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A Review on Fiber-Reinforced Foam Concrete †

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Abstract: Cost-effectiveness and affordability are important factors in the selection of construction material. To achieve this cost-effectiveness, new materials must be brought into use. One such material is foam concrete, which seems to be affordable and economical. Foam concrete has the best thermal insulation and fire resistance properties. However, using foam concrete as a construction material is a major challenge because of its low tensile strength and brittle nature. To improve the properties of foam concrete, researchers have added various fibers. This paper reviews the effects of various synthetic and natural fibers on the mechanical and physical properties of foam concrete. Incorporating fibers into foam concrete slightly increases its compressive strength, while increasing its tensile strength up to three times, its flexural strength up to four times, and its impact strength up to six times.

Keywords: foam concrete; fiber-reinforced foam concrete; fibers; mechanical and physical properties; tensile strength

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1. Introduction

Foam concrete (FC) is lightweight concrete with lower self-weight than conventional concrete. Foam concrete is concrete with a density (air-dried) below 2000 kg/m^3 as compared to conventional normal-weight concrete with a density in the range of 300–2350 kg/m^3 [1]. The specialties of FC are its very low density and thermal conductivity. It has several advantages over conventional normal weight concrete, such as less dead load, faster construction, flame protection resistance, and good sound insulation [2]. FC has good workability and belongs to its lightweight composites [3]. In preparation for FC, a pre-prepared foam is introduced, which provides a network of voids within the concrete-hardened composite [4]. Historically, the Romans were the first who added animal blood with a mixture of gravel, sand, and water with hot lime, which produced small air bubbles, making the mix more durable [5,6]. However, it was Erikson who prepared the first Portland cement-based foamed concrete [7]. Valora comprehensively investigated FC in the 1950s [8]. Later, detailed studies were conducted on foam concrete in the 1960s [9]. Rudnai reported the properties, composition, and application of FC [10].

However, the development of foam concrete in building materials has been restricted due to certain weaknesses, such as less strength, poor ability to control cracks, and, more importantly, brittleness [11]. Because of its poor mechanical and physical properties, FC application is limited in concrete structures construction. Researchers have incorporated several synthetic and natural fibers to improve the properties, specifically the mechanical properties like tensile and flexure, of foam concrete. To control the starting and spreading of cracks in concrete, fibers which effectively control cracks opening and spreading are used [12,13]. The inclusion of fibers enhances the FC's flexural strength and, most importantly, reduces shrinkage loads [14,15]. With the addition of polypropylene fiber (PPF) fibers, the concrete has less porosity and greater crack resistance [16]. In the previously listed studies, the inclusion of a variety of fibers, such as polypropylene with glass, steel, coconut, wood, kenaf, and other fibers, have been investigated.

2. Fibers Used in Foam Concrete

Several synthetic and natural fibers have been added to FC to improve its mechanical and physical properties. Fiber properties from previous fiber-reinforced foam concrete (FRFC) research are listed in Table 1.

Table 1. Fiber Properties from Previous Research.

Fibers Properties				Properties of FRFC at Max Compression Strength						
Ref.	**Fibers**	**Length (mm)**	**Density (kg/m^3)**	**Tensile (MPa)**	**Elastic Modulus (GPa)**	**Dia (μm)**	**Comp (MPa)**	**Density (kg/m^3)**	**Tensile (MPa)**	**Flexural (MPa)**
[17]	Polypropylene	19	900	552	3.8	70	2.14	734	0.341	-
	Henequen	19	1400	500	13.2	170	1.78	728	0.445	-
	Polymers	20	1000	520	-	0.54	12.44	835	-	2.35
[18]	Glass mesh	4 × 4 mm	125 m/kg^2	25	-	-	-	-	-	-
	Glassmesh + Polymers	-	-	-	-	-	11.67	822	-	7.05
	Polypropylene	12	1000	2.69	3.46	587	-	-	-	-
[19]	Polyvinyl alcohol	25	1500	0.9	29	398	-	-	-	-
	Polypropylene	12	15	2.79	3.48	25	-	-	-	-
[20]	Polyolefine	50.4	-	275	2.6	0.64	7.82	1600	-	1.53
[21]	Polypropylene	15	900	800	8	100	50	1500	8	-

2.1. Synthetic Fibers

2.1.1. Polypropylene Fibers

It was observed that with the inclusion of polypropylene fibers, the tensile strength of FC was greater than the FC without polypropylene fibers and it was found that the optimum percentage of PP fibers was 0.05% for both 1600 kg/m^3 and 1800 kg/m^3. With the inclusion of 0.4%, the bending strength of foam concrete improved up to 7–26% but a decrease was observed in flexural strength by about 8–16% [22]. The inclusion of PPF improved chloride resistance, sulfate resistance, carbonation resistance, fire resistance, and reduced water absorption, which led to the enhancement of durability. By adding PPFs, the concrete has higher crack resistance and drying shrinkage. However, the lower elastic modulus of PPE has not reduced the creep of concrete [16]. The average propylene fiber length is 19 mm, and the diameter is 19 mm with a tensile strength in the region 230–750 MPa and ultimate elongation is 14–75% [23].

2.1.2. Steel Fibers

The inclusion of steel fibers (SF) in foam concrete increased compressive strength, splitting tensile strength, and modulus of elasticity while decreasing workability. SF also increased the flexural strength because the SF prevents the micro cracks in foam concrete [24]. Shrinkage is the main issue faced by foam concrete and foam concrete shrinkage resistance is lower than normal concrete. However, the inclusion of SF proved effective to increase the shrinkage resistance of foam concrete [25,26].

2.1.3. Basalt and Asbestos Fibers

Basalt fiber can be produced by cutting from a continuous basalt fiber with a diameter of 17 μm and 2.5 times better tensile strength than high strength steel. It is recommended to use an average fiber length in the range of 6 to 24 mm [27]. Basalt fiber has the property of not breaking down, even in the severe alkaline environment of concrete, and retains its stability during concrete carbonation [28]. Further investigations reported the effects of basalt fiber inclusion on foam concrete, and the results are shown in Table 2.

Table 2. Physical and mechanical properties of basalt fiber-reinforced foam concrete [29].

Properties	Numerical Results	
	Foam Concrete	**Fiber Foam Concrete**
Tensile strength in bending, MPa	1.63	2.32
Drying Shrinkage, mm/m	3.18	1.37
Frost resistance, cycles	35	75
Compression strength, MPa	3.34	4.53
Heat conduction, W/(m °C)	0.182	0.176

Microstructure investigation has found that the inclusion of asbestos fibers by 2% (by weight) provides the concrete with better uniform size pores which effectively decreases the shrinkage deformation of FC by roughly 50% [30].

2.1.4. Plastic

The addition of plastic fibers in foam concrete significantly increased the water absorption, splitting tensile strength, and impact resistance, while compressive strength, dry density, and acoustic impedance were decreased [31]. Investigation results showed that the addition of waste plastic fibers has unfavorable effects on the fresh properties of foam concrete; however, it improved the tensile strength. The inclusion of 0.25% volume fraction of waste fibers of plastic can produce foam concrete with an approximately compressive strength of 21.15 MPa [32].

2.1.5. Polyvinyl Alcohol (PVA) Fibers

PVA has relatively strong tensile strength compared to other synthetic fibers and is very economical in cost. A comprehensive investigation of the inclusion of PVA and coir in foam concrete has been carried out. From the results, it was concluded that the optimum percentage of both fibers is 0.3% to obtain maximum strength. It is observed that both fibers increased the impact, abrasion resistance, and water absorption of foam concrete [33].

2.1.6. Carbon Fibers

Using 12 mm length carbon fibers contribute significantly to increasing thermal conductivity by 4.23%, flexural strength by 31.48%, and compressive strength by 10.63% while reducing the drying shrinkage ratio to 51.47% [22]. The inclusion of 1% carbon fibers in foam concrete increases the compressive strength from 17.1 MPa to 23.1% MPa [18].

2.2. Natural Fibers

Natural fibers can be used as a replacement for artificial fibers because they have excellent properties, such as good thermal conductivity and low cost.

2.2.1. Wood Fibers

Wood fibers are well known for their low cost and density, excellent corrosion resistance and heat resistance, good thermal and mechanical properties [34]. It has been found that with the increase of wood fiber content, porosity, and fluidity decreased, while density and thermal conductivity increased. It is also proved that adding 0.4% of fibers enhances the mechanical strength of aerated composite concrete [35].

2.2.2. Flax Fibers

Recently, flax fiber has gained familiarity due to its usage as reinforcement in composites for producing sustainable construction materials. Flax fibers are mostly utilized bio-fibers, and their usage dates back to 5000 BC. It has been found that flax fiber has the potential for next generation to be used as a structural application in infrastructure and also reported that flax fibers are cost-effective, as they have the potential to replace glass

fibers in composite [36]. Flax fibers enhance both the toughness and strength of concrete and its optimized size is 3 cm in length [37].

2.2.3. Bamboo Fibers

Due to its excellent tensile strength, bamboo has long been used in the construction industry. It has been found that the addition of bamboo fibers reduces cracks; however, it also reduces workability and concrete quality. It has also been reported that the optimum fiber addition is 40 g, which reduces the growth and propagation of cracks. Bamboo fibers' inclusion in concrete can enhance the ductility and post-cracking load-carrying capacity [38]. Adding 1% optimum bamboo fibers into concrete improved compressive strength (41 N/mm^2), split tensile strength (4.8 N/mm^2), and flexural strength (7.5 N/mm^2) [39].

2.2.4. Sisal and Coir Fibers

The addition of sisal fibers of 5 mm length and 0.75% fiber content significantly enhanced the mechanical properties of foam concrete [40]. It was also observed that compressive strength and flexural strength were increased by 17.8% and 47.8%, respectively. The inclusion of sisal fibers increased compressive and split tensile strength and improved absorption properties; however, it did not affect the workability of foam concrete [41]. The optimum content of sisal fibers in foam concrete was found to be 0.133% [42]. The addition of sisal fibers (50 mm to 60 mm in length) in foam concrete was able to reduce concrete brittleness [43]. The addition of coir fibers improved the elasticity modulus and the plastic deformation capacity of foam concrete. It was also observed that the inclusion of coir fibers significantly increased the energy absorption capacity of foam concrete [37].

2.2.5. Banana Fibers

Banana fiber is the strongest and most durable natural fiber, which can be produced from the stem of the banana tree. Banana fibers are agricultural waste and their effective use in concrete can decrease the land pollution that occurs due to the dumping of banana waste. Tests have been conducted on lightweight concrete block (containing 0.55% banana fibers) prisms and the results showed that the inclusion of banana fibers increased the compressive strength up to 15% [44]. Banana fiber-reinforced concrete (BFRC) flexural toughness index is increased while the modulus of rapture decreased with the addition of Banana fibers.

2.2.6. Coconut and Pineapple Leaves Fibers

The addition of coconut fibers in foam with different percentages (0.2% and 0.4%) was also investigated and found to have a significant effect on compressive strength, splitting tensile strength, and flexural strength [45]. All results show that the addition of 0.4% provides a higher value for compressive strength (8.63 N/mm^2), flexural strength (1.28 N/mm^2), and splitting tensile strength (0.63 N/mm^2). The addition of coconut fibers in foam concrete reduces the level of crack development and also crack width [46]. Pineapple fibers are stiff and lightweight fibers that can be produced from the pineapple plant. Pineapple fibers and polypropylene have the potential to increase the strength of concrete for both nonstructural elements and structural elements, such as beams and columns [47].

2.2.7. Hemp and Kenaf Fibers

Hemp fibers have long been used in the textile industry for rope. It is one of the most durable natural fibers. The inclusion of hemp fibers in concrete increased compressive strength by 2–125 and the modulus of elasticity by 1.5 to 3% [48]. The addition of hemp fibers positively affects dry shrinkage and also increases compressive strength [49].

A higher addition percentage of kenaf fibers contributed positively to flexural, tensile splitting, and shrinkage properties of lightweight concrete while it decreases work-

ability [15]. Kenaf fibers' inclusion in foam concrete increased water absorption, which consequently decreases the compressive strength of foam concrete [50].

3. Conclusions

The effects of adding various natural and synthetic fibers to foam concrete have been summarized. It has been observed that the addition of fibers in foam concrete enhances mechanical properties, such as splitting tensile, compressive, and flexural properties. This enhancement can allow the utilization of foam concrete in load-bearing structures, which are currently only limited to infill walls. It has also been revealed that synthetic fibers have greater strengths than natural fibers.

Future Research Recommendation

This work also recommended some future studies in foam concrete:

1. Further investigation is required for the thermal insulation properties of fiber-reinforced foam concrete.
2. Extra efforts should be made to investigate the acoustic properties of fiber-reinforced foam concrete.
3. Further studies are required to investigate the impact strength of fiber-reinforced foam concrete.

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