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Preliminary Investigation on the Flexural Behaviour of Steel Fibre Reinforced Self-Compacting Concrete Ribbed Slab

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ABSTRACT

A ribbed slab structure has the advantage in the reduction of concrete volume in between the ribs resulting in a lower structural self-weight. In order to overcome the drawbacks in the construction process, the application of steel fibre self-compacting concrete (SCFRC) is seen as an alternative material to be used in the slab. This preliminary investigation was carried out to investigate the flexural behaviour of steel fibre self-compacting concrete (SCFRC) as the main material in ribbed slab omitting the conventional reinforcements. Two samples of ribbed slab were prepared for this preliminary study; 2-ribbed and 3-ribbed in 1 m width to identify the effect of the geometry to the slab's flexural behaviour. The dimension of both samples is 2.5 m x 1 m with 150 mm thickness. The compressive strength of the mix is 48.6 MPa based on the cubes tested at 28 days. Load was applied to failure by using the four point bending test set-up with simple support condition. The result of the experiment recorded ultimate load carrying capacity at 30.68 kN for the 2-ribbed slab and 25.52 kN for 3-ribbed slab. From the results, the ultimate load of the 2-ribbed sample exceeds 3-ribbed by approximately 20%. This proved that even with lower concrete volume, the sample can still withstand an almost similar ultimate load. Cracks was also observed and recorded with the maximum crack width of 2 mm. It can be concluded that the steel fibres do have the potential to withstand flexural loadings. Steel fibre reduces macro-crack forming into *micro-cracks and improves concrete ductility, as well as improvement in deflection. This shows that steel fibre reinforced self-compacting concrete is practical as it offers good concrete properties as well as it can be mixed, placed easier without compaction.*

Keywords: *ribbed slab, steel fibre reinforced self-compacting concrete, hooked end, flexural, crack*

INTRODUCTION

Ribbed slab is a structure that consists of ribs spanning in one way and connected by structural concrete topping. The ribs are arranged in longitudinal direction and behave similarly to beams. The main advantage of the ribbed slab application is the reduction of the total structures weight by the removal of the concrete part below the neutral axis. This type of slab is suitable for the application in structures with light or moderate imposed loads, such as the hospital wards, school buildings and apartments [1].

Despite of the numerous advantages of a ribbed slab structure, there are drawbacks on the effectiveness of the ribbed slab especially in terms of its construction method. A ribbed slab that consists of small multiple ribs leads to the requirement of special formwork, complication in the placement of the reinforcements as well as improper concrete compaction [2]. The application of self-compacting concrete (SCC) in the construction of precast ribbed slab panel is seen as an alternative solution to the complication in placing the reinforcement with effective compaction of concrete in the ribs. Therefore, the development of the SCC that is high in flow and workability has been identified as an effective replacement to the conventional concrete used in construction industry that is dependent on the quality of the construction work [3].

The main advantages of SCC is its ability to be properly poured in place, filling the formwork corners and small voids between reinforcement bars by means of its own weight [3]. Its rheological property allows SCC to be effectively applied in complex shaped elements and congested reinforcements [4]. The engineering and mechanical properties of the hardened SCC is reported by a number of researchers to be almost similar to the ordinary well compacted concrete [5-7].

Plain concrete is a quasi-brittle material. Therefore, steel fibres are incorporated in the concrete mix in order to improve this behaviour and produce a more ductile material. However, the addition of steel fibres affects the workability of the fresh concrete significantly cause the mix to be much stiffer with lower slump measurement causing the mixture to be less workable [8]. Stiffer mixes further causes uneven distribution of steel fibres in the mix, whereas uniform fibre dispersion is very important especially for the structural application. The compaction process that is performed in the concrete casting process might also disturb the homogeneity of the steel fibre dispersion [9]. Therefore, by taking advantage of the rheological performance of self-compacting concrete (SCC) at fresh state, steel fibres are added to the mix to produce self-compacting steel fibre reinforced concrete (SCFRC) with a more uniform fibre dispersion in a highly workable mixture [4].

Steel fibres have been successfully used in concrete to improve its mechanical properties, such as post-cracking, load bearing capacity and energy absorption performance. Higher fibre volume in the mix results in an increment in the residual flexural strength, flexural toughness, energy absorption as well as the load bearing capacity by the fibre knitting between cracks that allows stress transfer at the crack openings [10-11]. Fibres are also used to limit the crack width, with beneficial consequences in terms of concrete durability. Apart from that, steel fibre can extend the technical benefits of SCC by providing crack bridging ability, higher toughness and long term durability.

EXPERIMENTAL WORK

The experimental work was carried out at the Heavy Structural Laboratory in Universiti Teknologi MARA, Malaysia. Two slab samples were prepared to assess the flexural behaviour of SCFRC in ribbed slabs, varying in the number of ribs; 2-ribbed and 3-ribbed as shown in Figure 1(a) and (b). Both samples were prepared with similar dimensions of 2.7 m x 1 m with the effective length of 2.5 m. The volume of ribbed slab constructed in this research is lesser than solid slabs due to the presence of void. The savings of the concrete volume is up to 14% and it is presented in Table 1.

Table 1: Percentage of Concrete Volume Reduction

Type of slab	Concrete volume (m^3)	% of concrete volume reduction
Solid	0.375	0 %
2-ribbed	0.323	14 %
3-ribbed	0.334	11 %

For this research, mix was prepared in accordance with the mix design in Table 2. The type of steel fibres used is hooked end with the tensile strength of 1100 MPa; measuring 0.75 mm in diameter and 60 mm in length as shown in Figure 2. The fibres were included in the mix by volume fraction of 0.5% amounting to 40 kg/m^3.

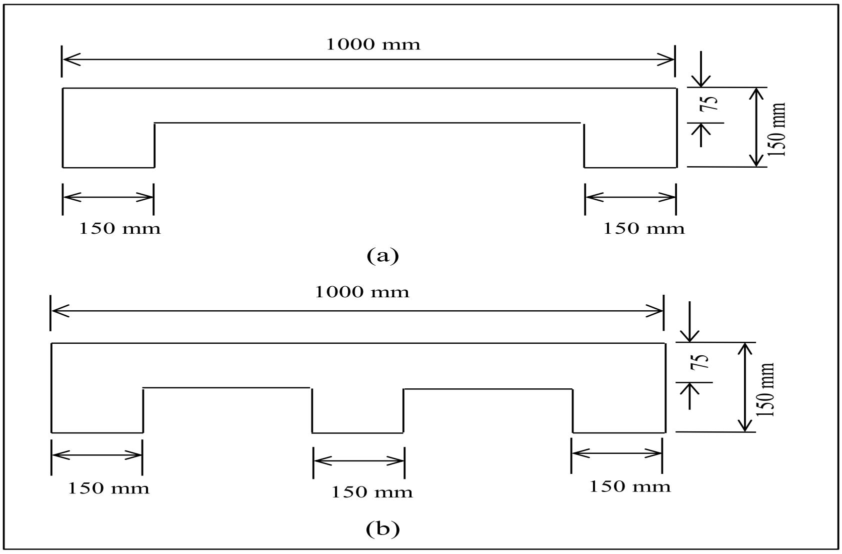

Figure 1: Slab Sample Dimensions; (a) 2-ribbed (b) 3-ribbed (source by author)

Figure 2: Hooked End Steel Fibre (source by author)

Table 2: Mix Design of SCFRC

Content	kg/m3	Remarks
Cement	465	CEM I 52.5 R
Fly ash	85	15%
Coarse aggregates	590	Maximum size 16 mm
Fine aggregates	910	Maximum size 5 mm
Water	227.7	w/p = 0.41
Steel fibres	40	0.5%
Superplasticizer	Glenium ACE 8589	0.75l / 100 kg binder

With regards to the self-compacting concrete rheological properties, the slump flow test was performed before the mix was poured into the formwork. This procedure was carried out to verify the ability of the mix to spread and self-compact without any vibration. Cubes were cast to measure the compressive strength of the mix used in this study.

The ribbed slab samples were tested under four- point bending test in accordance with the BS EN 12390:5 [12]. Conventional steel reinforcement bars or wire mesh were not provided in the samples in the attempt to fully assess the effectiveness of the steel fibres under flexure. Figure 3 shows the experimental setup of the experiment. Circular steel rollers were used to apply the loads on the ribbed slab. Figure 4 shows the arrangement of the loads applied to the slab samples. The loads were placed at two positions demonstrating the four-point bending load condition.

For the purpose of deflection measurement, linear variable displacement transducers (LVDT) were engaged to the ribbed slab sample at critical locations. The location of the LVDTs for the 2-ribbed and 3-ribbed slabs are shown in Figure 5(a) and (b), respectively.

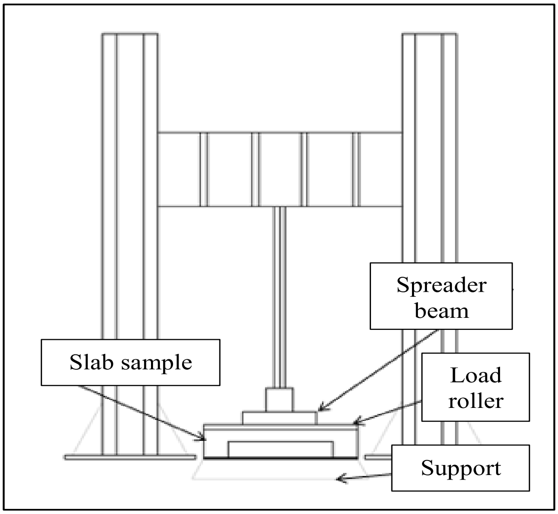

Figure 3: Experimental Setup (source by author)

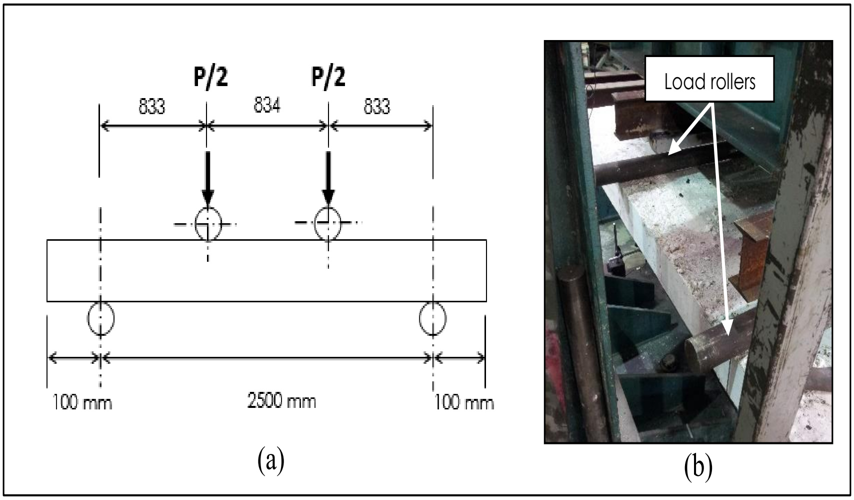

Figure 4: Loading Arrangement; (a) Schematic Diagram and (b) Laboratory Photograph (source by author)

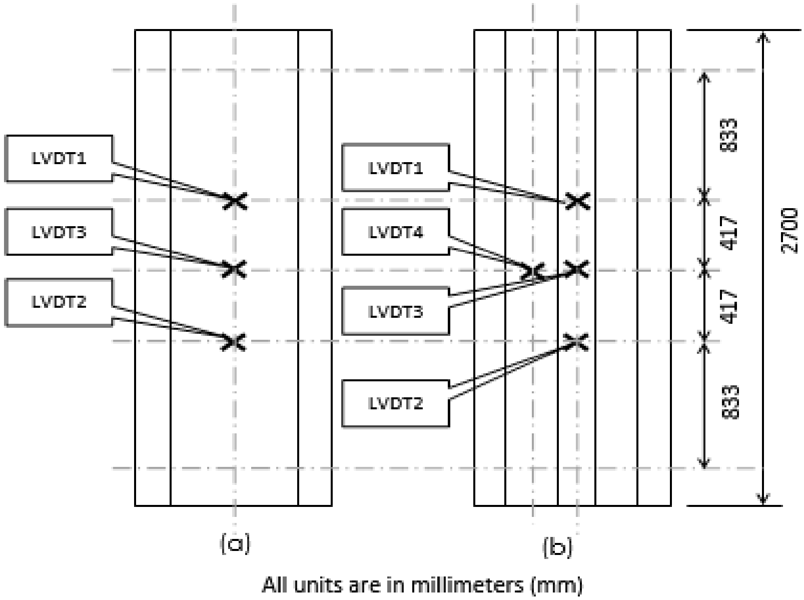

Figure 5: LVDT Locations; (a) 2-ribbed (b) 3-ribbed (source by author)

RESULTS AND DISCUSSION

Slump flow

Slump flow test was performed to assess the flow ability and flow rate of the SCC mix without any obstacle [13]. Table 3 shows the slump flow result from the experiment. From the results of the slump flow test, it can be observed that the slump flow and t500 of the plain SCC mix fulfilled the European Federation of National Associations Representing for Concrete (EFNARC) requirement [14]. However, as 0.5% steel fibres were added to the mix, the slump flow and t500 was significantly affected. Based on visual observation, the mix appear to be less viscous with the addition of the fibres. The steel fibres restrained the movement of the aggregates in the mix [15]. This behaviour is also attributed to the hooked end type of fibres as well as the dimension that is relatively large that causes blockage of the particles as it flows [16].

Table 3: Slump Flow Results

	Plain SCC	SCFRC
Slump flow (mm)	650	580
t500 (sec)	4	7

Compressive Strength

The compressive strength of the concrete mix used in the experiment is as shown in Figure 6. The characteristic strength of the SCC mix is 30 N/mm^2 with the target mean strength of 43 N/mm^2. The cubes were tested at 7 and 28 days.

Figure 6 shows the compressive strength of the cubes. At 28 days, the compressive strength exceeded the target mean strength by approximately 15%. This might be due to the type of cement used in the mix, which is CEM I 52.5R (Portland cement with high initial strength) as well as the high amount of cement.

In comparison of steel fibres provision, the results reveal that the compressive strength of cubes with steel fibres were lower than plain SCC without fibres. The reduction in strength with the addition of the steel fibres might be due to the decrease in the workability of the concrete[15][17]. A more viscous mix could be clearly observed in the slump flow results as reported in the previous section. This reduction might also be attributed to the disturbance cause by the steel fibres to the SCC matrix producing additional voids in the samples resulting lower compressive strength [15].

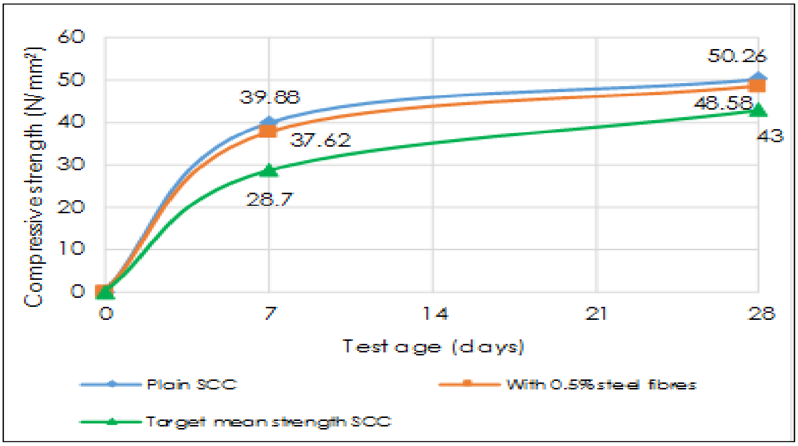

Figure 6: Compressive Strength of Concrete Cubes at 7 and 28 Days (source by author)

Ultimate Load Carrying Capacity and Deflection

Figures 7and 8 show the graphs of load-deflection for the 2-ribbed and 3-ribbed slab tested by the four-point bending test. The results showed that the ultimate load of the 2-ribbed and 3-ribbed slab samples were 30.68 kN and 25.52 kN, respectively. The ultimate load of the 2-ribbed slab exceeded that of 3-ribbed at approximately 20%.

Itexhibits that the 2-ribbed slab sample has the ability to withstand an almost similar load that can withstand by the 3-ribbed despite of its lesser volume of concrete as presented in Table 1. This might have been the result of a small difference between the concrete volumes that shows only 3% difference resulting almost equivalent load bearing capacity between these two samples. Therefore, since the steel fibres functions as the only reinforcement in the slab, the volume plays an important role in affecting the load bearing capacity of each sample.

Referring to Figure 7, the 2-ribbed slab sample showed almost similar curves for readings from LVDT 1 and 2 which is located under the load, the location as shown in Figure 5(a) recorded maximum deflection of 9.61 mm. All three transducers were placed at the bottom of the slab topping. Meanwhile, readings from LVDT 3 show a drastic drop with stagnant deflection at approximately 31 kN load. This might be attributed to the failure of the slab that caused the LVDT to abruptly lose its readings.

The results of the 3-ribbed slab sample are presented in Figure 8. Readings from LVDT 1, 2 and 4 show similar curves reaching maximum deflection of 25.12 mm. The maximum deflection value was recorded at the location of LVDT4 which is placed at the bottom of the slab topping which is similar to the 2-ribbed slab sample. At peak load, the slab deflects to a magnitude of 5.09 mm for the 2-ribbed slab while for the 3-ribbed, the deflection is smaller, achieving 3.82 mm. This result again shows that the 2-ribbed has almost similar performance as the 3-ribbed slab.

Based on the load-deflection graphs of both slab samples, it can be observed that the loads experienced a gradual decrease after achieving the ultimate load with an almost similar pattern. The gradual decrease was due to the effective bonding of the hooked ends fibres to the SCC matrix [5]. The graphs has proved that both slabs similarly experienced deflection softening [5][18] which is expected in the behaviour of steel fibre reinforced concrete material. However, the curve for the 2-ribbed slab is steeper as compared to the 3-ribbed slab.

The steep curve resulted from the failure of the 2-ribbed slab. At approximately 15 kN, the slab broke into two parts. The 3-ribbed slab showed a more gradual decrease of load and the curve extends further without causing sudden failure to the slab. This is due to the presence of the internal rib that assists in sustaining the subjected loads. This has proved that the steel fibres in the 3-ribbed slab have effectively bridge the cracks by holding the matrix together rather than allowing the structure to undergo brittle and sudden failure.

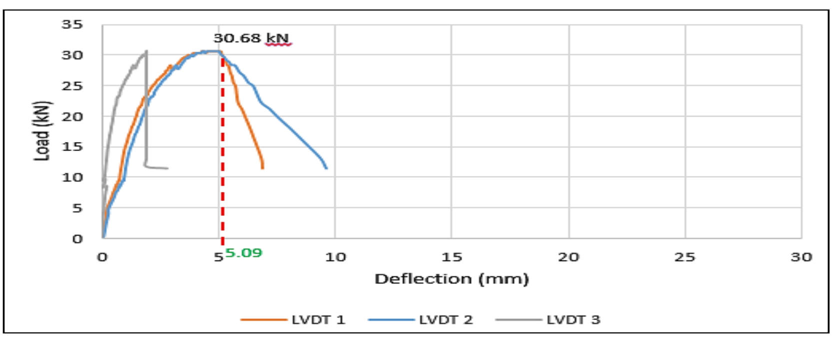

Figure 7: Load Versus Deflection Graph of the 2-Ribbed Slab (source by author)

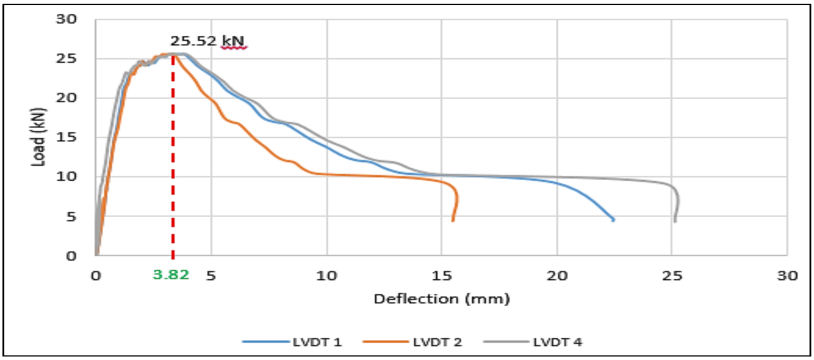

Figure 8: Load Versus Deflection Graph of the 3-Ribbed Slab (source by author)

Crack Propagation and Failure Modes

As the load imposed to the slab samples, visual observation was made to observe the crack propagation and its location. The crack was initiated at the bottom part of the ribs that is subjected to the highest tensile stress for both samples. The slab topping that is in the compression zone had manage to withstand the loads as no cracks was observed at the early stage. The cracks at the bottom of the ribs continued to propagate towards the top surface as the load progresses. Cracks were generated in the area of the mid span where the highest moment occurs. Table 5 shows the crack width of both samples.

Table 5: Crack Width of Ribbed Slab

Sample	Crack width (mm)
2-Ribbed Slab	1.55
3-Ribbed Slab	2.00

The 2-ribbed slab sample failed at the location of the load where LVDT 1 was placed. Based on visual observation, the failure might be caused by the presence of honeycombs at the top surface of the slab. The voids from the honeycombs had caused the section to easily lose its strength due to the absence of sufficient aggregates and fibres to bridge the cracks. The maximum crack width before total failure was observed to be 1.55 mm.

The failure location of the 3-ribbed sample is approximately at the mid span of the slab. The cracks started at the external rib followed by the middle rib. This is because the middle ribs is a T-section while the external are L-section. The geometry of the middle ribs provides advantage in terms of its rigidity [19]. The maximum crack length on the external rib is 175 mm while the maximum crack width is 2 mm.

From the visual observation of the crack propagation, it demonstrated that the incorporation of steel fibres in concrete has the ability to increase the energy absorption capacity of the structure, thus, improves the cracking behaviour and load bearing capacity. Cracks were formed progressively with smaller width due to the bridging effect of steel fibre that assist in clutching the concrete matrix together, increasing the ability of the structure to resist more loads.

CONCLUSION

From the results of this experiment, it can be concluded with the inclusion of 0.5% steel fibres in the SCC mix, the ribbed slab has the ability to sustain loads up to 30.68 kN and 25.52 kN, for 2-ribbed and 3-ribbed, respectively. Furthermore, the inclusion was found to effectively bridge cracks in the structure resulting a maximum of 2 mm cracks in the rib. The flexural behaviour of both ribbed slabs exhibits the deflection softening pattern with gradual decrease of load after first crack. However, the 3-ribbed slab showed a better flexural behaviour with a more gradual deflection softening curve than the 2-ribbed slab. This is observed even though the ultimate load resisted is lower. This is due to the presence of the internal rib that assists in sustaining the subjected loads.

The flexural test result shows that the steel fibres have effectively function as a restrain to the SCC matrix by still holding the slab intact even after peak load is reached avoiding sudden brittle failure of the structure. Further in depth investigation has to be carried out to determine the most optimal design of ribbed slab that can fully utilise the potential of SCFRC as reinforcements.

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