

Review Article

Yahya Mo. Yahya* and Alaa C. Galeb

Key effects on the structural behavior of fiber-reinforced lightweight concrete-ribbed slabs: A review

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Abstract: A concrete slab is one of the chief structural members in buildings, considered the most prominent member consuming concrete. Structural engineers are challenged to work on the new trend introduced using different slabs. One-way ribbed slabs are commonly used in construction due to their efficiency in spanning long distances while maintaining a low overall depth and giving the least possible number of columns. The main limitation of slab design in the construction of a reinforced concrete structure is the span between columns; a greater span between columns necessitates more supported beams or increased slab thickness; these requirements lead to an increase in the structure weight due to other concrete and steel which make the structure more costly. On the other hand, any increase in the structure's self-weight limits the horizontal slab's span, increases the structure's stress, and raises the inertia forces that must be resisted. Lightweight aggregate concrete has been effectively utilized for structural applications for a long time. The density of lightweight concrete (LWC) is sometimes more essential than its strength in structural applications. The dead load is reduced for structural design and foundations when the density is lower for the same strength level. Reinforced concrete ribbed slabs have become increasingly popular in industry construction as an alternative to solid slabs in building structures. The incorporation of steel fibers facilitates flexural softening, which takes longer than sudden brittle failure, indicating its ability to increase energy absorption and improve crack behavior. Designing structures requires materials with higher strength-to-weight ratios. Ribs and LWCs are two leading sustainable assets. The world is moving toward

sustainability by reducing the amount of concrete used and the overall weight of the unit. Studies have shown that the drop in compressive strength was about 4.85–65.55%. The structural performance of lightweight fiber-reinforced concrete slabs is influenced by the concrete mix ratio, fiber type and content, reinforcement detail, and rib geometry. The study provides valuable insights into the properties and performance of key effects on the structural behavior of fiber-reinforced LWC-ribbed slabs. It provides recommendations for future research and advancement of sustainable building methods.

Keywords: fiber reinforcement, lightweight concrete, one-way slab, ribbed slab geometry, weight reduction

1 Introduction

Concrete is widely used in construction due to its simple manufacturing process, affordability, and availability of raw materials [1,2]. It possesses flexibility, toughness, and adaptability suitable for conventional buildings [3,4]. However, traditional concrete has limitations such as weight, low tensile strength, brittleness, and lack of toughness [5]. As a result, it is unsuitable for constructing unique structures like bridge decks, offshore oil platforms, and field-fabricated beams [6]. To meet the demand for such constructions, there is a need for an improved concrete composite that is lighter in weight and offers superior mechanical properties [7,8]. Over the past three decades, there has been a significant increase in interest and utilization of lightweight concretes (LWCs) worldwide, owing to their potential in the construction industry.

Various fibers can be added to concrete, especially lightweight mixtures, to increase its energy absorption capacity after matrix breaking and overcome this drawback. Fibers decrease the crack opening, enhancing a material's fatigue strength [9]. The elasticity modulus in the post-cracking zone of cyclically stressed fiber-reinforced concrete (FRC) is influenced by the maximum deformation of the specimen and the width of the fracture in the matrix. These factors play a role in the rupture of the matrix.

* **Corresponding author: Yahya Mo. Yahya**, Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq, e-mail: yahyaalsahlawy@gmail.com

Alaa C. Galeb: Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq, e-mail: alaa.galeb@uobasrah.edu.iq

In FRC, the energy needed to surpass the reinforcing mechanisms provided by the fibers after matrix cracking is significantly higher than the energy absorbed during the initial matrix breakage. Therefore, the main advantage of fiber reinforcement lies in its capacity to absorb energy [10].

The increasing demand for living space has caused modern structures to grow taller, deeper, and wider [11]. These requirements have been met in the past 20 years by the development of new, highly durable, LWC [12,13]. Light-weight cement concrete (LCC), a recently developed material, has relatively little density and has adequate compressive strength [14,15], thermal resistance [16], impermeability, and good durability [17]. Due to the numerous applications for LCC in offshore and civil structures, it has received more attention [18].

In general, there are various approaches to reduce the weight of slabs. This is important because the self-weight of slabs contributes significantly to the total weight of multi-story building superstructures, especially in long-span and high-rise buildings. As a consequence, the structure's foundation is minimized in size. By reducing the weight of slabs, sustainable construction practices can be promoted through the efficient use of concrete. Two methods can be employed for weight reduction: the first method involves utilizing specialized slabs, such as one-way ribbed (joist) slab systems [19]. A ribbed slab is a structure constructed of equally spaced ribs that span in a single direction and are united by a flange, also known as the structural concrete topping (Figure 1). These systems consist of regularly spaced concrete ribs or beams extending in a single direction, reinforced concrete slabs cast in one piece along the ribs, and beams extending between columns perpendicular to the ribs. Weight is reduced by eliminating the concrete volume below the neutral axis of traditional solid slabs. The second approach involves the use of LWC [20], which effectively reduces the overall weight of the slab.

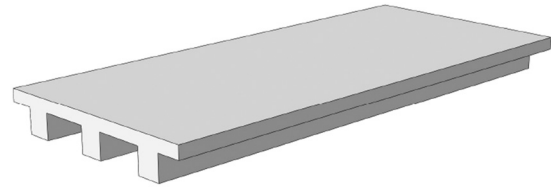


Figure 1: Cross section of ribbed slab.

Zhang *et al.* [21] did a study on the shrinkage of high-strength LWAC and found that it had reduced significantly compared to normal-weight concrete (NWC), which is an advantage that makes structures more durable.

In 2009, Henkensiefken *et al.* [22] used saturated LWAs in concrete mixes as a means to do internal curing and minimize early-age shrinkage cracks. This is again consistent with Zhang *et al.*'s results where they showed that the shrinkage value decreased more significantly with LWAC.

An example of a study exploring the mechanical features of LWAC is given by Bogas *et al.* [23]. They reported that such concretes were better in thermal insulation and fire resistance than those made from NWC but with lower strength.

One article by Hassanpour *et al.* [24] has shifted the focus of research in LWAC from non-structural to structural applications. They found that while using LWAC makes it lighter and results in simpler operations and lower transportation expenses, it may also require greater attention to design elements due to its lower modulus of elasticity.

Al-Aridhee [25] examined the viability of using native clays (Atapulgit) from southwest Iraq as a CA. Creating the LWA, examining the mechanical properties of the attapulgit aggregate concrete, and comparing the outcomes with porcelainite aggregate concrete comprised the experimental study. For the Attapulgit LWA, the results of the tests showed that the dry specific gravity was 1.45 and the bulk density was 808 kg/m^3 at a treatment burning temperature of $1,100^\circ\text{C}$ for a half-hour. The result of a density of $1,824 \text{ kg/m}^3$ for a cylinder compressive strength was 27.7 MPa with a ratio of $w/c = 0.4$. The percentages of increase for the corresponding porcelainite aggregate concrete with the same mix proportions were approximately 58.85, 41, 183, and 81%, respectively. This study showed the viability of using native clays as an aggregate, contributing to the sustainable sourcing of LWAC materials.

In a study by Al-Azzawi and Abbas [26] Researchers studied ways to reduce the self-weight of reinforced concrete structures, focusing on slabs. They explored two methods: reducing cross-sectional area with voids and using lightweight materials, with 23 and 29% weight

2 Review of literature

2.1 The effect of lightweight aggregate (LWA)

A review of the literature on LWA concrete (LWAC) covers a collection of investigations, each dealing with some aspect of LWAC: the issues such as shrinkage, mechanical properties, internal curing, and structural applications. Through comparing these studies, both similarities and differences in results can be seen; also, LWAC has its advantages and drawbacks.

reductions. Styropor block slabs showed the best results, with increased strength capacity of 8.6 and 5.7% compared to solid slabs. Cracks appeared earlier in styropor block slabs, but their development and width were significantly limited due to reinforcement mesh in the upper concrete layer.

Jomaa'h and Aljubory [27] highlighted a specialized study to replacing 0, 25, 50, 75, and 100% as volumetric ratios of normal CA by lightweight CA (claystone [bonza] and thermostone), in this study compressive strength, indirect tensile strength (splitting tensile strength and rupture modulus), and elastic modulus, as well as the unit weight, thermal conductivity, and absorption have been evaluated. The experimental results showed that a drop in compressive strength was between 4.85 and 63.31%, indirect tensile strength was between 5.66 and 72.75% for splitting tensile strength and 3 and 40% for modulus of rupture. Also, elastic modulus, oven-dry density, absorption, and thermal conductivity were between 3.85 and 40.93%, 9.11 and 40.04%, 4.58 and 11.8%, and 23.16 and 68.87%, respectively, compared to concrete with normal CA.

Al-Mamoori *et al.* [28] investigated the possibility of producing LWAC using waste and locally available natural resources. In this experiment, light CAs included pumice, gravel, porcelinite, and hybrid (brick + limestone). Both destructive and non-destructive experiments were conducted in this inquiry. They found that SLWAC with a density of no more than $2,000 \text{ kg/m}^3$ and a compressive strength of 25.3–36.1 MPa at 28 days for cylinders of $150 \text{ mm} \times 300 \text{ mm}$ may be made using waste, recycled, and naturally occurring materials. The following mechanical properties, when compared to natural gravel aggregate, showed reductions for different types of aggregate and volumetric ratio replacement: densities, modulus of rupture, splitting tensile strength, cylinder compressive strength, ultrasonic pulse velocity, elasticity modulus, and modulus of rupture.

Using pumice as 100% of the coarse aggregate results in lighter concrete while maintaining strength 27.17, porcelinite percentage (19.99, 27.66, 22, 38.65, 41.22, and 27.17). (21.50, 35.79, 32.59, 43.78, 51.22, and 28.26) percent, respectively; – 75% brick with 25% limestone, (20.71, 8.38, 28.31, 15.95, 19.39, and 12.32) percentage. This study contributed to understanding the environmental impact of LWAC and investigated producing LWAC using waste and naturally occurring materials, emphasizing the environmental advantages and the potential for using recycled materials.

Suseno *et al.* [29] studied 24 LWC slabs and analyzed the slabs' flexural behavior, bending moment, deflections, crack patterns, and failure modes using medium-K basaltic andesite pumice and scoria, as well as one normal concrete slab as a control. Their results suggested that in one-way

slabs, medium-K basaltic andesite pumice and scoria can be used to obtain satisfactory performance. The most significant factor was the reinforcement ratio. Ultimate bending moments were accurately estimated with theoretical calculations, while deflections and crack widths could not be predicted successfully. Failure modes were mainly reinforced yielding without spalling in the compressive concrete zone, whereas cracking patterns were typical flexural cracks.

Hama *et al.* [30] conducted a study to enhance the tensile strength of porcelanite LWAC using chopped carbon fibers. Their findings indicated that adding carbon fibers up to 2% (by volume) to the mix increased the compressive and splitting tensile strength as well as the elastic modulus of the porcelanite LWAC when compared to the reference LWAC (without fibers). The percentage of improvement was 14.40% for compressive strength, 68.00% for splitting tensile strength, and 10.66% for elastic modulus. However, the density of the LWC decreased as the amount of carbon fibers increased, as chopped carbon has a low density. Additionally, the use of chopped carbon fibers improved the ductility of the porcelanite LWA. Davidyuk *et al.* [31] discussed the use of high-strength reinforcing bars to erect LWC slabs, resulting in a 25–30% cost reduction compared to heavy concrete slabs without pre-stressed reinforcement. This method is commonly used in cities with limited land for high-rise buildings to reduce building mass and load. However, LWC is less common in Russia due to weaker aggregates, higher cement consumption, and poorer properties.

Fikry *et al.* [32] investigated the impact of LWC on structural elements by varying admixture content, cement content, and w/c ratio. It involved 25 mix trials and measured variables like slump loss, slump flow, compaction factor, compressive strength, and tensile strength. Results showed a slump range of 70–140 mm and an average slump loss similar to normal concrete. The use of mineral admixtures improved the compressive strength to 90–95% of normal concrete.

Jomaa'h *et al.* [33] centered on creating a control mixture and varying the usual weight using lightweight rubber, claystone (bonza), polystyrene, and thermostone (at varying volumetric ratios of 25, 50, and 75%) to evaluate the mechanical properties of concrete. As the lightweight CA increased, the test results demonstrated a decrease in the mechanical properties of the concrete. Specifically, the ranges of the reduction in the modulus of rupture, density, splitting tensile strength, and compressive strength were 24.58–72.27%, 5.72–31.36%, 15.09–71.73%, and 34.75–65.55% when compared to the control mixture, respectively.

Wiater and Siwowski [34] explored the use of glass fiber-reinforced polymer (GFRP) reinforcement and LWC for bridge deck slabs, highlighting their potential for

improved construction and rehabilitation. The study compares LWC slabs with GFRP bars for flexure and NWC slabs, finding inferior serviceability and ultimate behavior. Various techniques, including radial shear reinforcement, steel bars, GFRP rods, and high-strength bolts, were investigated for strengthening LWC flat slabs prone to punching shear failure. High-strength steel bolts with steel plates showed the highest ductility and changed failure mode. Finite element analysis supported experimental trends, while code equations underestimated punching shear capacity according to ACI 318.

Wei *et al.* [35] investigated the influence of the LWA size on the compressive strength, flexural strength, splitting tensile strength, and dry density of high strength-LWAC. In this investigation, four sizes of the expanded shale aggregate were adopted. The test results showed that the absence of medium-size particles declined the dry density and compaction of HSLWC. Meanwhile, specimens with medium-size LWA showed the highest cube compressive strength up to 72 MPa at 28 days. Furthermore, specimens with a single size of LWA displayed lower flexural and splitting tensile strengths than those with three LWA sizes.

Overall, the studies collectively emphasize the benefits of LWAC in terms of reduced shrinkage, improved thermal insulation, fire resistance, and environmental friendliness, balanced against challenges like lower strength and specific design considerations. The similarities across these studies lie in their focus on enhancing the practical and environmental aspects of LWAC, while the differences emerge in the specific attributes each study prioritizes, be it mechanical properties, shrinkage, or environmental impact.

2.2 Reinforcement details

Structural LWAC is a construction material that may achieve a reasonably high compressive strength while having a substantially reduced density. Nonetheless, using LWA instead of normal-weight aggregate in concrete must degrade certain composite properties. Incorporating fibers into concrete is one approach to increasing the characteristics of LWAC [36]. But Fibers, particularly steel fibers, can decrease the workability of structural LWAC. To increase workability, the use of superplasticizer, fine aggregate, and fly ash. Steel fiber increases LWAC's density, which can be compensated with mineral admixtures and small steel fiber content. Generally, steel fiber increases compressive strength, but over 2% volume fraction may reduce it. Fiber-reinforced LWAC has

higher splitting tensile strength than plain LWAC, especially at low fiber volume. The addition of fiber also increases flexural strength, with a higher effect than non-metallic fibers. The addition of steel fibers significantly affects the descending part of the stress-strain curve, preventing brittle failure. However, fibers have little effect on the ascending part of the stress-strain relationship. The effectiveness of fiber in improving LWAC's toughness is higher than NWC, and a combination of steel fiber and non-metallic fibers results in better toughness [24]. Steel fibers have been shown to have an uneven impact on compressive strength, with some studies reporting increases and others reporting losses or being unaffected [37]. According to studies, increasing volume percentages of steel fibers result in even greater compressive strength decreases [38,39]. The loss of workability is one factor that lowers compressive strengths. Due to the presence of fiber, steel fibers in the concrete mix provide additional voids and matrix disruption, which could lower compressive strength. Researchers observed that samples with fibers showed a decrease in this characteristic for all types and amounts of fiber in comparison to a reference combination of SCC without steel fibers [40]. The concentration of fibers in any region of the specimen should be kept to a minimum so that the system's ability to withstand loading is not compromised. This reduction relates to the aggregation of fibers at certain specimen spots, which reduces the resistive capacity of the concrete. The decline becomes more evident as the maximum aggregate size increases. In contrast, adding more fibers would increase the matrix's resistance to microcracks, notably in the section's tensile and bending characteristics [41]. Another research found that adding steel fiber to concrete increased its compressive strength significantly while maintaining a low w/c ratio of 0.24 [42]. This is done to guarantee that a durable concrete with lower porosity may be produced. Other research examined the direction, kind, and content of fibers, as well as the type of compaction. Each focuses on a distinct component of the work.

Gettu *et al.* [43] evaluated the fiber orientation and segregation in cylindrical specimens and prisms, which are commonly used for mechanical testing of steel fiber-reinforced concrete (SFRC). Moreover, the type of compaction, such as table vibration, hand tamping, or internal vibration, also significantly influences fiber distribution. The horizontal fiber orientation in prisms rises with increased table vibration; a small uniformity may be observed in cylindrical specimens after hand tamping. As part of the study, traditional concrete was used with 40 kg/m^3 of fibers. The study found that the activity of compaction may also disrupt the homogeneity of fiber dispersion during the concrete casting process.

In Zerbino *et al.* [44], the employment of fibers in concrete is helpful for strengthening the residual load-carrying capacity based on the type, quantity, and alignment of the fibers. The number of fibers present on the fracture surfaces and after peak parameters also has a major effect on the mechanical performance of the material. Fiber-reinforced self-compacting concrete (FR-SCC), which has a considerable flow and wall effects, is also necessary to influence fiber orientation. This study deals with fiber orientation in thin structural elements made of FR-SCC; therefore, its impact on residual mechanical properties. Results show strong heterogeneity in fiber orientation, varying with flow rate, wall effect, element thickness, and proximity to the bottom of the molds. The residual mechanical properties can vary significantly in thin elements when considering diverse zones and/or directions of the structural elements.

According to Fantilli *et al.* [45], the Soleri Viaduct in Northern Italy is undergoing a study to replace its reinforced concrete slabs with LWC structures without traditional steel reinforcing bars. The study found that a minimum amount of fibers or rebars is needed to prevent brittle failure and that a suitable mass of polymer fibers can increase structural ductility. The proposed procedure for evaluating the minimum amount of polymer fibers in LWC slabs is simple, but further tests are needed to establish a linear relationship between fiber amount and ductility index. Ahmad *et al.* [46] prepared three slabs with a volume fraction of 1% hooked ends steel fiber and an aspect ratio of 65. They compared the performance of reinforced steel fiber self-compacting concrete (SFSCC) ribbed slabs with conventionally reinforced ribbed slabs. They concluded that the performance of steel fiber-reinforced slabs was nearly equivalent to ordinary reinforced concrete ribbed slabs without fibers.

Rahman *et al.* [47] investigated the use of SFRC as a primary material for ribbed plates without traditional reinforcements through four-point bending tests. Three ribbed samples with different top layer thicknesses (100, 75, and 50 mm) were produced. Results showed similar flexural strength for 100 mm ribs and the lowest load capacity for 50-mm ply ribs. The addition of steel fibers improved the energy absorption capacity and cracking behavior of the sheet, prolonging deflection softening time and preventing sudden failure.

Galeb and Sabri [48] explored the impact of steel nails as fibers on the compressive strength of FRC using artificial neural networks. It tests cubic concrete samples with different mixing proportions and water-cement ratios. Results show that a 1:1.5:3 mixing ratio increases compressive strength with a 12% fiber addition, while a 1:2:4 ratio increases strength with a 20% fiber addition. The optimal water-cement ratio is 46% for the 1:1.5:3 ratio with a 12% fiber addition and 55% for the 1:2:4 ratio with a

20% fiber addition. The study also found that larger nail sizes with a lower fiber percentage increase compressive strength, but as the percentage increases, it decreases. Wang *et al.* [49] examined how the arrangement of the reinforcement affected the mechanical performance of a composite slab that included rebar and steel fiber. The slab is made up of three layers: a surficial layer reinforced with steel fibers, a core layer built of foam concrete, and ribs made of reinforced concrete with rebar. A 1.5 and 2.0% volume fraction were used, with a concrete strength of 30 N/mm². The research found that using steel fiber reinforcement with the proper volumetric ratio in a slab may help in resisting the development of cracks.

Fodzi and Mohd Hashim [50] explored the punching shear resistance and behavior of self-compacting fiber-reinforced concrete (SCFRC)-ribbed slabs. It is focused on a specially designed test arrangement that analyzes the relationship between punching shear load, shear plane angle, basic control perimeter critical value, and failure mode. The findings contribute to understanding the punching shear capacity of SCFRC-ribbed slabs and promote using SCFRC instead of regular concrete in structural designs. The punching shear test can be used as a suitable method for testing SCFRC and other fiber reinforcement composites. In Ahmad *et al.* [51], the flexural behavior of ribbed slabs produced from self-compacting concrete reinforced with steel fibers has been focused on this study. Thus, there are two aspects to the study: determining the effects of steel fiber distribution and flange thickness on flexural behavior. Six panels were fabricated with varying flange thicknesses and fiber reinforcement levels and then subjected to a four-point bending test as an experiment. Ultimately, it was found that panels that were fully reinforced had ultimate loads greater than those of partially reinforced ones.

In the 120 mm flange thickness case, the biggest difference was found. Additionally, load-deflection curves obtained from completely reinforced samples demonstrated high-deflection hardening that could be expected in one piece of a structural element. Based on these findings, the study concludes that fully reinforced samples with the greatest flange thickness showcased the best performance.

Another study looked into the behavior of SFSCC of the ribbed slab but under the effect of punching shear. In this study, the various parameters (topping thickness variation and material distribution) have been observed for each square slab sample cast with dimension 1,200 mm × 1,200 mm × 200 mm with the thickness of topping of 100 and 120 mm. They found that adding steel fibers to ribbed slabs enhanced punched shear resistance and had a similar load capacity to slabs reinforced by about 7–18%. This behavior has proven that SFSCC can slow down its cracking under concentrated load [52].

Depending on the results of this experimental study and numerical analysis of the finite element method by a software program (ABAQUS) carried out by the same researchers [50], it was observed that the type of slab with optimum performance the one entirely reinforced with steel fibers.

Ahmad *et al.* [53] examined the flexural performance of self-compacting concrete slabs blended with short-hooked-end steel fibers. The slabs were loaded until failure under four-point bending, and their load-bearing capacity, deflection, energy absorption capacity, and failure modes were analyzed. The study found that fully steel fiber reinforced samples had higher ultimate load and ductility, while partially reinforced samples had only one major crack. The study concluded that the full steel fiber reinforced sample with the highest flange thickness showed good performance under bending.

Wang and Wang [54] tested five groups of steel fiber-reinforced lightweight aggregate concrete with different steel fiber volumes to investigate the impact of steel fiber content on static mechanical properties and impact resistance. Results showed that adding steel fiber significantly improved flexural strength, splitting tensile strength, and impact resistance but had little effect on compressive strength. The study also found a logarithmic relationship between flexural toughness energy and impact energy. The feasible volume ratio of steel fiber was suggested to be 1–1.5%. The study suggests that steel fibers may increase initial linear elasticity before matrix microcracking.

In another study, as shown in Figure 2, load–deflection illustrates how FRC performs better in terms of flexural behavior than regular concrete. SFRC exhibits both deflection hardening, with multiple fine cracks, and deflection softening, typically with a single crack. These qualities are essential for building applications like seismic design, where

FRC's ability to sustain loads after initial cracking is particularly beneficial [55].

2.3 Effect of slab geometry

The distribution of fibers was profoundly affected by the shape and configuration of the structural component, the procedure of casting [56], and the fresh-state properties of the mix. A crucial factor to take into account while performing a flexural analysis on a structure made of FRC is the specimen geometry. It has been established by earlier studies. The way a slab specimen cracked was very different from how small prismatic examples cracked [57,58]. Owing to the specimen's shape, which might affect fiber orientation and distribution, larger specimens will produce superior flexural strength with more accurate results. Because of this, the information on the internal stress distribution from small samples does not adequately describe the behavior of steel FRC in slabs. As a result, if the design approach is based on small, rectangular samples of SFRC that are submitted to flexure, then, the creation of elevated slabs with steel fibers is not necessarily a viable option [58,59]. The majority of research dedicated to the utilization of SFRC and SCFRC in structural slabs was focused on panels that were flat in design [60,61]. The 1/4 scaled slab structure [59], panel thickness [58], panel form (square and round) [62], and panel size [63] are among the geometric adjustments that were looked into. Steel fibers were used in place of conventional reinforcing bars in small-sized concrete ribbed slab contoured panels by researchers [64]. The two and three rib counts that maintained the same overall slab panel thickness including the control slab were the criteria that were taken into account. The study made use of 60 mm steel

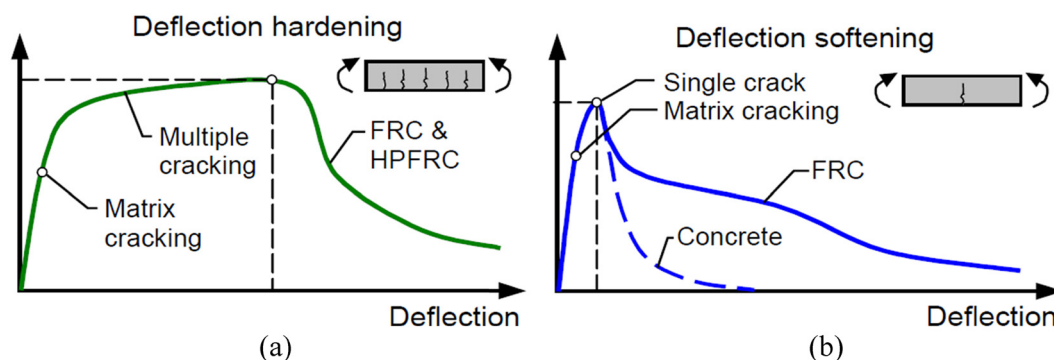


Figure 2: (a and b) The flexural response in FRC in terms of deflection hardening and softening [55]. (a) Deflection hardening and (b) deflection softening.

fibers at a volume fraction of 0.5% (40 kg/m^3) in a vibrated concrete mix that was normally graded C30/37. The fibers' remarkable flexural performance and ability to withstand loadings with the three-ribbed slab structure were demonstrated by the results. Upon reaching the ultimate load, the three-ribbed panel outperformed the control sample in progressive deflection softening, although having a lower ultimate load. A related study on ribbed slab panels was carried out, taking into account the geometry of the ribbed panels and utilizing the self-compacting concrete mix's flow ability [65]. The study concentrated on the quantity of ribs provided in a slab section, which is about the same as the research conducted with different kinds of concrete mixes by other studies [64]. The findings showed that during three-point bending, 0.5% of steel fibers may still withstand flexural pressure. Nevertheless, upon analyzing the cracking behavior, it was found that the samples only had one large fracture, suggesting that the steel fibers' stress dispersion was restricted to one area. One of the elements influencing the panels' structural behavior is the rib geometry; earlier research has looked into the effects of various rib and slab geometries. In Souza *et al.* [65], a laboratory study was conducted to understand the shear strength of single-rib reinforced concrete slabs without stirrups. The study involved fabricating eight slabs with different spacing between ribs and flange thickness. The ultimate strength of these slabs was evaluated using recommendations from NBR 6118, ACI 318, and EUROCODE 2. The results showed that as flange thickness increased, shear strength also increased, but this increase was accompanied by higher steel strain and greater deflection.

Abdulkareem and Alfeehan [66] consisted of two parts: the experimental work and the numerical work. The first portion was comprised of two sections. The primary variable under investigation in this research was the ratio (d/h) of the rib depth to the total depth of the beam. This ratio was equal to 0, 0.319, 0.477, and 0.625. The quantity of concrete and the percentage of steel reinforcement are the same in every test specimen. The bidirectional micro-reinforcement layers in the multiple layers of the reinforcing steel had a diameter of 1.55 mm and a clear spacing of 10 mm in each direction. Additionally, in every studied specimen, the rib width was set at the same thickness as the slab. The load capacity and deflection data were gathered at every step of the loading procedure. The ANSYS software was used to analyze the specimens and confirm the results, helping to finish the numerical part of the project. The findings showed that by raising the load-carrying capacity and lowering deflection to a certain limit, raising the (d/h) ratio improved structural behavior. It has been done to show that the numerical and experimental findings are compatible.

Farouk [67] used finite element theory to analyze continuous one-way normal reinforced ribbed slabs (ANSYS software). The impact of the cross-ribs and middle supports' stiffness on the behavior of a one-way ribbed slab was one of the study's factors. We assessed seven two-bay, one-way slabs. The dimensions of each bay on the reference slab were $6 \text{ m} \times 6 \text{ m}$. The top slab of the cross-sectioned ribs measured $0.1 \text{ m} \times 0.25 \text{ m}$ and had a thickness of 5 cm. The net gap between the ribs was 0.4 m. The width of the solid center portion was 1.8 m, while the width of the solid edge portions on each side was 0.3 m. The supporting beams' cross-section measures ($0.3 \text{ m} \times 1.05 \text{ m}$). The characteristics under study showed that the cross-ribs lessen the buckling of the slab as well as the loads and deformations that are created in the solid and main rib sections.

Sacramento *et al.* [68] conducted an experimental and computational study on ribbed slabs with wide-beam, examining their resistance to punching and shear strength. They tested two one-way slabs and two two-way slabs with variable depths. The findings of the study emphasized the significance of the connection between wide-beam ribs in the design of slabs, primarily due to the difference in stiffness in the transition zone. When estimating the ultimate load for the ribs, the most accurate predictions were obtained using EC 2 [69] guidelines. On the other hand, the estimates provided by ACI 318 [70] were relatively conservative, while those given by NBR 6118 [71] were deemed unsafe. The study highlights the importance of considering the wide-beam ribs connection in ribbed slab design to ensure structural stability and safety.

In Abdulkareem and Alfeehan [66], ribbed plates were investigated as a lightweight, stiffer alternative to traditional plates, aiming to achieve lighter structures while minimizing material usage. The study focused on the ratio of rib depth (d) to beam depth (h), with all slabs maintaining consistent concrete volume, reinforcement percentage, and rib width. Load capacity and deflection were measured during the loading phase, and ANSYS 15 software was used for nonlinear finite element analysis. The results showed that increasing the (d/h) ratio enhances load capacity and reduces deflection up to a certain threshold, leading to improved structural performance. Both numerical and experimental results confirmed compatibility, demonstrating the potential of ribbed plates in various applications. Al-Nasra *et al.* [72] examined the impact of rib spacing on LWC performance in reinforced concrete ribbed slabs. Five slabs were prepared and tested for flexural bending stress. The space between ribs was filled with polystyrene foam blocks and special fibers. Results showed that increasing rib spacing led to a decrease in slab strength and a slight reduction in the strength-to-weight ratio. The study also considered material costs.

Abdulhussein and Alfeehan [73] casted four flanged one-way ribbed lightweight-reinforced concrete slabs and tested them under two-point loading. The variable in this study was the ratio of the depth of the rib to the overall depth of the beam, which was equal to 0.5, 0.701, 0.835, and 0.92. On the other hand, all slabs have the same amount of steel reinforcement ratio and concrete volume. The rib width was also equal to the thickness of slabs as a limitation in all slabs. The findings indicated that increasing the ratio of the depth of the rib to the overall depth of the beam improved the structural behavior by increasing the ultimate load capacity and lowering the deflection up to a specific limit. It was found that the optimum ratio was 0.835.

Liu *et al.* [74] dealt with the development of a new type of composite slab – prestressed concrete composite slab with precast (CSPRP) inverted T-shaped Ribbed Panels. Three different rib shapes have been identified that produce different flexural behaviors. Numerical simulations and a series of bending tests on six full-scale specimens were performed to examine the issue in detail. Results from the tests show that composite behavior can be achieved between precast and cast-in-place concrete layers, as well as consistent static performance including cracking load, ultimate bearing capacity, and deflection for CSPRPs with various rib shapes.

An all-inclusive parametric study was carried out to investigate the static behavior of CSPRP, allowing spans, contact degrees, prestress ratios, and prestress grades to vary to capture practical considerations. Furthermore, to verify the precision and applicability of these formulas obtained through this research toward actual designs, a comparison has been made between theoretical values, test results, and parametric study findings.

Mohammed and Kadhim [75] analyzed the performance of single-rib structures by considering factors like concrete type, reinforcement ratio, rib geometry, and void ratio type. It found that substituting pumice for gravel in concrete resulted in high-strength LWC (HSLWC), with a compressive strength of 42.2 MPa and a density of 1,943 kg/m³. HSLWC had lower thermal conductivity and unit weight compared to HSNWC. However, the ultimate strength of HSLWC ribs decreased by 17.70%, requiring an increase in the reinforcement ratio. Changing the number of ribs while keeping tendons constant had minimal impact on strength capacity but demonstrated economic advantages. Increasing rib width to reduce void fraction significantly improved structural efficiency. Using ribbed plates with HSLWC improved ultimate strength by 130.37% and reduced deflection.

3 Conclusion

Several conclusions are drawn about the major influences on the structural behavior of fiber-reinforced LWC ribbed slabs based on the previously given reviews.

LWAs, as opposed to traditional aggregates, reduce weight in concrete compositions and enhance fire and insulating resistance. Simultaneously, it results in decreased compressive strength, elevated expenses, sensitivity to moisture, difficulties in mix design, and specific handling needs. Research has indicated that, depending on the kind of aggregate used and the characteristics of the concrete mix, the decrease in compressive strength was around 4.85–65.55%.

Because structural LWAC can achieve a good compressive strength at a significantly lower density than NWC, it offers an alternative to traditional concrete for construction applications. But when LWA is put to concrete instead of normal-weight aggregate, part of the composite's qualities have to deteriorate. One method of improving LWAC properties is the insertion of fibers into the concrete.

The addition of fibers to lightweight-ribbed slab concrete can have several beneficial effects, including:

1. Improved crack resistance: Adding fibers can help distribute stress more evenly throughout the concrete mixture, reducing cracking and improving its overall durability.
2. Increased toughness: Fibers can also aid in enhancing the concrete mixture's toughness, increasing its resistance to impact and other forms of damage.
3. Reduced shrinkage: By adding fibers, the concrete mixture's dimensional stability can be improved by reducing shrinkage.
4. The inclusion of steel fibers increases the structure's durability and service load while reducing the rate at which cracks propagate.

For lightweight-ribbed slab concrete, adding fiber may have a negative effect the effect of fibers varies according to kind, dosage, mix design, and curing circumstances; therefore, for best results and intended outcomes, considerable consideration is required.

Among the elements influencing the panels' structural behavior is the rib geometry, which includes

1. Rib width directly impacts slab load-carrying capacity, with wider ribs supporting more load than narrower ones. However, excessive width can lead to inefficient material use and increased weight.
2. Rib spacing affects a slab's load-bearing capacity, providing more support but also increasing its weight and construction cost. Closer spacing increases the slab's capacity to bear loads.

3. Rib depth is crucial for slab construction, as deeper ribs can support more weight due to better bending strength. However, they also add to the slab's weight and present construction and maintenance challenges.
4. The thickness of a concrete slab affects its capacity to support weight, enhancing load dispersion. Although a thicker slab helps disperse loads more efficiently, it also adds weight and material expense.
5. Fiber-reinforced LWC enhances tensile strength, which is traditionally a weak point in concrete structures. The type, amount, and distribution of the fibers can significantly affect the slab's structural behavior.
6. The structural behavior of a slab is influenced by its density, compressive strength, and tensile strength. LWC, although cost-effective and easier to transport, often has lower strength than regular-weight concrete, potentially reducing its capacity to support weight.

4 Recommendations

1. Extend current research with more comprehensive assessments of material properties such as. ultrasonic, shrinkage, split tensile, fresh properties, split tensile strength, chloride, water absorption, acid resistance, and sulfate.
2. Gain an understanding of and research the steel fiber-reinforced LWC's long-term performance to ascertain its robustness.
3. Shape and arrangement: The overall configuration of the ribs and their arrangement can also affect the behavior of the structure. Depending on the loading and boundary conditions, a square grid, for example, may react differently from a triangular or hexagonal grid.
4. A comprehensive and extended evaluation of the costs and benefits of incorporating steel fibers into LWC, taking into account implementation-related expenses.

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