Review: Experimental and Numerical Analysis of Self Piercing Riveted Joint

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Abstract - ***Self-piercing riveting (SPR) is a high-speed mechanical fastening technique which is suitable for point-joining of sheet materials. It is used heavily in automobile sector due to growing use of alternative materials and difficulty in welding the sheet materials. Published work related to self piercing process is reviewed in this paper. SPR mechanics of joint formation is introduced. Testing of SPR joint on experimental set-up is also studied. The simulation of joint formation by available software is discussed. The objective of this paper is to review recent development in SPR and to provide the basis for further research.***

Key Words: *Self-pierced rivet, sheet material, joint formation, finite element analysis*

1. INTRODUCTION

With active pursuit of lightweight vehicle structures in the automotive industry, there is an increasing interest in developing new joining technology as a replacement for spot welding in lightweight metals, such as aluminum alloys. Spot welding is the primary method of joining steel body panels. Although spot welding is considered a satisfactory joining method for aluminum body panels the difficulty of spot welding thin aluminum sheets is well recognized. The reasons for the difficulty with spot welding aluminum are due to its high thermal conductivity, low melting range and propensity to form oxide surface film Adhesive bonding, weld-bonding, riveting and clinching are some of the alternative joining techniques considered for aluminum alloys. Among these, self-piercing riveting (SPR) is gradually receiving recognition as a possible and effective solution for joining aluminum body panels and structures [1].
With the increased demands to improve fuel economy, performance, safety and reliability in the automotive industry have made it necessary to explore the usage of lighter materials and non-conventional joint such as riveted joint[2].Finite element computing technology is largely used for designing and optimizing a number of manufacturing processes[3].
Compared to the more traditional methods of sheet material joining, the advantages offered by SPR include

1. Joining a range of dissimilar materials and multiple material stacks
2. No need for a pre-drilled hole
3. Fast cycle times
4. Environment safely and friendliness
5. Ease of automation and process monitoring
6. Achievement of high strength and increased fatigue properties
7. Low energy requirements
8. Relatively low costs
9. No waste material produced
10. A 'water tight' joint is formed

As with any technology, however, SPR has some disadvantages which include the following

1. Access is required to both sides of the joint
2. Inappropriate for brittle substrates
3. Bulges and indents associated with the forming process may not be aesthetically acceptable
4. Relatively high force required for the forming process [5].

1.1 Riveting Process

SPR process is essentially a cold forming operation, in which a semi-tubular rivet is pressed by a punch into two (or more) sheets of material that are supported by a small die with a suitable geometry. Unlike the traditional riveting process, no preparatory hole is required: the rivet shape allows to pierce and join the sheets in one operation. Typical riveting cycle time ranges from 1.0 to 4 s. The SPR riveting process can be divided into four steps:

1. Clamping: the rivet is pushed by a punch perpendicularly to the sheet surface. In this phase the rivet clamps the sheets.
2. Piercing: the rivet causes the plastic strain of the sheets. The upper sheet undergoes a severe deformation or a blanking.
3. Flaring: the lower end of the rivet starts to flare inside the sheet

and follows the contours of the die. An overlapping is generated that is responsible for the required mechanical resistance.

4 Compression: the punch continues the stroke, pushing the rivet inside the sheet metals to be joined. The punch stops when it reaches a predetermined force or stroke. conjunction with the appropriate die, for each application (materials to be joined, total thickness, functional requirements or aesthetic appeal, etc.).

In Fig. 1 typical load–displacement curve of the SPR process is shown, together with the indication of the four process phases. Traditionally, the process design procedure is based on the experience and involves trial-and-error loops. This approach is highly time and cost expensive. The design procedure is nowadays carried out experimentally in the suppliers' technical laboratories, because the end user normally lacks the necessary knowledge and experience on this process. Numerical analysis, carried on by means of FEM tools, allows to drastically reducing the development phase, if conducted together with a limited number of experiments [5].

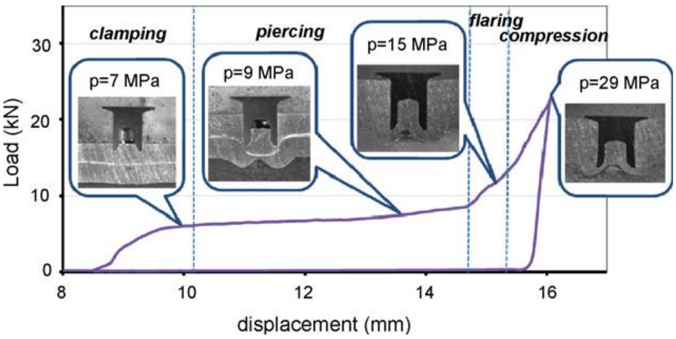

Fig -1: Joining Sequence [5]

2. EXPERIMENTAL PROCEDURE

2.1 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 [6].

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.

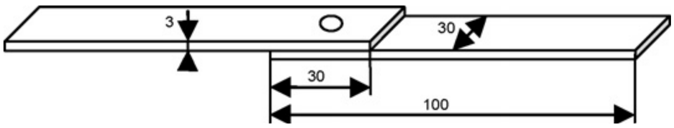

Fig-2: Schematic diagram of the tensile specimen for joint testing.

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 4430 N, making the SPR process competitive with spot-welding, while standard deviation was around 94 N [5].

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 [7].

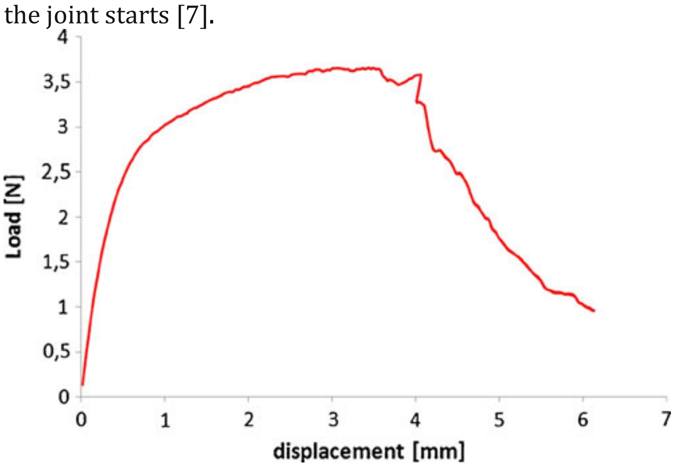

Fig. 3: Load vs. Displacement curve [7]

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 [8].

2.2 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 [6].The fatigue behavior of SPR joints in aluminium alloy was studied [1].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 [8].

3 NUMERICAL MODELING

5.1 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 andsheets as deformable bodies.Gurson–Tvergaard damage model was chosen.

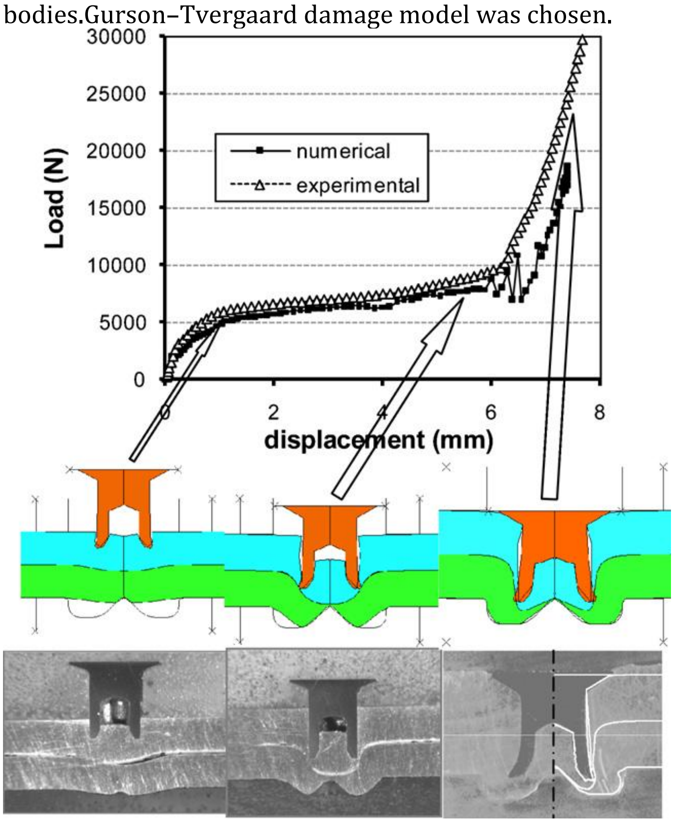

Fig- 4: Deformed shape and load–displacement curve in the 2D FEM model [5]

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 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 (material constitutive law, friction, etc.). 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. 9 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 [5].

The SPR process was simulated by commercial FE software LS-Dyna. 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 [11].

3. CONCLUSIONS

Self-pierce riveting is a sheet metal joining technique ION 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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