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Vol. 32, No. 1. \ 2024 ISSN: 2616 - 9916

Strengthening of Hollow Flanged Cold-Formed Beams by Different Materials

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Received:	26/6/2023	Accepted:	18/10/2023	Published:	15/2/2024

Abstract

This research is devoted to investigate experimentally the flexural behavior of cold-formed steel I-beam with strengthened hollow rectangular flange (RHFCFSIB) under four point loads at the same distance from the support. All specimens have the constant clear span of (L=1500mm), a constant beam specifications (t=4mm) web and flange thickness , (h=300mm) for beam′s depth and flange width of (bf=150mm) and flange depth of (h_f=60mm) .The spacing between the bolts that connect the web to the flanges was (L/6) and eight stiffener for each beam were placed under the load bearing points and at the support points on each side. The experimental program includes assembling the parts to make beams and testing of five specimens tested under four point loads, one of these specimens was not strengthened, which used as a control specimen. Four specimens strengthened with different strengthening materials, light weight, cost and strength are the main factors for choosing this material (normal concrete, normal concrete has been replaced coarse aggregate by recycled concrete, normal concrete has been replaced fine aggregate with 30% sawdust and normal concrete has been replaced fine aggregate with 30% coarse rubber). The strengthening beams were compared with the control specimens, It was found from this compaction that strengthening the flange with different strengthening materials improved the behavior of the beam, as the bearing capacity increased in rates ranging between 15.8% and 27.98%, the deflection decreased in rates ranging between 65% and 83% , this means that strengthening flange has a strong influence on the flexural behavior. The main conclusions drawn from the study were discussed and summarized, the research shows that the strengthening hollow flanged sections gave best results for flexural behavior.

Keywords: Cold formed sections, strengthen material, flexural load, load by weight ratio, safety, vertical load and cost- effectiveness.

1. Introduction

The advantages of cold-formed steel (CFS) include its extremely light weight, capacity to use standard joining techniques, dimensional stability, flexibility in manufacture, simplicity in handling and transport, and economy. [1]. In the building industry, on railroad coaches, and for vehicle bodies, cold-formed steel sections are applied. These sections are made from flat steel that is formed into rolls or press brakes using steel sheets, plates, and strips when applying the brakes. Steel sheet or strip thickness Cold-formed steel structural components are generally 0.5 to 6 mm thick. Cold-formed steel parts are lighter and less expensive to produce than hot-rolled steel equivalents (various shapes of cold-formed steel sections). The three most popular forms of cold-formed steel sections are C-channel, Z-section, and I-section. These sections often display several complicated buckling modes due to their thinness. This resulted in the creation of contemporary cold-formed steel sections with a hollow tube and flanges. With this component, the enhanced strength-to-weight ratio of classic cold-formed steel is paired with the reliability of hot-rolled steel. [2]

Here is a short summary of some recent research on how cold-formed hollow sections behave. Gardner L. et al. [3] did experiments to compare cold-formed and the hot-rolled steel hollow sections to see how the two different ways of making them affect how the materials react and how the structures behave. Two types of sections were found to have "geometric defects" of similar sizes, while cold-formed sections were found to have significant "residual stresses due to bending". Moreover, the corner portions of the cold-formed sections were indicated with strength improvements. Results from an experimental examination of the shear behavior of a rectangular hollow flange channel beam (RHFCB) with rivet fastening were presented by Keerthan and Mahendran [4], see Figure (1). A total of twenty-four shear tests were conducted with basic supports and RHFCB specimens until failure was achieved. The specimens' web shear buckling the performance and post-buckling strength were both enhanced when the rectangular hollow flanges were present.

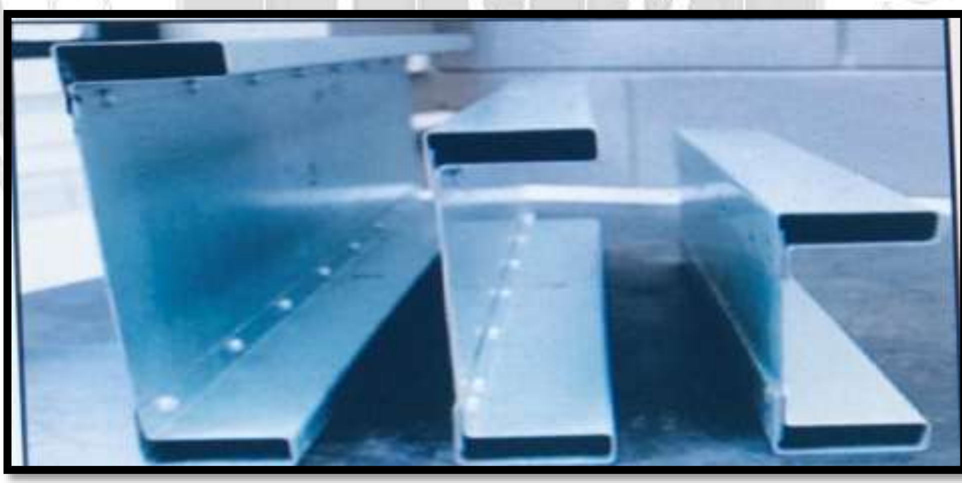

Figure (1): Rivet fastened rectangular hollow flange channel beam [4]

Under localized pressures, Gao et al. [5] analysed and modelled the bending behavior of a concrete-filled pentagonal flange beam (CFPFB). The numerical model predicted a difference in

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bending capacity of less than 10%. For a unique high-strength concrete-filled tubular flange beam, Gao et al. [6] employed theoretical and numerical research to produce a design formula for buckling resistance (HS-CFTFB). The experimental and computational LTB behavior of HS-CFTFBs examined by Gao et al. suggests that the inclusion of infill concrete may resist flange deformation [7]. Web distortion affects the flexural strength of triangular hollow flange beams (THFBs) under uniform bending, and this effect is described by a simple formula in the work of Pi and Trahair [8] on the lateral-distortion buckling of hollow flange beams (HFBs). Tondini and Morbioli [9] investigated the bending behavior of cold-formed RHFGs using both experimental and computational methods. The LTB and lateral distortional buckling of the RHFGs were studied by Hassanein et al. [10, 11]. They discovered that web distortion is readily apparent in constructions with medium to high span widths. Additionally, they revealed that the moment-gradient factor of RHFGs was personalized by the web's thickness and number of sides [12]. According to Kim and Sause's [13] research on the LTB of CFTFGs, even in beams with minimal stiffeners, web distortion can drastically reduce flexural strength. The part moment capacity of RHFGs was formed by Nilakshi and Mahendran [14, 15] using a four-point loading test and numerical analysis. According to the aforementioned studies, the section moment capacity of TFBs is significantly underestimated by current design requirements. The buckling behavior of TFBs is also clearly altered by the tubular flange. In their research of the mechanical behavior of bolted connections for built-up I-shaped columns comprised of two lipped channels, Tang and Ma [16] found that the load bearing ability reduced significantly when the longitudinal bolt spacing was greater than half the span.

2. Experimental Program

Cold-formed steel(CFS) sections are common sections to resist bending resulting from applied loads. Here in this research, the flexural behavior of cold- formed steel I-beams with strengthen rectangular hollow flanges and the effect of these strengthen rectangular hollow flanges on the flexural behavior were studied and the extent of improvement from the resistance of the sections to bending and reduce the deflection, and compare them with the control specimens. Table (1) shows the description of specimens . Table (2) shows the details of the five specimens tested in this research. The type of stiffener configuration are shown in Table (3).

Table (1): The description of specimens.

Specimen identification	Description
A60	CFS I-beam with rectangular hollow flange (hf=60mm)
A60NC	CFS I-beam strengthened the rectangular hollow flange by normal concrete, (h_f=60mm).
A60RC	CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced coarse aggregate by recycled concrete, (h_f=60mm).
A60CR	CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced coarse aggregate with 30% coarse rubber, (h_f=60mm).
A60S	CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced fine aggregate with 30% sawdust, (h_f=60mm).

Table (2): The dimensions of specimens.

Specimen identification	H mm	h_f mm	h_w mm	b_f mm	t_f mm	t_w mm	Location of connection
A60	300	60	180	150	4	4	L\6
A60NC	300	60	180	150	4	4	L\6
A60RC	300	60	180	150	4	4	L\6
A60CR	300	60	180	150	4	4	L\6
A60S	300	60	180	150	4	4	L\6

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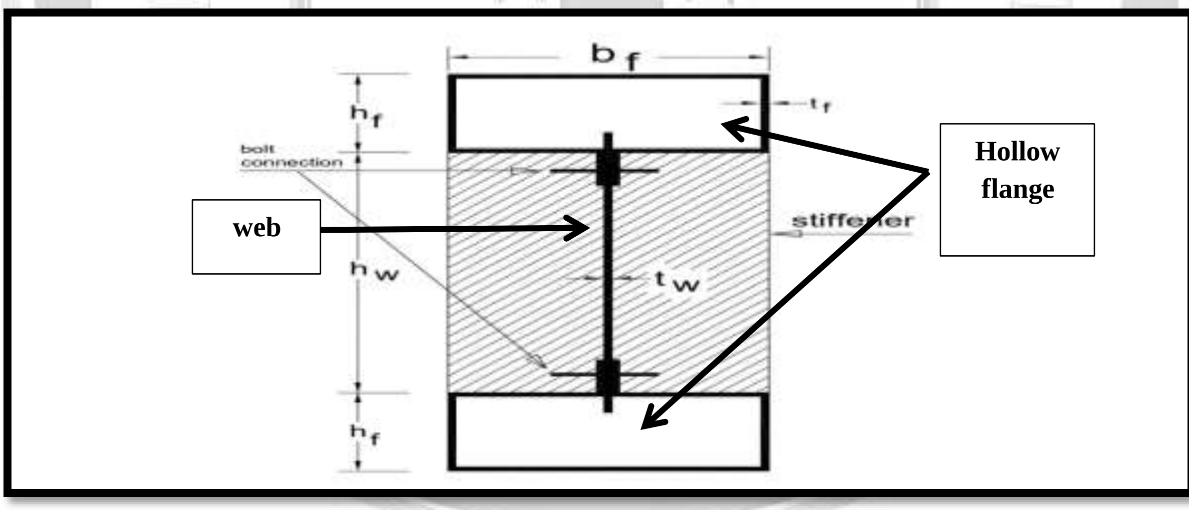
Table (3): Dimensions of stiffeners.

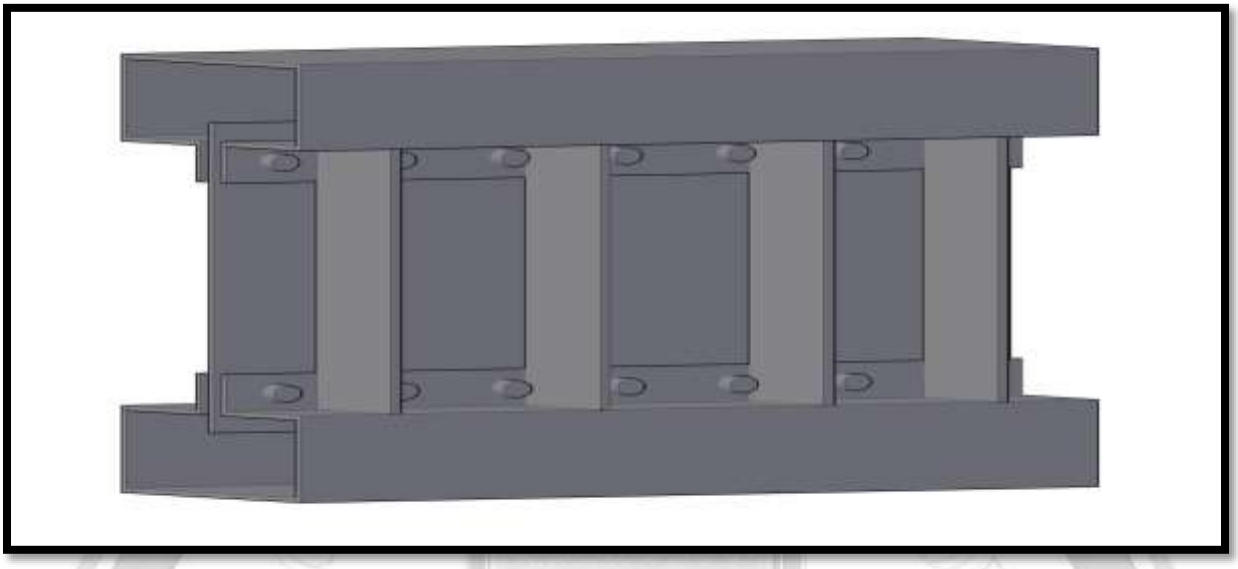
Specimen identification	Stiffener depth, mm	Stiffener width, mm	Thickness of stiffeners, mm
A60	180	69	4
A60NC	180	69	4
A60RC	180	69	4
A60CR	180	69	4
A60S	180	69	4

3. Section Specification

The experimental research takes into account sections with strengthen hollow flange by different materials and locations of bolt connections. The two characteristics of the five types of strengthen hollow rectangular flange cold-formed steel beams studied are thickness (4 mm) and bolt connection location (L/6) from the support. Length and breadth of I-sections are governed by their section specifications, including thickness and total depth, as well as IS 811-1987: "Code of Practice for Cold-formed Light Gauge Structural Steel Sections. The thickness of the beam (t = 4 mm), the flange width (bf = 150 mm), the flange depth (hf = 60 mm), the overall depth of the beam (h = 300 mm), and the connecting position between web and flange (L/6) for a total span of 1500mm are the section specifications for the I-Sections utilized for the experimental research. The specimen's details are shown in Figure (2).



(a)



(b)

Figure (2): (a) Side view of specimens (b) Three-dimensional section

4. Development and Research

4.1 Test specimens

Steel that has been cold formed at room temperature from sheets of steel with a 4 mm thickness which used in this study. The specimens are then formed into I shapes using one of the two methods currently in use: cold roll forming and press braking. In this study, I-section was created using the cold roll forming technique. Using a press braking machine, a "cold-formed" steel sheet of the required length is bent into one channels and two angles, which are then bonded by welding to create a rectangular hollow flange, as shown in Figure (3), these two rectangular hollow flanges were then bonded to the web with bolts.

(a)

(b)

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(c)

Figure (3): Fabricated Test specimens

4.2 Materials

In the experimental program, tensile test of steel plate was carried out on three steel plates with average yield strengths (f_y) of 266.7 MPa, and average ultimate strengths of 375 MPa which conform to the American specification ASTM/A615M-15a (ASTM , 2015). One types of concrete mixes were used (NC) after several trial mixes for making the specimens. Mix proportions of NC were(1:1.6:2.22) (w/c =0.46,cement content = 500kg/m3), The concrete was prepared with Portland cement from Iraqi plant name al-mass, crushed gravel from Al-Nibbaey region in Iraq of maximum size 12.5mm, natural sand from AL-UKhAIDIR city in Iraq of nominal maximum size 4.75 mm (fineness modulus =2.76),and fresh drinking water.

4.3 Loading Condition

To load the beam, two loads are symmetrically positioned between the supports. There are four critical points along the beam's span (two end supports and two loading points). It can therefore bend in four different directions. This technique is known as four-point bending. As shown in Fig. 1, the space between the loads is 500 mm, whereas the distance between the two supports is obviously 1500 mm . Four-point bending has a homogeneous bending moment, and there is no shear force between the loading points, thus it leads to pure bending loading.

4.4 Supporting conditions

The method adopted for the fabrication of a rectangular hollow flange cold-formed steel I-beam from two hollow flanges and web connected by bolts at various positions from the support is the press braking method. Figure (4) depicts a simply supported rectangular the hollow flange cold-formed steel I-beam with a roller at one end and a pined connection at the other; the span length of all the beams is maintained at 1500 mm , with support at 100 mm.

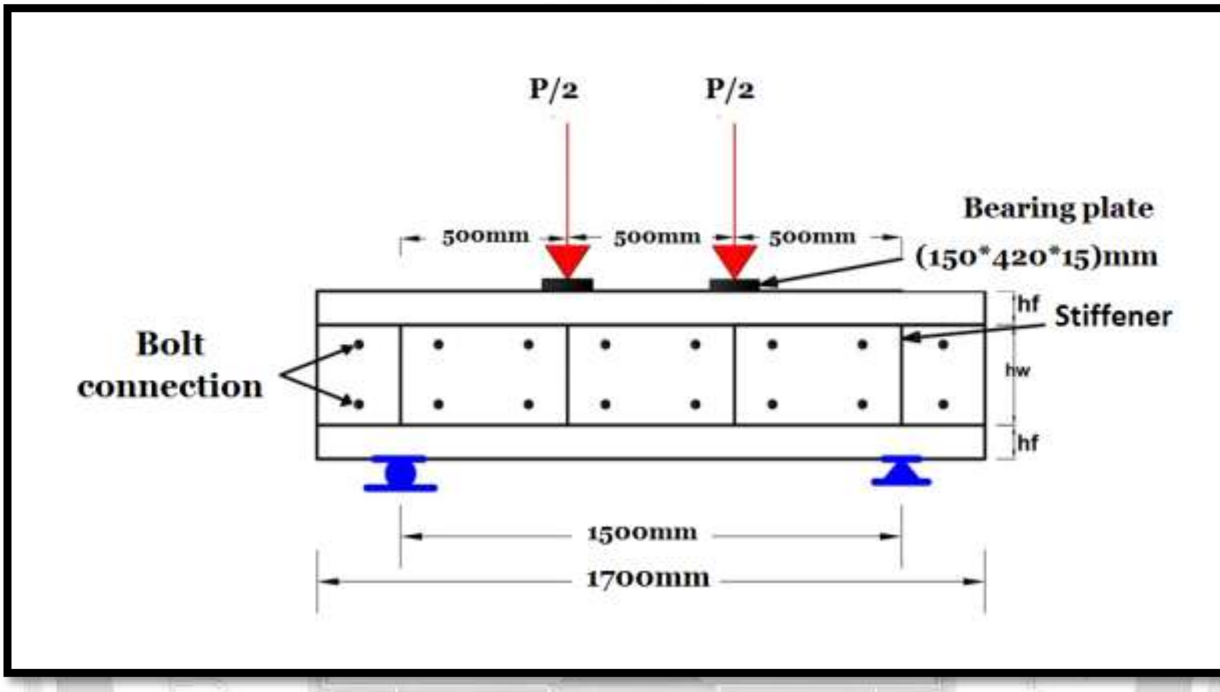

Figure (4): Loading and Support conditions

4.5 Limiting criteria

The limited criterion is a normalized scale or value that compares the results of different sections to see how well they work on a single scale. The load-bearing capacities of the sections in this article are compared using deflection as a standard metric. The deflection limit is given as span/300 in the **BS- 5950 -5: 1998. Code of Practice for the design of the Cold-- Formed Narrow Gauge Sections.**

5. Ductility Index

Ductility is the ability of a beam to resist plastic deformation without reducing its capacity of carrying loads till failure. Alternatively, ductility can be defined as the ratio of yield deformation to ultimate stage deformation. Deformations include strain, curves, and deflections, for instance. The deflection at the yield limit is shown by the intersection of two lines from the load-deflection curves, the line of best fit acting as a tangent line, and a horizontal line passing through the maximum load. This is for elastic-plastic behavior as shown in Figure(5).[17]

$$\textbf{Ductility ratio} = \frac{\Delta u}{\Delta y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(1)}$$

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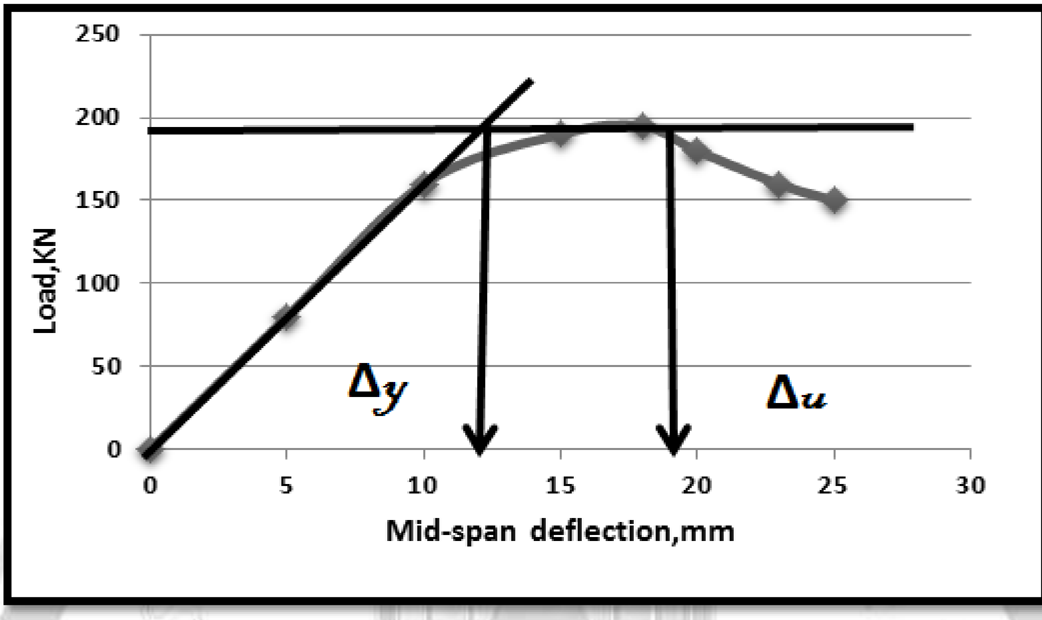

Figure(5): Yield Limit for Elastic-Plastic Behavior [17]

6. Efficiency of specimens

The load-to-weight ratio is a tool for calculating the efficiency of sections. This ratio means the amount of weight required to obtain an increase in the bearing capacity of the sections, which means the higher this ratio, the better the performance of the sections. [17]

Efficiency = Total applied load /Total weight of beam ………..(2)

7. Results and Discussion

Flexural beams were tested on five different types of specimens at Babylon university's college of engineering's construction laboratory using universal testing equipment with a 600 kN capacity and adjustable supports long enough for the required span. The obtained load and deflection are measured, recorded, and extrapolated as necessary. The specimen's deformation and loads are measured using the measurement system. The disc gauge is positioned in the middle of the bottom beam so that it can measure section deflection. It is also positioned directly under the point load at the bottom of the beam so that it can measure deflection in this region. As the load is gradually raised by the hydraulic jack, the cold-formed beam starts to deflect, and local buckling happens towards the bottom of the load.

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7.1 CFS I-beam with rectangular hollow flange (hf=60mm),A60

This beam consisted of two rectangular hollow flanges, the depth of each flange was 60mm and web was 180mm, the location of the bolt connection between the two flanges and web was at L/6, and the length of the span was 1500mm. This beam was not strengthened, which used as a control specimen.

Figure (6): Testing CFS I-beam with rectangular hollow flange (A60)

Figure (7): Failure of CFS I-beam with rectangular hollow flange (A60)

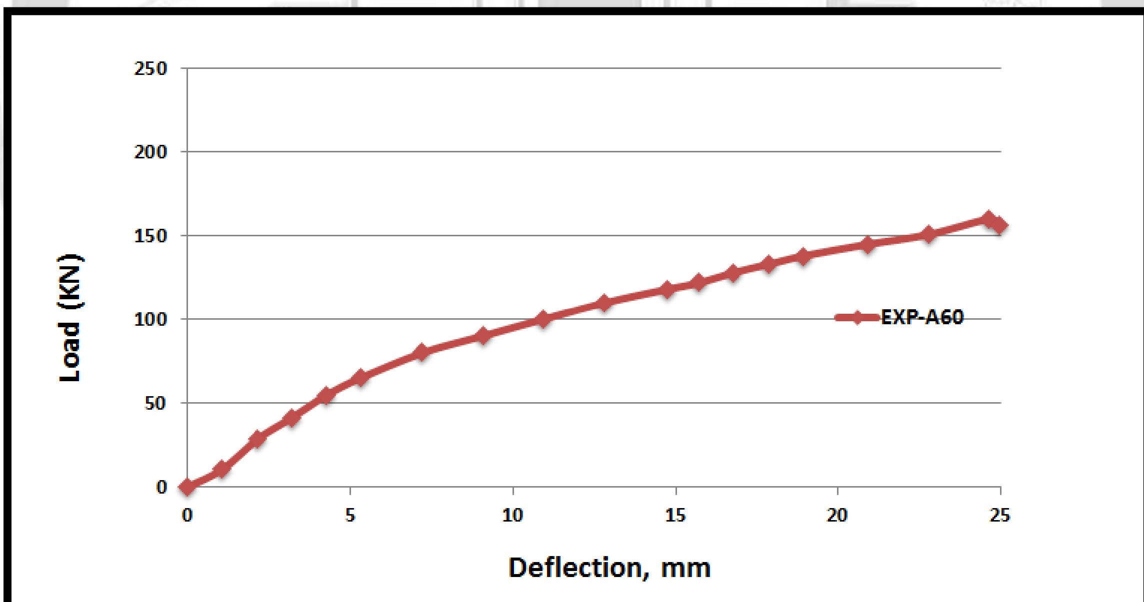

Figure (8): Load-mid span deflection curve for CFS I-beam with rectangular hollow flange (A60)

The ultimate load supported by the A60 section was 160kN, and the beam deflected (24.65 and 20.99) mm at mid-span and under point load, respectively, the section's ductility factor is 1.9.

7.2 CFS I-beam strengthened the rectangular hollow flange by normal concrete(A60NC)

This beam consisted of two rectangular hollow flanges, depth of each flange was 60m) and web was 180mm, the location of bolt connection between two flanges and web was at L/6 and length of span was 1500mm. This beam was strengthened with normal concrete.

Figure (9): Failure of CFS I-beam strengthened the rectangular hollow flange by normal concrete(A60NC)

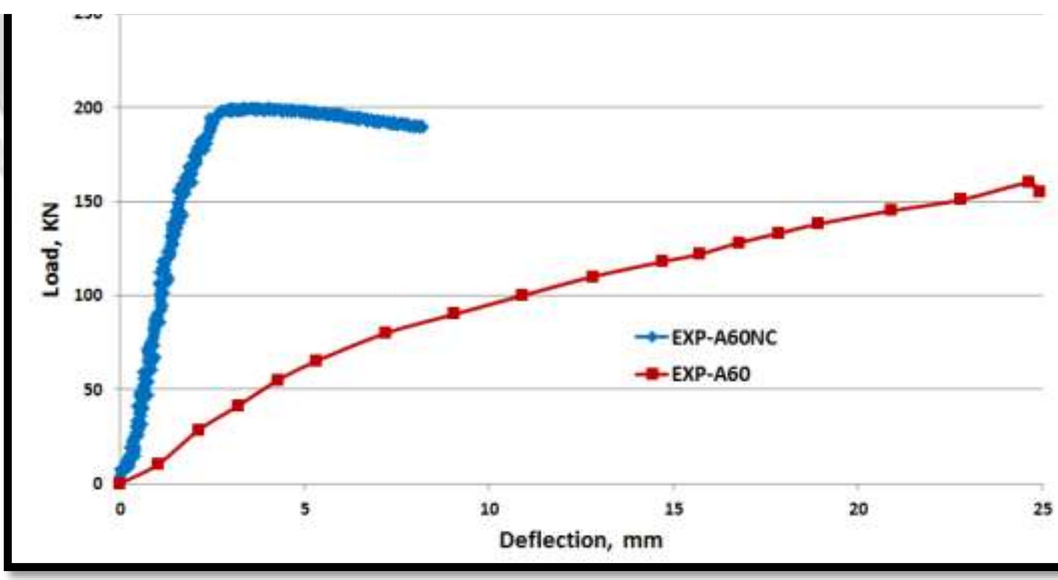

Figure (10): Load-mid span deflection curve for CFS I-beam strengthened the rectangular hollow flange by normal concrete (A60NC)

The ultimate load supported by the A60NC section was 199kN, and the beam deflected (4.64 and 4.5) mm at mid-span and under point load, respectively, the section's ductility factor is 1.32. Strengthening the rectangular hollow flange with normal concrete improved the behavior of the beam, as it increased the bearing capacity by 19.6% and decreased the deflection by 80.2% when compared with the control specimens, and this improved the flexural behavior.

7.3 CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced coarse aggregate by recycled concrete(A60RC)

This beam consisted of two rectangular hollow flanges, the depth of each flange was 60 mm and web was 180mm, the location of the bolt connection between the two flanges and web was at L/6, and the length of the span was 1500mm. This beam was strengthened with normal concrete has been replaced coarse aggregate by recycled concrete.

Figure (11): Failure of CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced coarse aggregate by recycled concrete(A60RC)

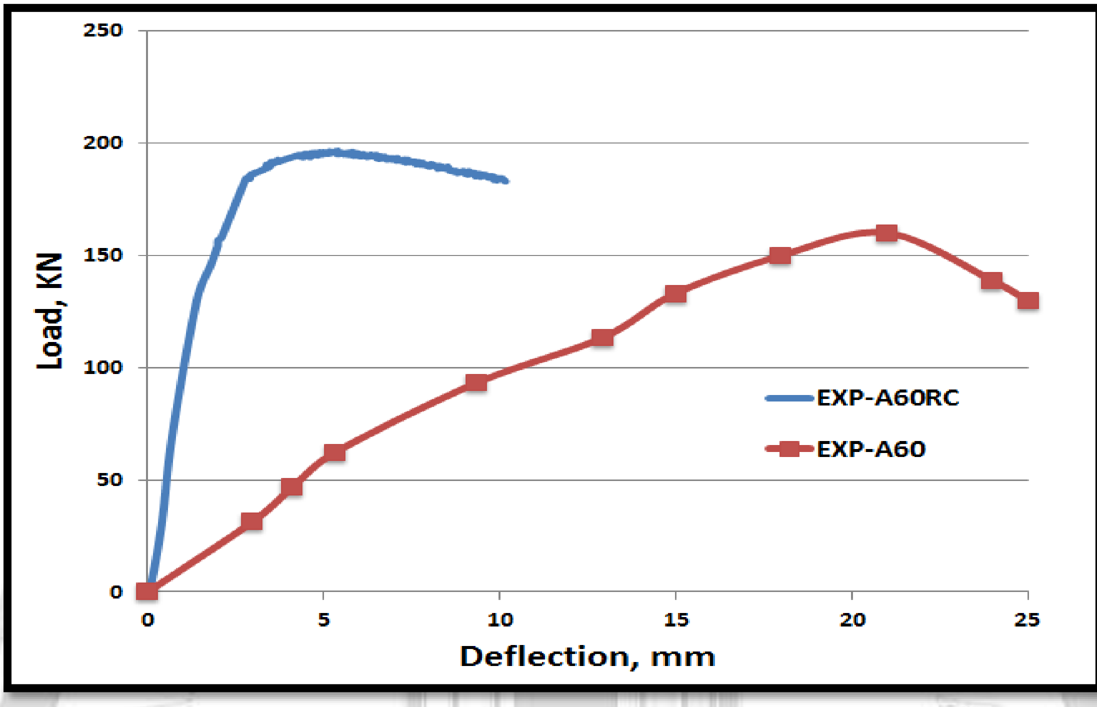

Figure (12): Load-mid span deflection curve for CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced coarse aggregate by recycled concrete(A60RC)

The ultimate load supported by the A60RC section was 195kN, and the beam deflected (4.13 and 4.04) mm at mid-span and under point load, respectively, the section's ductility factor is 1.45. Strengthening the rectangular hollow flange with normal concrete has been replaced coarse aggregate by recycled concrete improved the behavior of the beam, as it increased the bearing capacity by 17.9% and decreased the deflection by 83.25% when compared with the control specimens, and this improved the flexural behavior.

7.4 CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced coarse aggregate with 30% coarse rubber (A60CR)

This beam consisted of two rectangular hollow flanges, depth of each flange was 60mm, and web was 180mm, the location of the bolt connection between the two flanges and the web was at L/6, and the length of the span was 1500mm. This beam was strengthened with normal concrete has been replaced coarse aggregate with 30% coarse rubber.

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Figure (13): Failure of CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced coarse aggregate with 30% coarse rubber(A60CR)

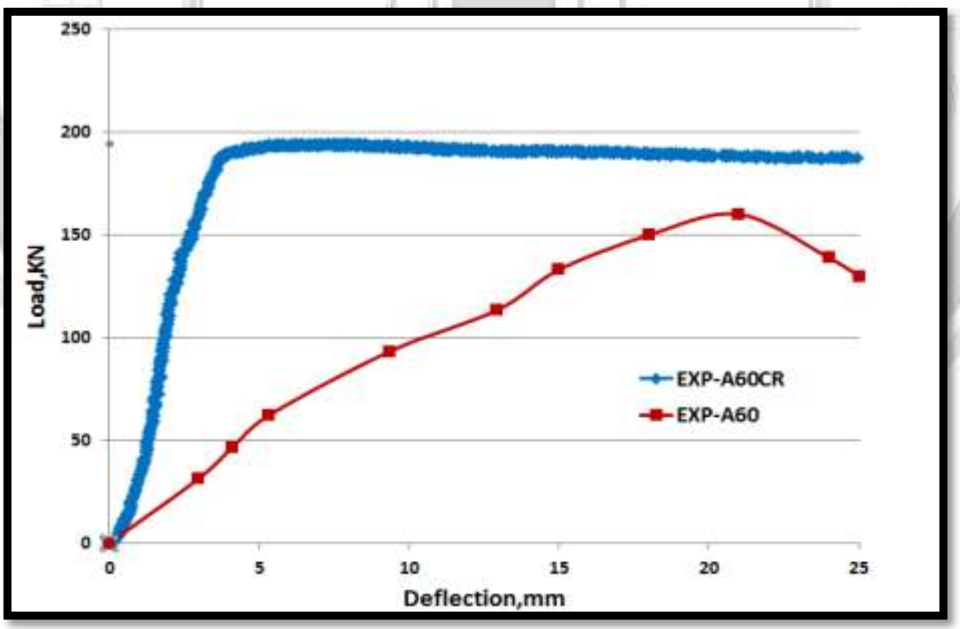

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Figure (14): Load-mid span deflection curve for CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced coarse aggregate with 30% coarse rubber (A60CR)

The ultimate load supported by the A60CR section was 190kN, and the beam deflected (5.6 and 5.2) mm at mid-span and under point load, respectively, the section's ductility factor is 2.21. Strengthening the rectangular hollow flange with normal concrete has been replaced coarse aggregate with 30% coarse rubber improved the behavior of the beam, as it increased the bearing capacity by 15.8% and decreased the deflection by 77.3% when compared with the control specimens, and this improved the flexural behavior.

7.5 CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced fine aggregate with 30% sawdust (A60S)

This beam consisted of two rectangular hollow flanges, depth of each flange was 60mm, and web was 180mm. The location of the bolt connection between the two flanges and the web was at L/6, and the length of the span was 1500mm. This beam was strengthened with normal concrete has been replaced fine aggregate with 30% sawdust .

Figure (15): Failure of CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced fine aggregate with 30% sawdust (A60S)

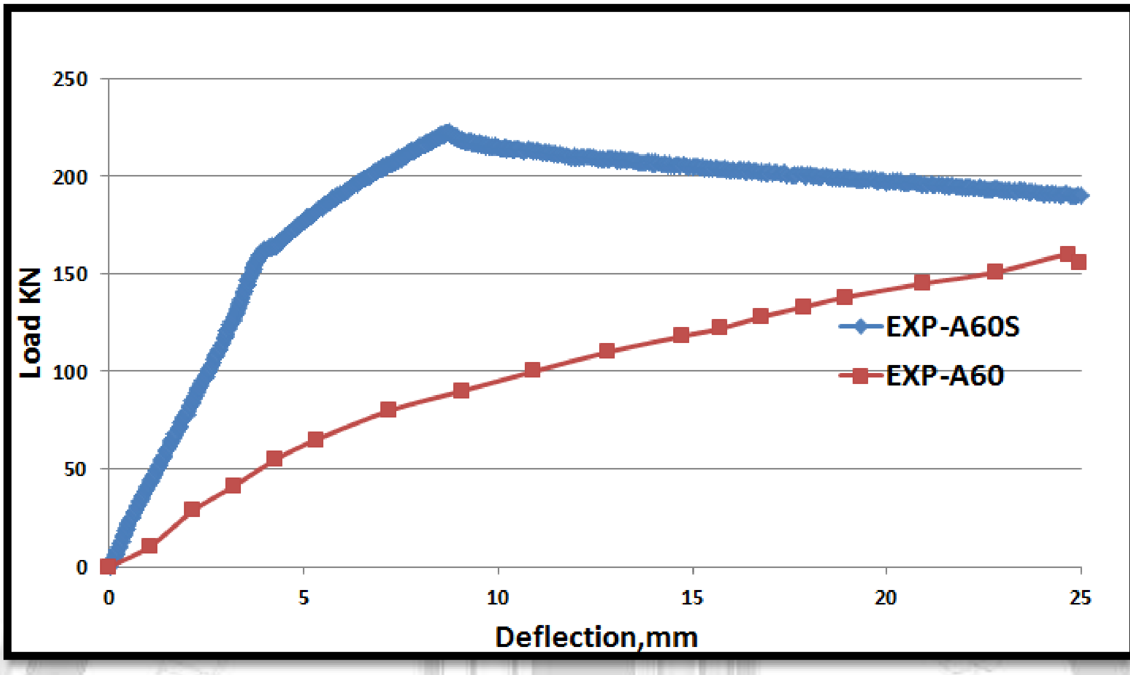

Figure (16): Load-mid span deflection curve for CFS I-beam strengthened the rectangular hollow flange by normal concrete has been replaced fine aggregate with 30% sawdust(A60S)

The ultimate load supported by the A60S section was 225kN, and the beam deflected (8.69 and 8.12) mm at mid-span and under point load, respectively, the section's ductility factor is 1.74. Strengthening the rectangular hollow flange with normal concrete has been replaced fine aggregate with 30% coarse sawdust improved the behavior of the beam, as it increased the bearing capacity by 28.93% and decreased the deflection by 64.75% when compared with the control specimens, and this improved the flexural behavior.

After completing all specimens tests, it was found that Strengthening the rectangular hollow flanges with different strengthen materials as mention above improved the behavior of the beam, as after comparing the specimens with the control beam, It was found that the bearing capacity has increased and the deflection has decreased, this improved the flexural behavior as shown in Figure (17).

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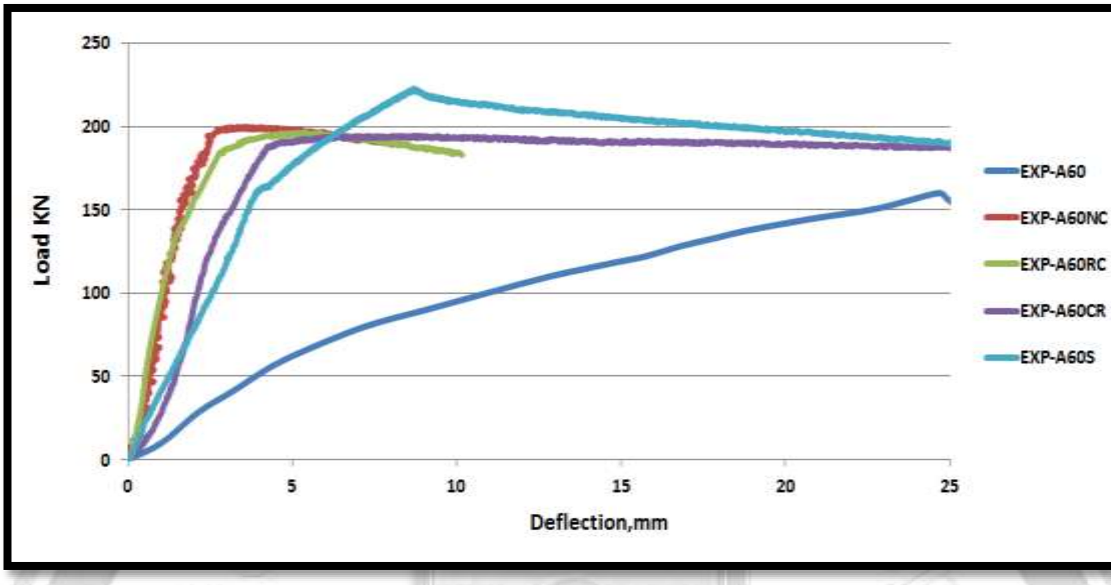

Figure (17): Load-Max. deflection of all specimens

8. Interpretation

The experiments have been completed, and the findings have been received. Mild steel (Yield stress: 266.1 MPa, Young's modulus: 200000 MPa) is used in the construction of the parts. According to the Code of Practice for the Design of Cold-Formed Narrow-Gauge Sections,'' the maximum permissible deflection is 5mm (**span/300**) (**BS 5950-5:1998**). The results of the five proposed parts of sections are shown below. The load-to-weight ratio is used to calculate the section's efficiency. This ratio represents the amount of self-weight required to sustain each increase in the section's load-bearing capacity; hence, the greater the ratio, the better the section's performance.

Table (5): The outcomes of the planned specimens' tests

Section type	Total applied load (KN)	Total weight of beams (Kg)	Ductility factor	Efficiency %
A60	160	53.6	2.24	3
A60NC	199	110.1	2.52	1.8
A60RC	195	108.02	1.8	1.81
A60CR	190	105.2	2.24	1.82
A60S	225	105.5	2.55	2.14

9. Conclusions

This research focused on the bending responses of cold-formed beams having hollow strengthening rectangular flange sections. These findings were arrived at:

- When fabricating a hollow rectangular flanged CFS section, it is important to consider web buckling and web aspect ratio.
- The bending strength of a beam depends heavily on its yield stress as well as its thickness, depth, and web aspect ratio.
- Failure of all beams are governed by the bending failure mode.
- In comparison to the A60, the percentage of load bearing capability increased by 19.6% for the A60NC, 17.9% for the A60RC, 15.8% for the A60CR and 27.93% for A60S.
- In comparison to the A60, the percentage of deflection decreased by 80.2% for A60NC, 83.25% for A60RC, 77.3% for A60CR and 64.75% for A60S.
- A60S was the most capable of carrying loads and more ductile, as it carried a load of 225KN, and this is 11.5% higher than A60NC, 13.33% higher than A60RC, and 15.63.1% higher than A60CR.
- Adding alternative materials for coarse or fine aggregate improved the behavior of concrete and thus improved the behavior of beams in terms of increasing the bearing capacity in rates ranging between 15.8% and 27.98%, and decreasing the deflection in rates ranging between 65% and 83%.
- It was shown that strengthening the rectangular hollow flange increases its bearing capacity in rates ranging between 15.8% and 27.98%,, decreases beam deflection in rates ranging between 65% and 83%, and increases the section's resistance to buckling. This shows that the strengthen flange of an I-hollow beam is better as flexural member.

Nomenclature

CFS	Cold-Formed Steel
RHFCB	Rectangular Hollow Flange Channel Beam
CFPFB	Concrete-Filled Pentagonal Flange Beam
HS- CFPFB	Buckling Resistance- Concrete-Filled Pentagonal Flange Beam
THFBs	Triangular Hollow Flange Beams
HFBs	Hollow Flange Beams
RHFGs	Rectangular Hollow Flange Girders
CFTFGs	Cold-Formed Triangle Flange Girders
TFBs	Triangle Flange Beams

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تقوية اعتاب الحديد المشكل على البارد ذات الشفاه المجوفة بمواد مختلفة

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الخلاصة

كرس هذا البحث لاستقصاء سلوك الانحناء لأعتاب من الحديد المشكلة على البارد ذات شفاه مستطيلة مجوفة مقواة تحت تأثير تحميل مركز بأربع نقاط على مسافات متساوية من المساند. جميع العينات لها نفس طول الامتداد الصافي للعتب بين المساند(1500ملم) ونفس السمك للويب والشفاه (4ملم) ونفس عمق العتب (300ملم) ونفس عرض الشفة (150ملم) ونفس عمق الشفاه المجوفة(60ملم) وكانت المسافة بين البراغي التي تربط الويب بالشفاه(ل/6) وثمانية مقاطع تقوية لكل عتب وضعت تحت نقاط تحميل الحمل وفي نقاط المساند من كل جهة. يتضمن البرنامج التجريبي تجميع الاجزاء لعمل الاعتاب وفحص خمسة عينات ,احدى هذه العينات تركت بدون تقوية حتى تكون نموذج مقارنة مع البقية والاربعة الاخرى تم تقوية كل عينة بمادة تقوية والعوامل التي اعتمدنا عليها لاختيار هذه المواد هي التكلفة وخفة الوزن والقوة ومواد التقوية التي استخدمت هي(الخرسانة العادية ، الخرسانة العادية تم استبدال الركام الخشن بالخرسانة المعاد تدويرها ، الخرسانة العادية تم استبدال الركام الناعم بنسبة 30٪ بنشارة الخشب والخرسانة العادية تم استبدال الركام الخشن بـــ 30٪ من المطاط الخشن). تمت مقارنة الاعتاب المقواة بعتب التحكم ، ووجد من هذه المقارنة أن تقوية الحافة بمواد تقوية مختلفة أدى إلى تحسين سلوك العتب، حيث زادت قدرة التحمل بنسب تتراوح بين 15.8% و 27.98% وانخفض الانحراف بنسب تتراوح بين 65% و 83% ، وهذا يعني أن تقوية الشفة لها تأثير قوي على سلوك الانحناء. تمت مناقشة وتلخيص الاستنتاجات الرئيسية المستخلصة من الدراسة. أظهر البحث أن تقوية الأجزاء ذات الشفاه المجوفة أعطت أفضل النتائج لسلوك الانثناء.

الكلمات الدالة: المقاطع المشكلة على البارد ,مواد التقوية ، الحمل حسب نسبة الوزن، الأمان، الحمل الرأسي والفعالية من حيث التكلفة.