IOP Conf. Series: Materials Science and Engineering **849** (2020) 012082 doi:10.1088/1757-899X/849/1/012082

Flexural performance of cold-formed steel section in a composite beam system

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Abstract. The application of Cold-Formed Steel (CFS) as a structural member in buildings as composite associate was rarely demonstrated due to limited technical information available about its usage in the system, despite the prospects of the CFS section in the composite system of construction in buildings as well as in light weight industrial applications as nowadays proven. Therefore, this paper aimed at demonstrating the potentials of using CFS section as a structural member in a composite beam system. Four-point bending test was used to determine the flexural strength capacities of the composite system. Results of flexural tests conducted on the composite specimens incorporating the CFS coupled with bolted shear connector proved it to be structurally feasible. In conclusion, the CFS can be employed as a structural member to eliminate the use of Hot Rolled Steel (HRS) section in small and medium size buildings and in lightweight industrial composite constructions as demonstrated.

1. Introduction

Recently the use of Cold-Formed Steel (CFS) section as a structural member is highly demonstrated as proven by research works [1-5] conducted to show case its potentials as structurally feasible and also in composite construction systems. Composite system of steel and concrete has been in practice in the construction of buildings and bridges for several decades [6].

Significant numbers of research studies were conducted to study and comprehend the structural behaviour of CFS section members with various connection configurations such as CFS beam-to-column connection, composite beam and floor systems connection etc. [7].

Many design codes and research studies [8-13] had highlighted the use of Hot Rolled Steel (HRS) section, headed stud connectors and conventional concrete in composite systems with few or limited highlights on CFS section. It was reported in [14] that orienting two CFS section back-to-back suppresses lateral-torsional and lateral-distortional buckling to a lesser extent and compressive bending stresses were also reported to be reduced. This benefit manifested encouraged the use of CFS sections in a broader range of structural applications.

Therefore, this paper, aimed at using doubly oriented back-to-back CFS section coupled with bolted shear connectors and Self-Compacting Concrete (SCC) as a composite floor system to proven it potentiality and prospects as structurally feasible. The structural capability of CFS section if established will go a long way to offer a step forward for its application in the construction of small and medium size edifices, as well as in light weight construction industries.

2. Materials Properties

Materials used in this study are CFS section, bolted shear connectors of M16, M14 and M12 of grade 8.8; welded wire fabric mesh A142 of 6 mm thick of strength 460 N/mm^2 and SCC of grade 40 N/mm^2 respectively. The materials were tested to obtain their actual strength properties by tensile, compression and modulus of elasticity tests respectively. The properties are presented in Table 1.

Table 1. Materials properties test

Materials	**Average Yield Strength f_y, (N/mm^2)**	**Average Ultimate Strength f_u, (N/mm^2)**
CFS	487.4	523.9
M16 Bolt	468.0	897.0
M14 Bolt	758.0	847.0
M12 Bolt	761.0	843.0
Welded wire fabric	502.4	594.9
	Average Compressive Strength at 28 days f_{cu}, (N/mm^2)	**Average Modulus of Elasticity at 28 days E, (kN/mm^2)**
Concrete	40.7	35.4

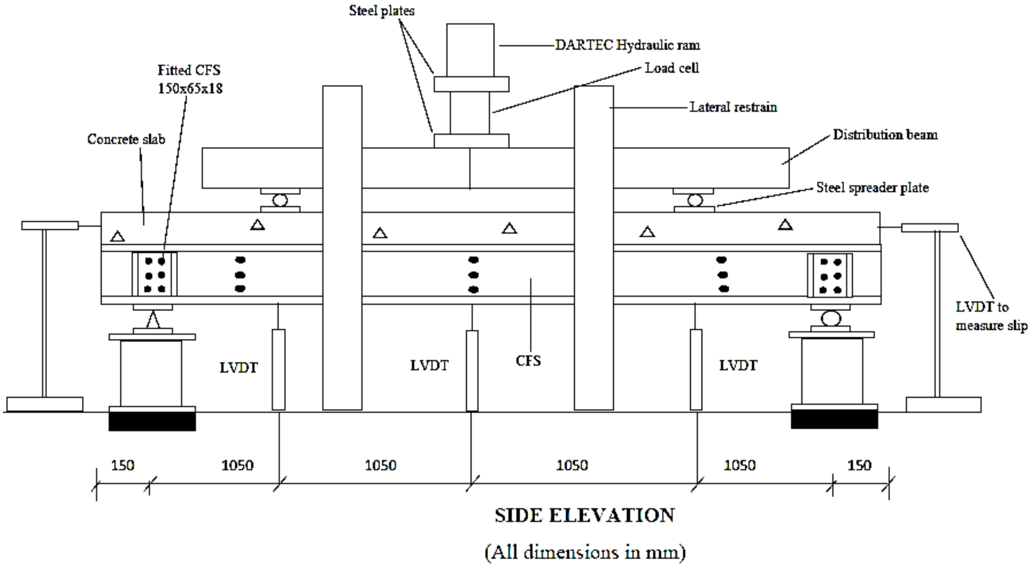
3. Methodology

In this study, a full scale for point bending test was used to evaluate and to determine the flexural capability as well as the behaviour of the CFS-SCC composite beam specimens.

3.1 Test specimens and arrangement

Full-scale flexural test was conducted to investigate the behavior of the composite beam system with the proposed bolted shear connectors incorporating SCC. Full-scale beam bending test was used to authenticate the configurations implemented in the push-out test [15, 16]. The test specimens were made simply supported with an effective length of 4200 mm between supports and were subjected to two point loads applied at 1050 mm (shear span) away from the support using a four-point bending test (figure 1 (a) & (b)). The four-point bending test is a system that provides pure bending moment along the section and therefore the ultimate flexural capacities of the composite beam specimens were determined. A detail of the composite specimens is presented in Table 2.

(a) Test set-up



(b) Schematic diagram of test set-up

Figure 1. Composite beam test arrangement.

Table 2. Details of the composite specimens

Specimen ID	Length, L (mm)	CFS flange width, bf (mm)	CFS web depth, h (mm)	CFS thickness, tc (mm)	Slab width, b (mm)	Slab thickness, ts (mm)	Type of shear connector	Diameter of shear connector (mm)	Spacing of shear connector (mm)
FS300-16	4500	150	250	2.3	1500	75	Bolt	16	300
FS250-16	4500	150	250	2.3	1500	75	Bolt	16	250
FS300-14	4500	150	250	2.3	1500	75	Bolt	14	300
FS250-14	4500	150	250	2.3	1500	75	Bolt	14	250
FS300-12	4500	150	250	2.3	1500	75	Bolt	12	300
FS250-12	4500	150	250	2.3	1500	75	Bolt	12	250

3.2 Test procedure

All the composite beam specimens were tested in similar manner using DARTEC jack machine with a load cell capacity of 2000 kN. The test specimen was subjected to four-point bending test, where the load from the jack machine was applied at 1050 mm (shear span) from the supports. The specimen was placed as simply supported beam (see figure 1 (a) & (b)). Due to high concentration of stresses at the supports, premature failure of the CFS may occur; therefore, it was prevented by fitting the supports with a CFS section of dimensions 150 mm x 65 mm x18 mm of thickness 2.3 mm as shown in figure 2.

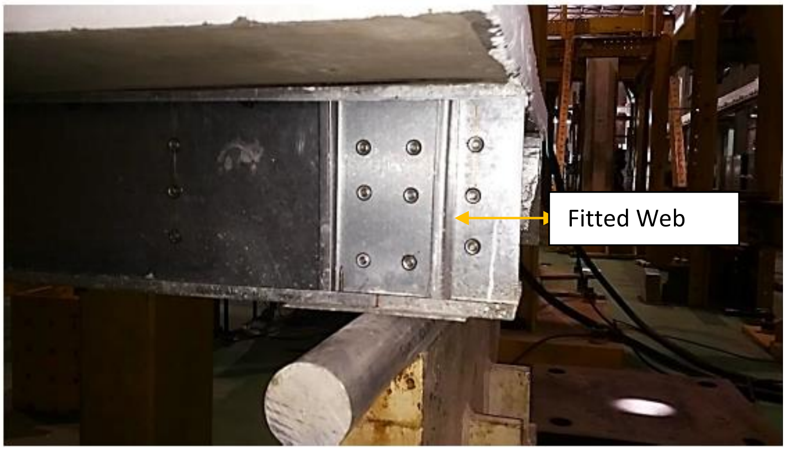


Figure 2. Fitted web at support position.

Load from the jack machine was applied on the specimen at a constant rate of 0.2 kN/s through the distribution beam which transfers it to the concrete slab through the line load beams. The line load beams were rested on a steel spreader plates of 200 mm x 150 mm x 12 mm thick (figure 3). This was to spread the point loads to the test specimen. The presence of the steel spreader plates reduced the possibility of the concrete slab and web of the CFS from local crushing and web crippling respectively. The specimen was loaded up to 15% of its predicted failure capacity and then zeroed. This was to ensure that the instrumentation process was in equilibrium state prior to the proper testing.

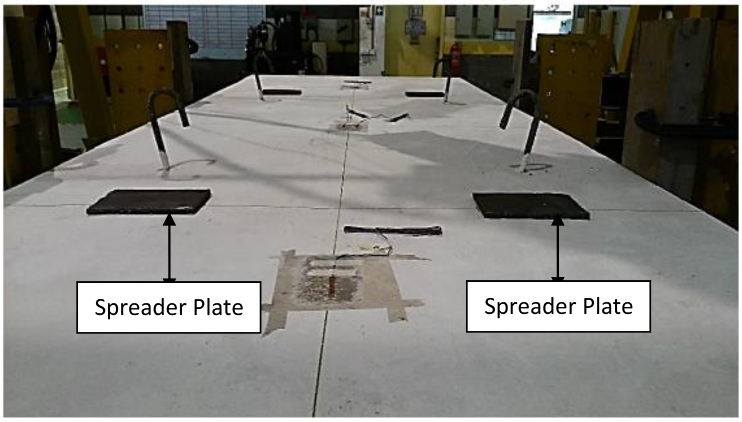


Figure 3. Spreader plates on the concrete slab.

Load was further increased until failure of the specimen occurred. The failure of the specimen was considered when there was a significant drop in the applied load or when a large deformation of the test specimen was observed. Lateral restrains were provided during the test (see figure 1(b)); this was to prevent the specimen from having torsional or lateral torsional buckling failure prematurely. After the test, the specimen was removed from the testing rig and the conditions of the shear connectors were checked. The conditions of the shear connectors after test will be shown in the discussion part for specimens with M16, M14 and M12 bolted shear connectors respectively.

3.3 Results and discussions

3.3.1 Beam behavior. The objective of flexural test is to evaluate the beam failure mode, behavior on deflection, slip behavior, strain distribution and moment capacity of the composite beam specimens. Details of the full-scale test specimens were illustrated in sub-section 3.1, Table 2. The experimental test results of the composite specimens are presented in Table 3 below.

3.3.2 Failure mode. The failure modes observed in the tested full-scale composite beam specimens was due to concrete cracking or crushing or both and in some cases combined with CFS web buckling underneath the point load position and torsional failure respectively. But, at the point loads positions, a combination of maximum moment and maximum shear was experienced. Figure 4 shows the shear and the maximum bending moment the specimens could suffer underneath the point loads positions. Details of the modes of failure are discussed in sub-sections 3.3.3, 3.3.4 and 3.3.5 for specimens with M16, M14 and M12 respectively.

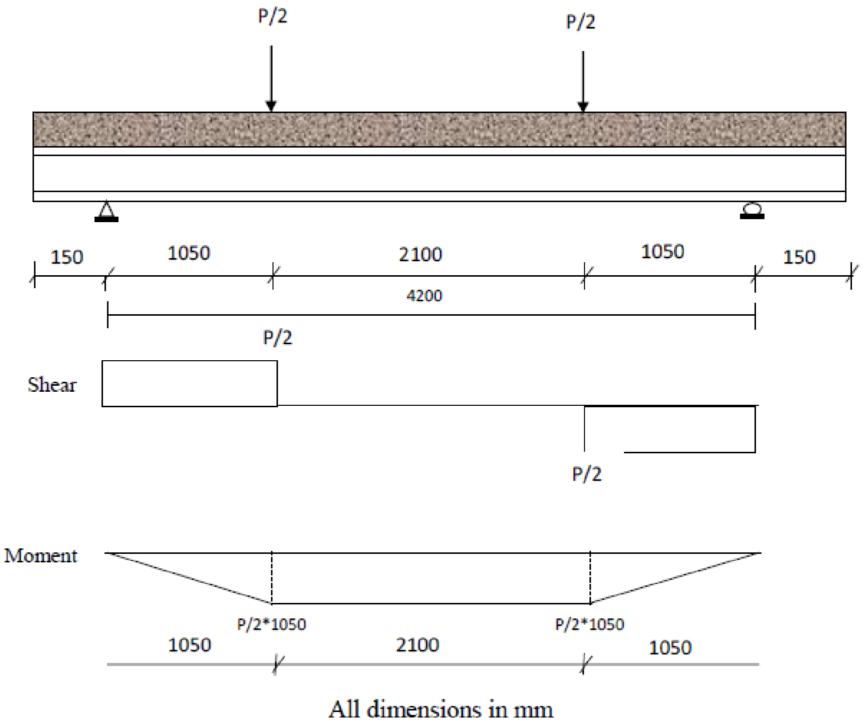


Figure 4. Schematic diagram of shear force and bending moment.

Table 3. Full-scale composite beams test results

Specimen ID	fck at test day (N/mm^2)	Ultimate load, Pu, exp. (kN)	Mid-span deflection at Pu, exp. δu, exp. (mm)	Ultimate moment, Mu, exp. (kNm)	Elastic load, Pe, exp. (kN)	Mid-span deflection at Pe, exp. δe, exp. (mm)	Ultimate moment, Me, exp. (kNm)
FS250-16	30.0	496.8	58.5	260.8	372.6	32.5	195.6
FS300-16	32.0	499.6	66.6	262.3	374.7	20.7	196.7
FS250-14	34.1	440.6	49.7	231.3	330.5	26.4	173.5
FS300-14	32.6	472.1	54.9	247.9	354.1	27.8	185.9
FS250-12	32.6	438.5	49.6	230.3	329.0	28.2	172.7
FS300-12	35.3	466.1	56.9	244.8	349.6	30.4	183.5

FS250-16: Full-specimen @ 250 mm spacing with M16 bolt diameter

3.3.3 Composite beams with M16 bolt. Load against mid-span deflection for FS250-16 and FS300-16 are depicted in figure 5. Based on Table 3 and figure 5, the ultimate loads ($P_{u, exp.}$) attained were 496.8 kN and 499.6 kN respectively. Also, mid-span deflections of 58.5 mm and 66.6 mm were recorded at ultimate load levels for the specimens respectively. At elastic stage, as the load was increased, linear increment of mid-span deflection was observed. Based on figure 5, the specimens had an elastic load (P_e) of 372.6 kN and 374.7 kN with a corresponding mid-span deflections of 32.5 mm and 20.7 mm respectively. The specimens first crack was observed at load levels of 228 kN and 230 kN under the point load position respectively. The observed cracks became wider as the load continued to increase and reached its ultimate level. The specimens exhibited the same failure modes by flexure which resulted in concrete crushing and transverse cracks underneath the concrete slab. Web buckling was noticed at the point load position on the CFS due to excessive stress that was developed when the specimens' ultimate load was reached. Figure 6 shows the failure mode of the test specimens. After the test, the specimens were dismantled to inspect the condition of the shear connectors within the slab. It was observed that no deformation occurred on the bolted shear connectors as shown in figure 7. This affirmed that the shear connectors were robust enough to transfer longitudinal shear from the concrete slab to the CFS without deformation occurred.

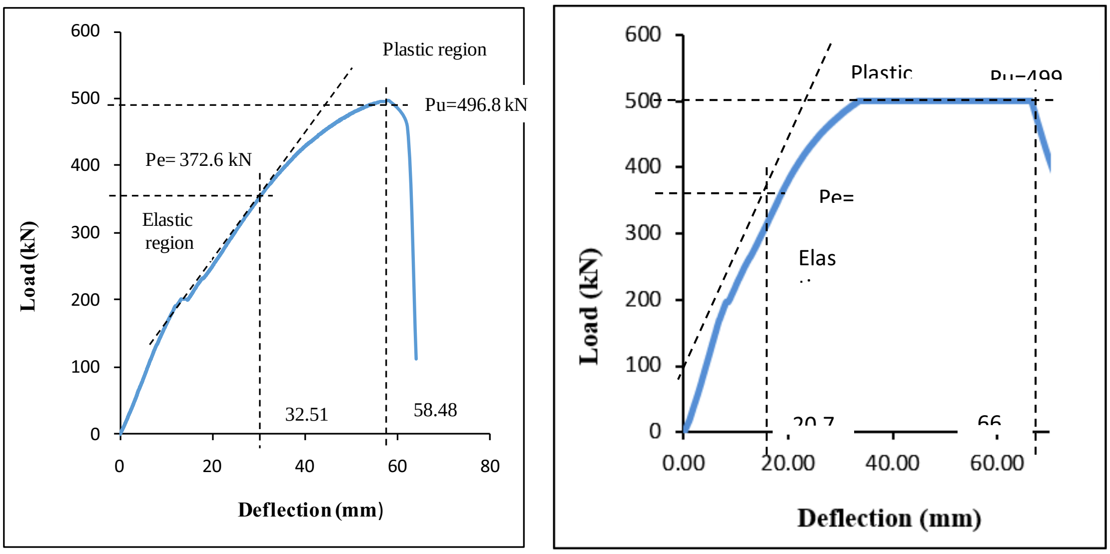


Figure 5. Load versus mid-span deflection of specimens with M16 bolt.

(a) Concrete crushing (b) Transverse cracks and web buckling

Figure 6. Failure modes of specimens with M16 bolt.

Figure 7. M16 bolted shear connector condition after test.

3.3.4 Composite beams with M14 bolt. Figure 8 shows the load versus mid-span deflection of specimens with M14 bolted shear connectors. From Table 3 and figure 8, the ultimate loads ($P_{u, exp.}$) attained for the specimens were 440.6 kN and 472.1 kN respectively. In this category, specimens initial crack was observed at loads level of 205 kN and 222 kN respectively. Failure mode experienced by the specimens was appearance of a longitudinal cracks along the shear connectors' line on the concrete slab surface and transverse cracks underneath the slab. CFS web buckling was also observed along the span of the specimens on the CFS when the ultimate load was reached. Figure 9 shows the failure mode of the specimens. After the test, it was found that no deformation occurred on the bolted shear connectors when inspected as shown in figure 9 (d). This asserts that the shear connectors were strong enough to transfer longitudinal shear from the concrete slab to the CFS without deformation.

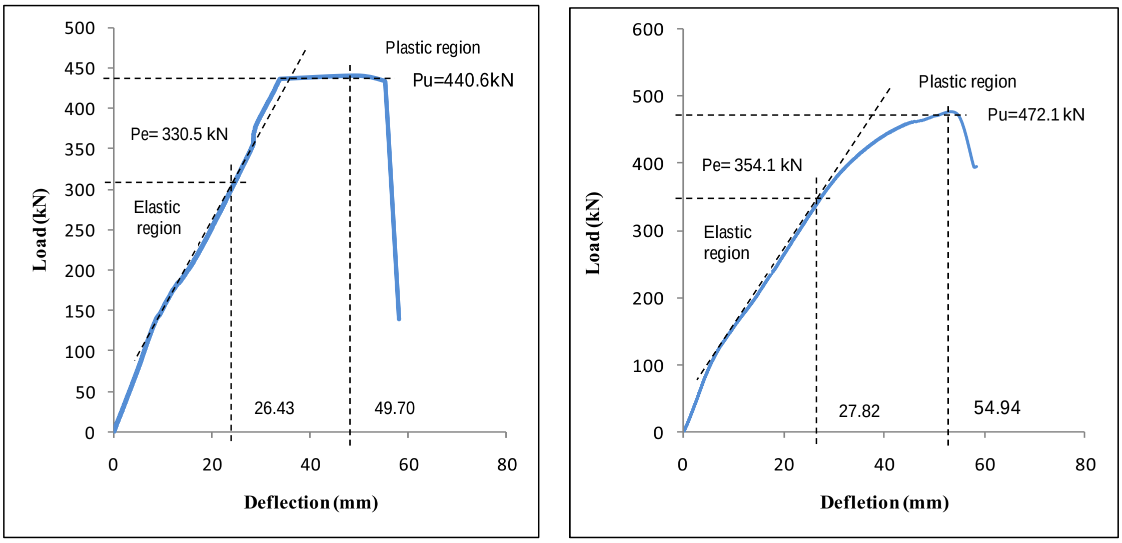


Figure 8. Load versus mid-span deflection of specimens with M14 bolt.

(a) Longitudinal cracks on slab surface (b) Transverse cracks underneath slab

(c) CFS web buckling (d) M14 shear connector condition after test

Figure 9. Failure modes of specimens with M14 bolt.

3.3.5 Composite beams with M12 bolt. Figure 10 shows the load versus mid-span deflection of specimens with M12 bolted shear connectors. Also from Table 3 and figure 10, the ultimate loads ($P_{u, exp.}$) attained for the specimens were 438.5 kN and 466.1 kN respectively. The failure mode initiated was formation of longitudinal cracks along line of shear connectors on surface of the concrete slab. Transverse cracks were observed underneath the concrete slab as well as shear connector pulled-out from the slab. This could be attributed to the smaller head diameter of the shear connector. And it was obvious because, as the head diameter of the shear connector was small, there was a tendency of pull-out of the connector from the concrete slab as the resistance of the connector to pull-out force was relatively small as evaluated. Finally, the specimens failed due to torsional buckling of the CFS when the ultimate load was reached. Figure 11 shows the failure modes of the test specimens. After the test, the specimens shear connectors status was checked within the slab. It was found that no deformation occurred on the bolted shear connectors as shown in figure 11 (d). This shows that the shear connectors have the ability to transfer longitudinal shear from the concrete slab to the CFS.

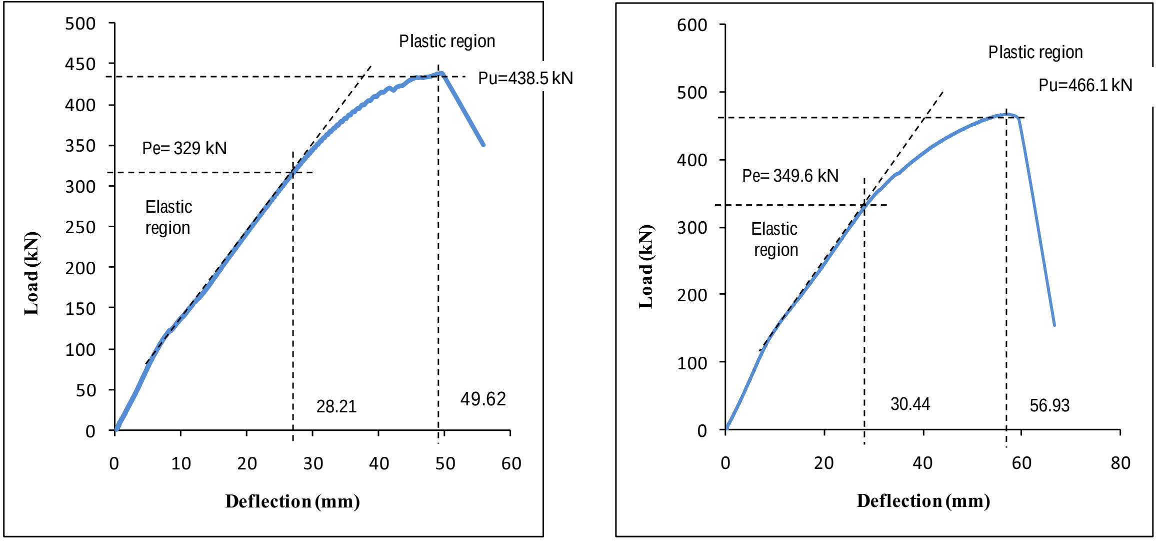


Figure 10. Load versus mid-span deflection of specimens with M12 bolt.

(a) Longitudinal cracks on slab surface (b) Transverse cracks underneath slab

(c) Shear connector pull-out and torsional buckling of CFS (d) M12 shear connector condition after test

Figure 11. Failure modes of specimens with M12 bolt.

4. Conclusion

From the results of this study, the following conclusions can be drawn.

- I. The composite beams with the bolted shear connectors of M16, M14 and M12 demonstrated good flexural strength capacities in terms of ultimate load and ultimate moment of resistance.
- II. The bolted shear connectors showed that they were robust enough to transfer longitudinal shear, and to provide the composite action that is required between concrete slab and the CFS section without occurrence of deformation.
- III. Among the three bolted shear connectors used, M16 bolted shear connector showed the highest ultimate load and ultimate moment carrying capacity followed by M14 then M12 bolted shear connectors respectively. This manifested that to achieve a high load and moment of resistance M16 bolted shear connector is recommended to be employed.
- IV. It is shown that CFS can be employed as a structural member due to its structural capability proven in this study in the construction of small and medium size buildings and in lightweight industrial composite constructions set up.

5. Acknowledment

The authors gratefully acknowledge the support provided by Kano University of Science and Technology, Wudil (KUST) and Universiti Teknologi Malaysia (UTM Vot Q.J130000.2522.18H02) for the support provided.

6. References

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