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Experimental Study Of Bolted Connections Using Light Gauge Channel Sections, Using Stiffener/Packing Plates At The Joints

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Abstract

Cold-formed structural members are being used more widely in routine structural design as the world steel industry moves from the production of hot-rolled section and plate to coil and strip, often with galvanised and/or painted coatings. Steel in this form is more easily delivered from the steel mill to the manufacturing plant where it is usually cold-rolled into open and closed section members. The present study is focus on examining the experimental investigation to study the effect of Stiffener/Packing plate (Mild steel Plates) only at the joints in cold formed channel sections by using bolts at the joints and which may increase the load carrying capacity of the bolted channel section subjected to axial tension. In the present study, the strength of the joint is increased by increasing the various thicknesses of Stiffener/Packing plates at the joints with three numbers of bolts at the connection. And also the experiment is executed with a single bolt to study the of failure pattern at the joints. Total Twelve experimental tests have been carried out on cold formed channel tension members fastened with bolts, to calculate the failure capacity and increase in strength of the member and also to trace the entire load versus elongation path, so that the behavior of the connection is examined.

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Keywords: Light Gauge Steel Sections, Steel Plates, Strain/Elongation, Failure Patterns.

Introduction

The use of cold-formed steel members in building construction began in the 1850s in both the United States and Great Britain. In the 1920s and 1930s, acceptance of cold-formed steel as a construction material was still limited because there was no adequate design standard and limited information on material use in building codes. One of the first documented uses of cold-formed steel as a building material is the Virginia Baptist Hospital, constructed around 1925 in Lynchburg, Virginia. The walls were load bearing masonry, but the floor system was framed with double back-to-back cold-formed steel lipped channels. According to Chuck Greene, P.E of Nolen Frisa Associates [2], the joists were adequate to carry the initial loads and spans, based on current analysis techniques. Greece engineered a recent renovation to the structure and said that for the most part, the joists are still performing well. A site observation during this renovation confirmed that "these joists from the 'roaring twenties' are still supporting loads, over 80 years later!" In the 1940s, Lustron Homes built and sold almost 2500 steel-framed homes, with the framing, finishes, cabinets and furniture made from cold-formed steel.[1]

Cold-Formed Steel (CFS) is the common term for products made by rolling or pressing thin gauges of sheet steel into goods. Cold-formed steel goods are created by the working of sheet steel using stamping, rolling, or presses to deform the sheet into a usable product. The use of cold-formed steel construction materials has become more and more popular since its initial introduction of codified standards in 1946. In the construction industry both structural and non-structural elements are created from thin gauges of sheet steel. The material thicknesses for such thin-walled steel members usually range from 0.0147 in. (0.373 mm) to about ¼ in. (6.35 mm). Steel plates and bars as thick as 1 in. (25.4 mm) can also be cold-formed successfully into structural shapes. These building materials encompass columns, beams, joists, studs, floor decking, built-up sections and other components. The manufacturing of cold-formed steel products occurs at room temperature using rolling or pressing. The strength of elements used for design is usually governed by buckling. [2]

Tension Member

Tension members are structural elements or members that are subjected to axial tensile forces. Fig.1 shows a member under tension. They are usually used in different types of structures. Examples of tension members are: bracing for buildings and bridges, truss members and cables in suspended roof systems.

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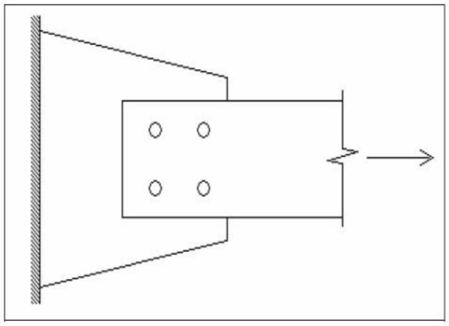

Figure 1: Member under Tension

Stress is given by, ***F =P/A***

Where, P is the magnitude of the load
A is the cross-sectional area

The increase in the length of a member due to axial tension under service load is

$$\Delta = PL / (E.A_g)$$

Where,
Δ is the axial elongation of the member (mm),P is the axial tensile force (un-factored) in the member (N),L is the length of the member (mm) and E is the modulus of elasticity of steel=2.0×10^5 MPa.

Note: That displacement is a serviceability limit state criterion and hence is checked

Material Details

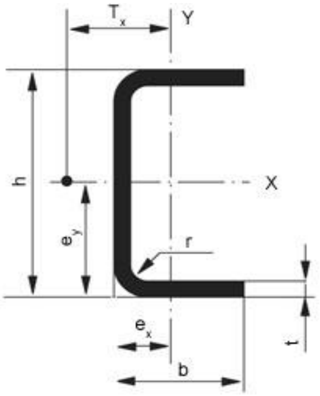

Fig 2: Cross section details of channal section

Where,

h - is the height of the section
b - is the width of the section
t - is the thickness of the section
r - is the radius section
Ixx and Iyy –is the moment of inertia about x and y axis

Yield Strength and Young's Modulus of the Cold Form Channel Specimen

The parallel length is kept between "Lo + b/2 & Lo + 2b"

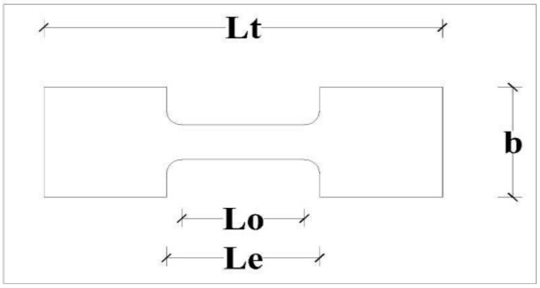

Fig 3: Tensile Test on Cold Formed steel Sheet

Where,

Lo = Original Gauge length
Le = Parallel length
Lt = Total length
b = Width of the test piece

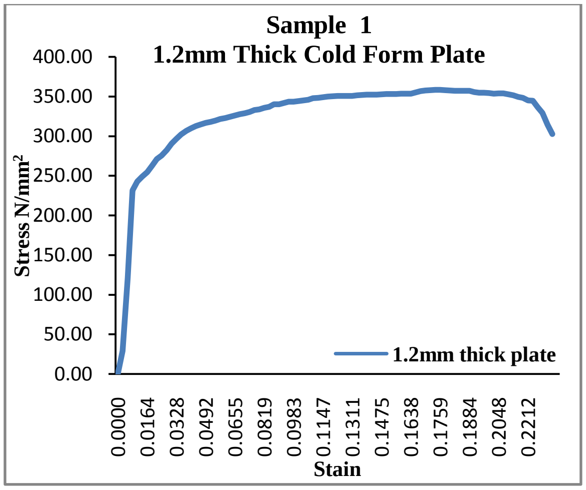

Fig 4: Graph Between Force and Elongation for 1.2mmThick Cold form plate

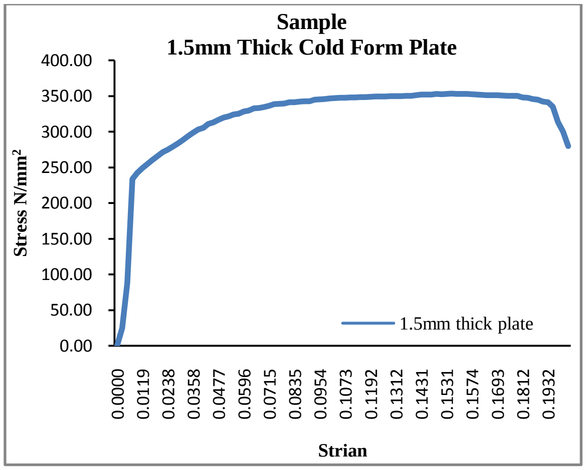

Fig 5: Graph Between Force and Elongation for 1.5mmThick Cold form plate

Table -1: Yield Strength and Young's Modulus Cold form steel plate

Test Samples	Thickness of sample	Yield Stress	ultimate strength	Young's Modulus
No	**mm**	**N/mm^2**	**N/mm^2**	**KN/mm^2**
1	**1.2**	**231.67**	**358.33**	**191.81**
2	**1.5**	**233.55**	**357.77**	**207.57**

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Hence from the **IS 1079-1973** the **Grade of the steel** is referred to as **St.42** for the **yield stress 235 N/mm^2**

Materials used as Stiffener/Packing Plate (Mild Steel Plate) at the Joint

1. A high amount of carbon makes mild steel different from other types of steel. Carbon makes mild steel stronger and stiffer than other type of steel. However, the hardness comes at the price of a decrease in the ductility of this alloy. Carbon atoms get affixed in the interstitial sites of the iron lattice and make it stronger.
2. Mildest grade of carbon steel or 'mild steel' is typically carbon steel, with a

comparatively mild amount of carbon (0.16% to 0.19%).

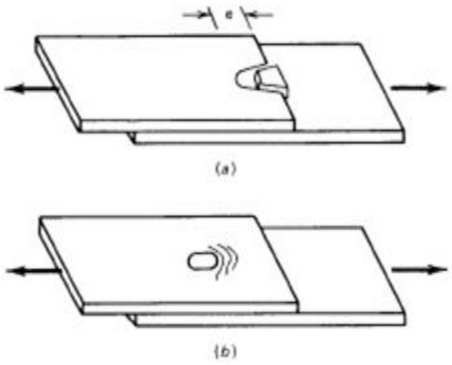
3. The calculated average industry grade mild steel density is 7.85 gm/cm^3. Its Young's modulus, which is a measure of its stiffness, is around 210,000 Mpa.
4. Mild steel is the cheapest and most versatile form of steel and serves every application which requires a bulk amount of steel.

Connections

Connections designed more conservatively than members because they are more complex to analyse and discrepancy between analysis and design is large. Connections are normally made either by bolting or welding. Bolting is common in field connections, since it is simple and economical to make. Bolting is also regarded as being more appropriate in field connections from considerations of safety.

Types of Failure Mode in Connections

(*a*) Longitudinal shear failure of sheet (type I).
(*b*) Bearing failure f sheet (type II).
(*c*)Tensile failure of sheet (type III)
(*d*) Shear failure of bolt (type IV).



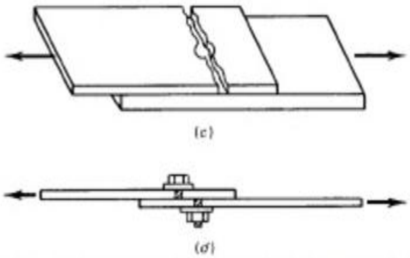


Fig 6: Types of failure of bolted connections

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Experimental Tests

Specimens Geometries

The experimental testing consists of channel of tension specimens fabricated from rolled steel sheets. All specimens are of 500 mm length. All specimens are fastened, with a single row of 12 mm diameter HSFG GR 8.8 bolts, through their webs at both ends. The tests consist of 3 sets of channel of size 50x40mm specimens with the 1.2 and 1.5mm thickness, with the same connection length for all the samples. At the connection Stiffener/Packing plates are used of different thickness. The end distance and number of bolts for each specimen are held constant at 24 mm and 3 numbers respectively, with Holes for the 12mm GR 8.8 bolts were specified to be drilled to a 14 mm diameter.

Table-2 Specimen Dimensions for 1.2mm Thick Channel with 3 Bolts Connection

Specimen Size	No of Bolts	End Dist	Connecting Length	Thickness of plate	Dia of Bolt	Dia of Hole
50X40	3	24	72	1.2	12	14
50X40	3	24	72	1.2	12	14
50X40	3	24	72	1.2	12	14
50X40	3	24	72	1.2	12	14
50X40	3	24	72	1.2	12	14

(All dimensions are in mm)

Table-3 Specimen Dimensions for 1.5mm Thick Channel with 3 Bolts Connection

Specimen Size	No of Bolts	End Dist	Connecting Length	Thickness of plate	Dia of Bolt	Dia of Hole
50X40	3	24	72	1.5	12	14
50X40	3	24	72	1.5	12	14
50X40	3	24	72	1.5	12	14
50X40	3	24	72	1.5	12	14
50X40	3	24	72	1.5	12	14

(All dimensions are in mm)

Table-4 Specimen Dimensions for 1.5mm Thick Channel with single Bolts Connection at the joint

Specimen No	No of Bolts	End Dist	Connecting Length	Thickness of plate	Dia of Bolt	Dia of Hole
50X40	3	24	72	1.5	12	14
50X40	3	24	72	1.5	12	14

(All dimensions are in mm)

Set up of Channel section moulds, are used to transfer the load from a 1000 KN universal testing machine (UTM) to a Channel specimen.

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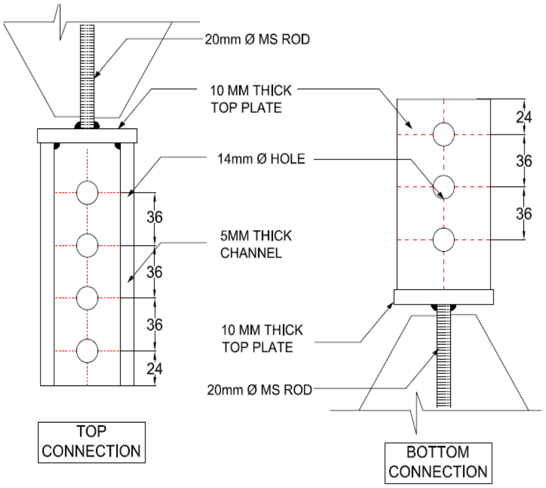
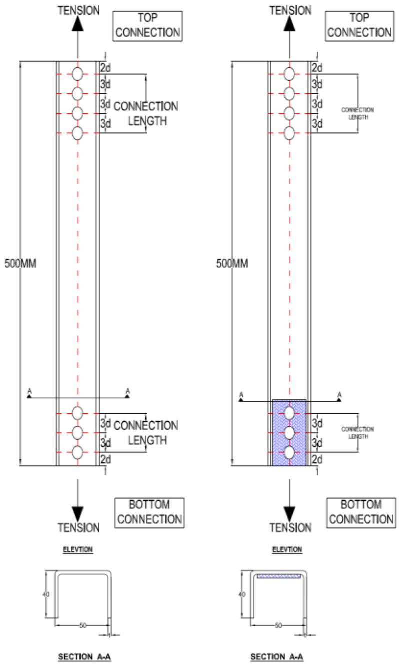
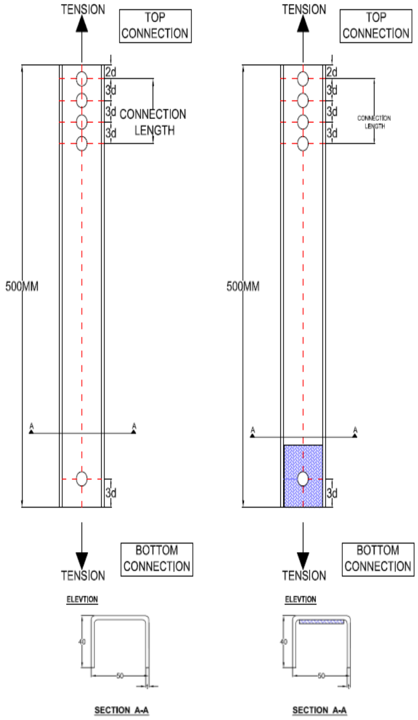


Fig 7: Channel moulds for the proper grip used for connecting channel section to UTM for Tensile test



a) Sample without Packing plate
b) Sample with packing plate

Fig 8: Specimen Geometries of the test sample with 3 bolts connection at the bottom



a) Sample without Packing plate
b) Sample with packing plate

Fig 9: Specimen Geometries of the test sample with single bolts connection at the bottom

Experimental Procedures and Results

Twelve full-scale bolted connections were tested in tension in a 1000 kN (tension) capacity universal testing machine. The load was applied quasi-statically. Readings of load and displacement were taken at regular intervals 12mm diameter HYSD Bolts were used, diameter hole of 14mm was drilled in both the 5mm thick plate as shown in the figure: 8. three such bolts were used to fasten these two plates together. These bolts were tightened using the turn of the nut method.

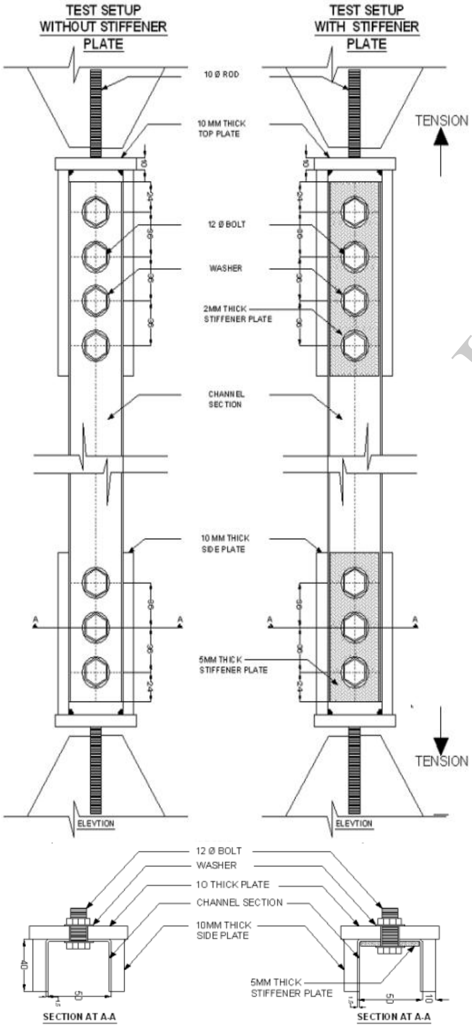


Fig 10: Arrangement made for tensile testing for UTM

Test Descriptions and Results

A summary of the test results and description of each test is presented in the following sections.

Specimens of Series A (1.2 mm Thick Channel Specimen with Three Numbers of Bolts at the Joint)

Specimens of Series B (1.5 mm Thick Channel Specimen with Three Numbers of Bolts at the Joint)

In this five specimens are used having the same cross section and the only variable was the thickness of the Stiffener/Packing Plate, which was 2mm, 3mm, 4mm, and 5mm. and first sample is tested without Stiffener/ packing plate. The results will be plotted to Load vs. deformation curves for these five specimens.

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Specimens of Series C (1.5mm Thick Channel Specimen with Single Number of Bolt at the Joint)

In this two specimens are used having the same cross section and the thickness of the Stiffener/Packing Plate used was 4mm, and first sample is tested without Stiffener/packing plate. The results will be plotted to Load vs. deformation curves for these five specimens.

Results

Specimens of Series A (1.2 mm Thick Channel Specimen with Three Numbers of Bolts at the Joint)

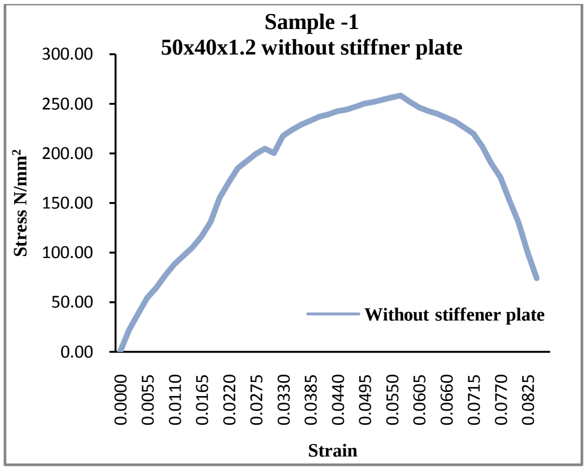

Fig 11: Graph between stress and strain for SMPL-1 without Stiffener/Packing plate

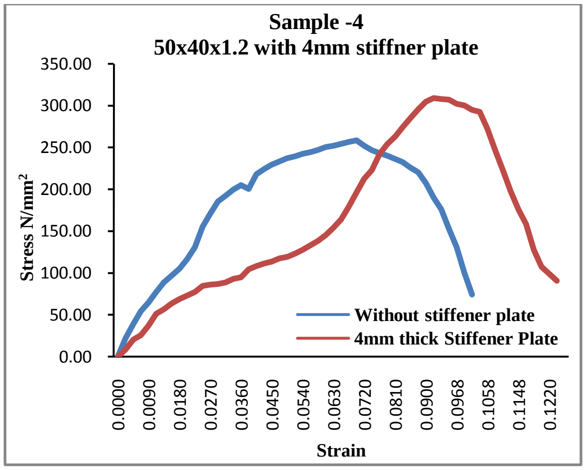

Fig 14: Comparison Graph between stress and strain for SMPL-4 with 4mm thick Stiffener/Packing plate

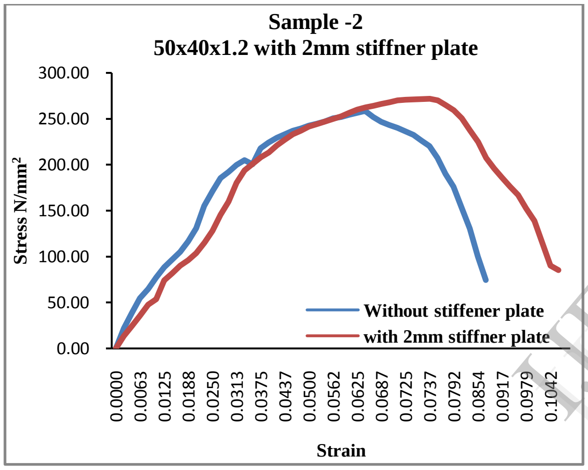

Fig 12: Comparison Graph between stress and strain for SMPL-2 with 2mm thick Stiffener/Packing plate

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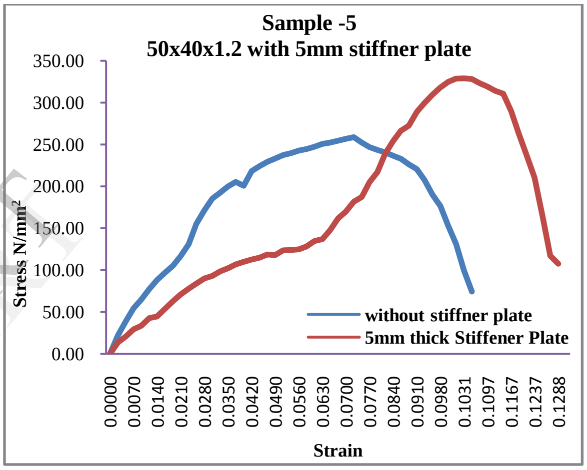

Fig 15: Comparison Graph between stress and strain for SMPL-5 with 5mm thick Stiffener/Packing plate

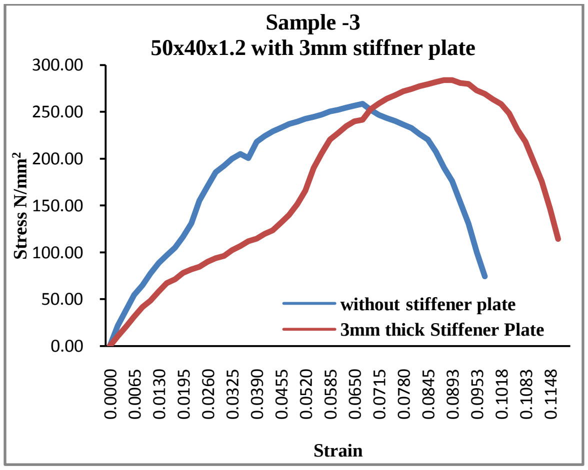

Fig 13: Comparison Graph between stress and strain for SMPL-3 with 3mm thick Stiffener/Packing plate

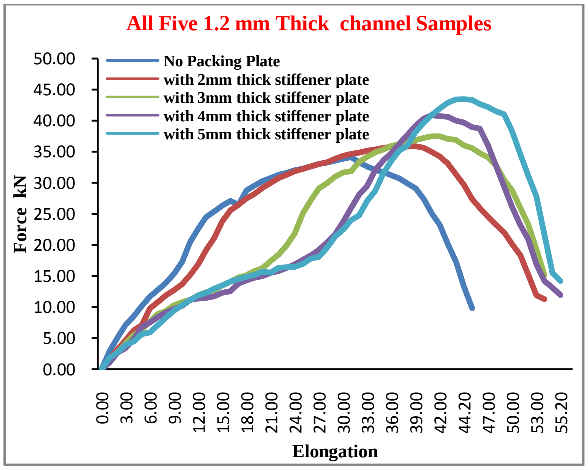

Fig 16: Comparison Graph between Force and Elongation for all the five samples

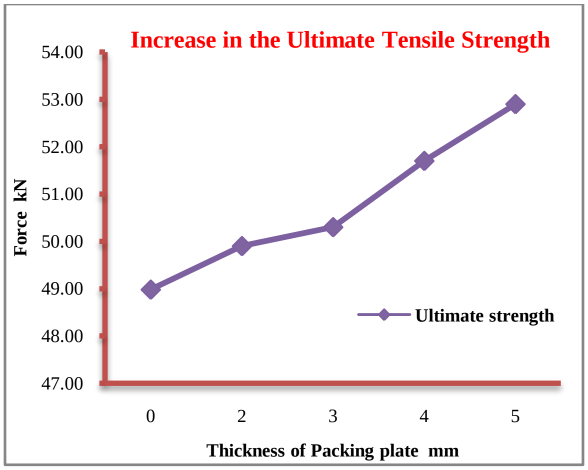

Fig 17: Graph between Thicknesses of the Stiffener/Packing Plate to ultimate Strength

Table-5 Results of All the 1.2mm Thick Channel Specimen

Specimen No	Net Section Area	Ultimate Tensile Strength	Thickness of Stiffener /Packing plate	Elongation at Peak Load	%of increase in strength
	mm2	kN	mm	mm	%
SMPL-1	136.32	34.16	-	31.00	0.00
SMPL-2	136.32	35.90	2	35.40	4.60
SMPL-3	136.32	37.50	3	40.80	7.15
SMPL-4	136.32	40.90	4	41.20	19.60
SMPL-5	136.32	43.50	5	43.80	26.90

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Specimens of Series B (1.5 mm Thick Channel Specimen with Three Numbers of Bolts at the Joint)

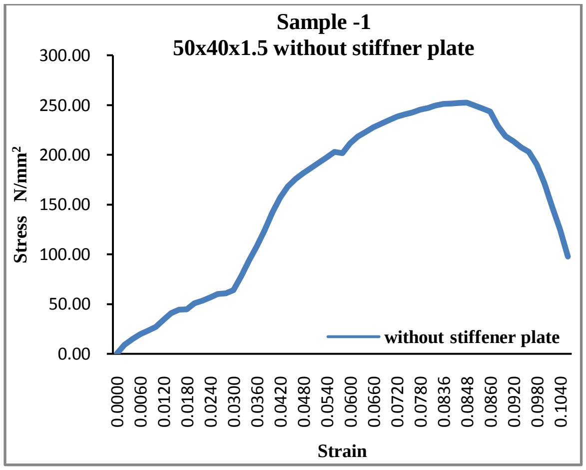

Fig 18: Graph between stress and strain for SMPL-1 without Stiffener/Packing plate

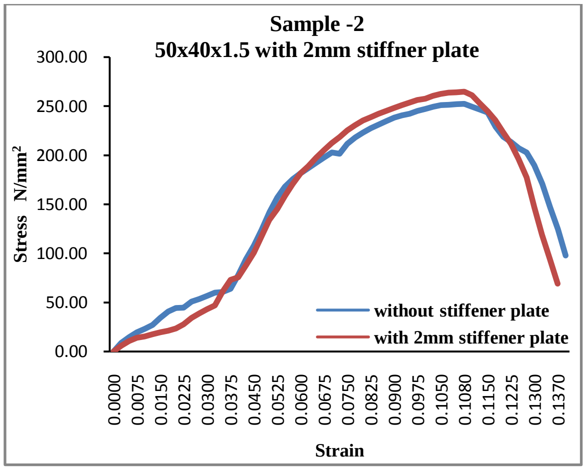

Fig 19: Comparison Graph between stress and strain for SMPL-2 with 2mm thick Stiffener/Packing plate

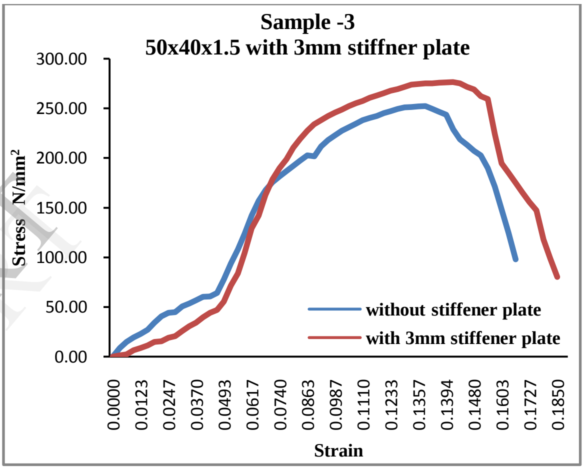

Fig 20: Comparison Graph between stress and strain for SMPL-3 with 3mm thick Stiffener/Packing plate

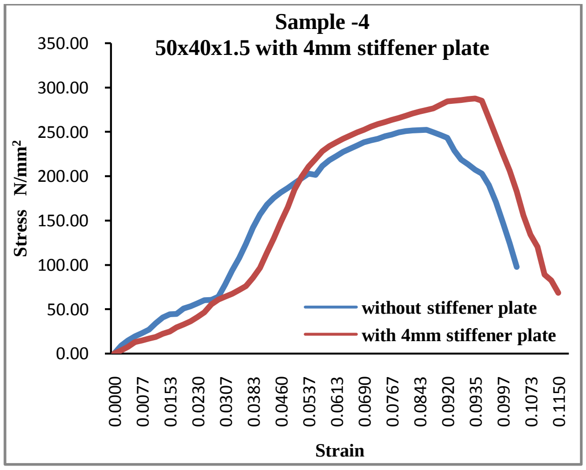

Fig 21: Comparison Graph between stress and strain for SMPL-2 with 2mm thick Stiffener/Packing plate

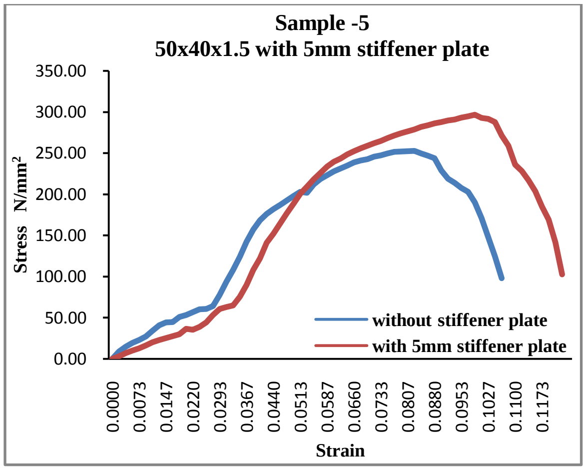

Fig 22: Comparison Graph between stress and strain for SMPL-2 with 2mm thick Stiffener/Packing plate

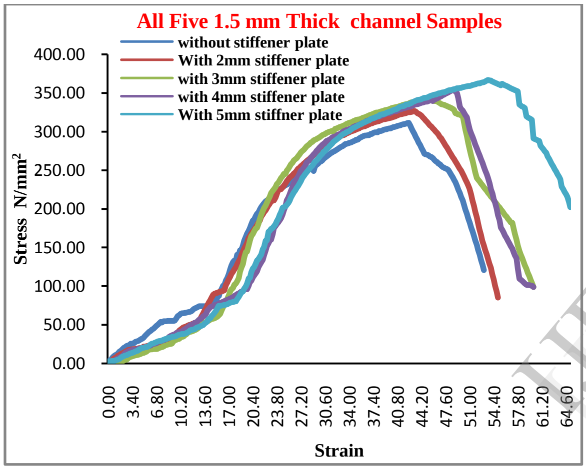

Fig 23: Comparison Graph between Force and Elongation for all the five samples

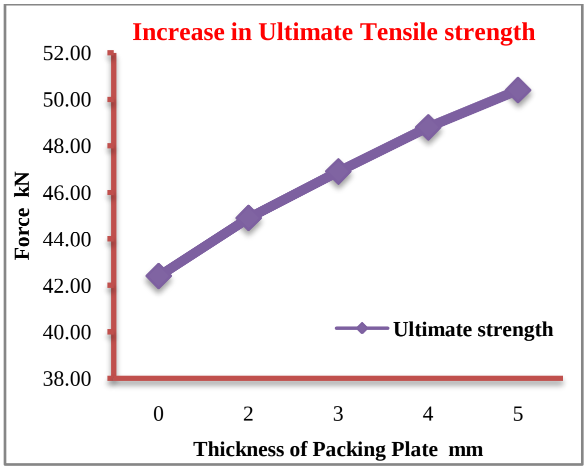

Fig 24: Graph between Thicknesses of the Stiffener/Packing Plate to ultimate Strength

Table-6 Results of All the 1.2mm Thick Channel Specimen

Specimen No	Net Section Area	Ultimate Tensile Strength	Thickness of Stiffener /Packing plate	Elongation at Peak Load	%of increase in strength
	mm2	kN	mm	mm	%
SMPL-1	169.5	42.40	-	42.80	0.00
SMPL-2	169.5	44.90	2	43.20	4.90
SMPL-3	169.5	46.90	3	45.40	9.50
SMPL-4	169.5	48.80	4	48.80	14.0
SMPL-5	169.5	50.40	5	53.60	20.00

Specimens of Series C (1.5 mm Thick Channel Specimen with single Bolt at the Joint)

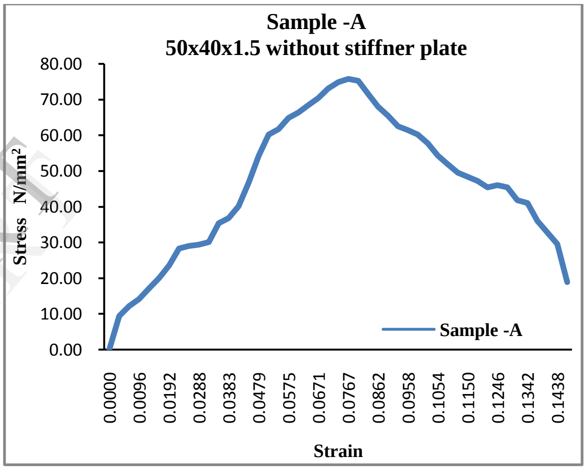

Fig 25: Graph 6.46: Between Force and Elongation for specimen SMPL-A without Packing plate

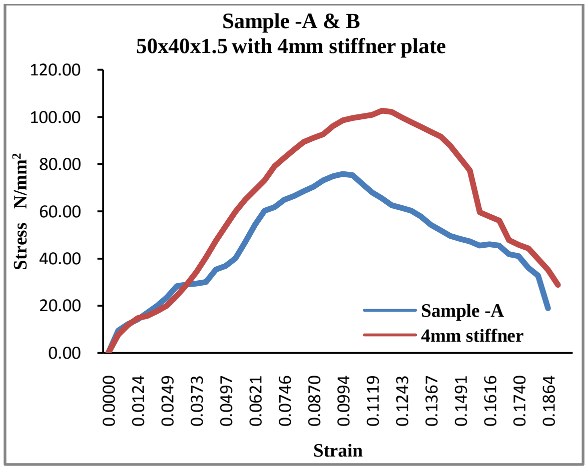

Fig 26: Graph 6.46: Between Force and Elongation for specimen SMPL-B with 4mm packing plate

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Table-7 Results of 1.5mm Thick Channel section with single bolt at joint

Specimen No	Net Section Area	Ultimate Tensile Strength	Thickness of Stiffener /Packing plate	Elongation at Peak Load	% of increase in strength
	mm2	kN	mm	mm	%
SMPL-1	136.32	12.85	-	24.00	0.00
SMPL-2	136.32	17.40	4	28.00	35.40

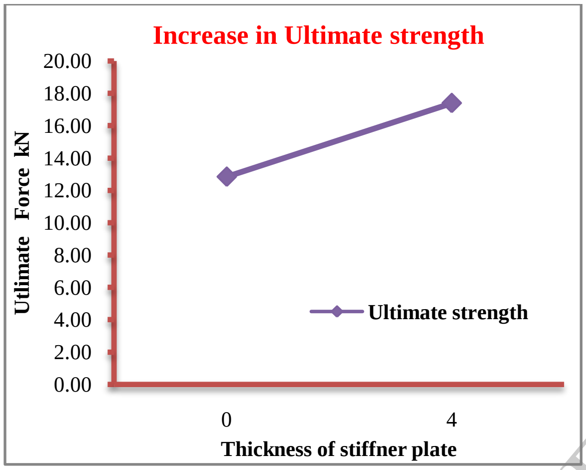

Fig 27: Graph between Thicknesses of the Stiffener/Packing Plate to ultimate Strength

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Failure Patterns

Bearing + Rupture Failure Observed

Bearing + Rupture Failure Observed With 2mm Thick Packing Plate for 1.2, and 1.5mm thick specimen sample

Bearing + Rupture Failure Observed With 3mm Thick Packing Plate for 1.2, and 1.5mm thick specimen sample

Vertical Shear Failure of 1.5mm Thick Sample Specimen using 4mm thick Stiffener/packing plate

Block Shear Failure of 1.5mm Thick Sample Specimen using 5mm thick Stiffener/packing plate

Buckling of Stiffener/Packing plate used 1.5mm Thick Sample Specimen

Bearing + Shear Failure Observed for 1.5mm thick specimen sample with single bolted connection

Discussions and Conclusions

Table-8 Results of 1.2mm Thick Channel section with 3 bolts at the Joints

Size of the Specimen	Thickness of Stiffener /Packing Plate	Ultimate Tensile Strength	% of increase in Strength	Types of Failure observed
mm	mm	(kN)	%	
50X40X1.2	-	34.16	0.00	Bearing + Rupture
50X40X1.2	2	35.90	4.60	Bearing + Rupture
50X40X1.2	3	37.50	7.15	Bearing + Rupture
50X40X1.2	4	40.90	19.6	Bearing + Rupture
50X40X1.2	5	43.50	26.9	Bearing + Rupture

Table-9 Results of 1.5mm Thick Channel section with 3 bolts at the Joints

Size of the Specimen	Thickness of Stiffener /Packing Plate	Ultimate Tensile Strength	% of increase in Strength	Types of Failure observed
mm	mm	(kN)	%	
50X40X1.5	-	42.40	0.00	Bearing + Rupture
50X40X1.5	2	44.90	4.90	Bearing + Rupture
50X40X1.5	3	46.90	9.50	Bearing + Rupture
50X40X1.5	4	48.80	14.00	Vertical shear
50X40X1.5	5	50.40	20.00	Block shear Failure

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Table-10 Results of 1.5mm Thick Channel section with single bolt at joint

Size of the Specimen	Thickness of Stiffener /Packing Plate	Ultimate Tensile Strength	% of increase in Strength	Types of Failure observed
mm	mm	(kN)	%	
50X40X1.5	-	12.85	0.00	Bearing + Shear
50X40X1.5	4	17.40	35.40	Bearing + Shear

1. It is observed from the above Tables by the use of packing plates the load carrying capacity of the joint increases. As the thickness of the light gauge section increases the variation in increase of joint strength reduces for

various thicknesses of Stiffener/packing plates.

2. For 1.2mm thick channel section it is observed that all failures are due to rupture with 3 bolts connection, and also for 1.5mm thick channel section up to 3mm thick Stiffener/Packing plate failure are due to rupture and for 4mm thick Stiffener/packing plate the failure is due to vertical shear failure along the line of vertical connection. With use of 5 mm thick Stiffener/packing plates the failure is due to block shear failure.
3. Hence with the use of thicker plates, bearing failure can be avoided. The increase in the tensile strength for change in each thickness of the Stiffener/packing plate is shown in Table 8 and 9.
4. By the use of lesser thickness of the Packing plate it is observed that the plate buckles along with the plate.
5. For 1.5mm thick channel section with single bolt at 3d end distance, it is observed that the failure is due to bearing and shear failure and the percentage of increase in tensile strength with 4mm thick Stiffener/packing plate is 35.40%.

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