© 2019 IJSRSET | Volume 6 | Issue 5 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology
DOI : https://doi.org/10.32628/IJSRSET19651

Experimental Analysis of Self Piercing Riveted Joint

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ABSTRACT

Joining is an important process in a number of industries, such as aerospace, automotive, oil, and gas. Many products cannot be fabricated as a single piece, so components are fabricated first and assembled later. Joining technology can be classified as a liquid-solid-state process and mechanical means. Liquid-solid-state joining includes welding, brazing, soldering, and adhesive bonding. Mechanical joining includes fasteners, bolts, nuts, and rivets. Metal joining is a process that uses heat to melt or heat metal just below the melting temperature. The main principle is a shear condition of material. In case of shear test of conventional riveting joints, their strength is determined by the mechanical properties of the fastener material is high. Hence, it is expedient to have more insight on the fracture mechanism of various joints during tensile tests. This paper discusses the strength of self piercing rivets of sheet materials that is aluminum alloy, and their arrangements. This thesis presents a study of the effect of controllable self piercing rivet parameters, mainly tensile force, rivet length, rivet diameter tolerance, hole countersunk depth and hole diameter tolerance, on the quality of formed rivet. The quality of a formed rivet is determined by the geometry of its head formation and the extent to which the hole is filled. The study determines. The study is performed using finite element simulation of the riveting process. Theoretical relations between tensile force and formed rivet geometry derived in this study is used to validate the finite element model. Statistical design of experiment is employed to analyze the simulation data of riveting and determine the effect of individual factors, their interactions and relationship with the quality of formed self piercing rivet. The results demonstrate that the correct formation of rivet head geometry depends upon all the factors studied.

Keywords : Tensile test, shear strength, failure of riveting joints, solid self-piercing riveting (SSPR).

I. INTRODUCTION

Selection of the optimal materials for construction of thin-walled structures is currently in a transient phase. The elements, which previously have been manufactured from steel, are now increasingly made of fiber-reinforced plastic and alloy of light metals, such as aluminum. The new materials generate the need for the development of appropriate joining technologies. The use of the new material types forced the use of alternative joining technologies, in comparison to traditional connecting techniques. This implies the need for experimental studies related to the evaluation of the formation and strength of new joints. New solutions are not always good enough to provide an adequate strength. In some cases, formation for new materials' joints is quite problematic. Hence, the classic riveting technologies with the blind rivet or with the blind hermetic rivet are still widely applied and will probably continue to be used in the future. In the industry of public utility buildings and residential houses, these joints are the most widely used because of their high degree of certainty. Thin profiles are joined by means of various fasteners, One of them is a solid self-piercing riveting technology proposed. During the formation of clinching, self- piercing riveting or clinching riveting joints the material can fracture, especially the bottom sheet from the die side. These joint types are characterized by embossments, which depend on the forming process. The SSPR joining technology provides a flat surface on the rivet punching side. This also allows one to effectively join materials of various mechanical properties, e.g. soft materials with hard ones. Notwithstanding the fact that many scientists have published their results of the research, most of them are related to static shear tests or the fatigue tests of the riveting lap joints.

1.1 Objective

a. To join a range of dissimilar materials and multiple material stacks
b. No need for a pre-drilled hole
c. For fast cycle times
d. Environment safely and friendliness
e. Ease of automation and process monitoring
f. Achievement of high strength and increased fatigue properties
g. For low energy requirements
h. To low costs
i. Low waste material produced
j. A 'water tight' joint is formation.

II. METHODS AND MATERIAL

The variation in self riveting process is studied using finite element simulations. Finite element simulations data are used because it is easy to see the contours of stresses and strains and see the effect of each parameter individually while keeping the others constant. The simulations for experiments are designed using factorial design of experiment method, after parameters of interest to study are decided. Finite element model data from simulations are compared with theoretical equations derived for validation. The data from simulations are analyzed statistically using analysis of variance technique to find out the individual effects of self riveting process parameters.

2.1. Modeling

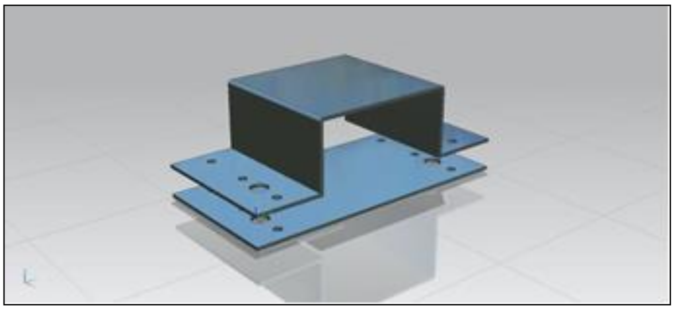
In order to study the variation in riveting process parameters finite element model of self riveting process is developed. Finite element model is used to study the effect of variations in rivet length, tolerances in rivet diameter and hole, riveting upset tensile force and countersunk depth. In finite element modeling, the contours of stresses and strains and the effect of each parameter can be studied individually while keeping the others constant.

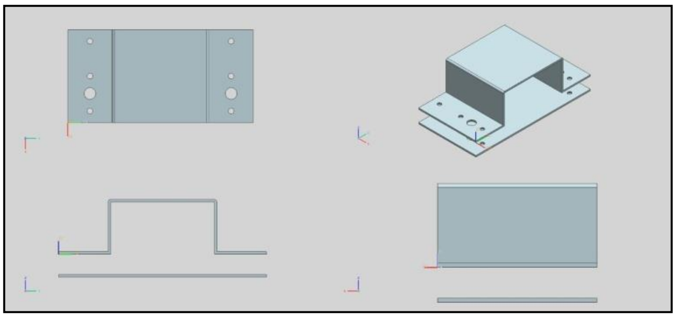
2.2 Model Development

The self-riveting process is similar to metal flow problem due to large plastic deformation of rivet and sheet material around the rivet. It includes contact problems at the interface between punch and rivet end, rivet shank and sheet, and in between upper and lower sheets.

2.3. Model Geometry

The configuration chosen for modeling is of a T4 aluminum alloy 100 degree flat countersunk rivet of aluminum alloy sheets.





2.4. Element Selection

By using axisymmetric 2D elements, the need for 3D modeling can be avoided. Four node axisymmetric shell elements with reduced integration of three points are used to represent sheets and rivet

2.5. Mesh Selection

Simulations of riveting allows for large plastic deformations of rivet, which results in distorted elements in rivet. When elements become distorted the calculation time increases and can even be terminated. To minimize the distortion of elements in rivet, adaptive mesh is used. Adaptive meshing makes it possible to maintain a high-quality mesh throughout an analysis, even when large deformations occur, by allowing the mesh to move independently of the material and rebuilding the mesh in a defined area during the simulation. A mesh size of 0.002" adaptive mesh is used for rivet. There is no need to have adaptive mesh in sheets because there is no excessive plastic deformation in sheets that lead to distortion of elements.

Different mesh sizes were tested in the model to find an optimal mesh density. The mesh

2.6. Boundary Condition

The edges of the sheet are constrained along x and z axis displacement and rotation, and allowed to move only in the y-direction. Rivet axis is constrained on all degrees of freedom along x and z, but allowed displacement along y-direction.

The riveting tools are modeled as rigid bodies with no rotational degrees of freedom.

2.7. Model Validation

The finite element model is validated by comparing the self piercing rivet geometry formed rivet diameter and height, from finite element model. Geometries and riveting upset tensile force is derived under ideal conditions

III. SELF PIERCING PROCESS

Compared with the traditional riveting process, SPR eliminates the requirement for pre-drilled/punched holes and the need for accurate alignment between components before joining. Unlike fusion welding process, SPR relies on mechanical interlocking rather than fusion to form the joint strength, so it can be used to join similar and dissimilar materials without the need of surface treatments and it will not degrade the material strength by heating. SPR is mainly used in combination with adhesives to increase joint stiffness and improve the noise, vibration and harshness (NVH) performance in automotive production. The most commonly used SPR system consists of a power and control unit, a C-frame, a die, a punch with a driving system and a rivet feeding system. Most of the modern systems also have a process monitoring system, which can be used to control some of the joint quality and process parameters, such as stack thickness, rivet length, punch displacement and setting force. If any of these parameters lie outside the tolerance, a warning will be generated. Most SPR systems are hydraulic or servo-driven, but there are some systems driven by other method.

3.1. Clamping. The nose piece is lowered down into contact with the workpiece against the die underneath and a force is applied to clamp the workpiece as a blank holder. The amount of clamping required depends on the joint stacks. Lower clamp force will facilitate the material flow of the bottom sheet to reduce the local work hardening and cracks around the joint buttons; on the other side, higher clamp force will increase the local work hardening and give sufficient squeeze to the adhesive at the joint interface.

3.2. Piercing. The punch of the SPR system is lowered down to force the rivet into the workpiece through either punching or pushing. At the initial stage, the rivet does not have much flare and only pierces through the material. This stage is material-dependent for soft materials, such as AA5754 aluminium alloy, the rivet may be able to penetrate the top sheet, while for hard materials, such as high-strength steel, the rivet may flare much earlier. This stage is also rivet hardness-dependent, as soft rivets will flare more easily than hard rivets. Typically, suitable rivet/ die combinations are selected to enable the rivet to penetrate through the top sheet and into the bottom sheet without too much flaring.

3.3. Flaring. The rivet will be punched or pushed further into the workpiece and starts to flare to form a mechanical interlock to hold all the sheets in the workpiece together. The flare of the rivet is caused by the piercing resistance from the workpiece with support and constraint from the die. During the piercing and flaring stages, gaps between the sheet materials may be generated due to the different deformation behaviours from different sheets, but these gaps will be closed-up or reduced with the force applied through rivet head during following riveting process. The punch will stop when it reaches the predetermined force or stroke.

3.4. Releasing. The punch and the nose piece of the SPR sys- tem will retreat to the working position and the workpiece will be released from the die

IV. EXPERIMENTAL CONDITION AND PLANNING OF EXPERIMENT

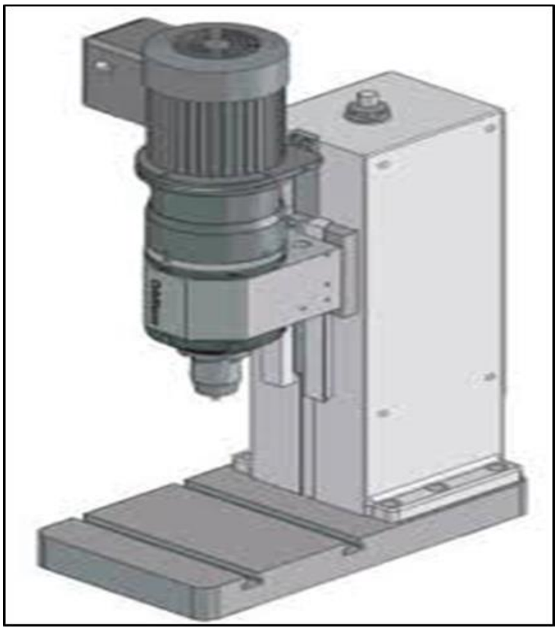


Fig.2: Experimental Setup

Dimensions of workpiece:

Workpiece is selected as a sheet of dimensions 120 X 95 X 72 MM thick. Basic diagram of workpiece is as shown:

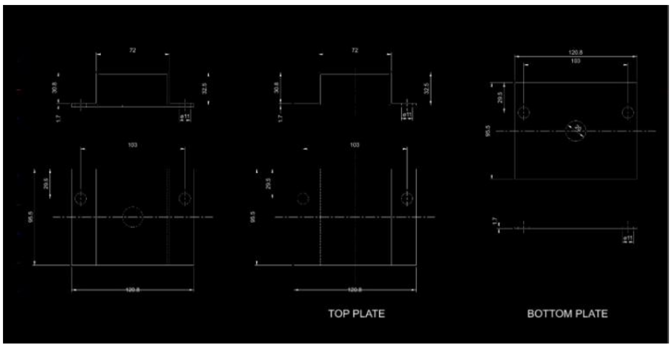


Fig.3 Dimensions of workpiece

Material Used for Experimentation:

Austenitic Stainless Steel AISI 304 with Properties given below,Steel rivets with a countersunk head and Silver Almac surface coating were used throughout. The diameter of the rivets was 3 mm and the setting force was 50bar for all specimens.

MECHANICAL PROPERTIES OF MATERIAL

Young's Modulus (GPa)	Tensile strength (MPa)	Elongation	Hardness (Hv)	
70	240	22%	63.5	
NOMINALCOMPOSITION (BALANCE Al)				
Si	Fe	Cu	Mn	Mg
0-0.40	0-0.40	0-0.10	0-0.50	2.60-3.60

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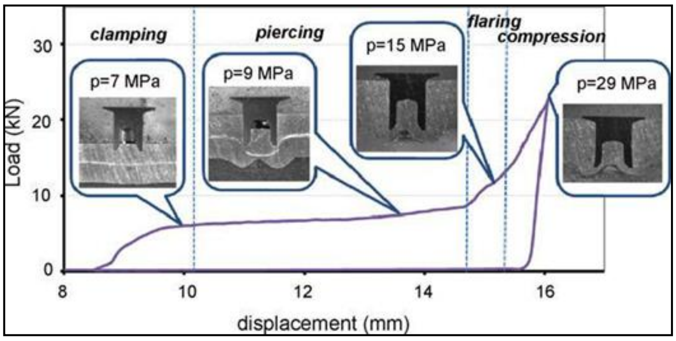


Fig -4: Joining Sequence

V. EXPERIMENTAL PROCEDURE

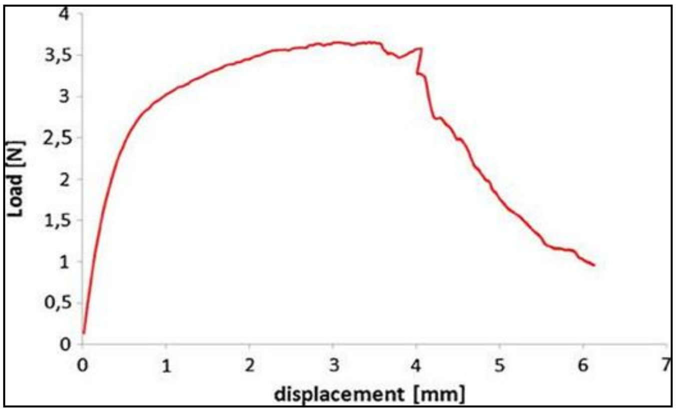
Tensile Tests

Deformation and failure of each specimen configuration with different rivets and different plate thickness combinations under monotonic tensile loading were studied. A servo hydraulic testing machine with hydraulic grips was used for conducting the tests, continuous records of the applied displacement versus the measured load were obtained during each test. They found that there is appreciable influence of plate thickness on tensile strength of the coach peel pop rivet. The ultimate load increase with plate thickness .Failure mechanism of the joint under shear test was the rivet pull-out as shown in figure. The bottom sheet is separated from the top sheet and the rivet. A large sheet distortion is visible around the joint: due to the unsymmetrical geometry of the riveted joint, the rivet rotates around a transverse axis

Fig-6: Schematic diagram of the tensile machine and specimen for joint testing.

The rivet is more rigid than the sheets and it applies a compressive force that leads to a damage in the contact area: the rivet head penetrates in the upper sheet and material of the lower sheet is pushed ahead of the rivet forming a relief on the sheet surface. The average max shear strength was 55 N, making the SPR process competitive with spot-welding, while standard deviation was around 45 N.

Furthermore static tensile tests were carried out in order to investigate the mechanical performances of the obtained joints. In the next Fig. 3 the typical load vs. displacement curve of tensile tests is reported. In the figure it is shown an increase of the carrying load up to a maximum value, such value, of course, depends on the used process parameters. Then the maximum load is reached, the bearing mechanics starts and the failure of the joint starts



Quasi static tensile tests of single lap joints were performed using universal testing machine. Cross head speed was 1 mm/min. The joint stiffness was relatively higher for modified SPR joint than bolted joint. The average maximum load was 8 KN for modified SPR joint and 7.2 KN for bolted joint.

Fatigue Tests

Constant amplitude load controlled fatigue tests were performed according to ASME standard. At least 12 specimens were used to generate the fatigue life data for each thickness. The applied cyclic loading waveform was sinusoidal and frequency of lading used varied from 5 to 30 Hz according to load amplitude. For given thickness combination the higher load ratio, result in longer fatigue lives for the tested specimens. Both plate thickenss and load level affected fatigue failure modes of CPPR specimens .The fatigue behavior of SPR joints in aluminium alloy was studied. The fatigue test on the lap joint were perfomed by a hydraulic fatigue testing machine. The stress ratio was fixed to 0.1.The maximum load was changed to 90 % to 40 % of static tensile strength. The relationship of the maximum load and number of cycles to failure was studied. The CFRP laminates failed when Pmax = 0.8PU. By contrast, the rivet body failed before the CFRP laminates when 0.55PU 5 Pmax 5 0.8PU. Both failures were randomly observed when Pmax = 0.8PU. The fatigue limit was 0.5PU if the maximum number of cycles was limited to Nf = 107

VI. NUMERICAL MODELING

FEA Model

A 2-D numerical model of the process was first set-up with explicit code abaqus v.6.4.Dies were modeled as rigid contact surfaces, while rivet and sheets as deformable bodies. damage model was chosen

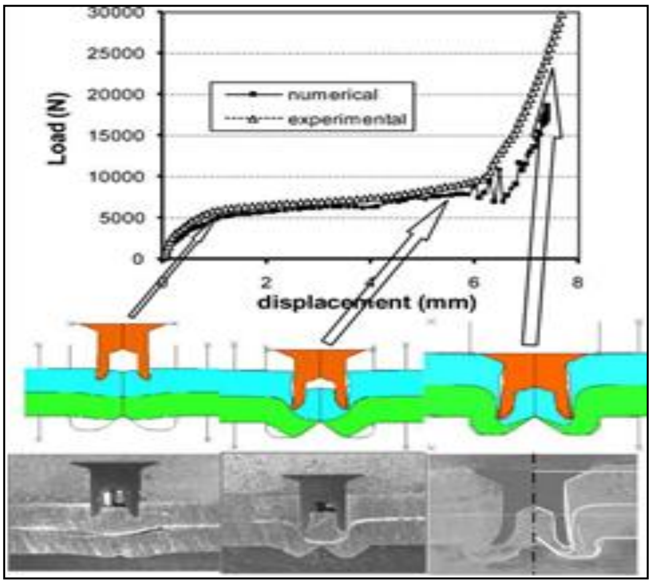


Fig 7. Deformed shape and load–displacement curve in the 2D FEM model

A constant shear friction factor law was used and the identification of the correct friction value was done by inverse modeling, comparing the resultant geometry of the simulation with the section of the experimental joint.

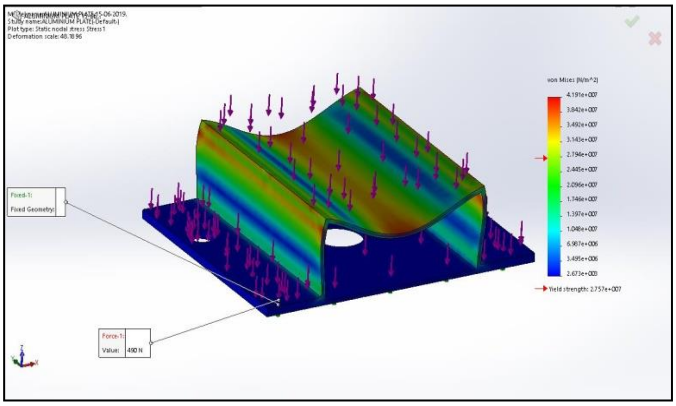
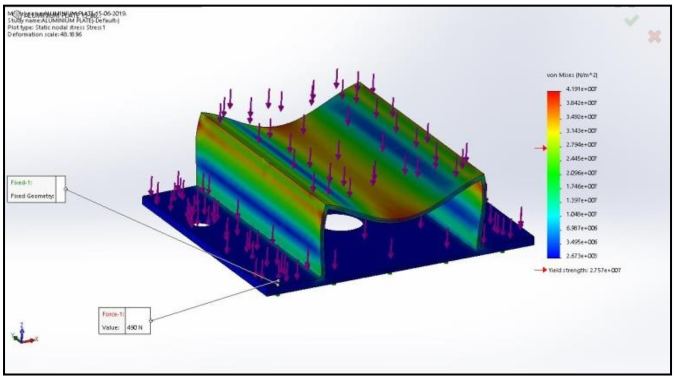


Fig.8. FEA Model

Fig shows the comparison between the simulated deformed geometry and the real section of the joint in three steps of the process. The comparison shows good geometric correlation. It can be observed that the simulation is capable to capture the key phases of the joining process: the filling of the rivet hole and then the flaring. The small divergence between the simulated and real.

A 3D model was then created, based on the same assumptions of the 2D model Because of the symmetry only half of the specimen was modeled. Rivet and sheets were meshed with hexahedral elements. Both the joining process and the shear tests have been simulated in sequence to take into account for the correct deformed shape and stress– strain distribution in the joint. Fig. shows a comparison between numerical and experimental results after the shear test. It can be seen that the simulated and experimental joints showed similar failure behavior with the rivet pulled out from the lower sheet. Further, the shear resistance obtained with the simulation was very close to the real one.

The SPR process was simulated by commercial FE software . A 2D axisymmetric model was generated. An implicit solution technique with langrange method and r-self adaptivity was used. The numerical model was validated against the experimental test results. The simulation results were in good agreement with experiments with respect to force displacement curves.



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VII. CONCLUSION

Self-pierce riveting is a sheet metal joining technique on which a rivet inserts into two or more sheets without pre-drilled hole. This technique is alternative to traditional spot welding due to the growing use of alternative materials which are difficult to weld. The analysis of SPR technology is still in its development phase. A literature survey on the SPR technique has shown a limited number of relevant articles. In this paper the research and progress in self-pierce riveting are critically reviewed from different perspectives. The mechanics of joint formation and joint failure have been studied. The main mechanical properties of the SPR joints such as strength, is discussed. The FE analysis for SPR is reviewed. This paper reviews recent progress of the SPR method and provides a basis for future research.

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Cite this article as :

R. T. Kolhe, Prof. V. L. Kadlag, "Experimental Analysis of Self Piercing Riveted Joint", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Online ISSN : 2394-4099, Print ISSN : 2395-1990, Volume 6 Issue 5, pp. 303-310, September-October 2019. Available at doi : https://doi.org/10.32628/IJSRSET1196555
Journal URL : http://ijsrset.com/IJSRSET1196555