

A BRIEF REVIEW OF STEEL FIBER SELF-COMPACTING CONCRETE IN RIBBED SLAB

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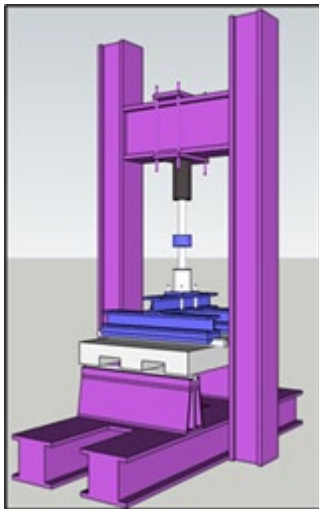
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Graphical abstract



Abstract

The use of Steel Fiber Reinforced Self-Compacting Concrete (SCFRC) as structural elements is seen as favorable alternative to solve typical issues of complex reinforcing spacing and compaction in normal reinforced concrete. The primary benefit of SCFRC is that it can be easily poured in-situ, filling corners of formwork and gaps between bars of reinforcement with its own weight. SCFRC's structural performance is constantly being investigated because of its superior engineering and mechanical properties. Steel fibers added to the mix improved the hardened properties of self-compacting concrete in terms of tensile strength, ductility, toughness, energy absorption capacity, and cracking resistance. This study reviews previous research on SCFRC performance in slab structures with an emphasis on flexural performance. Thus, the knowledge could provide guidelines for academia and industry players on the structural and materials behavior of the slab elements.

Keywords: Self-compacting concrete, ribbed slab, Steel fibers, flexural behavior, Full replacement.

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1.0 INTRODUCTION

The purpose of this study is to provide a literature overview of the structural and material capabilities of self-compacting steel fiber reinforced concrete (SCFRC) as a ribbed slab. The benefits of steel fiber inclusion in enhancing concrete properties, notably its contribution to stress transfer across cracks, prompted study into its capacity to replace conventional reinforcements partially or completely in concrete structures, particularly ribbed slabs.

A ribbed slab is a structure made up of evenly spaced ribs that span in a single direction and are joined by a flange which is also referred to as the structural concrete topping (Figure 1).

The ribs are arranged in longitudinal directions and behave in the same way as beams contributing to structural and material performance. There are different terms used by the design standards for the slab connecting the ribs such as “flange” (British Standards and Eurocode 2), “structural topping” [1, 2]; “topping flange”[3], “slab” [4] and “concrete table” in Brazilian code (NBR6118). The main benefit of using a ribbed slab is that it reduces the overall structural weight by eliminating the concrete below neutral axis. As a result, the reduction in weight leads to a lighter self-weight of the entire structure, minimizing the size of the foundation of the structure. The ribbed slab application can help to minimize the amount of concrete and thereby reduce the floor weight of reinforcements. This ribbed plate is appropriate for light to moderately heavy constructions

such as hospital wards, schools, and residences. [3]. Table 1 shows the brief overview of the association of self-compacting concrete-steel fiber-ribbed slab considering the problem associated with it, possible solution and direction of current and future research.

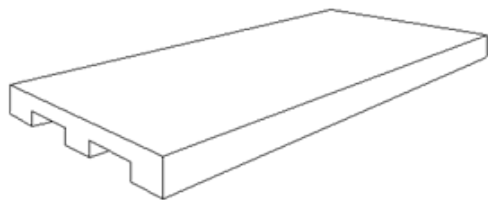


Figure 1. Cross section of ribbed slab

2.0 RIBBED SLAB DESIGN

The design method for conventional reinforced concrete ribbed slab is available in various codes [1, 2, 4, 5]. The design guidelines of the ribbed slab in Eurocode 2, Section 5.3.1 are like the British Standards, where the spacing between ribs is limited to 1.5 m and thickness of rib below the topping flange should not exceed four (4) times the rib width. The minimum requirement for the topping flange depth must be at least one-tenth (1/10) of the clear spacing between ribs or 50 mm, considering the greatest value. Similarly, the minimum rib and topping flange thicknesses should follow the fire resistance requirements stated in Section 5.7.5 of the EC2 for Structural Fire Design, BS EN [6].

The longitudinal reinforcements in the ribs are determined based on the design method of a flange beam, considering the effective flange thickness in MS EN [2]. Meanwhile, welded fabric (BRC) is provided for reinforcements in the overhead flange to provide strength and durability of the slab. The BRC in the topping flange is also function in reducing shrinkage or

thermal cracking, which can be calculated by the area of mesh that is equivalent to 0.13% of the flange area [3]. Section 6.2.1 (4) of the Eurocode 2 provides guidelines for the shear reinforcements in which the design shear force values lesser than the design shear resistance, $VR_{d,c}$, minimum shear reinforcement has to be provided in the structure. However, this minimum shear reinforcement or links provision can be ignored for the ribbed slab structure where V_{ed} (design shear force in the section considered resulting from external loading and prestressing (bonded or unbonded)) is less than half of $VR_{d,c}$ and transverse distribution of loads is possible.

3.0 OVERVIEW OF RESEARCH IN RIBBED SLAB

Wang et al. [7] investigated the effect of reinforcement configuration on the mechanical performance of composite slab containing both steel fiber and rebar. The slab composed of foam concrete as the core layer, steel fiber-reinforced concrete as the surficial layer, and rebar-reinforced concrete as the ribs. A volume fraction of 1.5% and 2.0% were used strength of concrete 30 N/mm². According to the study, an appropriate volumetric ratio steel fiber used as reinforcement in a slab can assist in resisting development of cracks. Ju et al. [8] proposed an “optimized-section precast slab” while maintaining the structural aesthetics (OPS) by adopting efficient arrangement of cross-section that may lower the quantity of materials used in a research that resembled a ribbed slab. The objective is to validate the structural performance of the composite pre-cast specimens by examining their flexure and shear behavior. This will result in specimens that can withstand both positive and negative moments. The results also revealed that there was no damage at the interface between the pre-cast unit and the topping concrete, and that the composite specimens behaved like full composites.

Table 1 Brief overview of SCC-steel fiber-ribbed slab research direction

Literature Analysis	Solution	SIZE FACTOR	Small, Thickness, Width and Length	Gap of Research	SIGNIFICANT	
		SCC	Slab Structures			<ul style="list-style-type: none"> • Full and Partial SF Reinforcement • Varies Topping Flange Thickness • Needs Full Scale Testing • Limited studies SFRC Slab with Ribbed Slab Profile
			Material Properties			
		Steel Fibers	Partial			
			Full			
		Ribbed Profile	SFRC			
	Conventional					
	Issues in Slab	SFRC Design				
		Fiber Distribution (Orientation)				
		Crowded Reinforcement				
Slab Geometry (Solid Slab/Flat)						
<ul style="list-style-type: none"> • Ribbed Profile • Reduce Slab Weights • Reduce Concrete • Optimize Use of SF Self-Compacting FRC Materials • Manpower Reduction • Time Saving • Ease Construction Process 						

Steel fiber as the main reinforcements in reinforced concrete (SFRC) was also explored by others [9, 10]. Both studies on the flexural performance of ribbed slab by considering normal

strength concrete ($f_{ck} = 30 \text{ N/mm}^2$) reinforced with 0.5% (40 kg/m³) volume fraction of steel fibers. The respective investigation studied on varying the topping flange thickness

[18] and considered different numbers of ribs [10]. These studies demonstrated promising performance of the SFRC ribbed slab under bending. The two previous research were extended to explore the performance of SCFRC ribbed slab with

steel fibers as the only reinforcement since most studies focused on conventionally reinforced cast in-situ reinforced concrete ribbed slab (reinforcement bars and wire mesh) [11].

Table 2 Selected previous studies in SFRC and SCFRC applications

Ref	Fiber types	Aspect Ratio (l/d)	% Volume	Type of structure
[10, 30]	Hooked end	80	0.5% (40 kg/m ³)	SFRC ribbed slab panels Variation: number of ribs
[9]	Hooked end	80	0.5% (40 kg/m ³)	SFRC ribbed slab panels Variation: rib depth
[29]	Hooked end	70	1.1% (90 kg/m ³)	SFRC Elevated slabs (1/4 scaled prototype)
[28]	Hooked end 35 & 60 mm	64 and 80	0.25% and 0.5% (20 and 40 kg/m ³)	SFRC Slab & beam Variation: Slab width and length
[27]	Hooked end	74	0.75% (60 kg/m ³)	SCFRC Sandwich panels
[26]	Hooked end	74	1.1% (90 kg/m ³)	SCFRC Elevated concrete slabs
[25]	Hooked end	80	40 kg/m ³ - walls & slabs 30 kg/m ³ - beams	SFRC Wall panels, slabs, beams
[24]	Hooked end	78	0.4% (35 kg/m ³)	SCFRC Slab, wall and beam
[23]	Undulated	39	1.25% (100 kg/m ³)	SFRC Flat slab
[22]	Hooked end	80	0.5% (45 kg/m ³)	SCFRC laminar structure
[20, 21]	Hooked end Undulated	60 38	0.9% (70 kg/m ³) 1.25% (100 kg/m ³)	SCFRC Free suspended elevated slab
[19]	Hooked end	80	0.3% (30 kg/m ³)	SCFRC Lightweight panels
[18]	Crimped	41.9 and 52.4	0.5% (25 kg/m ³), 1.0% (50 kg/m ³) and 1.5% (75 kg/m ³)	Small SFRC slab
[17]	Indented flat low carbon fibers	62 to 100	1-1.5%	Small SFRC slab

4.0 OVERVIEW OF RESEARCH IN RIBBED SLAB

4.1 Slump Flow and Passing Ability at the Fresh State

Incorporating steel fiber into a self-compacting concrete (SCC) mix can affect the fresh state mix owing to the volume, shape, and aspect ratio of the fibers [12]. The geometry of steel fibers has a significant impact on the fresh properties of self-compacting concrete [13]. Steel fibers can significantly have an impact on the workability of fresh concrete, making the mixture stiffer and with lower slump values, thus making it less workable [14]. Stiffer mixes might result in uneven fiber distribution, whereas a uniform fiber dispersion is especially important for structural applications. The activity of compaction can also interrupt the uniformity of the fiber dispersion in the concrete casting process [15]. The rheological effectiveness of SCC is an advantage to generate SCFRC when steel fibers are added, which disperses more uniformly in a highly workable combination [16]. The inclusion of steel fibers still requires higher amounts of paste for better fiber dispersion to maintain the workability of the SCC. This may be achieved by increasing the cement, filler, and fine aggregate content [12].

Slump flow, passing ability, and resistance to segregation are three of the tests that must be carried out to ensure that a self-compacting concrete meets its specifications. This notion was validated by incremental volumetric portions ranging from 0.33 percent to 1.1 percent [31]. The slump flow test demonstrated how fiber content affects the flowability of each concrete specimen prepared in the study, with the diameter of the patty decreasing as the dosage of steel fibers increases. Meanwhile, in the V-funnel test for passing ability, increasing the volume of fibers resulted in longer duration to empty the concrete inside the funnel. Studies also revealed that a large volume fraction of hooked end steel fiber (2%, 60-mm length) with an aspect ratio of 80 had an impact on the rheological characteristics of self-consolidating concrete by reducing slump spread [32]. Meanwhile, shorter steel fibers (35 mm in length) with a 45 aspect ratio exhibited an increase in slump that was within EFNARC's lower limit [33]. These findings suggest that concrete has the capacity to alter shape, flow past barriers, and fill the mold without any external mechanical stroke and to travel through small passages without blockage. However, the segregation resistance test is not applicable to SFRC containing steel fibers according to BS EN 206 2013 [34]. As an important consideration, the samples not reinforced with reinforcement

bars the ability to pass is not significant. Furthermore, samples that are lightly reinforced with reinforcement bar in the rib and the welded fabric (BRC) in the topping, therefore the passing ability is not necessary.

The inclusion of steel fibers to the SCC mix would alter the granular skeleton structure of the material. Thus, higher filler content is needed to increase the packing density of the mix [35]. Based on the criterion of EFNARC [33], a slump flow of less than 650 mm is still appropriate for structures that meet these requirements; the shape of the formwork allows the mix to flow easily, provides ample space between reinforcements, lightly reinforced, less than 500 mm thick and a short-distance discharge to the formwork. The slump flow in the SCFRC mix is also influenced by the fiber factor ($V_f l/d$) or by the fiber reinforcing index (RI) considering the fraction, length, and diameter of the steel fiber [14]. The slump flow time also increases with higher maximum aggregate size due to the loss of energy during particle movement, particularly with higher amounts of steel fibers [36].

4.2 Compressive Strength

Research has shown inconsistent effect of steel fibers on compressive strength, with some findings reported increases, while others reported decreases or not significantly affected [13]. One of the factors that reduce the compressive strengths in SCC is the decrease in workability that causes reduction in compaction level. This factor is closely related to the casting method. Both factors greatly influence the distribution and orientation of the fiber that will then affect the mechanical properties of the SCC mixture [24, 37]. Studies also found that higher volume percentages of steel fibers result in further reductions in compressive strength. [38-41]. The presence of steel fibers in the SCC causes the matrix to become disrupted, resulting in more voids that can lead to a reduction in compressive strength. A study indicated that samples containing fibers displayed a decrease in this characteristic for all types and amounts of fiber when compared to a reference mixture of SCC without steel fibers [42]. The concentration of fibers at any sections of the specimen should be avoided not to reduce the system ability to sustain loading capacity. This reduction refers to accumulation of fibers at some specimen points, which decreases the resistive ability of the concrete.

The reduction is more noticeable with the use of larger maximum aggregate size. In comparison, the addition of higher volumes of fibers would contribute to increasing the resistance to microcracks within the matrix, particularly in the tensile and bending behaviors of the section [39]. However, the use of fly ash to substitute cement in SCC concrete can benefit in reducing the compression strength of SCC as the percentage of the substitution increase [43]. Another study reported a noticeable improvement in the compressive strength of concrete with steel fiber while having low w/c ratio of 0.24 [44]. This is to ensure a durable concrete with decrease porosity can be achieved.

4.3 Splitting Tensile Strength

In contrast to the influence of volume fraction on compressive strength of SCFRC, tensile splitting strength values increase significantly as steel fiber volume increased. The bridging mechanism produced by steel fibers, which restrains

microcracks opening, contributes to the increase in tensile strength. The fibers aid in the restraining of interior microcracks, resulting in increased tensile strength. SCC matrix bonding with steel fibers also has an impact on the enhancement [13, 36, 38]. This bonding behavior could be influenced by the geometry of the steel fibers that improve the bonding of the fiber-matrix and increase the pull-out strength, especially if hooked-end fibers are applied. A study showed that adding hooked-end steel fibers to high-strength SCC concrete by 0.5% and 1.0% (by volume) resulted in 6% increases in splitting tensile strength for addition of 0.5% of steel fibers into 28 days concrete and increase by 12% for addition of 1.0% [45]. This demonstrates that steel fibers can effectively bridge between internal microcracks in concrete thus improving the splitting tensile strength of the concrete.

4.4 Flexural behavior

BS EN [46] and ASTM C78 / C78M [47] provided standard procedures for assessing flexural strength or modulus of rupture (MOR). However, these two standards mainly focused on the determination of the MOR which are more suitable for plain or reinforced concrete samples. Examination was done on the dependency of flexural behavior on fiber length and bond strength [48]. Hooked-end steel fibers contribute to curve deflection-hardening response, whereas straight fibers result in deflection-softening response. This action may be attributed to the bridging factor of the fibers to the concrete matrix after concrete cracking. The hooked end fibers have unique functions in bridging stresses across microcracks that can further restrain macrocrack propagation. The improvement of mechanical bonding may also contribute due to the deformed shape of the steel fibers.

In view of SFRC and SCFRC considering the effect of fibers, the behavior is therefore not only depending on the value of MOR, but also on its post-cracking energy absorption ability or on its toughness. For the industry to embrace the steel fiber application, RILEM published documents that suggest characterizations and designs that centered primarily on reinforced concrete applications for steel fiber. This is consistent with the aims of RILEM to promote research collaboration on construction materials and structures. RILEM TC 162-TDF provides guideline predominantly for the characterization of the SFRC flexural behavior which is also applicable for SCFRC [49]. This reference is preferable guide in determining the flexural strength (MOR) and additionally evaluate the sample in terms of its flexural toughness property. Flexural behavior is improved in a similar manner to splitting tensile strength, owing to the crack-bridging action imparted by the random distribution of the fibers. The bridging forces between the fibers through micro-cracks help prevent crack formation [38]. This will lead to the increases in the maximum bending load with the increase of the flexural strength. It is seen that steel fibers can improve the flexural strength of concrete, and the increase is practically linear.

Fischer [50] recommended using Eq. (1) to predict the flexural strength of concrete with addition of steel fibers, f_{flex} .

$$f_{flex} = k_1 f_{b,PSCC} + k_2 V_f L/d \quad (1)$$

Where, $f_{b,PSCC}$ - Flexural strength of plain concrete, V_f - Steel fibers volume fraction, L - Steel fibers length, d - Steel fiber

diameter, k_1 and k_2 - Parameters that are determined based on experimental values. The k_1 and k_2 values used in Eq. (1) are obtained from the experimental results performed with different volume fractions of steel fibers. The k_1 value has been defined as 0.9 for steel fibrous concrete by several works [13, 50-52]. Meanwhile, the k_2 value ranges from 0.04 to 0.1 in consideration of the type of fibers, strength of fibers as well hybrid fibers in the mix.

The Eurocode 2 also defined the relationship between the flexural tensile strength, $f_{ctm,fl}$ of a reinforced concrete member in relation to the mean axial tensile strength and the depth of the cross-section by Eq. (2). This relationship may be used as a guideline for estimating the flexural strength of the structural member, $f_{ctm,fl}$. Similar relation is also applicable for the characteristic tensile strength value.

$$f_{ctm,fl} = \max \{ (1.6-h/1000) f_{ctm}, f_{ctm} \} \quad (2)$$

where, h = total depth of member (mm), f_{ctm} = mean axial tensile strength (as calculated based on Table 3.1 (MS EN 1992-1-1, 2010)

Substantial differences in bending efficiency and test response between SCFRC and SFRC was also found [35]. It was found that that SCFRC could perform better by positioning the steel fibers in the direction of the flow and the pull-out test of a single fiber. Furthermore, bending performance of SFRC was significantly affected in comparison to SCFRC by the trapped air and neighboring fibers. Another parameter is the flexural toughness that indicate the ability of the concrete material to absorb the flexural energy. This value can be calculated by the area under load-displacement curve. The inclusion of steel fibers may help to improve flexural toughness as well as improve concrete ductility. Higher volume fraction and fiber geometry resulted in improved flexural toughening of the specimen [38, 52]. Another study discovered that steel fibers with a higher aspect ratio performed better than those with a lower one, with hooked-end steel fibers with 80 aspect ratio promoting greater values of residual flexural strength, MOR, and toughness as compared to 45 [32]. This is due to the fiber pullout process, which is primarily regulated by the interfacial shear mechanism, as well as increased fiber diameter and length values, which improve bonding in the composite matrix. There is a notable increase in flexural strength with increasing fiber content, with 60mm length fiber exhibiting a greater gain in average flexural strength than 30mm length fiber [53]. The results demonstrated a sizeable impact of fiber dimensional characteristics on the flexural performance of SFRC owing to the large number of 30 mm fibers intersecting a section while the volume content is still the same. Another study in a simple comparison to plain concrete found that SCC concrete with steel fiber resulted in a 12% improvement in flexural strength when compared to plain concrete. [44].

4.4 Modulus of Elasticity and Poisson's Ratio

Generally, according to ACI_Committee_544-96 [54] the values of the modulus of elasticity and the ratio of Poisson were taken to be equal to those of plain concrete for fractions of a volume of less than 2%. Researchers claimed that fiber inclusion increased the modulus value significantly up to the optimum amount of fiber volume [55] and a 9% increase compared to reference plain concrete was reported [44]. Others reported on

negligible differences in comparison to plain concrete [41, 56, 57].

5.0 FLEXURAL BEHAVIOR OF SFRC AND SCFRC SLABS

Steel fiber reinforced concrete slab performances with full and partial inclusion of steel fibers to replace conventional reinforcements has attracted attention of many researchers. SFRC can be found in a variety of on-ground applications, including industrial pavements, parking lots, highways, and airport runways [58]. Steel fibers offer advantages in terms of enhancing the ductility and durability of the elements against cracking at the early and hardened strength stages [59, 60]. Steel fibers are also found utilized in elevated slab structures owing the promising properties [19, 21, 23-25, 29, 61, 62]. As such, a focus can be given on the utilization of the SCFRC material in elevated slabs with emphasize on flexural behavior of SFRC slab structure, the effect of geometry as well as the crack propagation under loading based on the findings of previous studies. Fiber reinforced concrete elements is associated with two types of flexural responses. Figure 2 illustrates the SFRC load-deflection graph that characterizes the deflection hardening as well as deflection-softening. SFRC material experiencing hardening will produce multiple, finer cracks compared to material experiencing softening where only one cracking is produced [63].

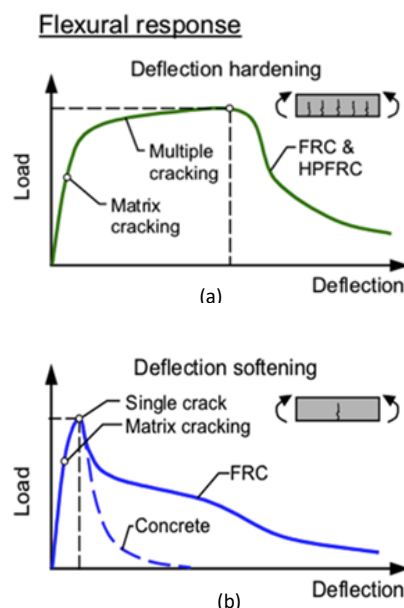


Figure 2 Flexural response in fiber reinforced concrete (a) deflection hardening and (b) Deflection softening [63].

The flexural behavior of SCFRC slab under load-deflection response behaves similarly to SFRC. The behavior of SFRC can be divided into four main stages [28, 64]. At the early stage of loading before the concrete cracks, the load-deflection curve of the SFRC slab behaves in linear elastic manner as the load increases. As the loading continuously being applied, the load deflection trend gradually deviates from the straight line. The non-linear behavior starts at stage 2 in which the tensile

strength of the matrix is reached, therefore initiating microcracks in the tensile zone. The cracks will propagate through the section and further shift the neutral axis location to the compression zone of the slab [17]. The occurrence of cracks will reduce the stiffness of the specimen. Hence, the microcracks in the concrete matrix eventually develop into macrocracks in plain concrete.

The inclusion of steel fibers can alleviate the cracking process by developing the adhering and toughening mechanism. At stage 3, the microcracking continues until reaching the ultimate load and the macrocracks starts developing. The macro cracks continue to widen at this stage and propagate towards the compression face of the structure. Eventually, the steel fibers are fully debonded resulting in the fiber pull-out. The stresses can still be measured with small increments in the load value as the deflection increases. In the final stage which is beyond the ultimate load the damage eventually causes the failure of the elements [64]. Fibers in the crack zone begin to experience complete pull out or fracture, resulting a traction free zone at the tensile face where the steel fibers no longer have any bonding to the concrete matrix. Steel fiber inside the concrete causes an increase in the flexural strength of the concrete due to the ductility within the tension zone that modifies the typical elastic stress-strain distribution over the depth of the structural member based on ACI_Committee_544-96 2002 [54]. The ductile stress distribution at the plastic state in the tension zone and elastic in the compression zone, causes the neutral axis to shift towards the compression face of the structure upon initiation of the cracks [17, 54, 65, 66]. Thus, the equilibrium below the neutral axis is covered by the pull-out resistance of the fibers provide the bridging of cracks within the tension zone [64]. This bridging action contributes to the structural damage tolerance in which able to prevent total splitting of the structural elements [67]. Fibers in SCFRC continue to carry and transfer the load to other fibers after cracking of brittle fracturing. The random dispersion of steel fibers throughout the fiber concrete, functions as bridging internal microcracks and transferring load by stitching together cracks in the concrete, thus contributes to the cohesiveness of the material [68].

6.0 SFRC AND SFRC IN STRUCTURAL APPLICATION

Table 2 shows the previous studies associated with SCC, steel fiber and slabs. Studies were found utilizing the steel fibers as reinforcement in concrete as the main material replacing the conventional reinforced concrete in SFRC slab elements [18, 69]. A design method was proposed within the allowable deflection and the volume applied of steel fibers in the mix [18]. The findings have shown that the steel fiber inclusion significantly improved the energy absorption capacity of the slab and longer fibers resulted in higher energy absorption capacity.

The utilization of steel fibers in self-compacting concrete is introduced in combination with concrete materials that is high flow ability to minimize the needs for vibration. Concrete without vibration is embraced to maintain the homogeneity of the fibers in the mix. Otherwise, the vibration will affect the distribution and orientation of the steel fibers [15].

In another study, SCFRC for a non-structural application of a façade lightweight panel with low volume fraction of fibers of 0.3% resulted in a slab capacity with high ductility under flexure [19]. The promising behavior in non-structural applications was extended to the slab in structural applications by investigating steel fiber inclusion in laminar structure in combination with provision of minimum reinforcing bars under flexure with steel fibers having low volume fraction (0.5%) [22]. The results demonstrated steel fibers significantly contribute at the cracking stage by improving the load carrying ability of the slab. The positive performance of the SCFRC material for slabs under flexure motivated a research on the application for a full replacement of conventional reinforcements [11, 20, 21, 23, 70]. A 1.25% (100 kg/m³) volume fraction of steel fibers in combination with the SCC mix is used in the study. The high flow ability of the SCC mix allows for the inclusion of higher volume of steel fibers. The investigation considered the application of the steel fibers as full replacement of conventional reinforcements in elevated suspended flat slab structure supported directly by columns. The performance of the SCFRC slab were tested in large scales under ultimate as well as serviceability limit states. The SCFRC slab were observed to be able to sustain loads and exhibited ductile behavior under flexure.

SCFRC was also studied in elevated slab elements for larger scale that tested a quarter (1/4) scaled slab prototype [26, 29]. A series of 6 slabs were built and supported directly by columns that incorporated 1.1% (90 kg/m³) of hooked end steel fibers. The results show SCFRC slabs satisfactorily behaved with no crack occurrence under service loads and exhibited high post-peak residual strength under ultimate load. SCFRC material was also utilized in precast sandwiched slab panels in combination with GFRP material [27] and hybrid fiber combination (steel fibers and polypropylene fibers) [62]. The specimen was found to be in ductile behavior and capable of withstanding substantial flexural and shear loading actions.

An investigation was also carried on the application of hooked-end steel fibers in a solid slab structure [25]. The study concluded that adding 0.5% fiber to the concrete mix improved the loading capacity of the slab by 68% when compared to the theoretically calculated load, demonstrating the efficacy of steel fibers. There was also a consideration on the effect of the steel fibers as reinforcements in structures that is structurally indeterminate that has higher stress distribution such as in flat slabs that are supported directly on columns or piles. With the inclusion of steel fibers, the results show a higher ultimate load carrying capacity than the cracking load [26].

7.0 EFFECT OF SLAB GEOMETRY

Fiber distribution was significantly influenced by the shape and geometry of the structural element as well as the practices involved during casting [29] and also the fresh state properties of the mix. The specimen geometry is one of the critical factors that need consideration in the flexural analysis of a fiber reinforced concrete structure. Previous studies concluded in agreement that the cracking behavior of a slab specimen significantly differ from the behavior of small prismatic specimens [18, 23, 54, 71, 72]. Larger scale specimens would predictably produce higher flexural strength with more reliable results due the geometry the specimens that has potential to

affect the fiber distribution and orientation in the specimen. Therefore, the data on the internal stress distribution from small specimens might not represent the behavior of steel fiber reinforced concrete in slab applications. As such, designing elevated slab with inclusion of steel fibers may not be reliable consideration if the design method is based on small SFRC standard prismatic samples under flexure [21, 23, 72]. Most of the research that have been carried out on the structural slab application of the SFRC and SCFRC considered flat slab panels [9, 20, 21, 23, 26, 28, 29]. Various geometric variations were considered such as 1/4 scaled slab structure [20, 21]; panel thickness [23]; panel shape, i.e. square and round [72]; and panel dimensions [28].

Samsudin et al. [10] also worked on the steel fiber inclusion to replace conventional reinforcement bars in small, scaled concrete ribbed slab profiled panels. The parameters being considered were the number of ribs (two and three ribs) with the same overall thickness of the slab panel including the control slab (without ribs). The study incorporated 0.5% (40 kg/m³) volume fraction of 60 mm steel fibers in a normally vibrated concrete mix Grade C30/37. Results were indicated that the fibers capable to sustain loadings with the three ribbed slab structure exhibiting a convincing flexural performance. Although the ultimate load obtained by the three ribbed panel was lower than the control sample, the ribbed panel behaved better in term of a more gradual deflection-softening upon reaching the ultimate load.

A related research on ribbed slab panels was carried out taking account of the geometry of the ribbed panels and utilized the flow ability of the self-compacting concrete mix [30]. The research focused on the number of ribs provided in a slab section, almost similar to the work done by Samsudin et al. [10] with different type of concrete mix. The outcomes demonstrated the ability of 0.5% steel fibers to sustain flexural loadings capacity under three-point bending. However, looking at the cracking behavior, only one major crack occurred in the samples, displaying the stress distribution by the steel fibers were concentrated within a single location.

8.0 CONCLUSION

Research related to the behavior of SCFRC incorporating steel fibers open a wide opportunity to fulfil the knowledge gap even with the presence of various types of precast slabs in the industry. Embarking studies on the performance of the steel fibers as the only reinforcing material in ribbed slabs of different geometry subjected to flexural loading is anticipated. Thus, to optimize the function of the steel fibers in the ribbed slab, the parameters considered for the structural response include the variation in the provision of steel fibers (full and partial reinforcement) with different topping flange thicknesses.

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