The Use of Demolished Concrete Lumps (DCL) in Rectangular CFSTs Under Flexure

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Abstract

This paper investigates the flexural performance of rectangular concrete-filled steel tube (CFST) beams that are partially incorporated with demolished concrete lumps (DCLs). In total, three CFST beams were prepared and tested under flexure through a four-point bending setup. These three specimens are selected from a bigger ongoing research project that considers further parameters. The three beams varied in the presence of DCLs within the CFST section and the maximum particle size of the DCLS. The DCLs were mixed with mortar and were isolated at the center of the CFST section and surrounded by normal concrete. The flexural behavior of the CFST beams was analyzed and discussed through the use of moment versus displacement, moment versus strain, and deflected shape graphs. The test results showed that the CFST beams with partially incorporated DCLs had similar flexural behavior to the normal CFST beam. The displacement at ultimate capacity was reported to be lower for the beams with incorporated DCLs, especially the beam with the higher DCL maximum particle size. However, the displacement at yield was found to be lower for the specimen that was fully cast with normal concrete. Finally, it was observed that the failure mode was the same for all three beams.

Keywords: Recycled concrete; DCL; CFST; Flexure; Beam

1 Introduction

Concrete-filled steel tubes (CFSTs) have been used over the past decade due to their superior mechanical properties. The steel tube provides confinement for the concrete infill and enhances its strength and ductility, while the concrete infill delays the local buckling of the steel tube (Roeder et al., 2010 and Han, 2004). CFSTs are mainly used as column members where the confinement is significantly utilized (Abdalla et al., 2013; Elyoussef et al., 2019; Abed et al., 2013). However, many studies have been conducted that investigated the flexural performance of CFST members under bending which can be found in the literature (Abed et al., 2018a; Abed et al., 2018b,; Abed et al., 2015; Wang et al., 2014; Hou et al., 2016).

Research interest in using recycled and waste materials in CFSTs has increased in the past decade. These recycled and waste materials include recycled aggregates, supplementary cementitious materials, and demolished concrete lumps (DCLs). For instance, (Abed et al., 2021) investigated the flexural response of rectangular and circular CFSTs with different recycled aggregates' replacement ratios up to 100%. The results showed insignificant changes in the flexural behavior or the moment capacities with different replacement ratios. In addition, it was reported that the increase in the concrete strength from 30 to 50 MPa led to a minor increase in the ultimate capacity, whereas the yielding moment was approximately the same. Another study, (Wu et al., 2018) investigated the effect of using DCLs on the axial behavior of CFST columns. The DCLs were poured into a mold with fresh concrete to create precast segments. These precast segments were then isolated at the center of the section and surrounded with normal concrete. It was reported that the precast segment's area had a negligible effect on the axial capacity of the CFST specimen.

As of now, one study was published (Khalaf et al., 2022) which investigated the flexural performance of circular CFST specimens with partially incorporated DCLs. This study was done by the authors of this paper, in which a very similar specimen preparation and testing procedure were followed. The DCLs were isolated at the center of the section and were surrounded by normal concrete. Test results revealed that the incorporation of DCLs had a negligible effect on the flexural performance of circular CFST beams. This paper aims to study the effect of DCLs on the flexural performance of rectangular CFSTs, and assess the feasibility of using DCLs in a unique arrangement without compromising any of the flexural properties. The main parameters of this study are the presence of DCLs, and the maximum DCLs particle size.

2 Experimental Program

2.1 Specimen Preparation

The experimental program investigated the flexural performance of three rectangular CFST beams. All beams had the same steel-tube section dimensions (200x100 mm), thickness (4 mm), and length (1.5 m). One of the three beams served as the control specimen, denoted R-Control-F, in which it was fully cast with normal concrete, while the other two beams incorporated DCLs with two different maximum particle sizes (19 and 25 mm). For the two beams that incorporated DCLs, they were isolated at the center of the section. The isolation process included installing 100x50 mm rectangular foams at the center of the section with the use of spacers, followed by pouring the normal concrete surrounding the foams. The foams were then removed using liquid thinner that dissolves the foam easily without harming the concrete. Finally, DCLs were poured together with mortar in the DCL's region. The section details of all three beams can be shown in Figure 1. The process of isolation of the DCLs at the center of the section was done for two main reasons: to avoid bond loss between the steel and the DCLs due to the excessive shrinkage expected, and minimize the flexural contribution of the DCLs as the stresses and the corresponding strains at the DCL's region is lower than the rest of the section. The DCL's region within the section remained constant between the two beams that incorporated DCLs. The test matrix for all three beams in this study is summarized in Table 1. It is important to note that this paper is a part of a bigger project which includes more specimens and parameters considered.

Table 1: Test matrix

Beam Label	Tube Height X base (mm)	Tube Thickness (mm)	DCL's particle size range (mm)	DCL's region dimensions (mm)
R-Control-F	200 X 100	4	N/A	N/A
R-100x50-D19	200 X 100	4	12.5-19	100 X 50
R-100x50-D25	200 X 100	4	19-25	100 X 50

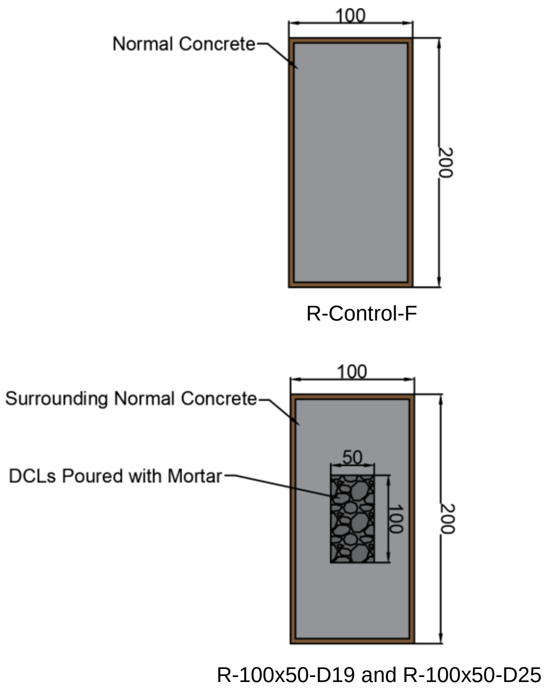

Fig. 1: Section details of CFST beam specimens, dimensions in mm

2.2 Material Properties

All CFST beams were filled from the same concrete batch. Three cylinders and three cubes were cast to obtain the compressive strength of the concrete after 28 days of curing. The compressive strength values were 28 and 36 MPa for the cylinders and cubes, respectively. Similarly, three cylinders and three cubes were cast with mortar and DCLs for each maximum particle size. The results showed that the two different DCLs sizes gave very close compressive strength values, which were 16 and 20 MPa for the cylinders and cubes, respectively. In addition, two steel coupons were shaped and fabricated from the original steel tubes according to the ASTM specifications to obtain the tensile properties. The average yield and ultimate strength reported were 230 and 274 MPa respectively.

2.3 Four-Point Bending Setup

All beams were tested under flexure using the four-point bending setup utilizing the universal testing machine (UTM), as shown in the schematic test setup in Figure 2. The beams had a clear span of 1350 mm and a pure moment region of 450 mm. Three strain gauges were installed at the top, center, and bottom of the section at the midspan to record the longitudinal strain values. In addition, three LVDTs were used to record the deflection at midspan and at a distance of 250 mm from the supports. One rigid plate was used as a spreader that was placed on top of two plates located at a distance of 450 mm from the supports. The load cell from the UTM was applied at a rate of 2 mm/min.

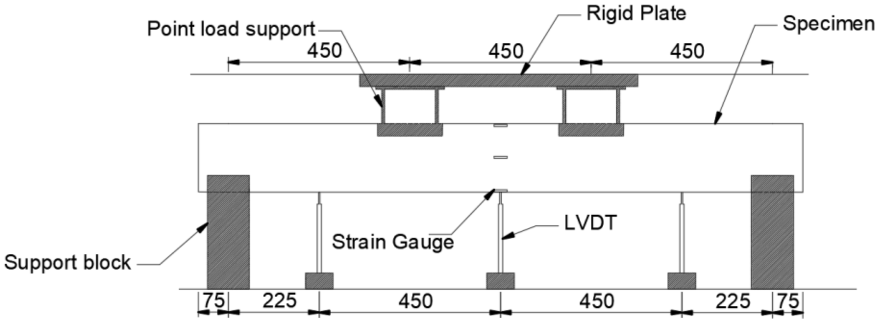

Fig. 2: Schematic test setup, dimensions in mm

3 Results and Discussion

The flexural performance of all three beams is evaluated through the use of moment versus midspan deflection, moment versus microstrain, and the deflected shape curves. In addition, the failure modes of the steel and the concrete infill for all beams are also discussed. Figure 3 shows the moment versus midspan deflection for all three beams. It is observed that the overall flexural response of all three beams is very similar. The initial stiffness of all three beams is approximately the same, and the transition from the elastic to the plastic stage is also comparable between the specimens. Furthermore, all three beams failed in a ductile manner as indicated by the deflections recorded after yielding. The flexural results of the specimens can be found in Table 2. The yielding moment (My) was recorded at a bottom microstrain equal to the yielding strain of the steel obtained from the coupon test. As for the ultimate moment (Mu), it was recorded at a bottom microstrain of 0.01, which is a value recommended by many researchers as the results are very comparable to design codes. It is observed that the yielding and ultimate moment values are close, where the maximum percentage difference is around 2% and 0.5%, respectively, which was between beams R-100x50-D25 and R-Control-F. As for specimen R-100x50-D19, the yielding and ultimate moment values were very similar to R-Control-F.

Table 2: Test results

Specimen Label	Yield Moment, My (kN.m)	Deflection at My (mm)	Ultimate Moment, Mu (kN.m)	Deflection at Mu (mm)
R-Control-F	53.2	6.44	65.2	19.26
R-100x50-D19	53.1	7.01	65	18.78
R-100x50-D25	54.3	7.8	64.9	16.39

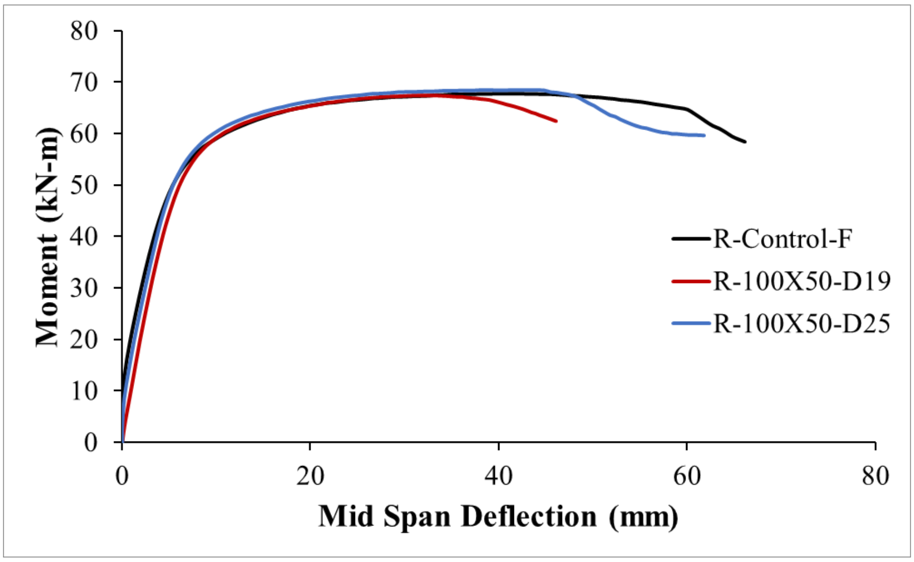

Fig. 3: Moment versus midspan deflection curves

The moment versus microstrain curves of the three beams can be shown in Figure 4. Similar to the moment versus deflection curves, the flexural behavior of the three beams was very similar. It is observed that for the bottom strain (positive x-axis), the moment values for the specimen R-100x50-D25 become slightly higher than the other two specimens. This behavior is also noticed for the top strain (negative x-axis). Figure 5 shows the deflected shape of the beams at the yielding and ultimate stages. It is observed that the deflection at yield for R-Control-F was the lowest, whereas beam R-100x50-D25 had the highest deflection with a percentage increase of 20%, indicating that its stiffness was the lowest out of the three beams. However, the pattern flips for the ultimate deflections, where beam R-100x50-D25 had the lowest deflection, while R-Control-F had the highest deflection, where the percentage increase was around 17.5%. When comparing the beams with DCLs, the deflection at yield of specimen R-100x50-D25 was around 11% higher than specimen R-100x50-D19, whereas the deflection at ultimate of specimen R-100x50-D19 was 14% higher than specimen R-100x50-D25.

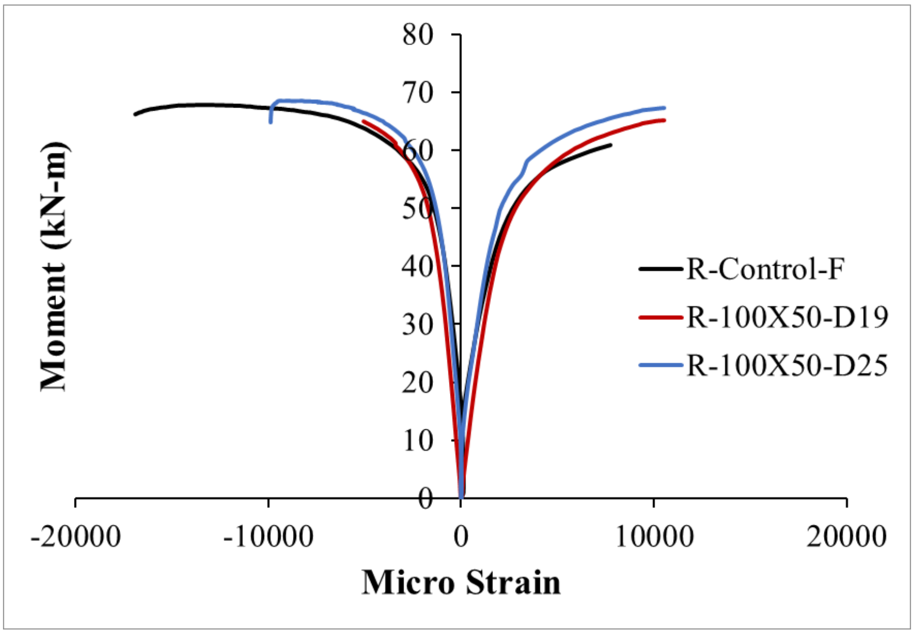

Fig. 4: Moment versus microstrain curves

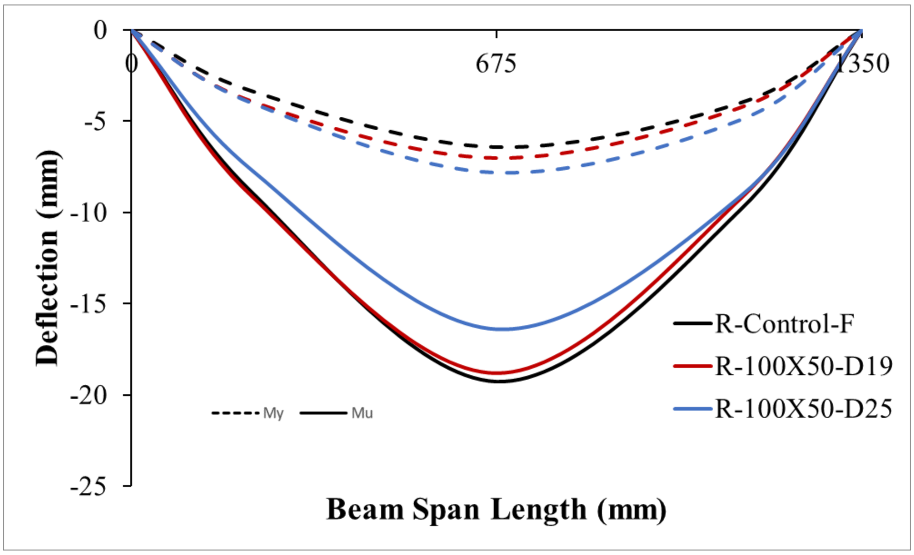

Fig. 5: Deflected shapes

Figure 6 shows the CFST failure modes of the steel and concrete, which was the same for all three beams. It was observed that an outward local buckling occurred in the compression zone of the steel between the two point loads. As for the concrete, it was observed that crushing occurred in the compression zone, and tensile cracks formed in the tension zone of the section.

Fig. 6: Failure mode of steel and concrete

4 Conclusion

This paper investigated the flexural performance of rectangular CFST columns with partially incorporated DCLs. The following conclusions can be drawn from this study:

- In general, the overall flexural response of all three beams was very similar, and they all failed in a ductile manner.
- The maximum percentage difference recorded between the specimens was 2% and 0.5% for the yielding and ultimate moment values, respectively.
- The highest and lowest deflection at yielding were reported by beams R-100x50-D25 and R-Control-F. However, the deflection at ultimate gave opposing results, where beam R-100x50-D25 had the lowest deflection, and beam R-Control-F had the highest deflection.
- All three beams had the same failure mode. The steel in the compression zone exhibited outward local buckling, while the concrete was crushed in the compression zone, and tensile cracks were formed in the tension zone.
- This study is limited to the used DCL maximum particle sizes, which were 19 and 25 mm. Further research on the effect of larger DCL sizes is recommended.

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