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

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Abstract—Recently increased search of materials alternative to very difficult to join with traditional techniques that is for steel is investigated in this paper. Owing to favourable weight to strength ratio polymer materials are vital in use. Most common method for connections of sheets is resistance spot welding. Production process is optimized by adhesive or rivet joints this is proven through review of literature. It is essential to ensure cost and time saving for car development to reduce experimental work using precise simulation.

There are problems in joining Aluminium to dissimilar materials. A critical problem with Aluminium assembly is that joining Aluminium requires different set of technologies and procedures from steel. Because of Aluminium properties, welding is more difficult. Also Aluminium and other lightweight material require smart techniques to join dissimilar material, which add complexity and cost.

In this paper investigation of riveted joints is model using Autodesk Inventor and model is studied by using FEA software and result is validated with experimental data and comparative study is done in between simple rivetted joint and self piercing riveted joint.

Keywords: Self Piercing Riveted Joint, Finite Element Analysis, Riveted Joints, Aluminium

I. INTRODUCTION

Self Piercing (SPR) is a technique which is use for joining of two sheet metals and it does not required preparatory hole.

Today, different technologies are available in the market to construct automobiles. Every automobile industry has challenge to reduce the weight of the vehicle for reducing fuel consumption. The characteristic properties of Aluminium, high strength stiffness to weight ratio, good formability, good corrosion resistance and recycling potential make it the ideal candidate to replace heavier material in the vehicle to respond to the weight reduction demand within the automotive industry. Aluminium usage in automotive application has grown more than 80% in the past years. Some of the major components that could see significant growth in the use of aluminium and contribute greatly to lowering the weight of vehicle are engine block, closure panels, and chassis components years [1]. The SPR process is a cold forming operation used to fasten two or more sheets of material. In this process, a semi-tubular rivet is pressed by a punch into two or more substrates of materials that are supported on a die. The die shape causes the rivet to flare inside the bottom sheet to form a mechanical interlock as shown in Fig. 1. It can be used for a wide range of advanced materials that are dissimilar, coated and hard to weld.

Step by step process of Self Piercing Riveting Joint.

1. The sheets are positioned to be joined together.
2. The punch pushes the rivet, which cuts through the upper-plate.
3. Rivet spreads in the bottom-plate.
4. Tool open plates and end joint.

1. Clamping: The substrates are clamped with a pre-clamping pressure (PCP) between a rivet setter (blank holder) and a shaped die. The pre-clamping pressure was set at 60 bar for the specimens used.
2. Piercing: A rivet gun is used to push the rivet into the top substrate. The rivet shank acts as a shearing punch as it cuts through the top substrate and also partially cuts through the lower substrate until the die reaction is encountered. The rivet setting pressure (RSP) depends on the rivet diameter.
3. Flaring: With the material of the lower substrate flowing into the die, the rivet shank begins to flare outward, forming a mechanical interlock between the upper and lower substrates. Since the rivet does not pierce through the bottom substrate, the sheared slug of material from the top substrate is entrapped between the bottom substrate and the rivet shank, thus producing a tight joint.

Advantages of Self Piercing Riveted Joint
1) No holes required.
2) Fast cycle time.
3) No heat fumes, dust or chips given off.
4) Doesn’t distort or tarnish painted coatings.
5) Joins range of different materials such as steel, Aluminium and plastics.
6) Less noisy operation.
7) Less wastage cost.
8) Less scatter in quality.
9) Better fatigue performance both in steel and aluminium.
10) Repeatable quality, visually checkable joint.
Simple Riveting:-
A Rivet is a short cylindrical rod having a head and a tapered tail. The main body of the rivet is called shank. According to Indian standard specifications rivet heads are of various types. Rivets heads for general purposes are specified by Indian standards IS: 2155-1982 (below 12 mm diameter) and IS: 1929-1982 (from 12 mm to 48 mm diameter). Self piercing rivet and simple rivet is the same but difference is that in self piercing rivet does not require pre drill hole and in simple riveting requires pre drill hole. In self piercing riveting drilling and riveting of the two sheet metals is done by single rivet and in simple riveting drilling is done by using separate drilling tool and then after drilling riveting is does.

Rivets are permanent fasteners. Riveted joints are therefore similar to welded and adhesive joints. There are different applications of the rivets like large scale applications including shipbuilding, boilers, pressure vessels, bridges and buildings etc. A riveted joint, in larger quantities is sometimes cheaper than the other options but it requires higher skill levels and more access to both sides of the joint. In recent years there has been a progressive move from riveted joints to welded, bonded and even bolted joints. There are strict standards and codes for riveted joints used for structural/pressure vessels engineering but the standards are less rigorous for using riveted joints in general mechanical engineering Mechanical joints are broadly classified into two categories viz., non-permanent joints and permanent joints. Nonpermanent joints can be assembled and disassembled without damaging the components. EG of such joints are threaded fasteners (like screw-joints), keys and couplings etc [2].

Permanent joints cannot be assembled without damaging the components. These joints can be of two kinds depending upon the nature of force that holds the two parts. The force can be of mechanical origin, for example, riveted joints, joints formed by press or interference fit etc, where two components are joined by applying mechanical force. The components can also be joined by molecular force, for example, welded joints, brazed joints, joints with adhesives etc [3].

Fig.1 Rivets

Installation Procedure of Blind Rivet:-
1) Blind rivets are a two-part fastener consisting of a shell and a headed stem (mandrel) assembled so the shell can be placed into the work to be fastened.
2) The rivet is ‘set’ by drawing the stem through the shell, which causes the shell to deform and clamp the material securely.
3) After the desired clamping force is achieved, the stem breaks off and is discarded.
4) A small portion of the stem remains trapped in the bottom of the shell to ensure the clamping force is retained in the joint.
5) Withdrawing the stem is done with special tools operated by hand, pneumatics or electricity.

PROBLEM STATEMENT:-
In automobile Industries to maintain vehicle body mass has become an important topic. By joining processes vehicle body mass is generally made. Joining of two dissimilar metals can be achieved by different processes. Most of these joining processes have many limitations. In case of vehicle body if it is joined by Spot welding or Laser welding the mass of the vehicle body increases which causes the less fuel efficiency. Therefore mechanical joining process like self piercing riveting and simple riveting is important to use in automobile industries.

II. LITERATURE SURVEY
Preetamkumar R. Inamdar [1] had studied and the SPR process has been numerically simulated using the commercial FEA software LS-Dyna. A 2D axisymmetric model was generated. Since the SPR process involves large deformation, FE may become severely distorted. They conclude that the force-deformation curves have shown oscillations during the process, which is due to high value of penalty scale factor. We can absorb that at displacement length after 1.5mm, the force has increased higher consistently than experimental result. The segment penetration between the mesh of rivet and top sheet was managed with high value of penalty scale factor than default value.
- In the SPR process, the force variation could be divided into two main stages: the rivet penetration region and the rivet-setting region.
- The penetrating force required to deform and penetrate the aluminium sheets was analyzed through explicit analysis.
- Explicit approach is an efficient tool to study the joining process and predict the mechanical strength and failure mechanism of the SPR joints. Force-deformation values were predicted from rivet being riveted.
- Han, M. Thornton, M. Shergold [2] had studied the comparison of the mechanical behavior for each joint type under different loading conditions. It covers symmetrical and asymmetrical assembly from thin gauge of 1.0mm to thick gauge of 3.0mm. The results suggest that generally RSW can provide similar strength performance to SPR with the exception of T-peel; the energy to maximum load needs be considered ‘case to case’ and is dependent largely on loading conditions and the failure mode particularly with respect to SPR. The spread of results for SPR is generally smaller than RSW, and the performance of SPR joints improves as the thickness increases. He also concluded that The selection of process parameters for both RSW and SPR joints affect their strength, energy absorption and failure mode. Correlations exist between increasing nugget diameter and strength for lap shear and X-tension loading geometries for RSW joints.
- UMA Shankarkrishnappa [3] had studied Self piercing riveted dual layer joint by numerically and they conclude that the basic aspects if SPR process forming by conducting explicit and implicit analysis have been investigated. Also spring back effect of SPR process is studied. In this thesis case study of SPR of dual sheets of aluminium A16060 T4 temper alloy using high strength steel rivet was simulated to numerical investigate. The model geometry is axisymmetric, which was developed and meshed using MSC PATRAN.
- Johannes Gårdstam [4] the aim with this thesis is concerned with the development of simulation models of the joining process as well as mechanical properties of self piercing riveted (SPR) joints and pierce nut joints. In both of these joining methods problems occur when introducing more high strength steel sheets. For SPR, fractures occur in the rivet, and for pierce nut the thread will be damaged. This work resulted in more knowledge about the fracture risk in the rivet and how to reduce it. The strain and stress, which was used as fracture indicators, were reduced to the half with modifications of the rivet and the die geometry.
- Jacek Mucha [5] had studied quality Parameters and Behaviors of Self-Piercing riveted Aluminium Sheets with different joining conditions. in this paper two sheets of the aluminium alloy using a steel rivet was investigated. Also shows research progress in the assembly dimensional prediction area, using finite element analysis results. To improve industrial productivity simulated analysis was adopted in this study. The comparison analysis has been performed within the numerical experiment range to cover the effect of various riveting process parameters on the rivet deformation. Proper selection of corresponding rivet material features, i.e. its yield point and strain hardening, enables a significant change of the sheet joining process and specific finished joint parameters; The energy consumption for the rivet strain depends, among else, on the strain hardening curve. text into it.
  - R. Neugebauer, M. Jäckel, C. Kraus and T. Kropp [6] had studied and demonstrated what effect happens on Self piercing riveting process by improving velocity of tool. In the present paper, characteristics of the joining process at conventional and elevated tool velocity are investigated. Thereby, the focus is put on the joining process of high strength steel sheets. Proper and reliable joining of these steels presents a major challenge for mechanical joining techniques. In the conventional joining process, where tool velocities well below 1 m/s are common, different problems during the joining process caused by the high strength of the steel sheets can occur. At the punch riveting process undesirable material flow or unwanted burr development can occur, and at the setting process of self piercing nuts a deformation of the nuts is possible. These problems can be reduced significantly by using elevated tool velocity. He also conclude that for the punch riveting process it was shown that the undesired effects of early die indentation into the lower piece of sheet metal and burr formation can be avoided by increased tool speed.
III. METHODOLOGY

Experimental Test Setup:
A test were perform by fixing test material in to Tensile Testing Machine. This machine generally use to conduct tensile testing of material. In this machine load indicator is available for indicating a load. By using this machine we can find tensile strength of the material. We taken shear test and Peeling test of the test specimen. The jaws which is use to fix the ends of the specimen. One jaw is movable and another is fix to its position. In this experimental test setup two types of joints are use 1) Lap Shear joint 2) T peeling joint. For test set up 150 mm length and 50 mm width alluminium sheet material is use. For manufacturing the automobile body Alluminium is the best option to the manufacturer because alluminium material is a weightless material and easy to recycled. In this project for experimental test thickness of the test specimen is 1mm and 2mm are selected and diameter of the rivet is 4mm, 5mm, 6mm are selected. Simple riveting is analyse by experimentaly and Self piercing riveting is very costly for taking its experimental set ups there for in this project only results are taken for Simple Riveting process and experimental results for Self piercing process is taken from literature papers. For simple riveting Alluminium rivet is use in this testing.

<table>
<thead>
<tr>
<th>Joint Type</th>
<th>Length X Breadth</th>
<th>Material 1</th>
<th>Material 2</th>
<th>Rivet Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear Test</td>
<td>150x50</td>
<td>Aluminium</td>
<td>Aluminium</td>
<td>4 mm</td>
</tr>
<tr>
<td>Peeling Test</td>
<td>150x50</td>
<td>Aluminium</td>
<td>Aluminium</td>
<td>4 mm, 5 mm, 6 mm</td>
</tr>
</tbody>
</table>

Experimental test specimen for 1MM - 1 MM Thick plate

<table>
<thead>
<tr>
<th>Joint Type</th>
<th>Length X Breadth</th>
<th>Material 1</th>
<th>Material 2</th>
<th>Rivet Size</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Aluminium</td>
<td>Aluminium</td>
<td>4 mm</td>
</tr>
<tr>
<td>Peeling Test</td>
<td>150x50</td>
<td>Aluminium</td>
<td>Aluminium</td>
<td>4 mm, 5 mm, 6 mm</td>
</tr>
</tbody>
</table>

Experimental test specimen for 2 MM - 2 MM Thick plate

The strength behavior of rivet is mainly influenced by the properties of its joints. The stiffness of rivet joint is depends on several parameters like upper sheet thickness, lower sheet thickness, rivet diameter, river hole and rivet and sheet material.

The picture shows different failure modes on the samples tested. In this experimental testing Tensile Testing Machine (TTM) is use for testing or finding tensile strength and shear strength. In this test two jaws is use to clamp the test specimen. Lower jaw is movable and upper jaw is fix jaw shown in fig. (17). In this test specimen length is 150mm and width is 50mm and thickness is 1mm is used for first shear test. Two sheets of same size is overlap 50mm on each other and riveted at centre. Before riveting, appropriate hole is drilled at the centre.

Fig.3 Experimental Test setup for Shear testing shear test specimen.
Experimental Test Result:

**Fig.4** Experimental setup for peeling test and peeling test specimen

**Fig.5** Results of 1mm-1mm thick plates

**Fig.6** Results of 2mm-2mm thick plates

**Fig.7** Average strength Comparison of SPR and SRJ

**Fig.8** Modeling of T-Peel joint in to Autodesk Inventor

**Fig.9** Meshing of T-Peel Joint.

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**Theoretical Values of stresses by using Experimental data for 1mm-1mm Specimen:**

<table>
<thead>
<tr>
<th>Diameter Of Rivet</th>
<th>Lap Shear joint Shear stress values (N/MM²)</th>
<th>Lap Shear joint Shear Strength (N)</th>
<th>T peel joint Shear stress values (N/MM²)</th>
<th>T peel joint Shear Strength (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 MM</td>
<td>143.239</td>
<td>1800</td>
<td>23.873</td>
<td>300</td>
</tr>
<tr>
<td>5 MM</td>
<td>127.323</td>
<td>2500</td>
<td>20.371</td>
<td>400</td>
</tr>
<tr>
<td>6 MM</td>
<td>109.640</td>
<td>3100</td>
<td>15.915</td>
<td>450</td>
</tr>
</tbody>
</table>

**Theoretical Values of stresses by using Experimental data for 2mm-2mm Specimen:**

<table>
<thead>
<tr>
<th>Diameter Of Rivet</th>
<th>Lap Shear joint Shear stress values (N/MM²)</th>
<th>Lap Shear joint Shear Strength (N)</th>
<th>T peel joint Shear stress values (N/MM²)</th>
<th>T peel joint Shear Strength (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 MM</td>
<td>222.816</td>
<td>2800</td>
<td>111.408</td>
<td>1400</td>
</tr>
<tr>
<td>5 MM</td>
<td>203.718</td>
<td>4000</td>
<td>101.859</td>
<td>2000</td>
</tr>
<tr>
<td>6 MM</td>
<td>159.154</td>
<td>4500</td>
<td>77.809</td>
<td>2200</td>
</tr>
</tbody>
</table>

**Modeling of Riveted Joints:**

For modeling of the rivet joint here used Autodesk Inventor. This is the 3D Modeling software. For modeling purpose of Lap joint and T peel joint thickness of upper plate and thickness of lower plate, hole diameter of hole, diameter of rivet, material of rivet and plate is important parameters.
Fig.7 Meshing of Lap Joint.

FEA Analysis of Rivet joints:

ANSYS Workbench was used as finite element analysis processor. ANSYS provides wide variety of options to define various input parameters such as those required for contact material properties.

Following material properties was use for analysis purpose:
Mass density = 2.800e-09 tonne/mm$^3$
Young’s modulus = 70.000 N/mm$^2$
Poisson’s ratio = 0.3

Following table showing experimental and numerical results for T peel joint it observed that maximum stresses is coming on 4mm diameter rivet and very less stresses is coming on the 6mm diameter and thickness of the plate is 1mm. Graph is showing comparison in between experimental data and numerical data so it observed that percentage error is less than 5%.

<table>
<thead>
<tr>
<th>Diameter Of Rivet</th>
<th>Experimental Shear stress values (N/MM$^2$)</th>
<th>Numerical Shear stress values (N/MM$^2$)</th>
<th>Differences</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 MM</td>
<td>23.873</td>
<td>22.783</td>
<td>1.09</td>
<td>4.57</td>
</tr>
<tr>
<td>5 MM</td>
<td>20.371</td>
<td>19.647</td>
<td>0.724</td>
<td>3.55</td>
</tr>
<tr>
<td>6 MM</td>
<td>15.915</td>
<td>15.317</td>
<td>0.598</td>
<td>3.76</td>
</tr>
</tbody>
</table>

Comparison of Theoretical and Numerical values for 2mm-2mm Specimen:

<table>
<thead>
<tr>
<th>Diameter of Rivet</th>
<th>Experimental Shear stress values (N/MM$^2$)</th>
<th>Numerical Shear stress values (N/MM$^2$)</th>
<th>Differences</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 MM</td>
<td>222.816</td>
<td>219.516</td>
<td>3.3</td>
<td>1.48%</td>
</tr>
<tr>
<td>5 MM</td>
<td>203.718</td>
<td>199.524</td>
<td>4.194</td>
<td>2.06%</td>
</tr>
<tr>
<td>6 MM</td>
<td>159.154</td>
<td>151.514</td>
<td>7.64</td>
<td>4.80%</td>
</tr>
</tbody>
</table>

Fig.8 Result of FEA Analysis

IV Results and Discussion

Analysis of Lap shear joint and T peel joint is done in to the FEA software Ansys workbench and results are shows shear stress values. For Lap shear joint maximum stress value is 143.239 N/MM$^2$ by Experimental shear stress in 4mm diameter rivet and very less stress value for 6mm diameter hole rivet is shown in to the following table. That experimental value is validated by using FEA software. The graph is showing comparison in between experimental data and numerical data and no very much difference was observed.

Comparison of Theoretical and Numerical values for 1mm-1mm Specimen:

<table>
<thead>
<tr>
<th>Diameter Of Rivet</th>
<th>Experimental Shear stress values (N/MM$^2$)</th>
<th>Numerical Shear stress values (N/MM$^2$)</th>
<th>Differences</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 MM</td>
<td>143.239</td>
<td>140.524</td>
<td>2.71</td>
<td>1.90</td>
</tr>
<tr>
<td>5 MM</td>
<td>127.323</td>
<td>121.423</td>
<td>5.9</td>
<td>4.63</td>
</tr>
<tr>
<td>6 MM</td>
<td>109.640</td>
<td>105.652</td>
<td>3.98</td>
<td>3.64</td>
</tr>
</tbody>
</table>
Diameter of Rivet & T Peel Joint & Experimental Shear stress values (N/MM²) & Numerical Shear stress values (N/MM²) & Differences & Error
4 MM & 111.408 & 106.587 & 4.821 & 4.33 %
5 MM & 101.859 & 105.455 & 3.591 & 3.53 %
6 MM & 77.809 & 80.235 & 2.426 & 3.12 %

IV. CONCLUSION

Numerical analysis and experimental investigation is carried out for simple and self piecing riveted joints. Aluminium material is used in rivet and sheet metal joints. Aluminium material is generally used in automobile parts. Study of riveted joint using aluminium material is carried out in this work. Also self piercing riveting process is new technique generally used in the automobile manufacturing industry. Therefore it is very important to compare these two riveting processes.

Many researchers had investigated the Self piercing riveting process and concluded number of results. This data is used in this paper and compared with simple riveting process. It is concluded that self piercing riveting gives higher strength as compared to simple riveting process. Efficiency and performance of the Self piercing riveted joint is increased by increasing thickness of the sheet. Strength of the rivet depends upon grip range between rivet and sheets. Also Lap shear joint has more strength as compared to T peel joint.

The self-piercing riveting using aluminium rivets is indeed a challenging task, since the strength of aluminium alloys are much weaker than that of steels. Aluminium rivet are easily deformed when compressed into the plates, and hence no interlocking occurs.

Performance of the riveted joint depends on the thickness of plates and different types of the sheet material.

Finite Element Method is found to be most effective tool for designing mechanical components like single lap riveted joints. ANSYS can be used for analysis of complex and simple models of different type economically.

The model seems to be more sensitive for the pull-out condition than for the shear condition. The model was able to reproduce the correct failure mode for most of specimens, but could not predict failure modes related to failure in the base material since material failure is not included in the model. The model can be used to understand behaviour of connection that is, opening of the plates, rotation of the rivet at failure and forces acting on the rivet. This work would be useful in designing new shell-based rivet model for large-scale crash analysis of car structure.

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VI. REFERENCES
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