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Study on the performance of GFRP strengthened, fiber reinforced lightweight foam concrete

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ABSTRACT

Regular clay bricks and concrete blocks are replaced with light-weight fibre-reinforced foam concrete modules. For light weight foam concrete, various natural and synthetic fibes are employed as micro- and macro-fibre reinforcement. Three distinct fibres were used as fibre reinforcement in this study, and their strength qualities were investigated. As microfibre reinforcement, synthetic-polypropylene fibre, natural-Jute fibre, and banana micro fibres were used at volume fractions ranging from 0.22 to 0.55 percent in the foam concrete mix. The compression behaviour of stack bonded masonry prisms was investigated in the first phase of the experiment. The second phase of research focused on the microfibre-reinforced prism, which was reinforced with multiple layers of GFRP sheets. Both jute and banana fibres added as microfiber reinforcement to the matrix, impart ductility to the brittle masonry unit and reduce the sudden failure mode of the Fibre-Reinforced Lightweight Foam Concrete (FRLWC) prism. The insertion of GFRP sheets between the masonry layers provides additional stiffness and ductility to the FRLWC masonry prism, which greatly improves the post-cracking behaviour. When compared to a standard LWC prism, failure patterns show that both synthetic and natural fibre-reinforcement provide improved fracture bridging mechanisms, which is mostly owing to the arresting of cracks by micro polypropylene, jute, and banana fibres. The GFRP layers provided between the masonry units prevented the formation of major crack planes.

1 Introduction

Lightweight structural concrete (LWC) is gaining popularity in recent days, as it significantly reduces the dead weight of masonry construction. Lightweight concrete with fiber reinforcement improves the tensile and shear strength, that imparts ductility to the brittle masonry structure, which in turn helps to improve the structural seismic behaviour. LWC are gaining popularity not only in the regular construction industry but also in the offshore and prefabricated construction industries [1]. Smaller and lighter prefabricated structural members are preferred in the offshore industry because they are easier to tow, handle, and transport. Along with the need for lightweight concrete, the concept of sustainability in concrete is becoming increasingly important. A large quantity of byproducts, such as fly ash and blast furnace slag, are produced and disposed of in the surrounding environment, resulting in pollution. Fly ash and blast furnace slag are now used as a partial replacement for ordinary Portland cement and aggregate in the production of sustainable light weight concrete [2]. Foam concrete is low density concrete which has better sound insulation and thermal resistance but less mechanical and durability characteristics due to the porosity of the foam paste. The addition of silica fumes and basalt fiber helps to improve the pore network and enhance the fiber paste matrix, which in turn increases the mechanical and durability performance of lightweight fiber reinforced foam concrete [3]. Researchers have proposed strengthening the concrete matrix with short discrete natural and synthetic fibres in the cement matrix, fibre sheets, external fibre wrapping, and fibre composites to overcome such failure [4],[5]. Microfibers due to their flexible nature, varied cross section, random orientation of fibers in the matrix and high aspect ratio can be effectively used as fiber reinforcement in concrete element, mortars and other polymer composites. The uniform distribution of fibers in different directions not only prevents microcrack formation in the elastic region, but also improves the post cracking performance of concrete and composites. Many natural fibers such as jute, kenaf, roselle, hemp, basalt, bamboo, banana, palm, coconut, sisal, etc., are also used as fiber reinforcement in concrete. Synthetic fibers such as

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polypropylene (PP), polyvinyl alcohol (PVA), acrylic, polyolefin, and polyterephthalate, etc., are used in concrete as microfiber reinforcement [6]. Despite the fact that synthetic fibres outperform plant-based natural fibres in terms of enhancing the tensile properties of concrete, the high cost of synthetic fibres drives up project costs. As a result, plant fibres are favoured, as they are low-cost, readily available, and entirely regenerative, resulting in a long-term sustainable concrete solution [7]. Many studies have recently been conducted to investigate the performance of natural and synthetic fibres in lightweight concrete [8, 9]. This section highlights a few of the research findings. Studies on the fresh properties and modulus of elasticity of carbon and Polypropylene hybrid fibers reinforced foam concrete showed that addition of 1.5 % carbon fibers increased the modulus of elasticity and also enhanced flexural toughness of foam concrete [10]. The effect of treated kenaf fibre on the durability properties of foamed concrete, specifically drying shrinkage, initial surface absorption, and weathering tests, revealed that chemical treatment of fibres helped to modify the surface morphology and thus increase the bond between the matrix and the hydration process [11]. Hybrid fiber reinforcement with poly vinyl alcohol and coir fiber at a percentage of 0.3% -0.5% showed that performance of hybrid fiber reinforcement is more effective at an optimum percentage is 0.3% [12]. The foamed concrete with a density range of 1000-1600 kg/m^3 with the addition of polypropylene fibers and silica fumes showed increase in tensile strength, creep resistance and reduced drying shrinkage [13]. The porosity, water absorption and sorptivity of foamed concrete increase with the increase in foaming agent. It also declined the mass loss and improves the mechanical property of bottom ash polypropylene fiber reinforced foam concrete [14]. The effect of PVA, PP and basalt fibers on the acoustical property of fiber reinforced alkali activated slag concrete was studied and concluded that PVA are more effective in terms of reducing the drying shrinkage compared to PP and Basalt fibers [15]. Foamed concrete with the addition of ground calcium carbonate and glass fiber showed increase in the mechanical property due to the filling effect of glass fibers in the matrix [16]. Foam concrete with fly ash and hemp fibers was carried out to study the temperature resistance, porosity, drying shrinkage, water absorption and dry unit weight. The addition of fly ash reduces the drying shrinkage and thermal conductivity of concrete [17].

According to the literature review, a large number of studies on synthetic fibre reinforced foam concrete have been carried out in order to study the mechanical and durability characteristics. However, there has been little research on using natural plant fibre as reinforcement in foamed concrete with densities ranging from 800-900 kg/m^3. As a result, the primary goal of this work is to compare the mechanical properties of jute fibre and banana fibre reinforced foam concrete with those of polypropylene fibre reinforced foam concrete. To improve the performance of light weight masonry units in seismic zones, additional layers of reinforcement are required to prevent the structure from collapsing. As a result, as part of the second phase of the research, glass fibre reinforced polymer sheets were used as an additional layer to improve the mechanical strength of masonry units and their performance in seismic zones. The study provides a thorough understanding of the failure pattern and compressive strength characteristics of light weight fibre reinforced foam concrete masonry prisms.

2 Experimental study

The lightweight foam concrete block without fibers were prepared in the first step. The strength of plain LWC blocks was tested under compression. In the second stage, fibers were added to the foam concrete mix to make the Fiber Reinforced Lightweight Concrete (FRLWC) block. Jute, banana and polypropylene fibers were added in different batched to cast FRLWC blocks. The nomenclature for the block was given in such a way to represent the fiber used and the percentage of fibers. For example, PP-LWC-0.22 is a polypropylene fiber-reinforced light weight block with a fibre dosage of 0.22%. Using LWC block and FRLWC blocks, plain and fiber reinforced lightweight concrete prisms were constructed. The plain specimen without fibers was considered as the control specimen for each case. All the plain and fiber-reinforced blocks and prisms were tested under compression load and the stress-strain responses were plotted. To enhance the performance of the FRLWC prism in seismic zone, additional layer of Glass Fiber Reinforced Polymer (GFRP) was used in the form of sheets and pasted on the top of each FRLWC block to fabricate Enhanced FRLWC prism (EFRLWC). The schematic view of fabrication of all types of specimens used in this research paper is shown in Figure 1. Finally, a LWC prism reinforced with micro fibres and different number of layers of GFRP sheets (one on the top of each LWC block) was subjected to axial uni- axial compression to obtain the stress strain plot. The number of layers of GFRP sheets was varied from one to three layers. For example, GFRP-3 refers to three layers of GFRP sheets. One sheet on the top of each block. The effectiveness of microfibres and GFRP sheets as reinforcement in LWC prism, as well as their energy dissipation capacity were investigated. The properties of the mortar used in the prism were tested by casting a cylinder using 1:6 mortar mix and the stress strain plot was obtained. The addition of microfibres increases the LWC prism tensile strength and shear resistance capacity. Microfibres coupled with GFRP play an important role in compressive strength, tensile strength, and shear resistance capacity with improved behaviour in post peak regime.

2.1 Mix proportion

Foam concrete was prepared by mixing cement, fly ash, and water in the proportion of 1:3:1 along with an ASTM C260 certified Stable Air Foaming Agent (SAFA). One part of cement, three parts fly ash, and one part water were used to prepare the fresh paste. To the fresh paste, SAFA was added at the rate of 1.4 kg/m^3 to produce the light weight foam concrete. The foaming agent was diluted with water in a 1:40 ratio before being added to the paste mixture. It was then added to the foam generator machine and mixed for 5 minutes to produce the aerated foam mix with a density of 75 kg/m3. The aerated foaming agent was added to the cement fly ash mixture to produce cellular light weight foam concrete. The water-binder ratio for light weight concrete is normally between 0.4 and 1.25; in this study, the water-binder ratio was kept constant at one. In this foam concrete, coarse and fibre aggregates were not added to achieve a density of 950 kg/m^3. To fabricate fiber reinforced lightweight foam concrete, fiber was added to the foam mix in the range of 0-0.55 % of the volume of foam concrete. The maximum fiber dosage corresponded to 5 kg/m^3 for 0.55% fiber content. The picture of fibers used in this study is shown in Figure 2. The physical proprieties of polypropylene, jute and banana fibers are listed in Table 1. The length of fiber was approximately around 6-8 mm. The polypropylene and GFRP sheets were procured from, Industrial fabric suppliers, Chennai, Tamilnadu, India. The natural fibers namely banana and jute fibers were procured from, Go Green products, suppliers Chennai, India. All the foam concrete specimens were casted and cured for 28 days. GFRP sheets of length 600 mm and width 200 mm and thickness 2mm were cut from the roll and kept ready to be pasted on the top surface of the FRLWC blocks after curing. The mix proportion of the foam concrete is given in Table 2.

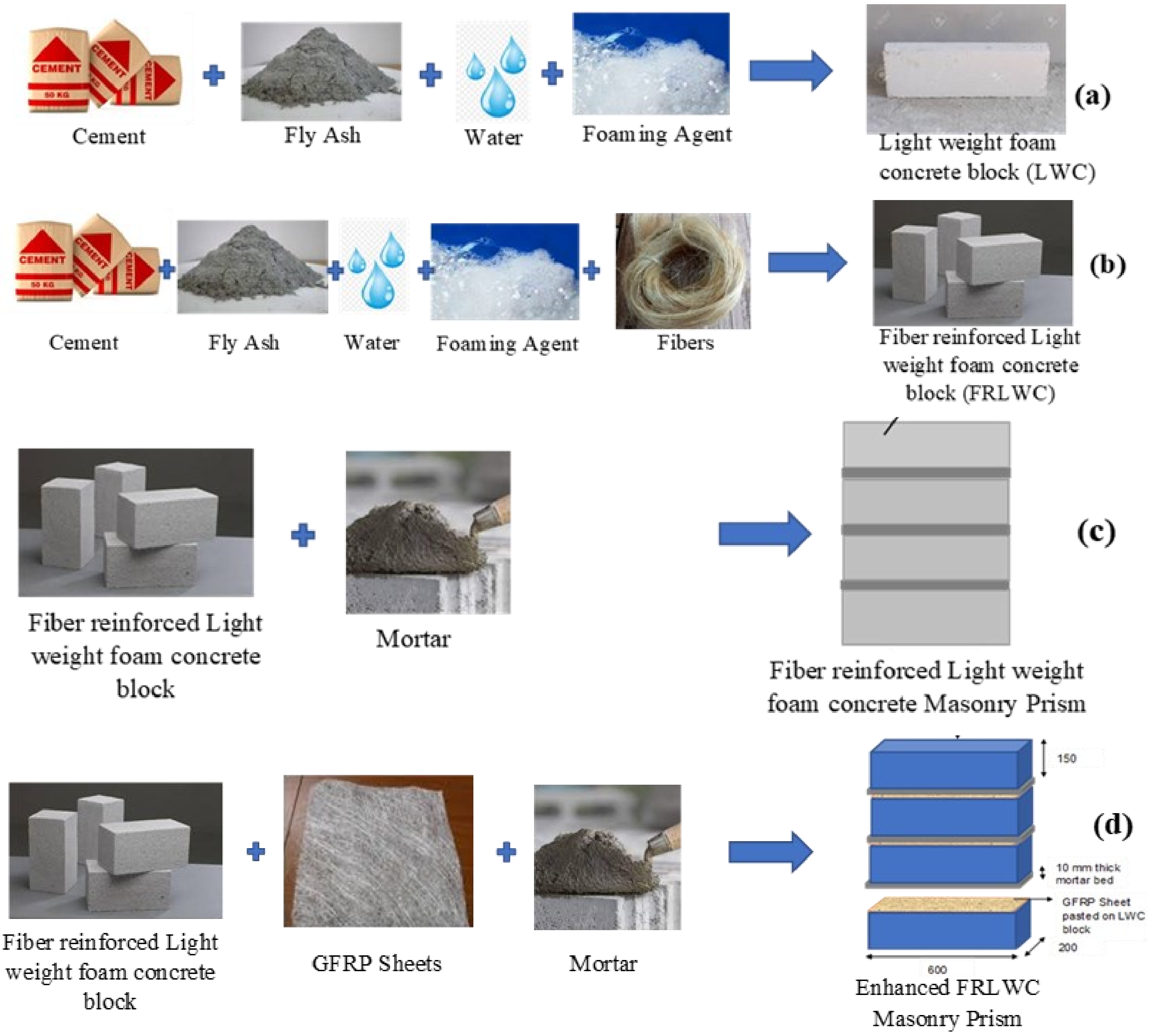


Figure 1. Schematic view of fabrication of different light weight foam concrete specimens (a) LWC block (b) FR LWC block (c) FR LWC Prism (d) Enhanced FRLWC prism

Figure 2. Fibers used in the foam concrete (a) polypropylne (b) Jute (c) Banana

Table 1. Physical properties of polypropylene, jute and banana fiber

Fibers / **physical properties**	Polypropylene	Jute	Banana
Tensile strength (GPa)	551	350	430
Youngs Modulus (Gpa)	3.45	17	23
Length (mm)	20	6-8	6-8
Diameter(mm)	0.03	0.08	0.08
Elongation (%)	40 to 100	2	1.6
Abrasion resistance	Good	Average	Average
Moisture absorption (%)	0 to 0.05	84	60
Softening point (ºC)	140	120	120
Melting point (ºC)	165	119	115
Chemical resistance	Excellent	Average	Average
Relative density g/cm^3	0.91	1.35	0.95
Electric insulation	Excellent	Average	Average

Table 2. The mix proportion of lightweight foam concrete

Mix ID	Cement (kg/m^3)	Fly ash (kg/m^3)	Water (kg/m^3)	Foaming agent (kg/m^3)	Polypropylene (kg/m^3)	Jute (kg/m^3)	Banana (kg/m^3)
LWC	270	810	270	1.4	-	-	-
PP-LWC-0.22	270	810	270	1.4	2	-	-
PP-LWC-0.33	270	810	270	1.4	3	-	-
PP-LWC-0.44	270	810	270	1.4	4	-	-
PP-LWC-0.55	270	810	270	1.4	5	-	-
Ju-LWC-0.22	270	810	270	1.4	-	2	-
Ju-LWC-0.33	270	810	270	1.4	-	3	-
Ju-LWC-0.44	270	810	270	1.4	-	4	-
Ju-LWC-0.55	270	810	270	1.4	-	5	-
Ba-LWC-0.22	270	810	270	1.4	-	-	2
Ba-LWC-0.33	270	810	270	1.4	-	-	3
Ba-LWC-0.44	270	810	270	1.4	-	-	4
Ba-LWC-0.55	270	810	270	1.4	-	-	5

2.2 Mixing, placing and curing

Foam concrete was prepared by mixing cement and fly ash in dry powder form. The dry powders were thoroughly mixed for five minutes. A measured quantity of water was added to the dry mixture to make it into a paste. To the wet mixture the synthetic foaming agent was added. Before adding foaming agent, it was diluted in the ratio of 1:40, i.e., one part of foaming agent was mixed with 40 parts of water and aerated to form the desired quantity of foam and then added to the wet mixture slowly at the rate of 35g per second. The mixture was then thoroughly mixed for 40-50 seconds. To the aerated foam cement mixture, fibers of length 6-8 mm length were added slowly part by part to avoid accumulation of fibers in one place. Then the foam concrete mix was thoroughly mixed for another five minutes and poured in the mould to the required dimension. Then the mould was kept undisturbed till the wet mix hardened. The foam concrete specimens were demoulded after one day (24 Hours) and cured for 28 days. The steps involved in the process of producing a FRLWC prism are shown in Figure 3.

2.3 Details of fiber reinforced lightweight concrete specimen

Different lightweight specimens fabricated for this study include LWC prisms without fibres, LWC prisms with polypropylene fibres, LWC prisms with jute fibres, LWC prisms with banana fibres, and finally GFRP sheet reinforced LWC prisms. The Length, width and depth of LWC prism is 600 x 200 x 630 mm respectively. The details of specimen ID, description of specimen and fiber volume fraction are listed in Table 3. Four FRLWC blocks were joined by applying mortar on the bed surface to form a FRLWC prism. GFRP sheets were pasted to the bed surface of each FRLWC block using epoxy resin and GFRP strengthened FRLWC blocks were fabricated. Using those blocks, a GFRP-enhanced FRLWC masonry prism was fabricated. The picture of FRLWC blocks and Prism and GFRP-strengthened blocks and prism is shown in Figure 4.

Figure 3. Manufacture of foam concrete specimen (a) Addition of foaming agent (b) Wet foam concrete mix (c) Addition of fibers (d) prepration of moulds (e) placing of foam mix into the mould (f) Fresh LWC block (g) Drying of foam concrete for 24 hours (h) demoulding of dry LWC blocks for curing

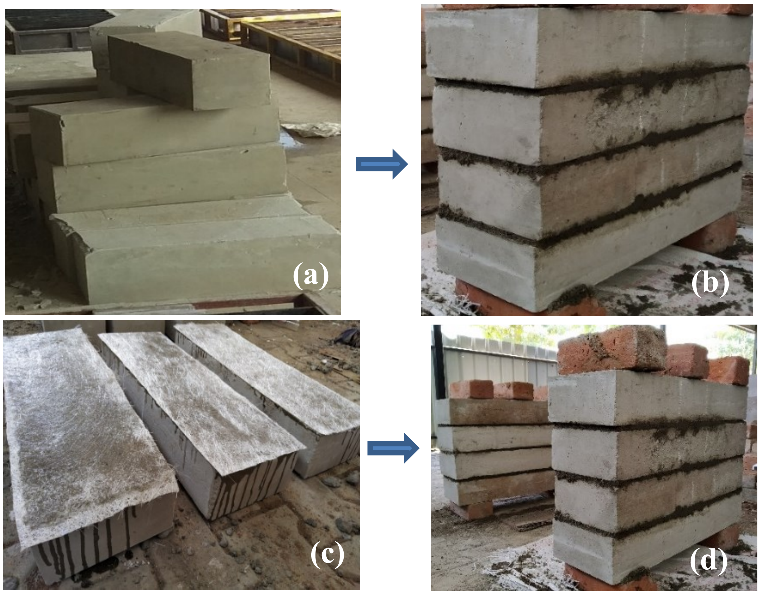


Figure 4. Tested specimen (a) FRLWC blocks (b) FRLWC prism (c) GFRP strengthened FRLWC blocks (d) GFRP strengthened FRLWC prism

2.4 Instrumentation for test specimen

The strength of masonry structures can be effectively predicted by testing a standard dimension masonry prism according to ASTM specifications. The minimum requirement for the dimension of the masonry prism to be tested should not be less than 600 mm. The cross-section dimension of each block should be around 150-250 mm. When compared to full scale testing, small-scale testing of prisms considerably reduces the testing cost. Before the start of the test, the top surface of the prism was checked for a uniformly level surface. To avoid uneven distribution of loads, wooden planks were placed on top of the prism, and the load was applied. The uniaxial compression load was applied to the specimen through a universal testing machine with a capacity of 2000 kN. The stress strain plot was recorded automatically using Data Acquisition System. The load was applied at a very small rate of 0.001 kN/sec. when the load dropped below 30% of the maximum load recorded, it was ensured that the specimen had failed and testing was stopped. The axial displacement was measured by using linear variable displacement transducers placed in four directions of the tested specimen. From the recorded reading in DAS, the stress strain plot was obtained for each specimen. The polypropylene and jute fiber reinforced LWC masonry prism ready for testing is shown in Figure 5.

3 Result and discussion

The testing of the masonry prism, started with the testing of the control prism (without any fibers) and load deflection behaviour was observed and plotted. The stress strain plot of the control prism was taken as the reference for all the other specimens. After testing the control specimen, fiber reinforced LWC masonry prism was tested in the second series. Polypropylene, jute and banana fiber reinforced LWC masonry prisms were tested one after another and the load deflection behaviour was observed. Three specimens were tested for each fiber dosage. In all, 36 pieces of FRLWC masonry prism were tested in the second series. Finally, the GFRP strengthened FRLWC masonry prism was tested and the stress strain plot was obtained. In the third series, the number of layers of GFRP sheet varied from 1-3 sheets. In total, 27 specimens were tested in the third series. The maximum strengths observed for all 22 types of masonry prisms including the control specimen are presented in Table 4.

3.1 Stress-Strain behaviour of control specimen

When the control specimen was subjected to uniaxial compression load, the deformation increased with the increase in load. Initially the load deformation behaviour was linear up to 30% of the peak load. After the elastic region, as the load increases the deformation is not proportional to the applied load, and the stress strain curve becomes non- linear. The specimen continues to be loaded until it reaches the peak load, also known as the ultimate load. When it reaches the peak load, cracks form across the prism's cross section, and the prism fails suddenly. From the stress strain plot shown

Table 3. Specimen details

Series	Specimen ID	Specimen type	Number of specimens	Fiber dosage (%)
1	LWC	Control LWC prism	3	0
2	PP-LWC-0.22	Polypropylene fiber reinforced lightweight concrete Prism (PFRLWC)	3	0.22
	PP-LWC-0.33		3	0.33
	PP-LWC-0.44		3	0.44
	PP-LWC-0.55		3	0.55
3	Ju-LWC-0.22	Jute fiber reinforced lightweight concrete Prism (JFRLWC)	3	0.22
	Ju-LWC-0.33		3	0.33
	Ju-LWC-0.44		3	0.44
	Ju-LWC-0.55		3	0.55
4	Ba-LWC-0.22	Banana fiber reinforced lightweight concrete Prism (BFRLWC)	3	0.22
	Ba-LWC-0.33		3	0.33
	Ba-LWC-0.44		3	0.44
	Ba-LWC-0.55		3	0.55
5	PP-0.44-GFRP-1	Polypropylene LWC Prism +GFRP	3	0.44
	PP-0.44-GFRP-2		3	0.44
	PP-0.44-GFRP-3		3	0.44
6	Ju-0.44-GFRP-1	Jute LWC Prism + GFRP	3	0.44
	Ju-0.44-GFRP-2		3	0.44
	Ju-0.44-GFRP-3		3	0.44
7	Ba-0.44-GFRP-1	Banana LWC Prism + GFRP	3	0.44
	Ba-0.44-GFRP-2		3	0.44
	Ba-0.44-GFRP-3		3	0.44

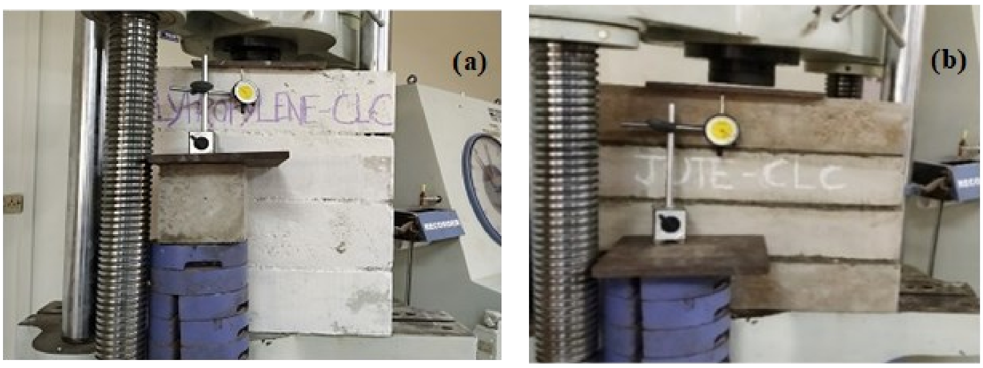


Figure 5. Test setup (a) polypropylene FRLWC prism (b) Jute FRLWC prism

in Figure 6, the ultimate strength of the control LWC prism was 3.66 MPa and the elastic modulus of the control LWC prism was 2100 MPa. The failure started from the mortar joint and then propagated in different directions, till the complete failure of the specimen. Due to the lack of fibers in the LWC prism matrix, a crack did not arrest, which propagated further and developed into wider splitting cracks which led to the sudden failure of the control LWC prism. The failure of control LWC prism is shown in Figure 6.

3.2 Stress-strain plot of FRLWC prism

Similar to the control specimen, the FRLWC prism was subjected to an uniaxial compression load, the load deformation behaviour was observed and the stress train plot was obtained and compared with the control specimen as shown in Figure 7. The addition of polypropylene, jute and banana fibers helps improve the stress strain behaviour of FRLWC prism. The stress strain plot for polypropylene, jute and banana fiber with 0.22%, 0.33% 0.44% and 0.55% of fiber content is shown in Figure 7 (a-d). On comparing the performance of FRLWC prism with a fiber content of 0.22% with Control prism (Figure 7a), the precracking behaviour of the FRLWC prism, when compared to the control prism was improved by the addition of fibers. When comparing the performance of three types of fibers, polypropylene was better compared to banana and jute fibers. After the elastic region, the specimen enters the post cracking region in which the control specimen showed a sudden failure compared to the fiber reinforced prism. Similarly, when the stress-strain of FRLWC prisms with 0.33% and 0.44% fibre content is compared (Figure 7b and 7c), the fibres help to improve the specimen's elastic property. The performance of jute and banana fiber is similar with, only a slight difference in the

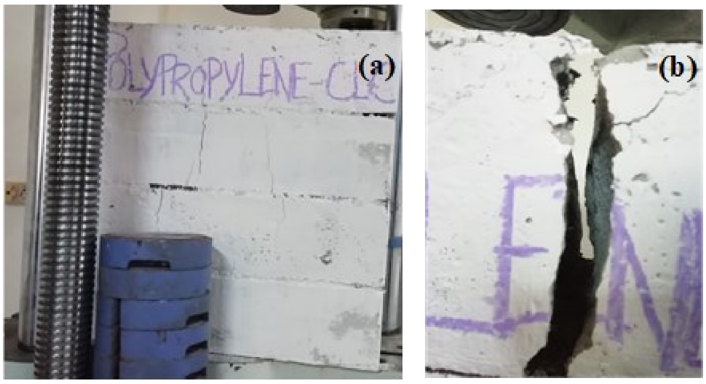


Figure 6. Crack formation in specimen (a) before peak load (b) wider crack after peak load

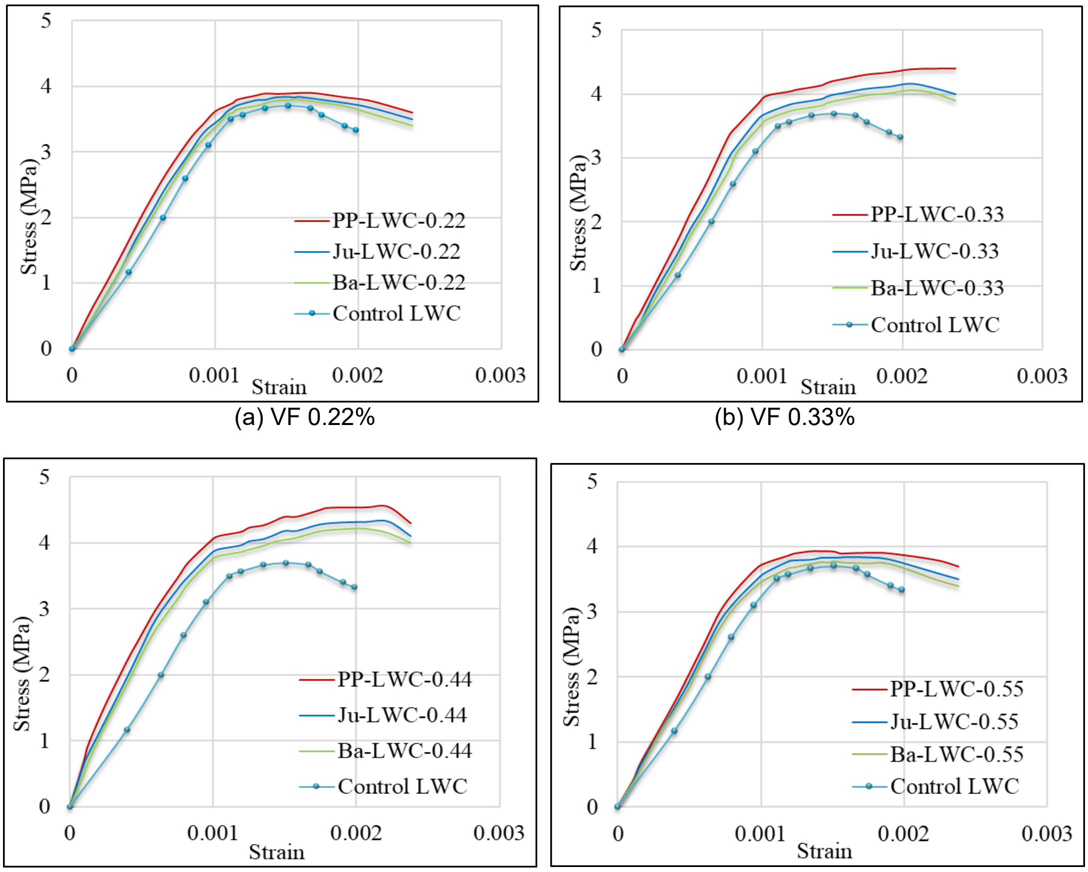
Table 4. Strength of control specimen, FRLWC prism and GFRP enhanced FRLWC prism

Type of specimen	Specimen ID	Peak Compressive Strength (MPa)			Mean Strength (MPa)	Mean strength /Mean strength of control prism
		1	2	3		
Control prism	LWC	3.66	3.56	3.75	3.66	1.00
Polypropylene fiber reinforced lightweight concrete Prism (PFRLWC)	PP-LWC-0.22	4.0	3.69	3.89	3.89	1.06
	PP-LWC-0.33	4.5	4.45	4.35	4.39	1.20
	PP-LWC-0.44	4.2	4.23	4.45	4.55	1.24
	PP-LWC-0.55	3.73	4.13	3.93	3.93	1.07
Jute fiber reinforced lightweight concrete Prism (JFRLWC)	Ju-LWC-0.22	3.84	3.64	4.04	3.84	1.05
	Ju-LWC-0.33	4.13	4.42	4.3	4.16	1.14
	Ju-LWC-0.44	4.12	4.22	4.15	4.32	1.18
	Ju-LWC-0.55	3.88	3.76	3.8	3.78	1.03
Banana fiber reinforced lightweight concrete Prism (BFRLWC)	Ba-LWC-0.22	3.6	3.91	3.90	3.8	1.04
	Ba-LWC-0.33	4.23	4.23	4.11	4.06	1.11
	Ba-LWC-0.44	4.02	4.08	4.1	4.20	1.15
	Ba-LWC-0.55	3.8	3.81	3.67	3.7	1.01
Polypropylene LWC Prism +GFRP	PP-0.44-GFRP-1	4.6	4.76	4.8	4.7	1.28
	PP-0.44-GFRP-2	4.75	4.8	4.9	4.8	1.31
	PP-0.44-GFRP-3	4.9	4.92	4.94	4.92	1.34
Jute LWC Prism + GFRP	Ju-0.44-GFRP-1	4.3	4.31	4.29	4.29	1.17
	Ju-0.44-GFRP-2	4.5	4.45	4.35	4.4	1.20
	Ju-0.44-GFRP-3	4.5	4.7	4.6	4.6	1.26
Banana LWC Prism + GFRP	Ba-0.44-GFRP-1	4.3	4.25	4.35	4.3	1.17
	Ba-0.44-GFRP-2	4.4	4.37	4.78	4.5	1.23
	Ba-0.44-GFRP-3	4.9	4.56	4.6	4.7	1.28

stress value. In all FRLWC specimens, the polypropylene fiber contribution was better than the unreinforced and natural fiber reinforced specimens. Even though the contribution of synthetic fiber is greater than that of natural fibers, the natural fibers also improve the elastic property of the specimen. Synthetic and natural fibres both improve prism stiffness, softening behavior, load carrying capacity, and prevent sudden failure. The peak strengths of polypropylene, jute and banana FRLWC with 0.44% fiber reinforcement are 4.5MPa, 4.32MPa, 4.2 MPa respectively. According to the stress-strain plot of FRLWC with 0.55% fibre content, the load carrying capacity of the specimen decreases as fibre content exceeds 0.44%. The addition of an excess percentage of fibers reduces the bond between the aggregate and binders. The stress transferee from the fibers to the aggregate does not take place properly, which results in the failure of specimen. Similar failure patterns were observed by the author in the previous study using fish tail palm fiber [18]; The peak strength of polypropylene, jute and banana FRLWC with 0.55% fiber content (Figure 7d) were 3.93 MPa, 3.78MPa, 3.7MPa. The strength of 0.55% FRLWC decreased by 13%, 12% and 11% when compared to 0.44% polypropylene, jute and banana FRLWC specimen respectively. The peak load carrying capacity increases with the increase in fiber content up to 0.44%, beyond which it decreases. The addition of fibers mainly improves the performance of the LWC prism in the post peak region by imparting elastic behaviour to the LWC prism. Therefore, it can be concluded that the FRLWC can be used as a better alternative to clay brick in the construction of masonry due to its improved residual strength and toughness. From this series of test, fiber content of 0.44% was taken as the optimum fiber content for the next series of experiments.

3.3 Failure pattern of FRLWC prism

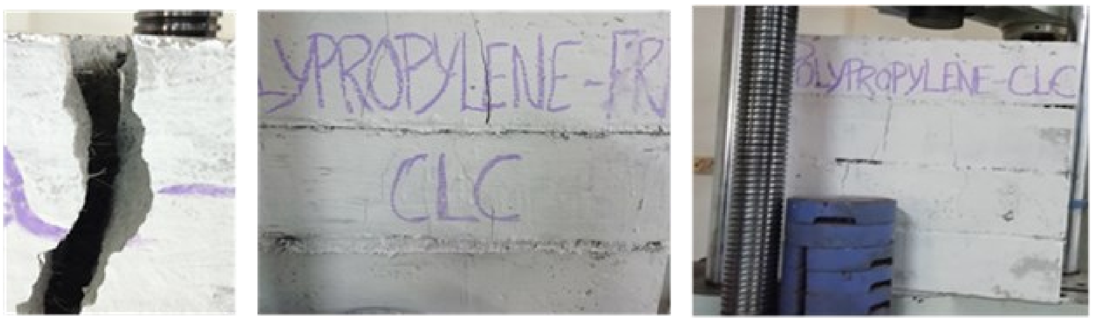
In Autoclaved Aerated blocks addition of fibers is not feasible, because the natural fibers would melt due to the high temperature during the autoclaving process. In such cases, the best alternative material is fiber-reinforced LWC block. As already mentioned in the previous section, an unreinforced LWC prism exhibits a sudden failure due to the stress concentration in particular region and the lack of stress transfer due to the absence of fibers. The failure pattern of the control prism is shown in Figure 6. The FRLWC prism, with polypropylene, jute, and banana fibres as microfibers inside the cement matrix, stops cracks at the microlevel, distributes stress in different directions, and reduces stress concentration in one weak region. As the fiber content increases, large network of fibers is involved in the crack arresting process. The addition of fibres not only prevents the prism from failing suddenly, but also improves its ductile behaviour after it has reached its maximum load carrying capacity. Therefore, it can be concluded that fiber helps to improve the strength and ductility of the LWC matrix under compression. The failure pattern of different FRLWC with different percentages of fiber reinforcement is shown in Figure 8.



(a) VF 0.22% (b) VF 0.33%

(c) VF 0.44% (d) VF 0.55%

Figure 7. Stress-Strain response of FRLWC prism with different volume fraction of fibers



(a) PP-LWC-0.22 PP-LWC-0.33 PP-LWC-0.44

(b) Ju-LWC-0.22 Ju-LWC-0.33 Ju-LWC-0.44

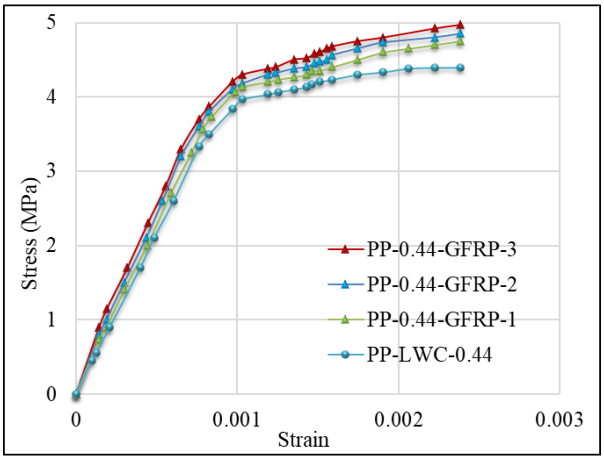
Figure 8. Failure mode of FR LWC prism (a) Polypropylene FRLWC prism (b) Jute FRLWC prism

3.4 Compression behaviour of GFRP strengthened FRLWC prism

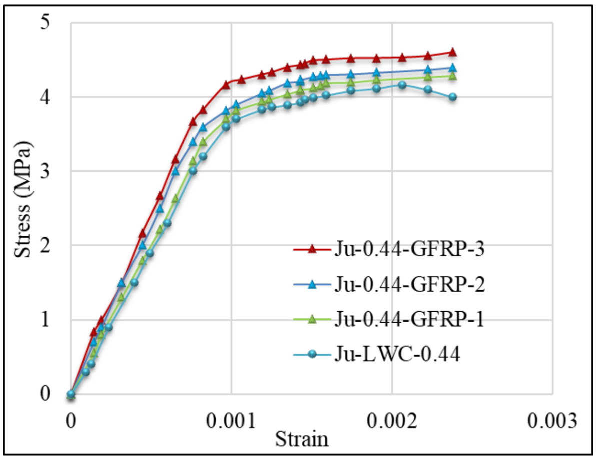
The stress-strain plot of FRLWC with synthetic and natural fibres revealed that jute and banana fibres performed similarly, while polypropylene fibres performed better in terms of load carrying capacity. On comparing the volume fraction of fibers, the FRLWC prism with 0.44% fiber content showed a better performance when compared to all other volume fractions. Therefore, for the third series of experiments, a volume fraction of 0.44% was considered constant. FRLWC with different layers of GFRP sheet provided additional protection to the masonry structures in the seismic zone. Major cracks are completely prevented. Along with microfibers in the matrix, GFRP layers prevent the formation of major crack planes and sudden failure of the specimen. The stress-strain curves for GFRP strengthened FRLWC prism is shown in Figure 9. The elastic modulus increased as the number of layers of GFRP sheet increased [Figure 9(a-c)]. While the softening behaviour got improved in the post-peak region. The peak strength of polypropylene FRLWC prism with one two and three layers of GFRP sheet (Figure 9 (a)) is 4.7 MPa, 4.8 MPa and 4.92 MPa respectively. The peak strength of JFRLWC prism with one two and three layers of GFRP sheet (Figure 9 (b)) is 4.29 MPa, 4.4 MPa, 4.6 MPa respectively. The peak strength of banana FRLWC prism with one two and three layers of GFRP sheet (Figure 9 (c)) was 4.3 MPa, 4.5 MPa, 4.7 MPa respectively. The peak compressive strength of all GFRP reinforced FRLWC prism increases when compared to Control prism. The GFRP strengthened polypropylene FRLWC prism showed peak strength up to a maximum of 4.92 MPa. The peak strength of polypropylene FRLWC is slightly higher than jute and banana FRLWC prism. The peak strength and elastic modulus increased with number of layers of GFRP. From the result it is evident that, GFRP reinforcement increases the strength of masonry construction in earthquake prone region where the sudden failure of masonry can be prevented.

3.5 Failure mode of GFRP strengthened FRLWC prism

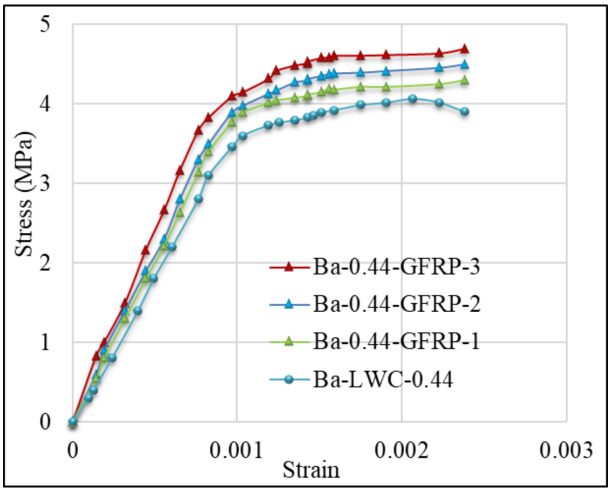
A single wide crack was developed in control prism which leads to failure, while the micro FRLWC prism, showed crack distributed across the cross section of the prism with the increase in fiber content. In case of GFRP strengthened FRLWC, the prism showed only hair line crack across the cross section (Figure 10). Stress concentration in the weak zones is reduced by GFRP reinforcement. Microfibers inside the cement matrix and GFRP layers involved in the crack arresting mechanism and prevent the formation of wider cracks. The development of hair line cracks was more uniform across the prism with one layer of GFRP reinforcement, as shown in Figure 10 (a). The formation of major cracks is arrested by the fibres in the LWC blocks which forms a closed network. As the load increases, the microcracks get wider, but the GFRP layers prevent the movement of cracks from one masonry layer to the next, and as a result, the formation of major cracks across the section of the prism is completely prevented. The development of hair line cracks decreases as the number of layers of GFRP reinforcement increases, as does the load carrying capacity. As shown in Figure 10(b), the formation of a single explicit crack is completely prevented. Fiber reinforcement also improves the post peak strength of LWC. Therefore, from the stress strain plot it can be concluded that, GFRP reinforcement give additional strength to the masonry structures, which can be adopted in seismic zone where the shear failure of masonry structures is severe. In such zone GFRP strengthened FRLWC concrete performs better and reduces the damage to life and structure.



(a) Polypropylene +GFRP



(b) Jute +GFRP



(c) Banana + GFRP

Figure 9. Stress-Strain behaviour of GFRP strengthened FRLWC with 0.44% fiber content

(a) Ba-0.44-GFRP-1 Ju-0.44-GFRP-1 PP-0.44-GFRP-1

(b) Ba-0.44-GFRP-3 Ju-0.44-GFRP-3 PP-0.44-GFRP-3

Figure 10. Failure of GFRP reinforced LWC prism with 0.44% fibers (i) 1 layer of GFRP (ii) 3 layers of GFRP

4 Recommendation from the study

The addition of fibers mainly improves the performance of the LWC prism in the post peak region by imparting elastic behaviour to the LWC prism. Therefore, the FRLWC can be used as a better alternative to clay brick in the construction of masonry due to its improved residual strength and toughness. Out of the different fiber contents added, LWC with a fiber content of 0.44 % performed better. Along with microfibers inside the matrix, GFRP reinforcement gives additional strength to the masonry structures, which can be adopted in seismic zones where the masonry structures are prone to shear failure. In such zones, GFRP strengthened FRLWC concrete performs better and reduces the damage to life and structure.

5 Conclusions

From the Compression study carried out on LWC prism with synthetic fibers, natural fibers and GFRP reinforcement the following conclusion can be drawn.

- Using synthetic and natural fibers as reinforcement in LWC masonry, increases the construction cost by only 15-20 %. But the overall lifecycle of the structure increases due to the addition of fibers which overweighs the additional cost.
- From the chosen percentage of fiber dosage used in the experimental investigation, 0.44% is the optimum. The maximum strength of the prism was obtained at the optimum fiber content.
- The failure of a control LWC prism without fibre occurred abruptly, with the development of a single explicit crack across the prism's cross section. However, in the case of the microfiber reinforced LWC prism, a large number of microcracks were formed as a result of the stress distribution caused by the close network of fibers, as well as the formation of a major weak plane.
- Polypropylene, jute and banana fibers help to arrest the cracks within the LWC matrix, while the GFRP sheets act as a crack arrester at the major level and prevent the movement of cracks from one layer to another.
- The addition of GFRP reinforcement to the FRLWC prism further increased the ductile behaviour and also increased the compressive strength of the prism. As the number of layers of GFRP increased the elastic modulus and stiffness also increased. Both the microfibers and GFRP layers involved in the crack arrest.
- Along with micro fibers inside the matrix, GFRP reinforcement gives additional strength to the masonry structures, which can be adopted in seismic zone where the masonry structures are prone to shear failure.
- This research study has been conducted for cellular lightweight foam concrete with fiber reinforcement. Further research has to be extended to hybrid fiber reinforcement and the high temperature effect on the strength and durability properties of natural fiber reinforced foam concrete.

Reference

[1] S. J. Choi, J. S. Mun, K. H. Yang, and S. J. Kim, "Compressive fatigue performance of fiber-reinforced lightweight concrete with high-volume supplementary cementitious materials," *Cem. Concr. Compos.*, vol. 73, pp. 89–97, 2016, doi: 10.1016/j.cemconcomp.2016.07.007.

[2] D. Y. Yoo and N. Banthia, "Impact resistance of fiber-reinforced concrete – A review," *Cem. Concr. Compos.*, vol. 104, no. June, p. 103389, 2019, doi: 10.1016/j.cemconcomp.2019.103389.

[3] O. Gencel *et al.*, "Basalt fiber-reinforced foam concrete containing silica fume: An experimental study," *Constr. Build. Mater.*, vol. 326, no. February, p. 126861, 2022, doi: 10.1016/j.conbuildmat.2022.126861.

[4] R. Vijayalakshmi, R. Sathia, S. Ramanagopal, G. Vikram, R. Yuvarani, and R. Yuvalatha, "Uni axial compression behaviour of lightweight expanded clay aggregate concrete cylinders confined by perforated steel tube and GFRP wrapping," *Rev. la*, pp. 200–212, 2020.

[5] R. Sathia and R. Vijayalakshmi, "Fresh and mechanical property of caryota-urens fiber reinforced flowable concrete," *J. Mater. Res. Technol.*, vol. 15, pp. 3647–3662, 2021, doi: 10.1016/j.jmrt.2021.09.126.

[6] R. Rostami, M. Zarrebini, K. Sanginabadi, D. Mostofinejad, S. Mahdi Abtahi, and H. Fashandi, "An investigation into influence of physical and chemical surface modification of macro-polypropylene fibers on properties of cementitious composites," *Constr. Build. Mater.*, vol. 244, p. 118340, 2020, doi: 10.1016/j.conbuildmat.2020.118340.

[7] M. S. Islam and S. J. Ahmed, "Influence of jute fiber on concrete properties," *Constr. Build. Mater.*, vol. 189, pp. 768–776, 2018, doi: 10.1016/j.conbuildmat.2018.09.048.

[8] R. Vijayalakshmi and S. Ramanagopal, "Experimental Investigation Into Banana Fibre Reinforced Lightweight Concrete Masonry Prism Sandwiched with GFRP Sheet," *Civ. Environ. Eng. Reports*, vol. 30, no. 2, pp. 15–31, 2020, doi: 10.2478/ceer-2020-0017.

[9] R. Vijayalakshmi and S. Ramanagopal, "Compression Behaviour of Polypropylene Fibre Reinforced Cellular Light Weight Concrete Masonry Prism," *Civ. Environ. Eng. Reports*, vol. 30, no. 1, pp. 145–160, 2020, doi: 10.2478/ceer-2020-0011.

[10] E. T. Dawood, Y. Z. Mohammad, W. A. Abbas, and M. A. Mannan, "Toughness, elasticity and physical properties for the evaluation of foamed concrete reinforced with hybrid fibers," *Heliyon*, vol. 4, no. 12, p. e01103, 2018, doi: 10.1016/j.heliyon.2018.e01103.

[11] M. S. Mahzabin, L. J. Hock, M. S. Hossain, and L. S. Kang, "The influence of addition of treated kenaf fibre in the production and properties of fibre reinforced foamed composite," *Constr. Build. Mater.*, vol. 178, pp. 518–528, 2018, doi: 10.1016/j.conbuildmat.2018.05.169.

[12] B. Raj, D. Sathyan, M. K. Madhavan, and A. Raj, "Mechanical and durability properties of hybrid fiber reinforced foam concrete," *Constr. Build. Mater.*, vol. 245, p. 118373, 2020, doi: 10.1016/j.conbuildmat.2020.118373.

[13] Y. H. Mugahed Amran *et al.*, "Performance properties of structural fibred-foamed concrete," *Results Eng.*, vol. 5, no. December 2019, p. 100092, 2020, doi: 10.1016/j.rineng.2019.100092.

[14] O. Gencel *et al.*, "Influence of bottom ash and polypropylene fibers on the physico-mechanical, durability and thermal performance of foam concrete: An experimental investigation," *Constr. Build. Mater.*, vol. 306, no. June, p. 124887, 2021, doi: 10.1016/j.conbuildmat.2021.124887.

[15] M. Mastali, P. Kinnunen, H. Isomoisio, M. Karhu, and M. Illikainen, “Mechanical and acoustic properties of fiber-reinforced alkali-activated slag foam concretes containing lightweight structural aggregates,” *Constr. Build. Mater.*, vol. 187, pp. 371–381, 2018, doi: 10.1016/j.conbuildmat.2018.07.228.

[16] G. Calis, S. A. Yildizel, S. Erzin, and B. A. Tayeh, “Evaluation and optimisation of foam concrete containing ground calcium carbonate and glass fibre (experimental and modelling study),” *Case Stud. Constr. Mater.*, vol. 15, no. April, p. e00625, 2021, doi: 10.1016/j.cscm.2021.e00625.

[17] O. Yavuz Bayraktar, G. Kaplan, O. Gencel, A. Benli, and M. Sutcu, “Physico-mechanical, durability and thermal properties of basalt fiber reinforced foamed concrete containing waste marble powder and slag,” *Constr. Build. Mater.*, vol. 288, p. 123128, 2021, doi: 10.1016/j.conbuildmat.2021.123128.

[18] V. Ramalingam, K. Ramesh, M. Arumugam, and V. Muralidharan, “Effect of natural fish tail palm fiber on the workability and mechanical properties of fiber reinforced concrete,” *Gradjevinski Mater. i Konstr.*, vol. 65, no. 1, pp. 7–22, 2022, doi: 10.5937/grmk2201007r.