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Comparative Study of Mechanical Behavior of Riveted and Spot Welded MS Sheets under Different Loading Conditions

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***Abstract*— The increased application of mild steel sheets in steel structures has initiated many investigations into joining techniques. The resistance spot welding (RSW) and riveting are the major production processes used to join mild steel sheet body structures for boilers and automotive industry. Investigations have been made in the present study on these two major joining technologies and an in depth comparison of mechanical behavior is reported for joints under different loading conditions (Shear, Tension, Peel, and Double Shear). It covers similar and dissimilar thickness joints (0.8 mm and 1.5 mm) and some multilayer joints. The results suggest that similar thickness riveted joints exhibit higher strengths than dissimilar thickness joints and similar thickness peel joint showing the highest energy absorption. Same was the case with RSW joints, reducing the thickness of one of the sheets reduces their strengths. The cross comparison of riveted and RSW joints revealed that similar and dissimilar thickness joints in peel show almost equal strengths while as in other loading conditions (similar and dissimilar thickness) riveted joints exhibited greater static strengths. The results also suggested that performance of riveted joint increases as thickness increases.**

Keywords*— Resistance spot welded joints; Riveted joints; Mechanical behaviour; Loading conditions; Failure modes

I. INTRODUCTION

Joining of sheets of metals is very common yet an important process of manufacturing. Whenever such joints are required to be permanent and capable of carrying high loads, the engineers find choice between riveted and welded joints. Resistance spot welding (RSW) has been widely employed in sheet metal fabrication for it is easy to operate, perform automate control, and thus is an ideal joining technology for mass production. On the other hand riveting is also an efficient joining technology for it is environment friendly due to the low energy requirement, low-noise and absence of particulate and fume emissions, and it does not introduce heat into the components.

TABLE 1 Nominal chemical composition of mild steel (wt. %). [12]

Carbon	Manganese	Phosphorous	Sulphur
0.18-0.30	0.30-0.60	0.40 max	0.05 max

Both RSW and Riveting technologies for various material assemblies and their mechanical properties have been investigated and compared by many researchers and institutes. Han, Thornton and Shergold [6] gives an in depth comparison of the mechanical behavior of an aluminium alloy for each joint type of Resistance Spot welded (RSW) and self-piercing riveted (SPR) joints under different loading conditions. Pouranvari and Marashi, [7] studied behavior of resistance spot welded joint under tensile shear and coach-peel loading condition. Yuh Chao J. [8] performed strength tests to reveal the failure mechanisms of spot weld in lap-shear and cross tension test samples. Han, Chrysanthou and Young [9] studied the effect of specimen configuration on the mechanical behaviour of self-piercing riveted, multi-layer joints in aluminium alloys.

The key objective of the present study is to provide engineering solutions and a comparison between strengths of various riveted and RSW joints of mild steel. Mild Steel sheets with different thicknesses (1.5 mm and 0.8 mm) were used to fabricate the joints. Industry standard lap shear, T-peel and H-tension samples were made using the two joining processes and tested to investigate their mechanical behaviour and corresponding static strengths. The present study aims to offer design and manufacturing engineers a better insight into the two processes.

II. WORKING PROCEDURE AND EXPERIMENTATION

A. *Sample material specification*

The specimens were prepared by cutting the workpiece material (mild steel) into suitable dimensions and then cleaned and abraded to prevent high contact resistance which is created due to presence of oxide layer.

TABLE 2 Nominal mechanical properties of mild steel. [12]

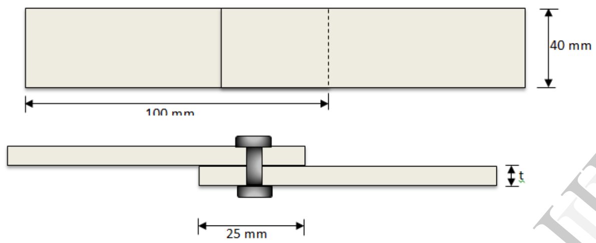
Tensile strength (MPa)	Yield strength (MPa)	Elongation %
395	295	37

TABLE 3 Properties of Mild Steel. [12]

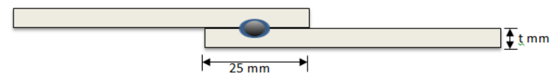
Material	Mild Steel
Major alloying element	Low carbon up to 0.3 %
Density gm/cc	7.8
Melting Point °C	1483
thermal conductivity $Jm^{-1}K^{-1}s^{-1}$	50
Thermal expansion $10^{-6}K^{-1}$	11.7
Specific heat cals/gm/°C	0.118
Resistivity (10^{-4} ohm/m)	12

B. Test Specimens

The Standard specimens of riveted and spot welded joints [6, 9, 10] in lap-shear, T-peel and U-joints, double shear, and double strap were fabricated in sheet metal shop of central workshop of NIT Srinagar as shown in Fig. 1-11.



(a)



(b)

Fig. 1 Joints in lap shear (a) riveted (b) RSW.

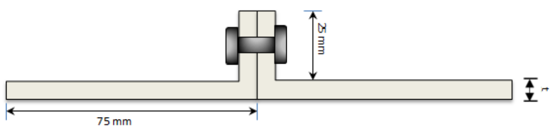


Fig. 2 Riveted Joint in peel.

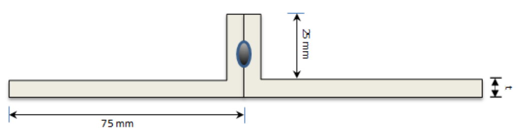


Fig. 3 RSW joint in peel with 4mm spot dia.

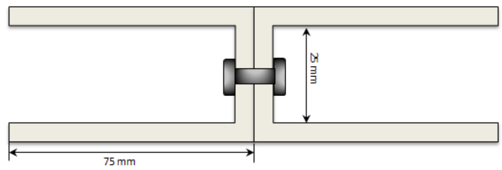


Fig. 4 Riveted joint in Tension with 4mm hole

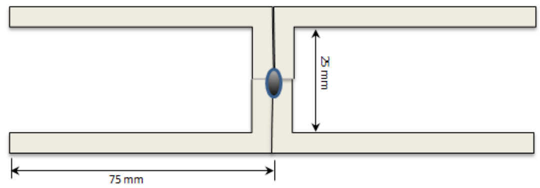


Fig. 5 RSW joint in tension

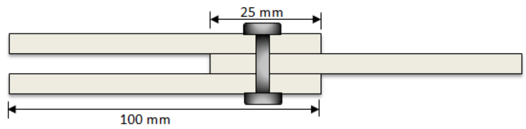


Fig. 6 Riveted joint in Double Shear

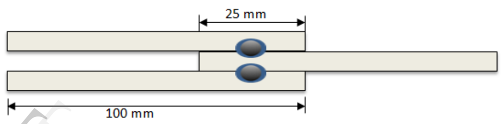


Fig. 7 RSW joint in Double Shear

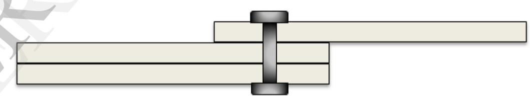


Fig. 8 Multi-layer lap shear

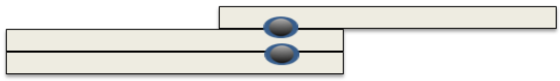


Fig. 9 Multilayer RSW lap shear

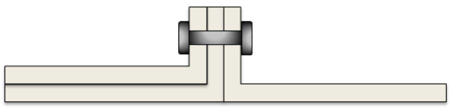


Fig. 10 Multilayer Riveted joint in peel

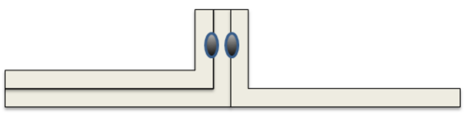


Fig. 11 Multilayer RSW joint in peel

A. Working Procedure

Mild steel sheets of thicknesses 0.8 mm and 1.5 mm were cut in standard samples in sheet metal shop on a 5.5 kW power shearing machine as shown in Fig.12.

Table 4 Experimental results of constant thickness (1.5 mm) riveted joints.

S.No.	Specimen	Elongation (mm)	Peak Load (kN)	Failure Load (kN)
1	Rive Lap	7.2	9.6	4.56
2	Riveted T-peel	26	4.4	4
3	Riveted U-tension	17	6.88	2.08

Table 5 Experimental results of constant thickness (1.5 mm) multilayer riveted joints.

S. No.	Specimen	Elong. (mm)	Peak Load (kN)	Failure Load (kN)
1	Double shear Rivet lap	20	11.92	2.56
2	Double strap Rivet lap	8	10.96	10.64
3	Double strap Rivet T-peel	9.8	3.76	2.32

Fig.12 Power sheet shearing machine, Central workshop, NIT Srinagar

The samples were divided into two major sets, one set was riveted and the other set was spot welded. Holes were drilled on the samples to accommodate the rivets. Flat head carbon steel rivets were used to fabricate the joints. Appropriate die was used to blind the rivets at the other end. Riveted joints in Lap shear, Tension, double shear, and T-peel with constant thickness and

Fig. 13 Spot Welder

variable thickness were hence fabricated for further testing. Samples for RSW joints were fabricated on a water cooled , foot operated, pneumatically controlled, spot welding machine with a 50 Hz transformer, primary voltage 415 V and a current of 18 kVA as shown in Fig.13.
The testing for the ultimate strength of the specimens were meticulously performed on a Computer interfaced servo hydraulic universal testing machine of 1000 kN shown in Fig. 14. Stress-extension graphs were generated for each specimen. Peak loads for each specimen were also recorded.

Fig. 14 Servo hydraulic universal testing machine (SANS testing machine co. Ltd.).

Table 6 Experimental results of constant thickness (1.5 mm) RSW joints.

S.No.	Specimen	Elongation (mm)	Peak Load (kN)	Failure Load (kN)
1	RSW lap	3.5	6.48	3.52
2	RSW T-peel	16.4	4.8	4.8
3	RSW U-Tension	4.75	4.64	4.64

Table 7 Experimental results of constant thickness 1.5 mm) multilayer RSW joints.

S.No.	Specimen	Elongation (mm)	Peak Load (kN)	Failure Load (kN)
1	Double shear RSW lap	2.2	9.76	8.16
2	Double strap RSW lap	1.9	5.68	4.80
3	Double strap RSW T-peel	5.3	3.76	3.76

Table 8 Experimental results of variable thickness (0.8mm +1.5 mm) riveted joints.

S.No.	Specimen	Elongation (mm)	Peak Load (kN)	Failure Load (kN)
1	Riveted Lap	14.8	4.4	0.48
2	Riveted T-peel	32	2.508	1.8
3	Riveted U-tension	12.7	5.52	3

Table 9 Experimental results of variable thickness (0.8 mm + 1.5 mm) multilayer riveted joint.

S.No.	Specimen	Elongation (mm)	Peak Load (kN)	Failure Load (kN)
1	Double shear Rivet lap	19	8.94	2.52

Table 10 Experimental results of variable thickness (0.8mm +1.5 mm) RSW joints.

S.No.	Specimen	Elongation (mm)	Peak Load (kN)	Failure Load (kN)
1	RSW lap	19	5.76	0.36
2	RSW T-peel	19.8	1.62	1.32
3	RSW U-Tension	7.9	2.88	2.04

Table 11 Experimental results of variable thickness (0.8 mm + 1.5 mm) multilayer RSW joint.

S.No.	Specimen	Elongation (mm)	Peak Load (kN)	Failure Load (kN)
1	Double shear RSW lap	3.2	9.24	6.96

C. study

A comparison of static strengths of simple riveted joints, dissimilar thickness riveted joints, simple RSW joints and dissimilar thickness RSW joints under different loading conditions have been put forward. The joints are compared for their ultimate strengths and fracture loads taken for final failure.

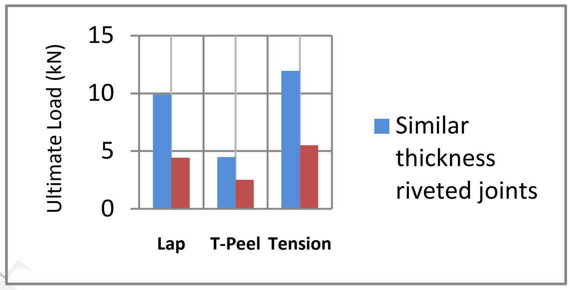


Fig. 21 Ultimate Strength comparison for similar and dissimilar thickness riveted joints.

Similar thickness and dissimilar thickness riveted joints have been compared for their ultimate strengths in Fig. 21. As is clearly indicated similar thickness riveted carry higher ultimate loads compared to corresponding dissimilar thickness joints.

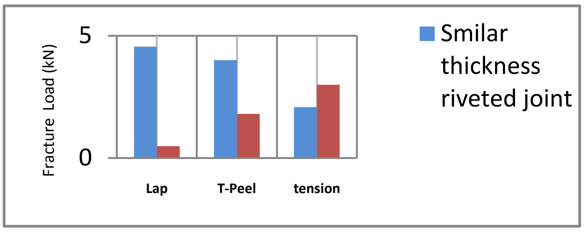


Fig. 22 Fracture Load comparison for similar and dissimilar thickness riveted joints.

Fracture load comparison of similar thickness and dissimilar thickness riveted joints in Fig 22 reveal that for joints in Lap and T-peel, the fracture of similar thickness joints take place at higher loads compared to the corresponding dissimilar thickness joints. In tension, dissimilar thickness riveted joints show higher fracture loads than similar thickness joint.

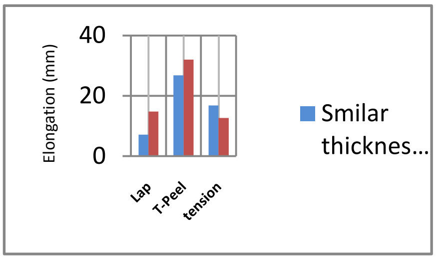


Fig. 23 comparison of elongations for similar and dissimilar thickness riveted joints.

Fig. 23 indicate the elongation/deformation of the similar and dissimilar thickness riveted joints in lap, peel and tension. Dissimilar thickness joints in lap and peel underwent more elongation compared to corresponding similar thickness joints and the vice-versa takes place in joints in tension.

D. Comparison of strengths of similar and dissimilar thickness RSW joints

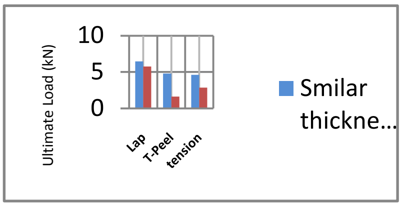


Fig. 24 comparison of ultimate loads for similar and dissimilar thickness RSW joints.

Fig. 24 compared the ultimate loads taken by similar and dissimilar thickness RSW joints. Similar thickness joints in all the cases i.e. lap, peel and tension, took higher ultimate loads than corresponding dissimilar thickness joints.

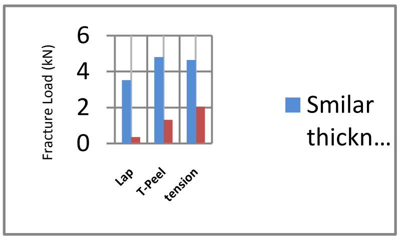


Fig. 25 comparison of Fracture loads for similar and dissimilar thickness RSW joints.

As shown in Fig. 25, Fracture load comparison of similar thickness and dissimilar thickness RSW joints reveal that for joints in Lap and T-peel and Tension, the fracture of similar thickness joints takes place at higher loads compared to the corresponding dissimilar thickness joints.

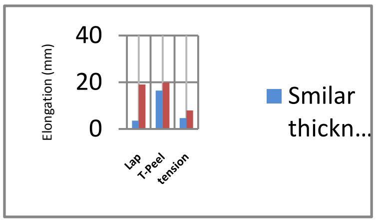


Fig. 26 comparison of Elongation for similar and dissimilar thickness RSW joints.

Fig. 26 indicate the elongation/deformation of the similar and dissimilar thickness RSW joints in lap, peel and tension. Dissimilar thickness joints in lap and peel and tension underwent more elongation compared to corresponding similar thickness joints and the joint failed due to tearing of the thin sheet.

E. Comparison of strengths, simple and multilayer Riveted joints in lap and peel

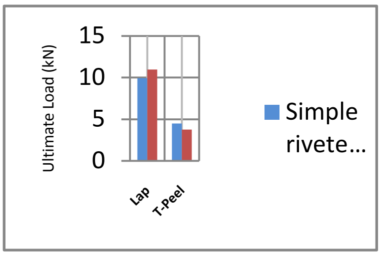


Fig. 27 Comparison of ultimate loads for simple and multilayer riveted joints.

In Fig. 27 ultimate loads of simple and multilayer riveted joints have been compared for lap and peel loading conditions. For lap shear multilayer riveted joint shows higher ultimate strength that simple riveted joints while as for multilayer joint in peel the ultimate load is higher compared to corresponding simple riveted joints.

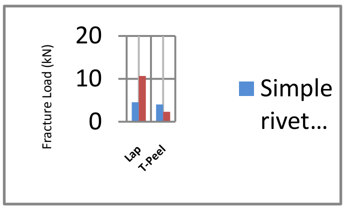


Fig. 28 Comparison of Fracture loads for simple and multilayer riveted joints.

Fig. 28 shows the column chart comparison of fracture loads of simple and multilayer riveted joints in lap and peel. Lap joint in case of multilayer joints fails at higher fracture loads while as joint in peel in case of simple riveted joint fails at higher fracture loads.

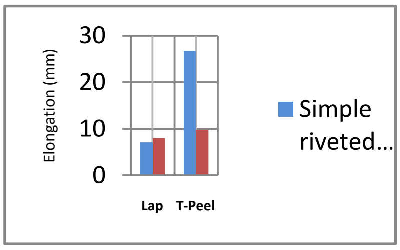


Fig. 29 Comparison of Elongations for simple and multilayer riveted joints.

Fig. 29 shows the elongation of simple and multilayer joints in lap and peel. Multilayer riveted joint in lap shows a higher elongation for final failure while as simple riveted joint in peel shows a higher elongation.

F. Comparison of strengths of simple and multilayer RSW joints in lap and peel

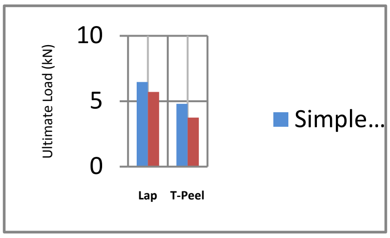


Fig. 30 comparison of ultimate loads for simple and multilayer RSW joints.

Fig. 30 shows the ultimate loads for simple and multilayer RSW joints in lap and peel. Simple joints show higher ultimate loads than corresponding multilayer joints.

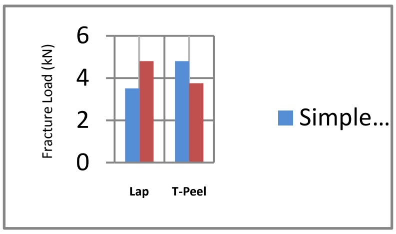


Fig. 31 comparison of fracture loads for simple and multilayer RSW joints.

Fig. 31 show the fracture load comparison of simple and multilayer RSW joints in lap and peel. For shear, multilayer joint fails at higher loads than corresponding simple joint while as for peel, simple joint fails at higher load than corresponding multilayer joint.

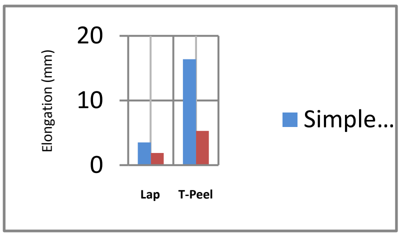


Fig. 32 comparison of elongations for simple and multilayer RSW joints.

Fig. 32 shows the elongation of simple and multilayer RSW joints. For a final failure, the simple joint in lap shear and peel show higher deformation than corresponding multilayer joints.

G. Comparison of mechanical behaviour of similar thickness riveted and RSW joints

Various riveted and RSW joints have been studied and compared with respect to their mechanical behaviour. Fig. 33 shows the comparison of strengths of riveted lap and RSW lap joint. Riveted lap joint carry higher ultimate load, higher fracture load and undergoes greater deformation than RSW joint in lap shear. Moreover riveted lap joint exhibit higher energy absorption which is indicated by the area under the Load-Elongation curve.

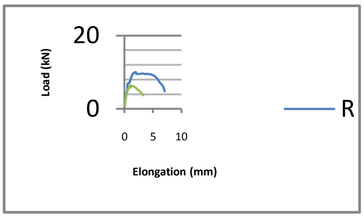


Fig. 33 Comparison of mechanical behaviour of riveted and RSW lap joint.

Fig. 34 shows the Load-Elongation curve for riveted and RSW joint in peel. The RSW joint shows higher peak loads, higher fracture load and lesser elongation/deformation than the riveted joint in peel. Although riveted joint shows higher energy absorption.

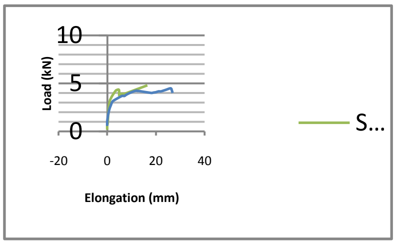


Fig. 34 Comparison of mechanical behaviour of riveted and RSW joints in peel.

The Fig. 35 shows how the applied static load varies with elongation of the specimen under tensile loading condition. Riveted joint under such loading condition exhibit higher ultimate load with the specimen failing at lesser fracture load compared to the RSW joint in tension. Moreover riveted joint takes on a greater deformation till final failure than the RSW joint.

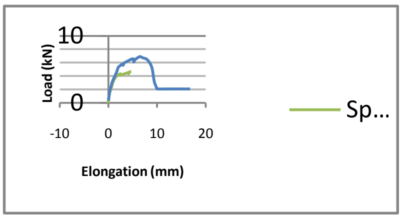


Fig. 35 Comparison of mechanical behaviour of riveted and RSW joints in tension.

The Fig. 36 shows how the applied static load varies with elongation of the specimen under double shear loading condition. Riveted joint under such loading condition exhibit higher ultimate load with the specimen failing at lesser fracture load compared to the RSW joint. Moreover riveted joint takes on a greater deformation till final failure than the RSW joint.

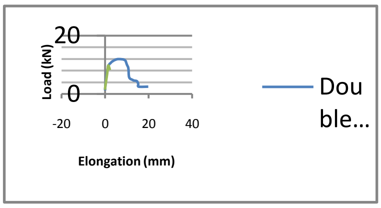


Fig. 36 Comparison of mechanical behaviour of double shear riveted and RSW joints.

II. CONCLUSION AND FUTURE SCOPE

A.Conclusion

Samples of riveted and resistance spot welded joints (similar, dissimilar and multilayer) for different specimen configurations (lap, peel, tension and double shear) have been fabricated. Mechanical static strengths for such joints have been compared by testing the samples on a servo hydraulic UTM. Following conclusions have been drawn from the results obtained :

1. Similar thickness riveted joints carry higher ultimate loads and fracture loads compared to the dissimilar thickness joints although dissimilar thickness joints undergo more deformations.
2. Similar thickness riveted joint in peel has shown prominent mechanical strength compared to other specimen configurations.
3. Although similar thickness RSW lap joint carries the highest ultimate loads, similar thickness peel joint fails at a higher load than the lap joint and undergoes maximum deformation thus absorbing maximum energy.
4. The results of similar and dissimilar RSW joints reveal that the latter exhibit lesser strengths. Thus reducing the thickness of one or more of the sheets leads to lesser joint strengths.
5. Among simple and multilayer riveted joints, multilayer joint in lap shows an effective strength compared to others.
6. In RSW simple and multilayer joints, simple joint in peel shows higher energy absorption and exhibits a greater strength than others.
7. Among similar thickness, simple riveted and RSW joints, the riveted lap joint shows a comprehensive ultimate load carrying capacity with a lower elongation till final failure. On the other hand, RSW joint in peel shows an appreciable ultimate load carrying capacity and a prominent deformation thus absorbing a good amount of energy till final failure.
8. Among similar thickness multilayer joints, riveted joint in double shear witnessed the highest load carrying capacity and a prominent deformation till final failure. While as RSW Peel joint and riveted peel joint show almost equal ultimate loads.
9. Among dissimilar thickness Riveted and RSW joints, RSW joint in lap shows the highest ultimate load and a prominent deformation. In double shear, both RSW and riveted joint exhibit same ultimate loads although riveted joint shows a greater deformation.
10. In similar thickness joints, failure occurred mostly by shearing of rivet and nugget interfacial failure. Sheet crushing and shearing were also noticed although there was no trace of sheet tearing witnessed during the testing.
11. In dissimilar thickness joints, failure mostly occurred by plate shearing and nugget pullout.

B. Future Scope

The present investigation has been made by taking different loading conditions and specimen configurations to put forward a comparison for better joint strengths. The work could be extended to Finite Element solutions of the specimen configurations under various loading conditions and comparing the results with the experimental one. There is also a scope to use an adhesive in addition to riveting or spot welding and see the effect and compare the results. The present work considered mild steel sheets for experimentation. Similar work could be done on different materials or dissimilar materials under different specimen configurations.

III. ACKNOWLEDGMENTS

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