STEEL FIBRE REINFORCED SELF-COMPACTING CONCRETE (SCFRC) RIBBED SLAB COMPARATIVE FLEXURAL PERFORMANCE WITH DIFFERENT FIBRE PROVISION AREA

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ABSTRACT.

In this article, the flexural performance of three SCFRC ribbed slabs with various fibre provision areas—in the ribs and flange (SFWS), in the ribs only with extra welded mesh in the flange (SFT), and in the ribs only—was examined (SFR). The material for the slabs was flowable self-compacting concrete (SCC) mixed with short hooked end fibres of 35 mm length and 1% volume fraction. Construction of 2.8 1.2 0.2 m-long slab samples that were loaded until they broke under four-point bending. Investigations were conducted with regard to the failure modes, deflection, energy absorption capacity, and load bearing capacity. Examined was how the steel fibre provision affected the distribution of strain.

KEYWORDS: Ribbed slab, self-compacting concrete, steel fibres.

1. INTRODUCTION

Because steel fibres (SF) can minimise brittleness and improve the mechanical characteristics of concrete, they can be used in structural slabs that typically cater to uniformly distributed low and moderate loads. This study focuses on the usage of self-compacting fibre reinforced concrete (SCFRC), which may be cast in place without any vibration, while taking the workability and fibre dispersion of the employed fibre concrete into account. The SCFRC's capacity to flow offers advantages to the construction process, which further reduces the need for labour and saves time and money [1]. Steel fibres are now included as the primary reinforcing material in slab applications, replacing conventional reinforcements to some extent. Many investigations [2–7] had been carried out using SCFRC material in flat slab. Unfortunately, few investigations on ribbed profiled structures could be discovered in the literature. Studies on the use of steel fibres in slab buildings with rib profiles are still limited to their use in regular, low volume fraction (0.5%) steel fibre reinforced concrete [8–10].

2. This study's goal is to experimentally ascertain the ultimate flexural strength, load-deflection curves, and energy absorption capacity of SCFRC ribbed slabs with different steel fibre supply areas (fully and partially steel fibre rein-forced).

EXPERIMENTAL PROGRAM

SCFRC ribbed slabs in nine (9) numbers, each measuring 2800 mm in length, 1200 mm in breadth, and 200 mm in total thickness, were cast. A clear effective span length of 2600 mm was provided by simply supporting the ends of the slabs on rollers. The slabs received two-line loads while being subject to a 0.1 mm/sec displacement control. Measurements of the displacement at the slab centre were made using sensitive linear voltage differential transducers (LVDT) (rib and flange soffit).

The ribbed slab samples were created using Grade C30/37 plain self-compacting concrete (PSCC) mix with the mix proportions stated in Table 1. The volume fraction of the steel fibres with hooked ends was 1%, or 80 kg/m3. Table 2 displays specific steel fibre characteristics. The PSCC and SCFRC combination employed in this study's mechanical properties are covered elsewhere [11].
SCC mixtures similar to this one were combined with steel fibres in the SCFRC mixture. Although the SCFRC mix was designated as SF1 [12], no vibration was used during the sample casting process. Table 3 contains information on the variance of the slab samples, and Figure 1 shows the steel fibre inclusion in the slab samples used for this research. There are three types of SCFRC ribbed slabs: complete steel fibre reinforced (SFWS), partially reinforced with welded mesh (SFT), and partially reinforced without welded mesh (SFR). The topping flange thicknesses of each type of sample also vary (80, 100 and 120 mm).

Cement CEM I 42.5R	Pulverized fly ash	10 mm coarse aggregate	Fine aggregate	Water	w/c	Steel fibre content
315 kg/m³	105 kg/m³	830 kg/m³	865 kg/m³	185 kg/m³	0.44	80 kg/m³

TABLE 1. SCC mix composition.

Fibre type	Tensile strength (N/mm²)	Length L (mm)	Diameter d_f (mm)	Fibre aspect ratio L/d_f
Hooked end	1250	35	0.55	65

TABLE 2. Steel fibre properties.

Reinforcement	Designation		Topping flange thickness (mm)
Fully steel fibre reinforced	SFWS	SFWS80	80
		SFWS100	100
		SFWS120	120
Partially steel fibre reinforced with BRC	SFT	SFT80	80
		SFT100	100
		SFT120	120
Partially steel fibre reinforced without BRC	SFR	SFT80	80
		SFT100	100
		SFT120	120

TABLE 3. SCFRC sample details.

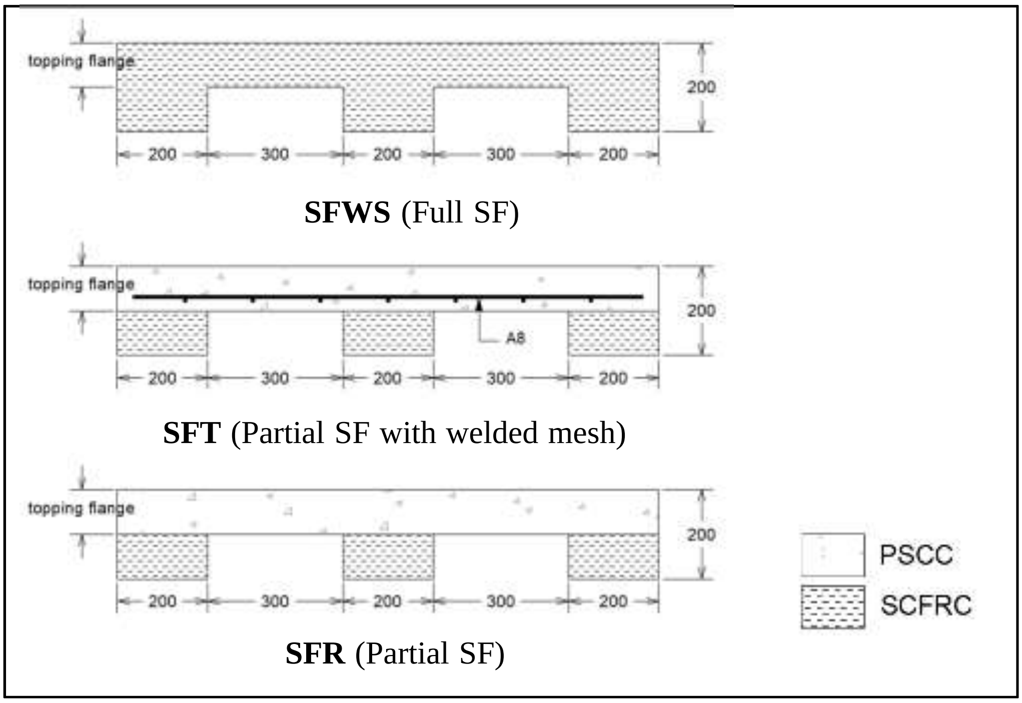

FIGURE 1. Steel fibre provision area.

Sample	First crack load P_{cr} (kN)	Ultimate load P_{ult} (kN)	Displacement at ultimate load δ_{ult} (mm)	Energy absorption at P_{ult} (kNmm)	Total energy absorption (kNmm)
SFWS80	35.78	57.83	8.75	403.15	1298.91
SFWS100	47.67	60.00	7.8	367.56	1379.22
SFWS120	46.04	74.71	12.47	716.73	1540.65
SFT80	42.89	50.66	3.17	104.23	823.49
SFT100	49.14	51.64	2.97	99.96	1019.92
SFT120	39.53	49.25	7.95	320.01	794.38
SFR80	47.89	55.65	3.17	117.11	482.52
SFR100	44.69	49.3	2.1	66.72	375.83
SFR120	46.26	54.79	2.61	87.46	264.72

TABLE 4. Flexural test results.

3. EXPERIMENTAL RESULTS AND DISCUSSION

First crack and ultimate strength of ribbed slabs

The presence of the steel fibres significantly influences the first crack occurrence of the SCFRC ribbed slab. The experimental results of the flexural test are presented in Table 4. The first crack load of all SFWS, SFT and SFR samples were found to be approximately double the first crack load of conventional ribbed slab sample without any steel fibres. The first crack values used for comparison are 17.59, 21.39 and 21.99 kN for 80, 100 and 120 mm flange thickness, respectively. These results are reported elsewhere [13]. Additionally, the first crack load of all samples was observed to be more than 60% of the ultimate load achieved, proving the ability of the steel fibres to transfer stresses across the cracks within the concrete matrix.

Furthermore, the provision of steel fibres also significantly influences the ultimate strength of the ribbed slab that corresponds to the major crack initiation in the ribbed slab samples. The SFWS samples that were fully reinforced with steel fibres achieved the highest ultimate load even with the absence of any conventional reinforcements. Partially reinforced samples (SFT and SFR) however, achieved lower ultimate loads. This might be due to the faster occurrence of the major crack in the sample since the steel fibres were only provided in the ribs causing the stress transfer within the matrix to be more rapid. The presence of the welded mesh in the topping flange also showed no significant contribution to the ultimate strength of the partially steel fibre reinforced samples as it is not in the tension zone.

Load-displacement

The load-displacement curves for all SCFRC ribbed slab samples are shown in Figure 2. Before the first crack occurrence, the elastic region was steeper for the partially SF reinforced samples (SFT and SFR) in comparison to the SFWS samples that showed a more gradual increment. Beyond the first crack occurrence, only the SFWS samples exhibited displacement-hardening response towards the ultimate load displaying the efficiency of the SF to transfer the stresses within the cracked samples.

This hardening behaviour is in relation to the existence of the SF in the topping flange that played an important role in resisting the formation of the cracks as it propagates from the ribs to the flange section. At this point, some of the steel fibres will be subjected to pull-outs as the loading continues. This displacement-hardening response was less significant in the partially SF reinforced samples (SFT and SFR) even with presence of the welded mesh reinforcement in the topping flange.

Beyond the ultimate load, all samples experienced displacement-softening response where the load carrying capacity gradually decrease as the vertical displacement continues to increase further. Gradual softening curves are exhibited by the SFWS and SFT samples reaching up to 32 mm displacement. In contrast, the SFR samples underwent more abrupt softening resulting lower displacement reflecting to a more brittle behaviour of the structure.

In view of the topping flange thickness for each type of samples, the increase in the topping flange thickness significantly affects the softening curves. Steeper curves were observed for 120 mm topping flange thicknesses of all ribbed slab samples exhibiting a more brittle post-cracking behaviour as the topping thickness increases beyond half of the total slab depth (100 mm). This brittleness might be as the result of the topping thickness that enters the tensile zone of the sample reducing the function of the rib section. This finding also agrees well with the previous findings where higher slab thickness resulted in higher brittleness of the section [3, 14].

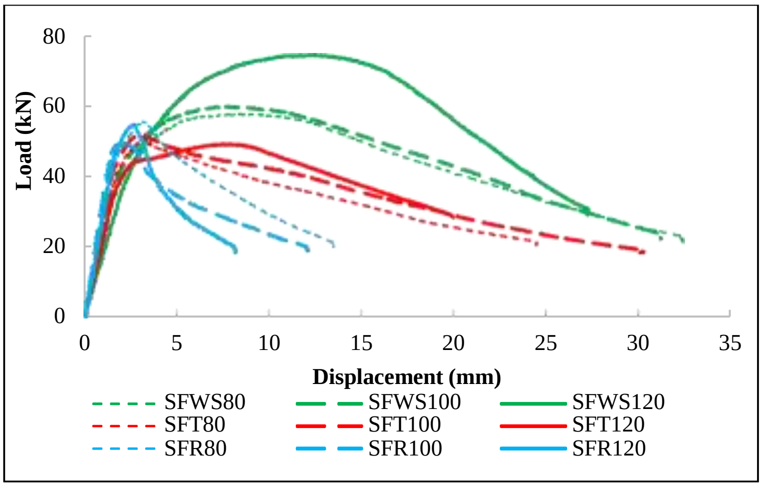

FIGURE 2. Load-displacement curves.

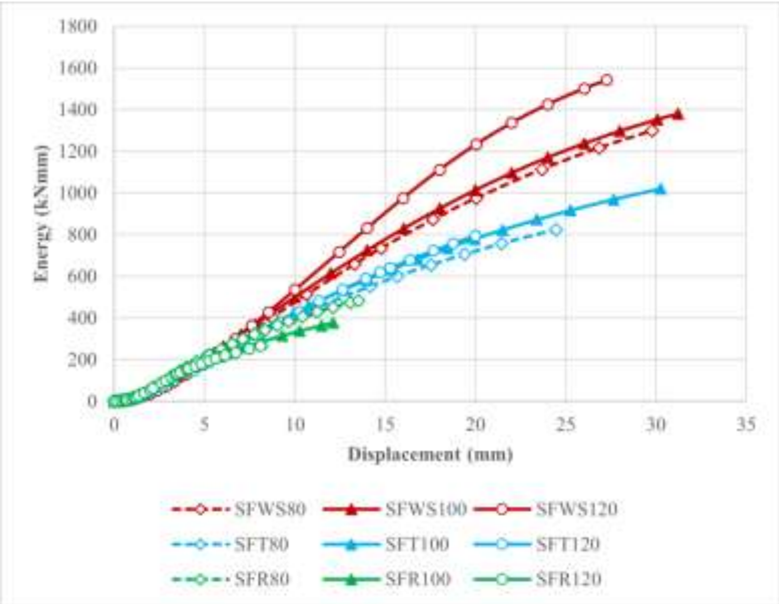

FIGURE 3. Energy absorption capacity.

Vertical disPlacement

At ultimate load, the highest displacement was exhib- ited by the SFWS samples at both ultimate load andat final failure of the samples (Table 4). This was followed by the SFT and SFR samples. The SFR samples which are more brittle experienced the low- est vertical displacement at ultimate load as well asat final failure exhibiting a lower level of ductility. Nevertheless, all samples fulfilled the displacement requirement at service load whereas the values are within the allowable limit (L/500) as stated in the Eurocode 2 revealing the capability of the SCFRC samples under flexural load.

In view of the topping flange thickness, the lowest displacement at ultimate load was observed in thesamples with 100 mm topping flange thickness for all types of samples. This can be related to the locationof the neutral axis and the transmission of the stresses between the rib and flange section of the ribbed slab.

At final failure, however, the 120 mm samples expe-rienced the lowest displacement that is as the result of the brittle behaviour of the SCFRC ribbed slab asthe topping flange thickness increases.

EnergY aBsOrPtiOn caPacitY

Steel fibre inclusion enhances the energy absorptioncapacity of the slab as calculated by the area underthe load-displacement curve. Higher volume of steelfibres in concrete resulted in an increase in the energyabsorbed by the slab structure. The SFWS samplesshowed the highest energy absorption capacity at theultimate load as well as the total energy (see Table 4).The energy absorption capacity is in close relation with the total volume of SF in the slab. The SFWSsamples showed higher energy absorption for higherflange thicknesses. However, a contradict trend wereobserved in the SFT and SFR samples showing therelation towards the provision area of the SF (Figure 3).

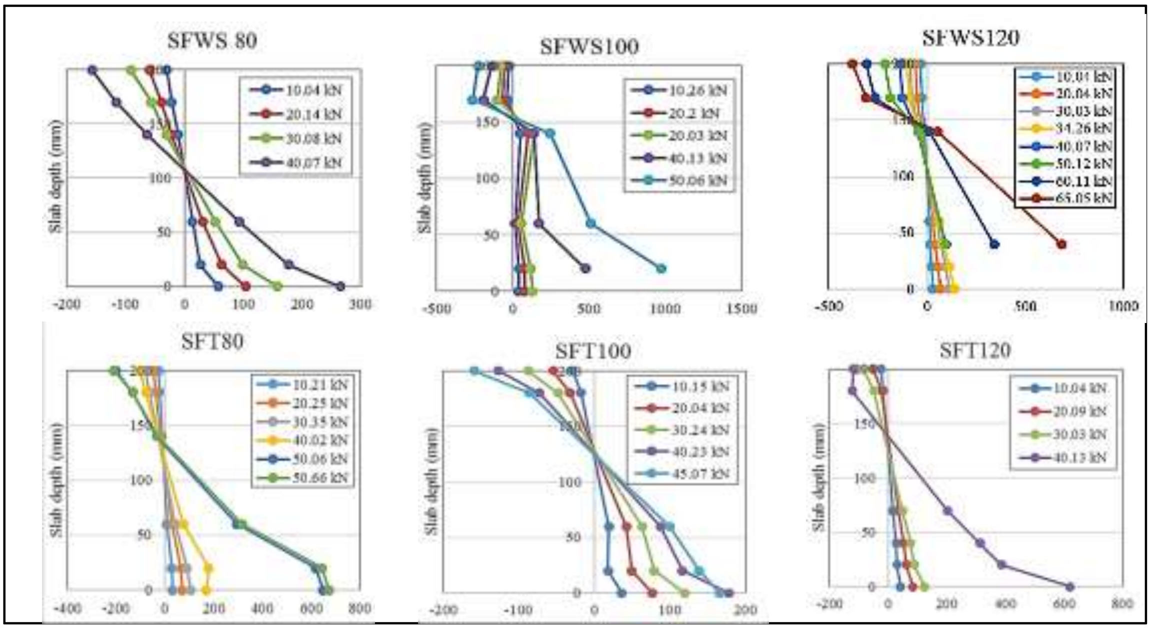

FIGURE 4. Strain distribution of SFWS and SFT samples.

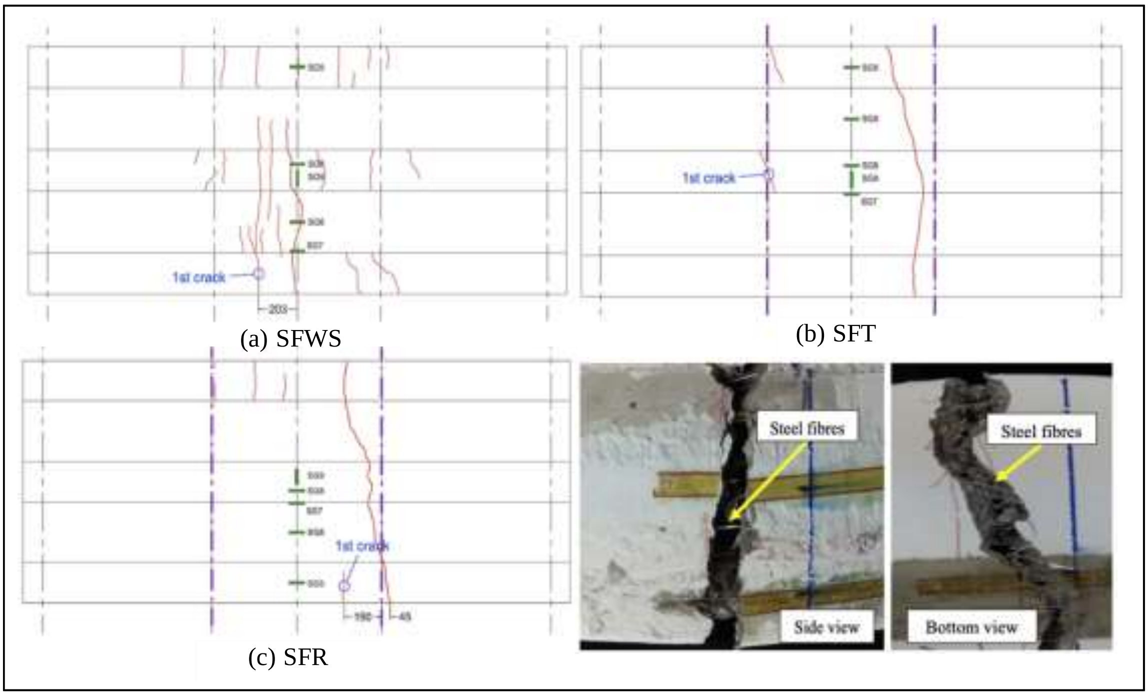

FIGURE 5. Crack pattern of the SCFRC ribbed slab and steel fibres bridging the cracks.

Strain distriBution

The neutral axis location of the SCFRC ribbed slab samples can be determined based on the strain distri-bution across the depth of the slab at various stages of loading. For the SFWS samples, only for 80 mm top- ping thickness, the neutral axis falls below the top- ping flange. The neutral axis falls in flange for all other samples, including all SFT and SFR samples. No significant effect of the topping flange on the neu- tral axis location thickness was observed. The strain distribution for the SCFRC ribbed slab samples is presented in Figure 4.

The view of the bridging steel fibres is also pre- sented in Figure 5. From the crack openings, it can be observed that most of the steel fibres were in the lon- gitudinal direction that is perpendicular to the crack direction. The steel fibres had effectively bridged the cracks by holding the matrix together and the hooked end shape had assisted in increasing the bonding tothe concrete matrix contributing to the structural strength to resist loads.

The crack pattern for the partially reinforced sam- ples (SFT and SFR) were different from the SFWS samples whereas it only experienced one major crack

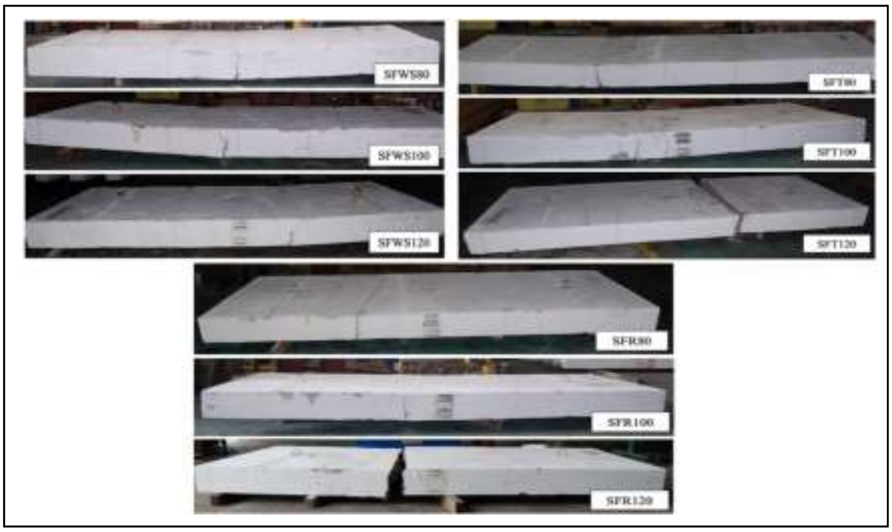

FIGURE 6. SCFRC ribbed slab at final failure.

line with very minimal minor cracks across the sam-ple. The crack started at the rib's soffit and propa- gated to the flange soffit. The SFT samples under- went ductile failure, gradually failing after the ulti- mate load was reached. The SFR samples on the other hand experienced a more rapid crack propaga-tion experiencing a more brittle failure.

Crack Pattern and failure mOdes

Figure 5 showed the crack pattern of the SFWS sam-ples. The first crack of all three SFWS samples wasdetected within the central region of the ribbed slab located at the external rib soffit.

After the occurrence of the first crack, more cracks developed at the external rib's soffit on both sides of the sample as well at the middle rib soffit. These cracks then continued to propagate to the sides of therib sections and further to the soffit of the flange as the loading continued. As the cracks continued to widen at the ribs, it could be visually observed fromthe slow propagating cracks that the steel fibres hadeffectively bridged the cracks as the loading continuedto increase further.

The view of the bridging steel fibres is also pre- sented in Figure 5. From the crack openings, it can be observed that most of the steel fibres were in the lon- gitudinal direction that is perpendicular to the crack direction. The steel fibres had effectively bridged the cracks by holding the matrix together and the hooked end shape had assisted in increasing the bonding tothe concrete matrix contributing to the structural strength to resist loads.

The crack pattern for the partially reinforced sam-ples (SFT and SFR) were different from the SFWS samples whereas it only experienced one major crack line with very minimal minor cracks across the sam-ple. The crack started at the rib's soffit and propa- gated to the flange soffit. The SFT samples under- went ductile failure, gradually failing after the ulti-mate load was reached. The SFR samples on the other hand experienced a more rapid crack propaga- tion experiencing a more brittle failure.

In view of the topping thickness variation, the cracks were observed to be more concentrated on therib soffit of the SFWS samples with lower flange thick-nesses (80 mm and 100 mm). Consequently, more cracks were observed to be distributed over the flange soffit for the 120 mm topping thickness.

At the end of the loading test, all SFWS samples still remained intact, held by the steel fibres in the ribs and topping flange (Figure 6). As for the SFT and SFR samples, all samples except for the sam- ples with 120 mm topping thickness remains intact at final failure with the assistance of the welded mesh and bridging of the fibres in the ribs section. Samples with 120 mm thickness experienced brittle failure, i.e. breaking into two at the end of the loading process. These conditions might be due to the reduced thick- ness of the rib section resulting smaller volume of the steel fibres to bridge the cracks.

4. Conclusion

Based on the results, these conclusions can be drawn:

1. All SCFRC ribbed slab underwent flexural failure. The fully SF reinforced samples experienced multi- ple cracks while the partially SF reinforced samples experienced only one major crack, displaying the significant effect of the steel fibre provision under flexural load.
2. The fully SF reinforced samples also achieved the highest ultimate load at higher deflection exhibit- ing higher level of ductility amongst all samples
3. Increase in the flange thickness resulted an increase in the ultimate load for the SFWS samples but shows no significant increase in the SFT samples. Beyond the ultimate load, samples with higher flange thickness becomes more brittle resulting ina more rapid strength loss.

Overall, based on the experimental results, it can be concluded that the fully steel fibre reinforced sam- ple (SFWS) with the highest flange thickness dis- played a good performance under bending.

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