Experimental Analysis of Self Piercing Riveted Joint for Cold Rolled Steel and Aluminium Sheets

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***Abstract*— In India the self-piercing riveting process has not been used in the most of automobile industries. Most of vehicle manufacturers are using spot welding for joining vehicle body sheets but there are problems with spot welding such as difficulty in joining aluminium sheets, emission of heat, fumes, scatter, and change in mechanical properties of sheet metals. Also there is problem with conventional riveting as this requires preparation of hole. Hence it is required to find new technique that will join the aluminium sheets to be used for automobile body for weight reduction and avoid above said problems related with conventional riveting and resistance spot welding. Self-piercing riveting process is new technique in which a cold forming operation is used to fasten two or more sheet materials. In this paper experimental analysis of self piercing riveted joint of mild steel and aluminium sheets has been presented. The cold rolled steel and aluminium sheets have been used for project because these are being utilized mostly in automobile industries. The different samples of cold rolled steel and aluminium sheets were made by self piercing riveting technique using rivet gun. These have been made by varying sheet thickness, rivet material, rivet diameter, and type of joint. The samples of spot welding were also made. All samples have been tested on tensile tester machine to find joint strength. The result has been shown in form of load verses displacement graph. The photographs of failed samples have been shown. Finally comparison of self piercing rivet joints and spot welded joints has been made in terms of joint strength. The joint strength of self piercing riveted lap joint is nearly equal to that of resistance spot welded joint. Also joint strength of self piercing riveted peel joint is more than that of resistance spot welded peel joint.**

***Keywords*—Joint strength, Resistance spot welding, Self piercing riveted joint, Tensile testing machine**

I. INTRODUCTION

Self piercing riveting is a technique which is used to for joining of two or more sheet metals and does not require preparatory hole. In this process a semi tubular rivet is pressed by a punch into two or more sheets that are supported on the die. The die shape causes the rivet to deform inside the bottom sheet to form a mechanical joint as shown in figure 1. It can be used for a wide range of advanced materials that are dissimilar and hard to weld.

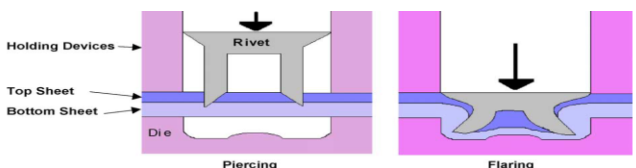

Fig. 1. An illustration of self piercing riveting process [1]

The spot welding is being used to join steel sheets such as high strength steel for automobile body panels because of high production. The welding of aluminium alloy sheets is not simple unlike steel sheets due to low melting range, high thermal conductivity, and surface oxide layer. It is difficult to weld aluminium alloy and steel sheets together because two melting points are different. It is desirable in industry to search new joining technologies of aluminium alloy and steel sheets. The application of high strength steel to automobile parts rapidly increases. High strength steel sheets have a wide range of strength from 340 MPa close to mild steel sheets to 1500 MPa for very high strength steel sheets. Since the strength of high strength steel sheets is much higher than that of aluminium alloy sheet the piercing of sheets with a rivet becomes difficult. The aluminium alloy sheet of tensile strength 133 MPa is used as material of automobile body panel. The high strength steel sheets below 600 MPa are employed as materials of automobile body panels.

II. LITRATURE REVIEW

Franco G. *et.al.* considered the possibility to join aluminium alloys blanks and carbon fibre composites panels by SPR process. Few case studies were carried out at the varying of the process parameters. The effectiveness of the obtained joints was tested through tensile tests and through fatigue ones. The failure mechanics of the obtained joints were also

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considered in order to highlight the mechanisms which occur and determine the lost of the load carrying capability of the joints. Finally a numerical model of the process was carried out and the residual stress state after piercing was highlighted. The developed experiments and simulations demonstrated that self-piercing riveting can be effectively used to join carbon fiber composite panels and aluminum blanks. They studied that in self pierce riveting, a very important process parameter is the oil pressure of the riveting system that must be carefully chosen in order to get effective mechanical performances of the obtained joints.

Y. Abe et al. have found out the joinability of aluminium alloy and mild steel sheets using a self piercing rivet by a finite element simulation and experiment. The self piercing riveting can be a replacement for spot resistance welding generally used for steel sheets, because it is not simple to apply resistance welding to joining of aluminium and mild steel sheets which have very different melting points. Defects in the riveting were classified into the penetration through the lower sheet, the necking of the lower sheet and the separation of sheets to get optimum joining conditions. The penetration, necking and separation had been caused by the small total thickness, small thickness of lower sheet, and the large total thickness respectively. The joinability for the combination of the upper sheet of steel and the lower sheet of aluminium is greater than that of the reverse combination.

R. Porcaro et.al. had investigated a self-piercing riveted connection experimentally and numerically. An extensive experimental programme was conducted on elementary riveted joints in aluminium alloy AA6060 in two different tempers, T4 and T6. The experimental programme was focused on the influence of important model parameters such as thickness of the plates, geometry of the specimens, material properties of the plates and loading conditions. An accurate 3D numerical model of different types of riveted connections subjected to various loading conditions was generated based on the results of the numerical simulation of the riveting process. A new algorithm was generated in order to transfer all the information from the 2D numerical model of the riveting process to the 3D numerical model of the connection. Thus, the 3D model was initialized with the proper deformed shape and the current post-riveting stress–strain state. The residual stresses and the local changes in material properties due to the riveting process were an important factor in order to get the correct structural behaviour of the model. The simulations have been carried out using the explicit finite element code LS-DYNA. The model was validated against the experimental results in order to get the correct deformation modes and the force–displacement characteristics. The numerical force–displacement curves fitted the experimental ones with reasonable accuracy. Furthermore, the model seemed to be able to describe the correct structural behaviour and thus the failure mechanisms of the self-piercing riveted connections.

III. OBJECTIVES

1. To find the static strength of automobile body panels such as cold rolled steel and aluminium sheets joined by self piercing rivet technique.
2. To test and compare between lap and peel joint in terms of static strength.
3. To investigate effect of sheet thickness on strength.
4. To find joint strength when there is change in rivet material
5. To compare the spot welded and self piercing riveted joint.

IV. METHODOLOGY

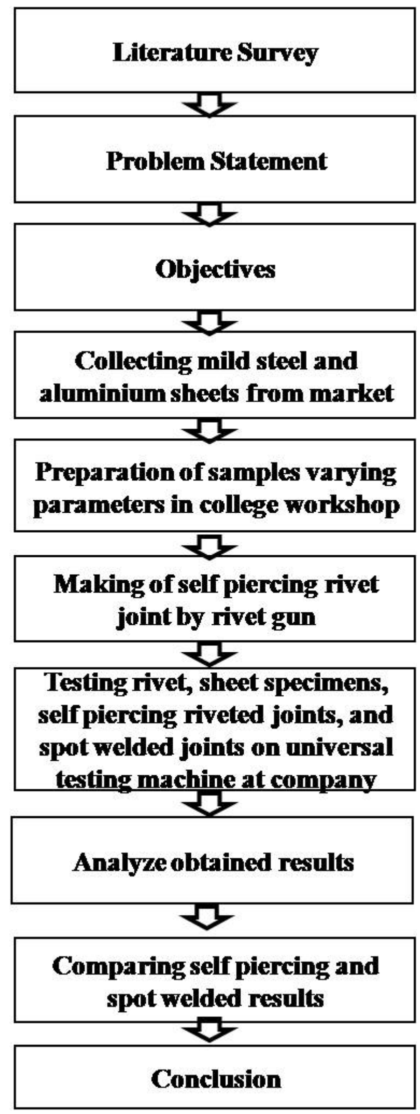


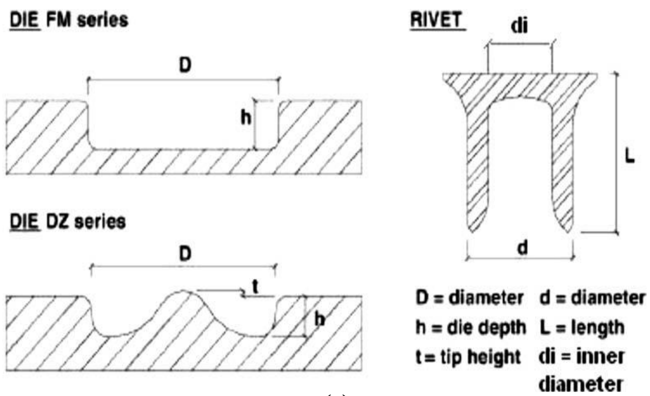
Fig. 2. Methodology Implemented

V. EXPERIMENTATION

Different parts have been used to make the joints. Different rivets of varying diameter and materials, different sheets materials of different thicknesses, type of joint have been used for making different types of joint. Sheet samples joined by spot welding have also been prepared. Universal testing machine has been used for measuring joint strength for all samples. The following sections describe the parts, devices and machines used for preparation of specimens

A. Rivet Material

It is a cylindrical hollow part with a head on its top. Standard rivets such as steel and aluminium of size 5x6 were used (5 mm tube part diameter and 6 mm total height) as shown in figure 3. They are based on Bollhoff standards. The chemical composition and hardness of both rivets had been tested at Shanmukh laboratories, Ambad, Nashik. The hardness of steel and aluminium rivets is 107 HV 10 and 47 HV10 respectively. The following tables I and II show the chemical composition of used rivets.



(a)

(b)

(c)

Fig. 3. (a) Rivet & die geometries (b) Steel rivet (c) Aluminium rivet

TABLE I
CHEMICAL COMPOSITION OF STEEL RIVET

Rivet material	Composition				
	C%	Si%	Mn%	P%	S%
steel	0.110	0.075	0.475	0.026	0.044

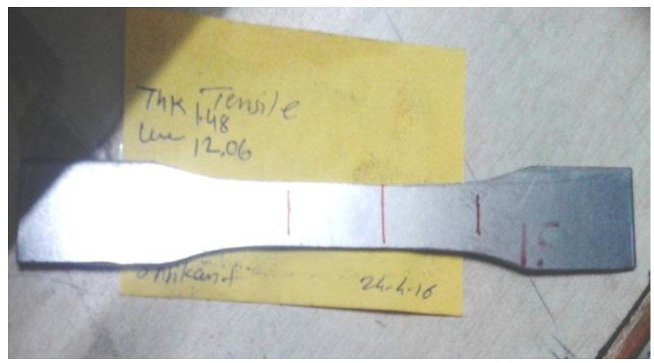
TABLE II
CHEMICAL COMPOSITION OF ALUMINIUM RIVET

Rivet material	Composition					
Al	Si%	Fe%	Cu%	Mn%	Mg%	Zn%
	0.086	0.091	<0.001	<0.002	<0.001	<0.002
	Ni%	Pb%	Ti%	Cr%	Al%	
	0.002	0.014	<0.001	<0.002	99.80	

B. Sheet Materials

Two sheet materials of thickness 0.8 mm and 1.5 mm each such as aluminium and cold rolled steel sheets were used. These sheets are being utilized in automobile industries. The tensile testing of both sheets has been done to check the mechanical properties of materials at Shanmukh laboratories, Ambad, Nashik. The samples were made properly as shown in figure 4.

(a)



(b)

Fig. 4. Sheet specimens (a) aluminium sheet (b) cold rolled steel sheet

The force verses displacement graphs and mechanical properties have been shown for both samples as shown in figures 5 & 6 and tables III & IV.

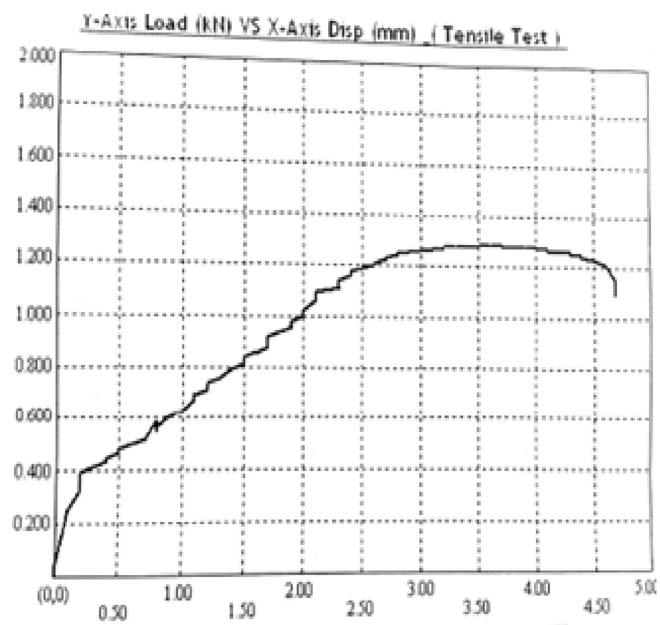


Fig. 5. Load vs. Displacement graph of aluminium

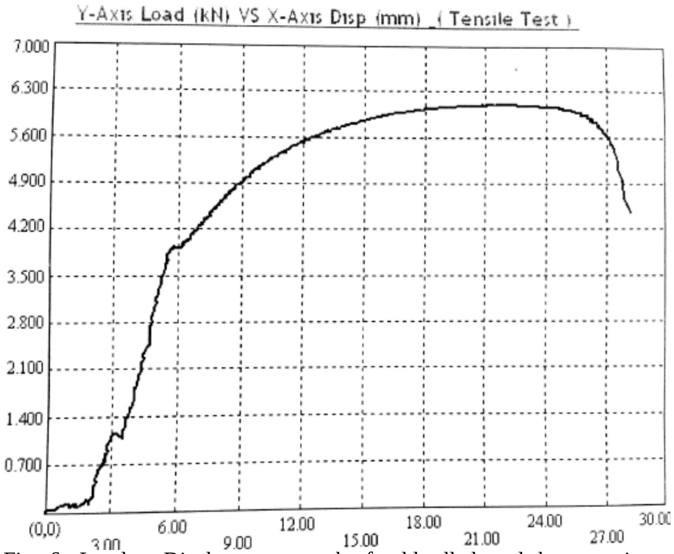


Fig. 6. Load vs. Displacement graph of cold rolled steel sheet specimen

TABLE III
MECHANICAL PROPERTIES OF COLD ROLLED STEEL SHEET SPECIMEN

Specimen	Ultimate load (KN)	Uitimate tensile strength (KN/mm^2)	Breaking load (KN)	% elongation at breaking load	Yield load (KN)	Yield Stress ($KN/m m^2$)
CRS	6.090	0.341	5.035	34.42	3.92	0.220

TABLE IV
MECHANICAL PROPERTIES OF ALUMINIUM SHEET

Specimen	Ultimate load (KN)	Uitimate tensile strength (KN/mm^2)	Breaking load (KN)	% elongation at breaking load	Yield load (KN)	Yield Stress ($KN/m m^2$)
Al sheet	1.285	0.133	1.23	5.96	1.19	0.123

C. Plan of Experiment

The table V shows the plan of experiment implemented for actual test. First 12 samples have been made by self piercing technique and sample number 13 and 14 have been made by spot welding.

TABLE V
PLAN OF EXPERIMENT

Sample No.	Rivet material	Rivet size	Top and bottom sheet material	Sheet thickness	Type of joint
1	Steel	5x6	Al	0.8	lap
2	Steel	5x6	Al	0.8	peel
3	Al	5x6	Al	0.8	lap
4	Al	5x6	Al	0.8	peel
5	Steel	5x6	Al	1.5	lap
6	Steel	5x6	Al	1.5	peel
7	Al	5x6	Al	1.5	lap
8	Al	5x6	Al	1.5	peel
9	Steel	5x6	CRS	0.8	lap
10	Steel	5x6	CRS	0.8	peel
11	Steel	5x6	CRS	1.5	lap
12	Steel	5x6	CRS	1.5	peel
13	Spot welding	5 mm nugget diameter	CRS	0.8	lap
14	Spot welding	5 mm nugget diameter	CRS	0.8	peel

D. Sample Preparation

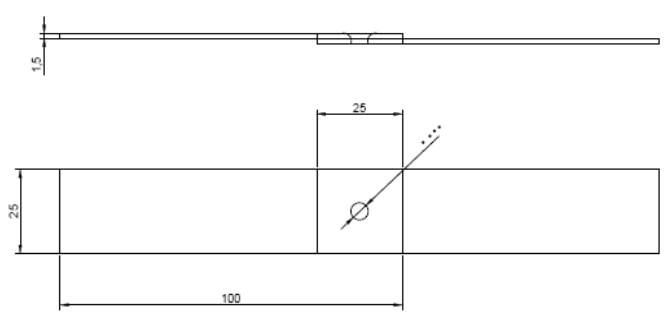
Lap and peel types of self pierced joints were made with the help of riveting gun. The geometries and actual joint of lap and peel specimens are shown in figures 7 and 8. Each sample is of 100 x 25 sizes for aluminium and cold rolled sheets for each of 0.8 mm and 1.5 mm thickness. About 14 samples were made by varying different parameters such as thickness, sheet material, rivet material, rivet diameter, type of joint

E. Testing Machine & Its Specifications

A test was performed by fixing test material into tensile testing machine as shown in figure 9.This tensile testing machine was available at Shanmukh Laboratories, Ambad Nashik. This is machine fully automatic, menu driven software, automatic data capture, and storage and graphic display capacity. The following table VI shows the specification of machine. This machine is generally used to conduct the tensile testing of material. In this machine load indicator is available for indicating a load. The jaws are used to fix ends of the specimen. One jaw is fixed and another is movable.

TABLE VI
SPECIFICATIONS OF TESTING MACHINE

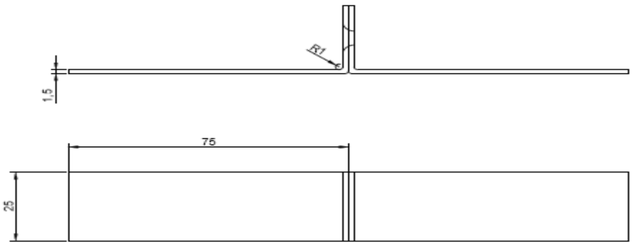
SN	Specifications	Details
1	Load measurement	By Load cell
2	Standard load resolution	20000 counts
3	Finer resolution	10000 counts
4	Standard displacement resolution	0.1 mm
5	Maxmum capacity	200 N to 25 KN
6	Load accuracy	within 1 %
7	Speed variation	upto 25 mm/ min
8	Elongation range with least count	1 mm



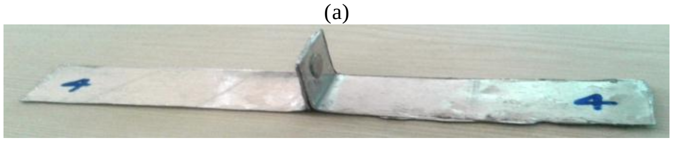
(a)

(b)

Fig. 7. Lap Joint (a) geometry (b) actual joint



(a)



(b)

Fig. 8. Peel joint (a) geometry (b) actual joint

In this experiment test setup two types of joints are used i) lap shear joint ii)T peel joint For test set-up 100 length and 25 width size sheets of aluminium and cold rolled steel materials were used.

The thicknesses of sheet materials were 0.8 mm and 1.5 mm. The diameters of the rivet were. 14 samples of self piercing rivet joints and two spot welded joints were tested one by one. Load verses displacement graphs were plotted for testing materials. By using this machine we can find out the tensile strength of material.

(a)

(b)

(c)

Fig. 9. Test set-up (a) Universal testing machine (b) lap joint attached to jaws (c) peel joint attached to jaws

VI. RESULTS AND DISCUSSION

A. Mode of Failure

Experimental work had been done for about sixteen samples. The photographs of some of the samples have been shown in figure 10 to see the actual failure of specimens.

(a)

(b)

(c)

(d)

(g)

(h)

Fig. 10. Mode of failure (a) samlpe 1 lap joint (b) sample 2 peel joint (c) sample 3 lap joint (d) sample 4 peel joint (g) sample 11 lap joint (h) sample 12 peel joint

After testing samples were examined to see mode of failure There were rivet pull out for most of peel types of samples.

B. Joint Strength

After testing the joint strengths have been found out in the form of load verses displacement graphs as shown in figures from number 11 to 22. The figures from 23 to 24 show joint strength for self piercing rivet joint and resistance spot welded joint for comparision purpose.

TABLE VII
JOINT STRENGTH

Sample No.	Rivet material	Rivet size	Top and bottom sheet material	Sheet thickness	Type of joint	Joint Strength (KN)
1	Steel	5x6	Al	0.8	lap	1.74
2	Steel	5x6	Al	0.8	peel	0.665
3	Al	5x6	Al	0.8	lap	0.975
4	Al	5x6	Al	0.8	peel	0.220
5	Steel	5x6	Al	1.5	lap	2.680
6	Steel	5x6	Al	1.5	peel	0.935
7	Al	5x6	Al	1.5	lap	2.203
8	Al	5x6	Al	1.5	peel	0.138
9	Steel	5x6	CRS	0.8	lap	3.583
10	Steel	5x6	CRS	0.8	peel	1.303
11	Steel	5x6	CRS	1.5	lap	6.123
12	Steel	5x6	CRS	1.5	peel	1.57

C. Comparison between Lap and Peel Types of Joint

Keeping the sample material, thickness, rivet same the sample 1 and 2 and sample 9 and 10 have been compared. Figure 11 and 12 show the lap and peel joints graphs respectively for aluminium sheets. Here the static strength of lap joint is 1.74 KN and that of peel joint is 0.665 KN.

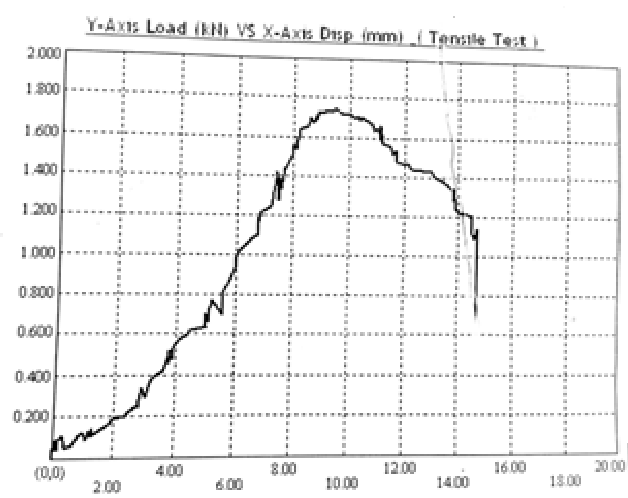


Fig. 11. Load vs. Displacement graph of sample 1

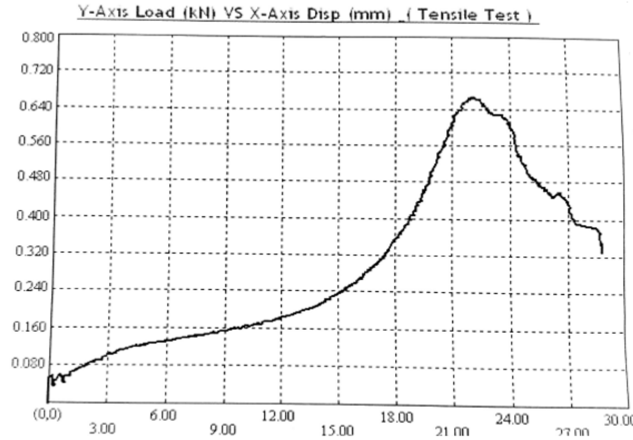


Fig. 12. Load vs. Displacement graph for sample 2

Figure 13 and 14 show lap and peel joint load verses displacement graphs for cold rolled steel sheets. The static strength of lap joint is 3.583 KN and that of peel joint is 1.303 KN.

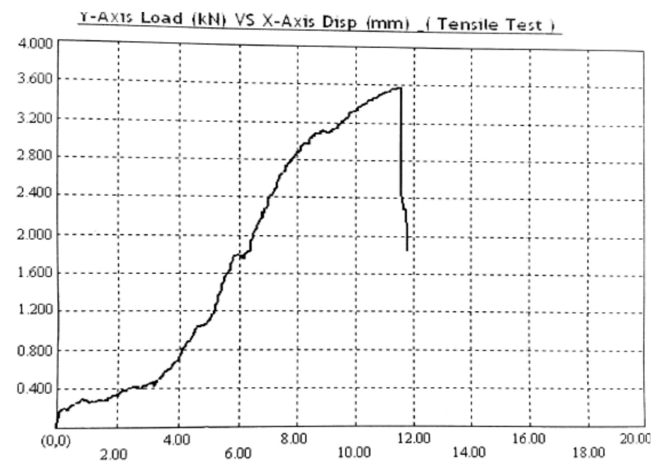


Fig. 13. Load vs. Displacement graph for sample 9

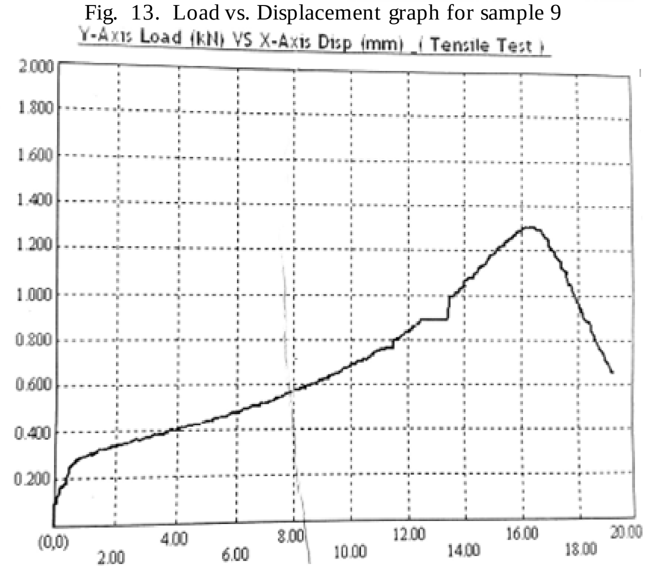


Fig. 14. Load vs. Displacement graph for sample 10

From the value of joint strength for lap and peel samples we can see that joint strength for lap joint is always greater than peel joint irrespective of sheet material, sheet thickness, and rivet diameter.

D. *Effect of Material Thickness on Static Strength*

Figure 15 and 17 show the load verses displacement graphs for aluminium and cold rolled steel sheets of thickness 0.8 mm each. Figure 16 and 18 show the load verses displacement graphs for aluminium and cold rolled steel sheets of thickness 1.5 mm each. The joint strength of 0.8 mm aluminium sheets is 0.975 KN and that of 1.5 mm thickness is 2.680 KN as shown in figure 15 and 16.

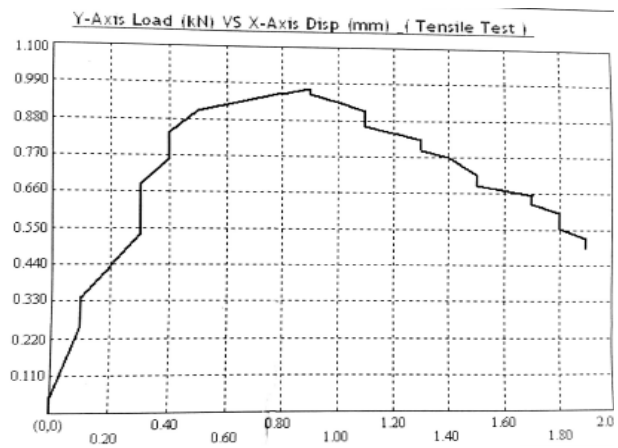


Fig. 15. Load vs. Displacement graph for sample 3

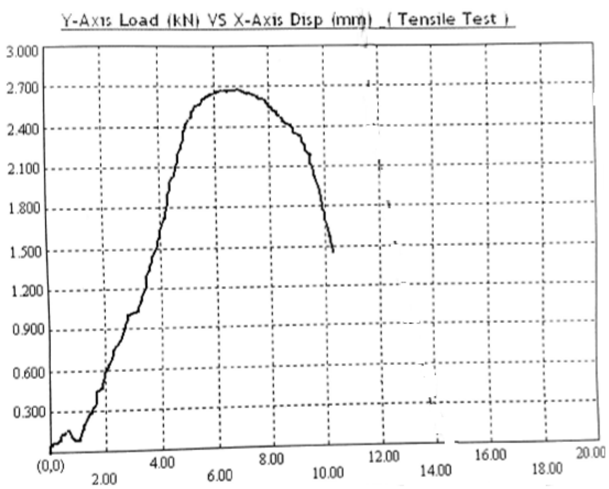


Fig. 16. Load vs. Displacement graph for sample 5

The peel joint strength of 0.8 mm aluminium sheets is 0.220 KN and that of 1.5 mm thickness is 0.935 KN as shown in figure 17 and 18.

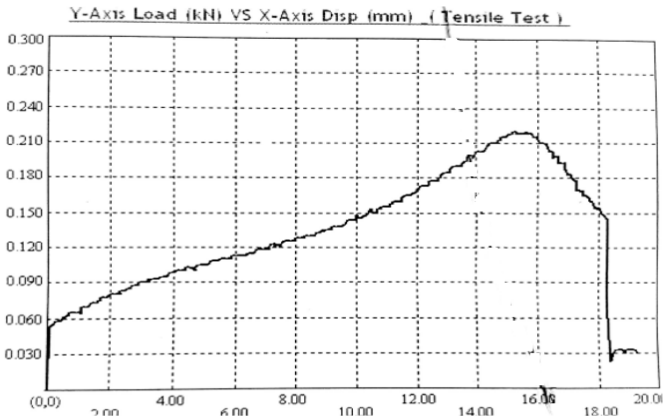


Fig. 17. Load vs. Displacement graph for sample 4

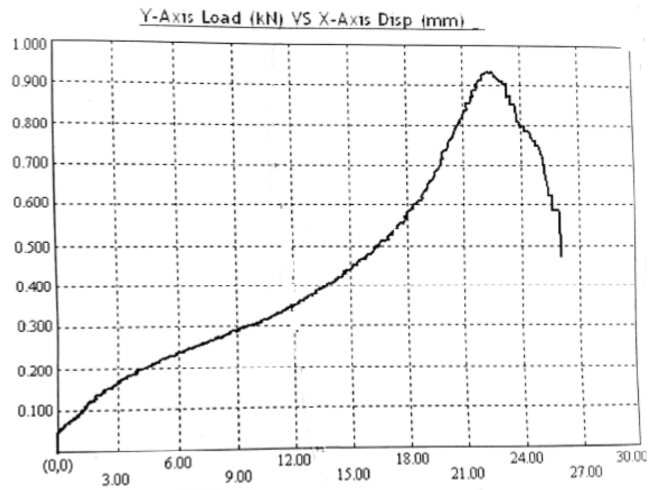


Fig. 18. Load vs. Displacement graph for sample 6

When the material thickness increases then static strength also increases.

E. *Effect of Rivet Material on Static Strength*

Figure 19 and 20 show graphs for self piercing rivet joint made by steel and aluminium rivet materials respectively for lap joint. Joint strength of sample 5 is 2.68 KN and that of sample 7 is 2.203 KN.

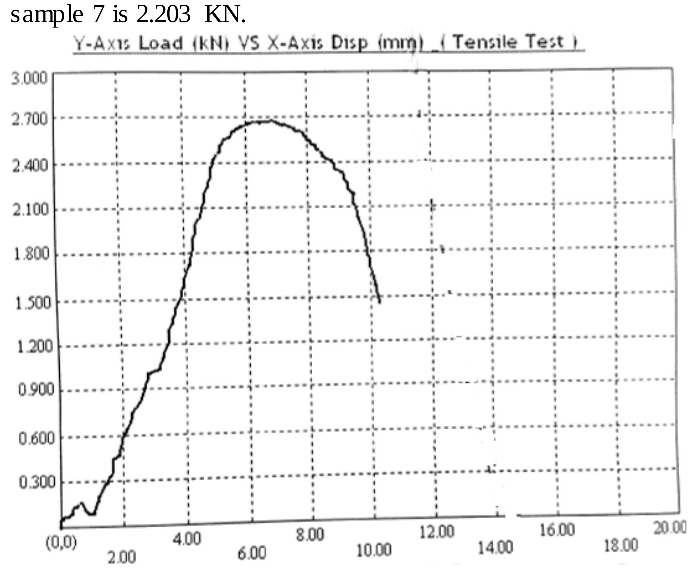


Fig. 19. Load vs. Displacement graph for sample 5

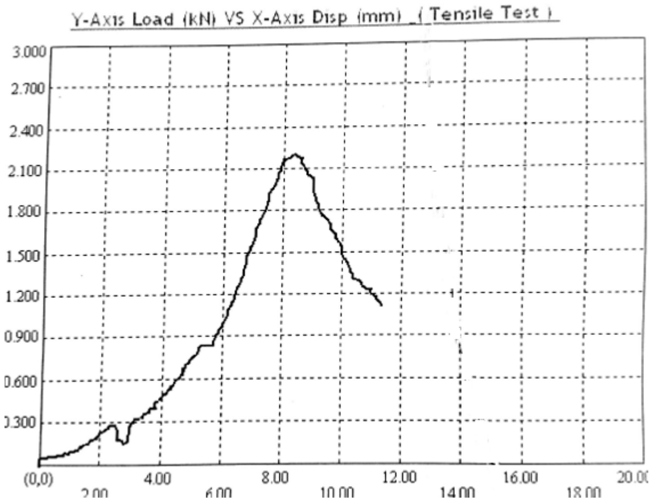


Fig. 20. Load vs. Displacement graph for sample 7

Figure 21 and 22 show graphs for self piercing rivet joint made by steel and aluminium rivet materials respectively for peel joint. Joint strength of sample 6 is 0.935 KN and that of sample 7 is 0.138 KN.

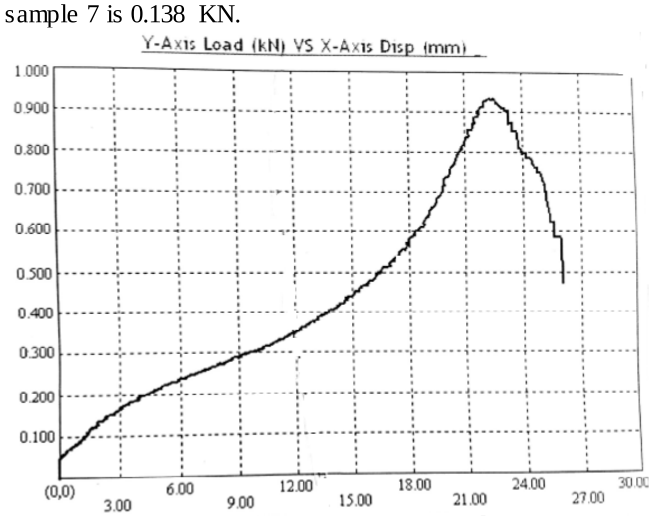


Fig. 21. Load vs. Displacement graph for sample 6

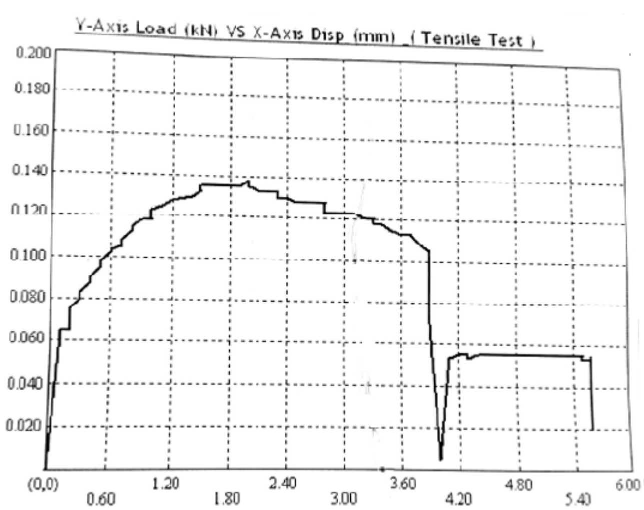


Fig. 22. Load vs. Displacement graph for sample 8

Joint strength is larger in case we use steel rivet than aluminium rivet for joint formation.

VII. Comparison of Spot and Self Piercing Rivet Joint

The spot welded samples were prepared with nugget diameter 5 mm. The samples 15 and 16 of weld joints were made of keeping all the parameters same as self piercing rivet joint samples 11 and 12.This is shown in table VIII. It is clear from table VIII that strength of self piercing rivet joint is comparable with resistance spot welded joint. The self piercing lap rivet joint has joint strength i.e. 3.583 KN near to resistance spot welded lap joint i.e. 4.033 KN as shown in figure 23. Peel self piercing rivet joint (1.33 KN) has more strength than spot welded peel joint (0.820 KN) as shown figure 24.

TABLE VIII
COMPARISON OF SPOT AND SELF PIERCING RIVET JOINT

Sample No.	Rivet material	Rivet size	Top and bottom sheet material	Sheet thickness	Type of joint	Joint Strength (KN)
11	Steel	5x6	cold rolled steel	0.8	lap	3.583
15	Spot weld	5 mm nugget diameter	cold rolled steel	0.8	lap	4.033
12	Steel	5x6	cold rolled steel	0.8	peel	1.33
16	Spot weld	5 mm nugget diameter	cold rolled steel	0.8	peel	0.820

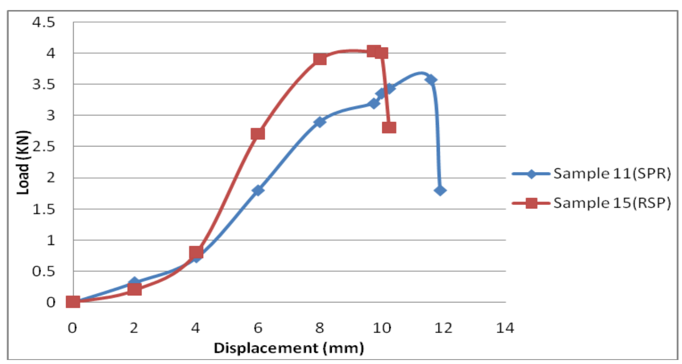


Fig. 23. Comparison of self piercing riveted and resistance spot welded lap joints

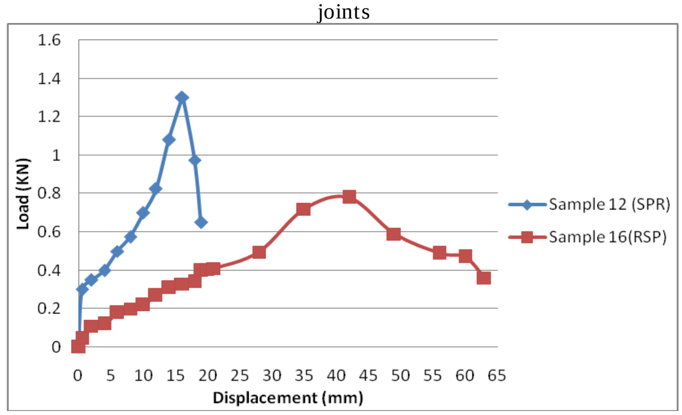


Fig. 24. Comparison of self piercing riveted and resistance spot welded peel joints

VIII. CONCLUSIONS

From the value of joint strength for lap and peel samples we can see that joint strength for lap joint is always greater than peel joint irrespective of sheet material, sheet thickness, rivet diameter. Joint strength is larger in case we use steel rivet than aluminium rivet for joint formation. When rivet diameter is increased then joint strength increases. If material thickness increases then strength also increases for lap and peel joint. Cold rolled sheet riveted joint has high strength than aluminium sheet riveted joint. Finally comparison of self piercing rivet joints and spot welded joints has been made in terms of joint strength. The joint strength of self piercing riveted lap joint is nearly equal to that of resistance spot welded joint. Also joint strength of self piercing riveted peel joint is more than that of resistance spot welded peel joint. Thus the self piercing riveting process is new technology and it does not require formation of pre hole for making the joint. It eliminates the disadvantages of spot welding. Joining aluminium alloy is very difficult by spot welding but same can be joined very easily by self piercing technique. Hence self piercing rivet process can be alternative option to spot welding and conventional riveting.

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