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EXPERIMENTAL INVESTIGATION OF THE STRENGTH OF HOLLOW FLOOR SLABS MANUFACTURED FROM FIBER-REINFORCED EXPANDED CLAY CONCRETE

Raxmonova Nazokat Umaraliyevna
Stajyor-tadqiqotchi
Hakimov Shukrullo Abduraxmanovich
texnika fanlari nomzodi (t.f.n.), professor

Abstract

Fiber-reinforced expanded clay concrete has emerged as a promising lightweight construction material due to its low density, high thermal insulation capacity, and improved mechanical performance. However, the structural behavior of hollow-core floor slabs manufactured from this material has not been sufficiently investigated. The present study aimed to experimentally evaluate the strength characteristics of hollow-core floor slabs produced using fiber-reinforced expanded clay concrete. Concrete mixtures containing different steel fiber dosages (0%, 0.5%, 1.0%, and 1.5% by volume) were prepared under laboratory conditions and compared with a control mixture. Mechanical properties, including compressive strength, flexural strength, crack development, ultimate load-bearing capacity, and deformation characteristics, were determined using standardized testing procedures. The experimental results demonstrated that fiber reinforcement significantly enhanced the compressive and flexural strength of expanded clay concrete while reducing crack width and improving ductility. The mixture containing 1.0% steel fibers exhibited the most favorable balance between mechanical performance and workability, achieving the highest structural efficiency. Furthermore, fiber reinforcement improved the internal homogeneity of the concrete matrix and transformed brittle failure into a more ductile fracture mechanism. The findings indicate that fiber-reinforced expanded clay concrete is a suitable material for manufacturing lightweight hollow-core floor slabs with improved structural reliability, durability, and long-term service performance. The developed composite material has considerable potential for application in modern sustainable construction requiring lightweight and high-strength structural elements.

Keywords: fiber-reinforced expanded clay concrete, hollow-core floor slab, lightweight concrete, compressive strength, flexural strength, steel fiber, crack resistance, structural performance, experimental investigation, sustainable construction.

Introduction

The rapid development of modern construction requires structural materials that simultaneously provide high mechanical strength, reduced self-weight, durability, and energy efficiency. Among lightweight concrete materials, expanded clay concrete has gained widespread attention because of its relatively low density, good thermal insulation properties, fire resistance, and satisfactory durability. The use of expanded clay aggregate significantly reduces the dead load of reinforced concrete structures, allowing designers to decrease foundation dimensions, improve seismic performance, and reduce construction costs. However, conventional expanded clay concrete

exhibits lower tensile and flexural strength compared with normal-weight concrete, which limits its application in heavily loaded structural members such as floor slabs and bridge elements (1).

Recent advances in cementitious composite technology have demonstrated that the incorporation of discrete fibers into lightweight concrete can effectively overcome these limitations. Fiber reinforcement enhances crack resistance, increases tensile strength, improves post-cracking behavior, and delays crack propagation under mechanical loading. Depending on the fiber type, including steel, polypropylene, basalt, glass, or synthetic fibers, the mechanical performance of lightweight concrete can be substantially improved without significantly increasing its density. Fiber-reinforced expanded clay concrete (fiber-expanded clay concrete) therefore represents a promising construction material capable of combining lightweight characteristics with improved structural reliability (2).

Hollow-core floor slabs are among the most commonly used prefabricated structural elements in residential, industrial, and commercial buildings. Their popularity is attributed to reduced self-weight, improved thermal and acoustic insulation, efficient material consumption, and rapid installation. Nevertheless, the presence of longitudinal voids inevitably influences stress distribution and load-bearing capacity, making the mechanical behavior of hollow slabs considerably more complex than that of solid reinforced concrete members. Consequently, accurate evaluation of their structural performance is essential for ensuring safety, durability, and compliance with modern engineering standards (3).

The incorporation of fibers into expanded clay concrete is expected to improve the structural behavior of hollow-core slabs through several mechanisms. Fibers bridge microcracks that develop during loading, redistribute internal stresses, enhance energy absorption capacity, and reduce brittle failure. Furthermore, the porous surface texture of expanded clay aggregate contributes to improved mechanical interlocking with the cementitious matrix, while appropriate fiber dosage promotes greater cohesion between the aggregate and hydrated cement paste. These mechanisms collectively improve compressive strength, flexural performance, crack resistance, and overall durability of structural elements subjected to repeated or dynamic loading (4).

In recent years, considerable attention has also been directed toward sustainable construction materials. Expanded clay aggregate is produced using naturally occurring clay materials through energy-efficient manufacturing processes, while modern fiber technologies enable the production of durable lightweight composites with reduced environmental impact. The application of fiber-reinforced expanded clay concrete in precast hollow-core slabs not only decreases the overall structural weight but also contributes to improved thermal efficiency, lower transportation costs, and reduced carbon emissions throughout the service life of buildings. These advantages support global efforts toward environmentally sustainable construction and resource-efficient engineering practices (3,4).

Although numerous investigations have examined either fiber-reinforced concrete or expanded clay concrete separately, relatively limited information is available regarding the structural performance of hollow-core slabs manufactured specifically from fiber-reinforced expanded clay concrete. In particular, insufficient experimental evidence exists concerning the influence of fiber reinforcement on compressive strength, flexural capacity, crack development, and ultimate load-

bearing behavior of hollow floor slabs under laboratory conditions. Addressing this research gap is essential for optimizing material composition and improving the structural efficiency of lightweight precast elements.

Therefore, the objective of the present study is to experimentally investigate the mechanical strength of hollow floor slabs manufactured from fiber-reinforced expanded clay concrete by evaluating their compressive strength, flexural behavior, crack resistance, and overall load-bearing capacity under controlled laboratory conditions. The findings are expected to contribute to the development of lightweight, durable, and sustainable structural systems suitable for modern civil engineering applications.

Methods

The present experimental study was conducted to evaluate the mechanical strength of hollow floor slabs manufactured from fiber-reinforced expanded clay concrete under laboratory conditions. Ordinary Portland Cement (OPC 42.5R) conforming to international cement standards was used as the primary binding material. Expanded clay aggregate with a particle size of 5–20 mm served as the lightweight coarse aggregate, while natural river sand with a fineness modulus of 2.4–2.8 was used as the fine aggregate. Hooked-end steel fibers with a length of 35 mm, diameter of 0.55 mm, and tensile strength exceeding 1,000 MPa were incorporated into the concrete mixture at different volume fractions (0%, 0.5%, 1.0%, and 1.5%) to evaluate their influence on the mechanical behavior of hollow-core slabs. Potable water meeting standard construction requirements and a polycarboxylate-based superplasticizer were used to ensure adequate workability and uniform fiber dispersion throughout the mixture (5).

Concrete mixtures were prepared in a laboratory mixer under controlled environmental conditions. Initially, cement, sand, and expanded clay aggregate were dry mixed for approximately three minutes to obtain a homogeneous distribution of solid materials. Steel fibers were then gradually introduced into the dry mixture to minimize fiber agglomeration. Water mixed with the superplasticizer was subsequently added while continuous mixing was maintained for an additional five minutes to achieve a uniform concrete mixture. The fresh fiber-expanded clay concrete was cast into specially fabricated hollow-core slab molds reinforced with conventional steel reinforcement according to the structural design requirements. Mechanical vibration was carefully applied to ensure proper compaction while preserving the integrity of the expanded clay aggregate and maintaining uniform fiber distribution. After casting, the specimens were covered with polyethylene sheets to prevent moisture loss during the initial hydration period. The slabs were demolded after 24 hours and cured in water at a temperature of 20 ± 2°C for 28 days before mechanical testing (6).

The experimental program included the preparation of four groups of hollow-core slab specimens corresponding to different fiber contents. A control group without fibers was used as a reference, while three experimental groups contained increasing fiber dosages. Each experimental group consisted of three identical specimens to improve the statistical reliability of the obtained results. Standard cube specimens measuring 100 × 100 × 100 mm were simultaneously prepared for compressive strength testing, allowing comparison between the mechanical properties of the concrete material itself and the structural performance of the hollow-core slabs. All specimen

dimensions and reinforcement arrangements were maintained constant throughout the investigation to eliminate variables other than fiber content (7).

Mechanical testing was performed after the 28-day curing period using a calibrated hydraulic universal testing machine with a loading capacity of 2,000 kN. Compressive strength of cube specimens was determined according to standardized testing procedures, while the structural performance of hollow-core slabs was evaluated through four-point bending tests. During flexural testing, the applied load, mid-span deflection, crack initiation load, crack propagation, and ultimate failure load were continuously recorded using digital displacement transducers and electronic load measurement systems. Crack widths were measured using a precision crack microscope at predefined loading intervals to evaluate the influence of fiber reinforcement on crack control and post-cracking behavior. The failure mode of each specimen was visually documented and compared among experimental groups (8).

In addition to mechanical testing, the physical properties of fiber-expanded clay concrete were evaluated by measuring dry density, water absorption, and ultrasonic pulse velocity. Dry density was determined after oven drying the specimens to constant mass, whereas water absorption was measured by complete immersion following standard laboratory procedures. Ultrasonic pulse velocity testing was employed as a non-destructive technique to assess the internal quality and homogeneity of the concrete matrix. Selected specimens were further examined using optical microscopy to observe the distribution of fibers, the quality of the fiber–matrix interface, and the characteristics of crack bridging after failure. These observations provided additional information regarding the mechanisms responsible for the improved structural performance of the fiber-reinforced expanded clay concrete (9).

The experimental data were statistically analyzed using descriptive statistical methods. Mean values, standard deviations, and coefficients of variation were calculated for all measured parameters. Differences between the control and fiber-reinforced groups were evaluated using one-way analysis of variance (ANOVA), with statistical significance accepted at $p < 0.05$. Correlation analysis was also performed to determine the relationship between fiber dosage, compressive strength, flexural strength, crack width, and ultimate load-bearing capacity. The obtained results were interpreted according to internationally recognized principles of structural concrete behavior and fiber-reinforced cementitious composites (10).

Results

The experimental investigation demonstrated that the incorporation of steel fibers into expanded clay concrete significantly improved the structural performance of hollow-core floor slabs. Compared with the control specimens, all fiber-reinforced slabs exhibited higher compressive strength, increased flexural capacity, delayed crack initiation, and improved ductility. The effectiveness of fiber reinforcement increased with fiber content up to 1.0%, while a slight reduction in workability and only marginal strength improvement were observed at the highest fiber dosage of 1.5%. These findings indicate that an optimum fiber content exists for maximizing structural efficiency without negatively affecting concrete placement and compaction (11).

The compressive strength results obtained after 28 days of curing confirmed the beneficial effect of fiber reinforcement on lightweight expanded clay concrete. The control mixture without fibers achieved an average compressive strength of **31.6 MPa**, whereas the mixtures containing 0.5%, 1.0%, and 1.5% steel fibers reached average strengths of **35.2 MPa**, **38.9 MPa**, and **39.6 MPa**, respectively. The highest percentage increase compared with the control mixture was observed for the 1.0% fiber content, representing an improvement of approximately **23.1%**. Although the mixture containing 1.5% fibers produced slightly higher compressive strength, the difference was statistically insignificant, suggesting that fiber contents exceeding 1.0% provide limited additional benefit for compressive behavior (11).

Table 1. Compressive strength of fiber-reinforced expanded clay concrete

Mix ID	Fiber content (%)	7 days (MPa)	14 days (MPa)	28 days (MPa)	Strength increase (%)
C0	0.0	20.8	27.5	31.6	—
F1	0.5	23.7	30.8	35.2	11.4
F2	1.0	26.1	34.6	38.9	23.1
F3	1.5	26.8	35.3	39.6	25.3

The structural performance of hollow-core slabs under four-point bending clearly demonstrated the advantages of fiber reinforcement. The first visible crack appeared much later in the fiber-reinforced slabs than in the control specimens. The average cracking load increased from **46.8 kN** in the control slabs to **61.7 kN** in slabs containing 1.0% fibers. Likewise, the ultimate load-bearing capacity increased from **128.6 kN** to **162.9 kN**, corresponding to an improvement of approximately **26.7%**. Furthermore, fiber-reinforced slabs exhibited significantly greater deformation capacity before failure, indicating enhanced toughness and ductility. Instead of brittle fracture observed in the control specimens, the reinforced slabs failed gradually through progressive crack development while maintaining structural integrity during loading (12).

Table 2. Flexural performance of hollow-core slabs

Mix ID	First crack load (kN)	Ultimate load (kN)	Mid-span deflection (mm)	Failure mode
C0	46.8	128.6	14.2	Brittle flexural failure
F1	53.9	146.7	16.5	Controlled cracking
F2	61.7	162.9	19.4	Ductile flexural failure
F3	63.1	165.8	20.3	Highly ductile failure

Observation of crack propagation during loading revealed substantial differences between the experimental groups. The control slabs developed a limited number of wide vertical cracks that propagated rapidly toward failure. Conversely, the fiber-reinforced slabs exhibited numerous fine cracks distributed uniformly along the tensile zone. Steel fibers effectively bridged developing cracks, preventing sudden crack widening and delaying structural failure. This crack-bridging mechanism allowed stresses to be redistributed throughout the concrete matrix, thereby improving both stiffness and post-cracking load-carrying capacity. The average maximum crack width decreased from **1.82 mm** in the control specimens to **0.76 mm** in the slabs reinforced with 1.0% fibers, representing a reduction of approximately **58%** (13).

Table 3. Crack development characteristics

Mix ID	Initial crack width (mm)	Maximum crack width (mm)	Number of major cracks
C0	0.28	1.82	5
F1	0.21	1.14	8
F2	0.17	0.76	11
F3	0.16	0.72	12

The physical characteristics of the concrete were also affected by fiber incorporation. Dry density increased only slightly because of the relatively small amount of steel fibers added to the mixtures. However, water absorption decreased gradually as fiber reinforcement improved the compactness of the concrete matrix and reduced microcrack formation during curing. Ultrasonic pulse velocity measurements indicated improved internal homogeneity of the fiber-reinforced specimens, confirming that fibers enhanced the continuity of the cementitious matrix and minimized internal defects. The highest ultrasonic pulse velocity was measured in the mixture containing 1.0% fibers, indicating superior internal quality and reduced structural discontinuities (14).

Table 4. Physical properties of expanded clay concrete

Mix ID	Dry density (kg/m³)	Water absorption (%)	Ultrasonic pulse velocity (m/s)
C0	1786	9.8	3680
F1	1798	8.9	3815
F2	1812	8.1	3948
F3	1821	8.0	3965

Microscopic examination of fractured surfaces further confirmed the strengthening mechanism provided by steel fibers. In the control specimens, cracks propagated directly through the cement matrix and around expanded clay aggregates, resulting in rapid brittle failure. In contrast, fiber-reinforced specimens showed numerous fibers crossing crack surfaces and remaining firmly anchored within the surrounding cement paste. Fiber pull-out rather than fiber rupture was the predominant failure mechanism, indicating efficient stress transfer between the fibers and the concrete matrix. Expanded clay aggregates remained well bonded to the surrounding mortar, while

fiber bridging effectively restricted crack opening and enhanced energy absorption during loading (12,13).

Statistical analysis demonstrated statistically significant differences between the control and fiber-reinforced specimens ($p < 0.05$). Pearson correlation analysis revealed a strong positive relationship between fiber content and flexural strength (**r = 0.95**) as well as between fiber content and ultimate load-bearing capacity (**r = 0.93**). Conversely, a strong negative correlation was identified between fiber dosage and crack width (**r = –0.91**), confirming that increasing fiber content substantially improves crack resistance. Nevertheless, the results indicate that fiber contents greater than approximately **1.0%** produce only marginal additional improvements while reducing workability, suggesting that **1.0% steel fiber represents the optimum dosage** for manufacturing hollow-core floor slabs from expanded clay concrete.

Overall, the experimental findings clearly demonstrate that fiber reinforcement significantly enhances the mechanical behavior of expanded clay concrete hollow-core slabs. Improvements in compressive strength, flexural capacity, crack resistance, and ductility indicate that fiber-expanded clay concrete has considerable potential for application in lightweight structural systems requiring both reduced self-weight and high structural reliability.

Discussion

The results of the present study clearly demonstrate that the incorporation of steel fibers into expanded clay concrete significantly improves the structural performance of hollow-core floor slabs. Compared with the control specimens, all fiber-reinforced mixtures exhibited higher compressive strength, greater flexural capacity, improved crack resistance, and enhanced ductility. These findings are consistent with previous investigations reporting that discrete fibers effectively bridge microcracks and delay crack propagation, thereby improving the load-bearing capacity and post-cracking behavior of lightweight concrete structures (7).

The observed increase in compressive strength can be explained by the synergistic interaction between steel fibers and the cementitious matrix. During hydration, the expanded clay aggregate forms a relatively strong bond with the surrounding cement paste, while randomly distributed fibers restrain the initiation and propagation of microcracks. As compressive loading increases, fibers redistribute internal stresses throughout the matrix, reducing localized stress concentrations that normally lead to brittle failure. Consequently, the concrete exhibits greater resistance to compressive loading and maintains its integrity for a longer period before failure. Similar strengthening mechanisms have been described in previous studies on fiber-reinforced cementitious composites (8).

One of the most significant findings of this investigation is the substantial improvement in the flexural behavior of hollow-core slabs. Unlike conventional expanded clay concrete, which generally fails abruptly after crack initiation, fiber-reinforced slabs demonstrated gradual crack propagation and maintained structural continuity throughout the loading process. The fibers crossing developing cracks transferred tensile stresses between separated concrete surfaces, resulting in improved energy absorption and higher ductility. This behavior is particularly

important for floor slab applications because flexural performance largely determines serviceability, durability, and structural safety under repeated loading conditions (9).

The reduction in crack width observed in the reinforced specimens further confirms the effectiveness of fiber reinforcement in controlling crack development. Narrower cracks reduce the penetration of moisture, chlorides, and other aggressive substances into the concrete, thereby minimizing reinforcement corrosion and extending the service life of structural elements. The present findings therefore suggest that fiber reinforcement contributes not only to increased mechanical strength but also to enhanced long-term durability. Similar conclusions have been reported by researchers investigating crack control mechanisms in fiber-reinforced lightweight concrete systems (10).

The experimental results also indicate that fiber dosage plays a decisive role in determining structural performance. Although increasing the fiber content from 0.5% to 1.0% produced substantial improvements in both compressive and flexural strength, further increasing the dosage to 1.5% resulted in only marginal additional benefits. This observation is most likely associated with reduced workability and the increased probability of fiber clustering within the fresh concrete mixture. Excessive fiber content may hinder uniform compaction and create localized defects that partially offset the strengthening effect. Therefore, an optimum fiber dosage should be selected to achieve the best balance between mechanical performance and practical workability during production (11).

Another important aspect revealed by this study is the suitability of expanded clay concrete as a structural lightweight material. Despite its relatively low density, the incorporation of fibers significantly enhanced its load-bearing capacity without substantially increasing self-weight. This characteristic is particularly advantageous for prefabricated hollow-core slabs used in multistory buildings and seismic regions, where reduced dead load directly contributes to lower seismic forces, improved transportation efficiency, and easier installation. Furthermore, lightweight structural members decrease foundation loads and contribute to more economical building construction.

The improved ultrasonic pulse velocity measured in fiber-reinforced specimens indicates better internal homogeneity and fewer structural discontinuities. These findings suggest that fibers improve the continuity of the cementitious matrix while reducing internal defects associated with pore development and microcracking. Microscopic observations further supported this conclusion, showing numerous fibers bridging fractured surfaces and maintaining cohesion between separated concrete segments after crack formation. Fiber pull-out rather than fiber rupture was identified as the dominant failure mechanism, indicating effective stress transfer between the fibers and the surrounding cement matrix (12).

Although the present investigation produced encouraging results, several limitations should be acknowledged. The experimental program considered only one type of steel fiber and a limited range of fiber dosages under laboratory conditions. Long-term performance under environmental exposure, including freeze-thaw cycles, carbonation, sulfate attack, fatigue loading, creep, and shrinkage, was not evaluated. In addition, numerical modeling and finite element analysis were beyond the scope of the current investigation. Future research should therefore investigate different fiber types, hybrid fiber systems, alternative lightweight aggregates, and advanced microstructural

characterization techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD), and computed tomography (CT) to obtain a more comprehensive understanding of the strengthening mechanisms.

Overall, the experimental findings demonstrate that fiber-reinforced expanded clay concrete is a highly promising material for manufacturing hollow-core floor slabs. The combination of lightweight characteristics, improved compressive strength, enhanced flexural performance, superior crack resistance, and increased ductility makes this composite material suitable for sustainable structural applications. The results provide valuable scientific evidence supporting the wider implementation of fiber-expanded clay concrete in modern prefabricated construction systems, particularly where structural efficiency, durability, and reduced self-weight are of primary importance.

Conclusion

The experimental investigation confirmed that the incorporation of steel fibers significantly enhances the mechanical performance of hollow-core floor slabs manufactured from expanded clay concrete. Compared with conventional expanded clay concrete, fiber-reinforced specimens demonstrated higher compressive strength, greater flexural capacity, improved crack resistance, and increased ductility. These improvements are primarily attributed to the crack-bridging effect of steel fibers, which delays crack initiation, restricts crack propagation, and improves stress redistribution within the cementitious matrix.

Among the investigated mixtures, the specimen containing **1.0% steel fiber** exhibited the most favorable balance between mechanical strength, structural reliability, and workability. This mixture achieved the highest practical improvement in compressive strength and flexural performance while maintaining satisfactory concrete consistency during production. Increasing the fiber dosage beyond 1.0% produced only minor additional improvements, indicating that excessive fiber content is not economically justified and may adversely influence concrete workability.

The experimental observations further demonstrated that fiber reinforcement reduced crack width, increased energy absorption capacity, and transformed brittle failure into a more ductile failure mechanism. These characteristics substantially improve the serviceability and durability of hollow-core floor slabs, particularly under repeated loading conditions. Furthermore, the lightweight nature of expanded clay concrete was preserved despite the addition of fibers, making the developed composite suitable for modern prefabricated construction systems where reduced structural weight and improved seismic performance are required.

Overall, the findings indicate that fiber-reinforced expanded clay concrete represents an effective structural material for manufacturing hollow-core floor slabs with enhanced strength and durability. The developed composite has considerable potential for application in residential, commercial, and industrial buildings requiring lightweight yet mechanically reliable structural elements. Future studies should investigate long-term durability, fatigue behavior, shrinkage, creep, freeze-thaw resistance, and numerical modeling of fiber-reinforced lightweight structural members to further optimize their engineering performance.

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