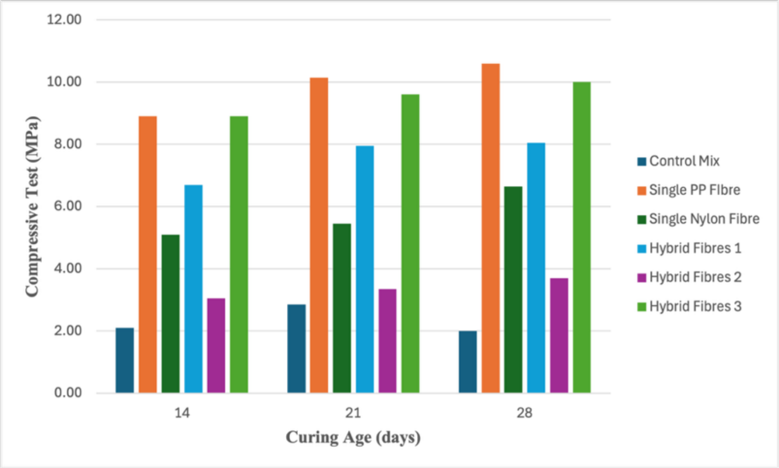

Figure 11: Development of Compressive Strength

Source: (Anuar et al., 2026)

The Control Mix had the lowest compressive strength at 7 days, 2.10 MPa. The addition of fibres significantly enhanced early-age strength. The Single PP Fibre and Hybrid Fibres 3 mixes had the maximum strength of 8.90 MPa, followed by Hybrid Fibres 1 with 6.70 MPa, Single Nylon Fibre with 5.10 MPa and Hybrid Fibres 2 with 3.05 MPa. The strength of all the fibre-reinforced mixes increased with the age of curing. The blends of single PP fibre and Hybrid Fibres 3 achieved 10.15 MPa and 9.60 MPa at 21 days, respectively. The maximum compressive strength of 10.60 MPa after 28 days was found in the single PP fibre specimen and 10.00 MPa for the Hybrid Fibre 3 specimen. The Control Mix had a minor decrease from 2.10 MPa to 2.00 MPa, which might be attributed to the moisture loss during the open-air curry. The layout of compressive strength testing is shown in Figure 12 along with the usual failure patterns of the Control Mix and Hybrid Fibres 3 specimens.

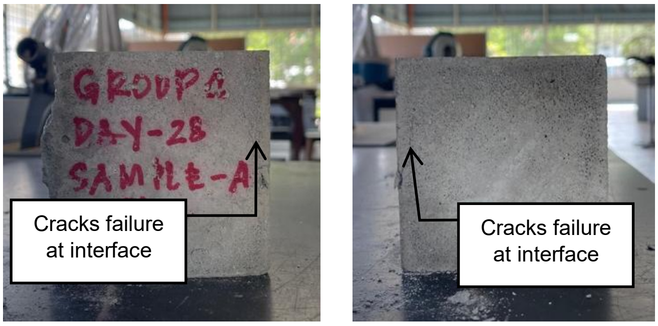

Figure 12: Cracking Behaviour of Control Mix (Left) and Hybrid Fibres 3 (Right) Specimens After 28 Days

Source: (Anuar et al., 2026)

The continual enhancement in hybrid and single-fibre compositions indicates that the incorporation of PP and nylon fibres has fortified the structural integrity of the LWC, diminishing microcrack propagation and augmenting load distribution efficiency within the matrix. These findings align closely with the bulk density measurements, indicating that hybrid fibre mixtures exhibit denser and more cohesive matrices. The relationship between increased density and enhanced compressive strength substantiates the beneficial effect of hybrid fibre reinforcement on the mechanical properties of LWC, consequently affirming its suitability for semi-structural applications in open-air curing environments.

The continual increase in strength in the fibre-reinforced mixes indicates that the PP and nylon microfibres led to an enhanced resistance to cracking during curing, in comparison to the unreinforced Control Mix. The addition of fibre improved the compressive strength significantly compared to the Control Mix. However, the maximum compressive strength of 10.60 MPa achieved in this study is comparable to the 7 – 14 MPa range reported for semi-structural LWC in the literature. This indicates that the incorporation of hybrid PP–nylon microfibres produced LWC with adequate mechanical performance for semi-structural applications, such as lightweight wall panels and other non-load-bearing building components. The greater density and compressive strength consistently attained with Hybrid Fibres 3 demonstrated that the hybrid PP-nylon fibre combination was able to establish a more advantageous balance between physical and mechanical performance during open-air curing than the other fibre combinations studied. Moreover, the current study indicates that hybrid PP-nylon microfibres may be efficient in improving the mechanical performance of LWC under actual open-air curing circumstances, unlike many of the prior studies dealing with single-fibre reinforcement or controlled curing settings.

Conclusion and Recommendations

The inclusion of fibres constantly enhanced both qualities with respect to the control mixture. Hybrid Fibres 3 showed the greatest bulk density over the curing period, with a value of 1765 kg/m³ at 28 days, an increase of around 26% compared to the control specimen. The Control Mixture after 28 days had the lowest compressive strength of 2.00 MPa and the combination with a single PP fibre was the highest at 10.60 MPa followed by Hybrid Fibres 3 with 10.00 MPa. These results show the potential of hybrid PP-nylon microfibre reinforcement for improved physical and mechanical performance of LWC under real open-air curing conditions. Previous research was mostly focused on single-fibre reinforcement or was conducted under control curing situations. This work provides insight into the efficiency of hybrid microfibre reinforcement during open-air curing, which may be used in the field. However, while there were large gains over the control mixture, the compressive strengths were still below the minimum required for structural LWC. Consequently, the developed hybrid fibre-reinforced LWC mixtures are considered suitable for semi-structural and non-load-bearing building components, where reduced self-weight, adequate mechanical strength, and improved physical performance are desirable.

In future studies comprehensive microstructural investigations should be carried out to validate the processes responsible for the increased performance of the hybrid fibre-reinforced LWC. Advanced characterisation techniques such as scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), X-ray computed tomography (XCT) or mercury intrusion porosimetry (MIP) would provide valuable evidence on fibre dispersion, fibre-matrix interaction, crack propagation and pore structure. Such studies would reinforce the interpretation of the physical and mechanical behaviour seen in the current investigation. Further optimisation of the PP and nylon fibre volume fractions is also proposed to determine the best balance between workability, density, mechanical performance and cost-effectiveness. Moreover, further research is required to explore the effects of different curing methods, such as sealed, water, steam, and membrane curing, on the long-term durability of hybrid fibre-reinforced LWC under various climatic circumstances. The created mixes should be tested for long-term durability in order to determine their feasibility for real building applications. When appropriate, these tests should look at the drying shrinkage, water absorption, permeability, carbonation resistance, chloride penetration, thermal conductivity, and freeze-thaw resistance. Finally, since the compressive strengths obtained in this study are still below the limit for structural LWC, future work should consider the use of supplementary cementitious materials, different LWA or alternative binder systems that could possibly improve strength while still benefiting from reduced density and sustainable construction.

Acknowledgements: The authors would like to express their sincere gratitude to Universiti Teknologi MARA (UiTM) Perak Branch for providing the necessary resources and support throughout the course of this research. Special appreciation is extended to Petra batch, third-year Bachelor of Science (Hons) Architecture students, for their commitment and assistance in the experimental procedures. Sincere gratitude is also extended to the technical staff of the Materials Laboratory, Faculty of Built Environment and peers who contributed valuable insights and constructive feedback, which greatly enhanced the quality of this paper.

Funding Statement: This research received financial support from *Panel Pembangunan Sumber Manusia,* Universiti Teknologi MARA (UiTM) Perak Branch. The funding body had no role in the design of the study, data collection, analysis, interpretation of results, or the decision to publish this manuscript.

Conflict of Interest Statement: The authors declare that there is no conflict of interest regarding the publication of this paper. All authors have contributed to this work and approved the final version of the manuscript for submission to the International Journal of Innovation and Industrial Revolution (IJIREV).

Ethics Statement: This study did not involve any human participants, animals, or sensitive data requiring ethical approval. The authors confirm that the research was conducted in accordance with accepted academic integrity and ethical publishing standards.

Author Contribution Statement: All authors contributed significantly to the development of this manuscript. Izzat Anuar was responsible for the conceptualization, methodology, and overall supervision of the study. Muhammad Assyahmizi Mohd Yunus and Mohd Zikri Mohd Zaki handled data collection, analysis, and interpretation of results. Ahmad Faisol Yusof contributed to the literature review, drafting, and critical revision of the manuscript. All authors read and approved the final version of the manuscript prior to submission.

References

Abdulameer, M. Z. (2015). *PROPERTIES OF FOAMED CONCRETE WITH OIL PALM ASH INCLUSION AND ITS APPLICATION AS AN INTERLOCKING MORTARLESS BLOCK*.

ACI Committee 544. & American Concrete Institute. (2008). *Guide for specifying, proportioning, and production of fiber-reinforced concrete*. American Concrete Institute.

Ahmad, J., Zaid, O., Aslam, F., Martínez-García, R., Elharthi, Y. M., Hechmi EI Ouni, M., Tufail, F. & Sharaky, I. A. (2021). Mechanical properties and durability assessment of nylon fiber reinforced self-compacting concrete. *Journal of Engineered Fibers and Fabrics*, *16*. https://doi.org/10.1177/15589250211062833

Alshannag, M., Alshmalani, M., Alsaif, A. & Higazey, M. (2023). Flexural performance of high-strength lightweight concrete beams made with hybrid fibers. *Case Studies in Construction Materials*, *18*. https://doi.org/10.1016/j.cscm.2023.e01861

Amizah, W. & Jusoh, W. (2017). *MECHANICAL PROPERTIES OF HYBRID FIBRE REINFORCED COMPOSITE CONCRETE. (HYFRCC)*. https://www.researchgate.net/publication/298281524

Ammari, M. S., Belhadj, B., Bederina, M., Ferhat, A. & Quéneudec, M. (2020). Contribution of hybrid fibers on the improvement of sand concrete properties: Barley straws treated with hot water and steel fibers. *Construction and Building Materials*, *233*. https://doi.org/10.1016/j.conbuildmat.2019.117374

Anuar, I., Ismail, S. & Saleh, A. M. (2025). Influence of Density and Compressive Strength on Intrinsic Air Permeability and Porosity of Hybrid Fibre-Reinforced Lightweight Foamed Concrete. *Semarak International Journal of Civil and Structural Engineering*, *4*(1), 31–45. https://doi.org/10.37934/sijcse.4.1.3145

Aslam, H. M. S., Rehman, A. U., Onyelowe, K. C., Noshin, S., Yasin, M., Khan, M. A., Latif, A., Aslam, H. M. U. & Hussain, S. (2024). Evaluating the mechanical and durability properties of sustainable lightweight concrete incorporating the various proportions of waste pumice aggregate. *Results in Engineering*, *24*. https://doi.org/10.1016/j.rineng.2024.103496

Azzmi, N. M., Ahzahar, N., Hashim, S. Z., Zakaria, I. B. & Jamaludin, N. (2025). TRANSPORT PROPERTIES OF CONCRETE USING DIFFERENT REPAIR MATERIALS. *Malaysian Journal of Sustainable Environment*, *12*(2), 243–254. https://doi.org/10.24191/myse.v12i2.7080

Blazy, J. & Blazy, R. (2021). Polypropylene fiber reinforced concrete and its application in creating architectural forms of public spaces. *Case Studies in Construction Materials*, *14*. https://doi.org/10.1016/j.cscm.2021.e00549

Chaipanich, A. & Chindaprasirt, P. (2015). The properties and durability of autoclaved aerated concrete masonry blocks. In *Eco-efficient Masonry Bricks and Blocks: Design, Properties and Durability* (pp. 215–230). Elsevier Inc. https://doi.org/10.1016/B978-1-78242-305-8.00009-7

Chen, B. & Liu, J. (2005). Contribution of hybrid fibers on the properties of the high-strength lightweight concrete having good workability. *Cement and Concrete Research*, *35*(5), 913–917. https://doi.org/10.1016/j.cemconres.2004.07.035

Chinnu, S. N., Minnu, S. N., Bahurudeen, A. & Senthilkumar, R. (2021). Recycling of industrial and agricultural wastes as alternative coarse aggregates: A step towards cleaner production of concrete. In *Construction and Building Materials* (Vol. 287). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2021.123056

Effendi Amran, M., Nabil Muhtazaruddin, M. & Haron, N. (2019). Progress in Energy and Environment Renewable Energy Optimization Review: Variables towards Competitive Advantage in Green Building Development. *Progress in Energy and Environment*, *8*, 1–15.

Elshahawi, M., Hückler, A. & Schlaich, M. (2021). Infra lightweight concrete: A decade of investigation (a review). *Structural Concrete*, *22*(S1), E152–E168. https://doi.org/10.1002/suco.202000206

Guler, S. (2018). The effect of polyamide fibers on the strength and toughness properties of structural lightweight aggregate concrete. *Construction and Building Materials*, *173*, 394–402. https://doi.org/10.1016/j.conbuildmat.2018.03.212

Halvaei, M., Jamshidi, M. & Latifi, M. (2016). Investigation on pullout behavior of different polymeric fibers from fine aggregates concrete. *Journal of Industrial Textiles*, *45*(5), 995–1008. https://doi.org/10.1177/1528083714551437

Hedjazi, S. & Castillo, D. (2020). Relationships among compressive strength and UPV of concrete reinforced with different types of fibers. *Heliyon*, *6*(3). https://doi.org/10.1016/j.heliyon.2020.e03646

Jhatial, A. A., Goh, W. I., Mohamad, N., Alengaram, U. J. & Mo, K. H. (2018). Effect of Polypropylene Fibres on the Thermal Conductivity of Lightweight Foamed Concrete. *MATEC Web of Conferences*, *150*. https://doi.org/10.1051/matecconf/201815003008

Kaplan, G., Bayraktar, O. Y. & Memis, S. (2021). Effect of high volume fly ash and micro-steel fiber on flexural toughness and durability properties in self-compacting lightweight mortar (SCLM). *Construction and Building Materials*, *307*. https://doi.org/10.1016/j.conbuildmat.2021.124877

Khan, M. & Ali, M. (2016). Use of glass and nylon fibers in concrete for controlling early age micro cracking in bridge decks. *Construction and Building Materials*, *125*, 800–808. https://doi.org/10.1016/j.conbuildmat.2016.08.111

Lamond, J. F. & Pielert, J. H. (2006). *Significance of Tests and Properties of Concrete and Concrete-Making Materials STP 169D*. http://www.copyright.com/.

Lee, H. J. & Yang, K. H. (2023). Compressive and flexural toughness indices of lightweight aggregate concrete reinforced with micro-steel fibers. *Construction and Building Materials*, *401*. https://doi.org/10.1016/j.conbuildmat.2023.132965

Liao, Q., Zhao, X. D., Wu, W. W., Lu, J. X., Yu, K. Q. & Poon, C. S. (2024). A review on the mechanical performance and durability of fiber reinforced lightweight concrete. In *Journal of Building Engineering* (Vol. 88). Elsevier Ltd. https://doi.org/10.1016/j.jobe.2024.109121

Liu, H., Elchalakani, M., Karrech, A., Yehia, S. & Yang, B. (2021). High strength flowable lightweight concrete incorporating low C3A cement, silica fume, stalite and macro-polyfelin polymer fibres. *Construction and Building Materials*, *281*. https://doi.org/10.1016/j.conbuildmat.2021.122410

Lu, J. X. (2023). Recent advances in high strength lightweight concrete: From development strategies to practical applications. In *Construction and Building Materials* (Vol. 400). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2023.132905

Mahyuddin, M. N., Korish Azahari, Q., Abd Rashid, M. N. & Ismail, S. (2024). DEMOLISHED WASTE INTO AN INNOVATIVE RESOURCE FOR SAND REPLACEMENT IN CONCRETE (THE DWARF TECHNIQUE). *Malaysian Journal of Sustainable Environment*, *11*(1), 301–322. https://doi.org/10.24191/myse.v11i1.1122

Mousa, A., Mahgoub, M. & Hussein, M. (2018). Lightweight concrete in America: presence and challenges. *Sustainable Production and Consumption*, *15*, 131–144. https://doi.org/10.1016/j.spc.2018.06.007

Mydin, M. A. O. (2022). Influence of Density, Porosity and Void Size on Thermal Conductivity of Green Lightweight Foamed Concrete. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *92*(2), 25–35. https://doi.org/10.37934/arfmts.92.2.2535

Navilesh J, R. B. K. S. B. K. S. P. V. A. G. (2017). A Study on Hybrid Fiber Reinforced Concrete. *International Research Journal of Engineering and Technology*. www.irjet.net

Nematzadeh, M., Maghferat, A. & Zadeh Herozi, M. R. (2021). Mechanical properties and durability of compressed nylon aggregate concrete reinforced with Forta-Ferro fiber: Experiments and optimization. *Journal of Building Engineering*, *41*. https://doi.org/10.1016/j.jobe.2021.102771

Nensok, M. H., Mydin, M. A. O. & Awang, H. (2021). Investigation of Thermal, Mechanical and Transport Properties of UltraLightweight Foamed Concrete (ULFC) Strengthened with Alkali Treated Banana Fibre. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *86*(1), 123–139. https://doi.org/10.37934/arfmts.86.1.123139

Peng, M., Huang, R., Peng, K., Wang, S. & Hai, L. (2025). Engineering properties of sustainable high strength lightweight concrete with recycled fibers. *Construction and Building Materials*, *495*. https://doi.org/10.1016/j.conbuildmat.2025.143652

Ramkumar, K. B., Kannan Rajkumar, P. R., Noor Ahmmad, S. & Jegan, M. (2020). A Review on Performance of Self-Compacting Concrete – Use of Mineral Admixtures and Steel Fibres with Artificial Neural Network Application. In *Construction and Building Materials* (Vol. 261). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2020.120215

Seydmoradi, A., Tavana, M. H. & Habibi, M. R. (2024). Investigation on the response of steel fiber reinforced lightweight aggregate concrete slab under sequential impact loading. *Engineering Failure Analysis*, *161*. https://doi.org/10.1016/j.engfailanal.2024.108221

Shahpari, M., Bamonte, P. & Jalali Mosallam, S. (2022). An experimental study on mechanical and thermal properties of structural lightweight concrete using carbon nanotubes (CNTs) and LECA aggregates after exposure to elevated temperature. *Construction and Building Materials*, *346*. https://doi.org/10.1016/j.conbuildmat.2022.128376

Sivanantham, P. A., Prabhu, G. G., Vimal Arokiaraj, G. G. & Sunil, K. (2022). Effect of Fibre Aspect-Ratio on the Fresh and Strength Properties of Steel Fibre Reinforced Self-Compacting Concrete. *Advances in Materials Science and Engineering*, *2022*. https://doi.org/10.1155/2022/1207273