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Simulation and Parametric Study of Clinched Joint

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Abstract - *The growing demand for more fuel efficient vehicles to reduce energy consumption & air-pollution is a challenge for automotive industry. The characteristic properties of Aluminum, high strength stiffness to weight ratio, good formability, good corrosion resistance & 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. Aluminum 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 aluminum & contribute greatly to lowering the weight of vehicle are engine block, closure panels, & chassis components. However there are problems in joining the Aluminum to dissimilar materials. A critical problem with Aluminum assembly is that joining Aluminum requires a different set of technologies & procedures from steel. Because of Aluminum properties welding is more difficult. Also widespread Aluminum & other lightweight material use require techniques to join dissimilar material, which add complexity & cost. Clinching is one of the promising technologies for joining dissimilar metal sheets. In this report the clinching joints of Aluminium & steel sheets is studied. The simulation of clinching process & parametric study for better quality clinched joint is presented. The software used for simulation is Ls-Dyna. A comparison between experimental & simulated is provided.*

Key Words: Clinching Process, Simulation of Clinching Joint, Mechanical Joining Methods, Clinching Joints in Automotive, Parametric study of Clinched Joint

1. INTRODUCTION

Current trend in Automotive industry is to reduce the weight of the vehicle growing to reduce the reduce energy consumption & air-pollution. The growing demand of fuel efficient vehicle is a challenge for automotive industry. The characteristic properties of Aluminium, high strength stiffness to weight ratio, good formability, good corrosion resistance & 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 & contribute greatly to lowering the weight of vehicle are engine block, closure panels, & chassis components.[1]

1.1 Issues in joining of aluminum and steel

Besides hydrogen porosity, solubility, surface oxides and difference in metallurgical properties the most important issue causing hindrance to commercial application of heterogeneous jointing is formation of IMC (Inter Metallic Compounds) at the joining surfaces. Phase formation is accompanied by an embrittlement of the joining zone. The solubility of Al in Fe is high upto approximately 25 vol.-percent. At 51 vol.-% of aluminum the α-phase and the β2 -phase are generated respectively. At 25vol.-% and 50vol.-% of aluminum, the superstructures Fe_3Al and FeAl could be formed. The solubility of iron in aluminum is close to zero. At approximately 66vol.-%, 71 vol.-% and 77 vol.-% aluminum, the Inter Metallic Phases $FeAl_2$, Fe_2Al_5 and $FeAl_3$are formed respectively.[2]

1.2 Basics of Clinching Process

Clinching is the process by which two sheet metal parts are joined by plastically deforming them into each other & locking them in place in a way that prevents them from pulling apart under tensile loads. In the clinching process shown in the figure the joining occurs by the action of a punch, which forces both sheet metals into a die & forms an interlocking button of the shape of the die between the two sheets. The materials in the button area undergo plastic deformation, first due to deep drawing & then by a cold upsetting.[1]

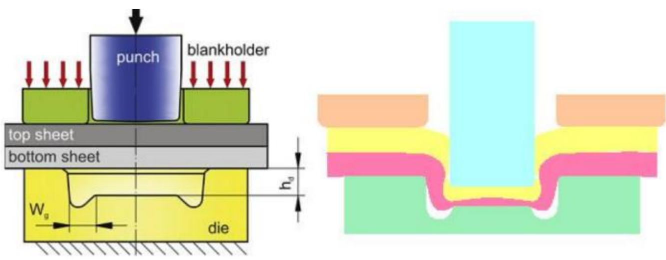

Fig -1: Clinching Process

2. Visit to TOX Company

For clear understanding of the process we have visited one of the leading company in Clinching Technology TOX. TOX is a German based company provides solution of Mechanical Joining processes. The pune plant of TOX is situated at Pirangut. From the visit we got good understanding & information about Clinching Technology. TOX uses special type of Powerpackage for Clinching Process. They have given general guidelines for clinching joints as follows.

2.1 Quality Criteria of Clinched Joints

For round button non-cutting clinching techniques the strength of the connection is determined by the magnitude of the undercut and the neck thickness. These values are influenced by the tool dimensions, such as the punch diameter and the depth and diameter of the die cavity, as well as by the setting of the displacement limits for the upper-die. The residual bottom thickness correlates well with the joint strength.[3]

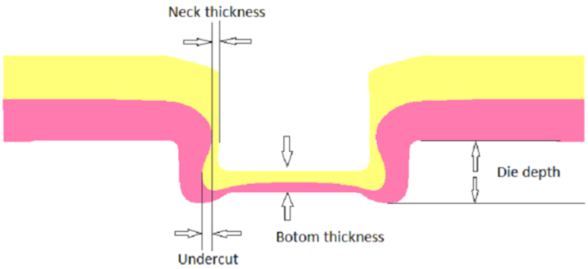

Fig -2: Quality Criteria of Clinched Joints

A larger undercut can be achieved by reducing the residual bottom thickness. However, to avoid overloading the tools and work piece due to excessive joining forces, a compromise between maximum joint strength and tool life is required. The strength of a clinched joint depends basically on four main factors:

1. The type of Aluminium alloy/Steel of the work pieces,
2. The sheet thickness,
3. The clinch button size (the diameter should be as large as possible),
4. The surface condition of the material – a completely dry, grease free surface will give a stronger joint than if the surface is oily or wet .[3]

2.2 Selection of Clinched Joint Diameter

The flange width "D" - distance from the edge where the clinch spot is to be placed - must be sufficient to ensure that there is material to contain the deformed clinch spot and sheet. The button may otherwise burst out of the edge of the flange or cause distortion in the joint. Proper overlap of the layers to be joined and a correct flange width will also help ensure proper alignment between the work-piece, punch and die. A pre-clamping step may be helpful if joining a flange width close to the minimum width is to be undertaken.

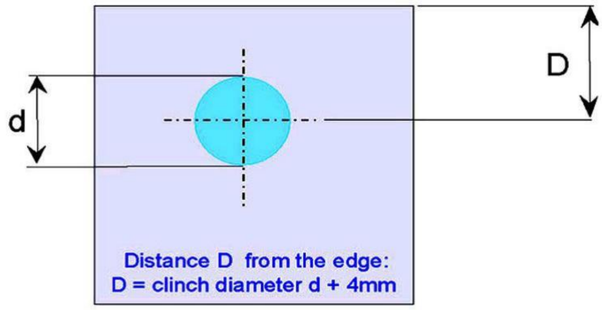

Fig -3: Distance from the Edge

The clinch spots should be spaced to avoid contact with previously driven clinch spots or the strained area immediately around them. Placing several clinch spots too near to each other may cause distortion or some bending of the joint. A pre-clamping step can help to minimize this. A sufficient number of clinching spots must, however, be used to guarantee the overall design strength of a section. The size of the joint is selected according to the thickness and material being joined. The strength of the joint can be easily monitored by measuring the remaining thickness at the bottom of the joint. This quality control dimension X allows for non-destructive testing of the joint. In general, the larger the joint size, the higher the strength of the resulting connection.[5]

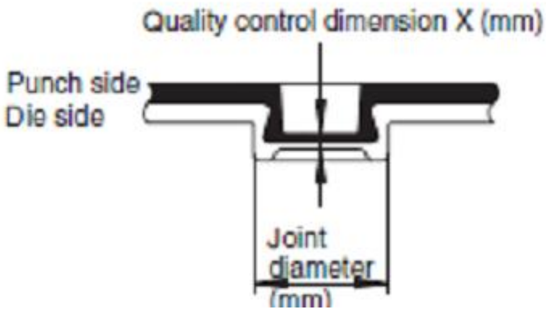

Fig -4: Joint Diameter

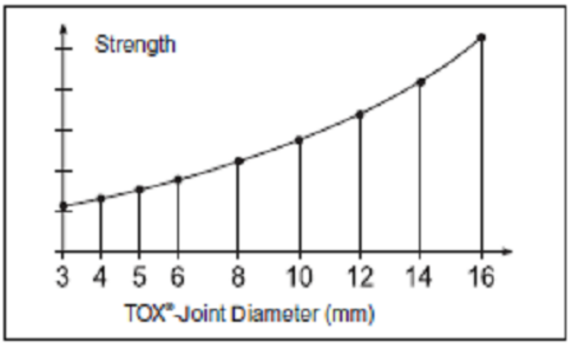

Chart -1: Strength Vs Joint Diameter

Graph shows that as the diameter of joint increases strength of the joint increases.

3 Material Properties

The material selected for making Clinched joint is mild steel 1.5mm & aluminum 1.5mm due to their wide applications in Automotive industry. Material is to be tested to know the exact properties for making good quality clinched joint. Tests were performed at ARAI-AML (Automotive Materials Laboratory) test facility. INSTRON 5582 Universal Testing Machine was utilized of 100 kN capacity and to measure elongation Longitudinal Extensometer was used. A Universal Testing Machine is used to test the tensile & compressive properties of material. Load cells & extensometers measure the key parameters of force & deflection as the sample is tested. These machines are widely used & would be found in any material testing laboratory. All systems of Electromechanical Universal Testing Machine systems are fully computer controlled & include state of the art Pentium IV computer data acquisition & control system with fully PC features & capability including database analysis & networking. Testing can be controlled based upon Displacement, load, stress or strain.

We have tested 3 specimens of both materials with ASTM standard specimen as given in figure

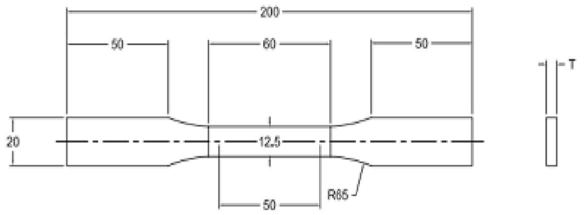

Fig -5: Standard Specimen

Properties obtained from stress-strain curve:

Table -1: Material Properties of mild Steel

Sr.No	sample	Material	Thickness in mm	Yield in N/sq mm	UTS N/sq mm	% Elongation
1	S-1	Steel	1.139	261.5	350.5	38.2
2	S-2	Steel	1.127	262.2	344.3	38.9
3	S-3	Steel	1.14	261.4	349.4	38.9

Table -2: Material Properties of Aluminium

Sr.No	sample	Material	Thickness in mm	Yield in N/sq mm	UTS N/sq mm	% Elongation
1	A-1	Aluminum	1.93	127.7	138.5	6.9
2	A-2	Aluminum	1.939	127.1	137.8	5.2
3	A-3	Aluminum	1.925	127.4	138.4	7.2

4. Preparation of 2D Axissymetric model for Simulation in LsDyna.

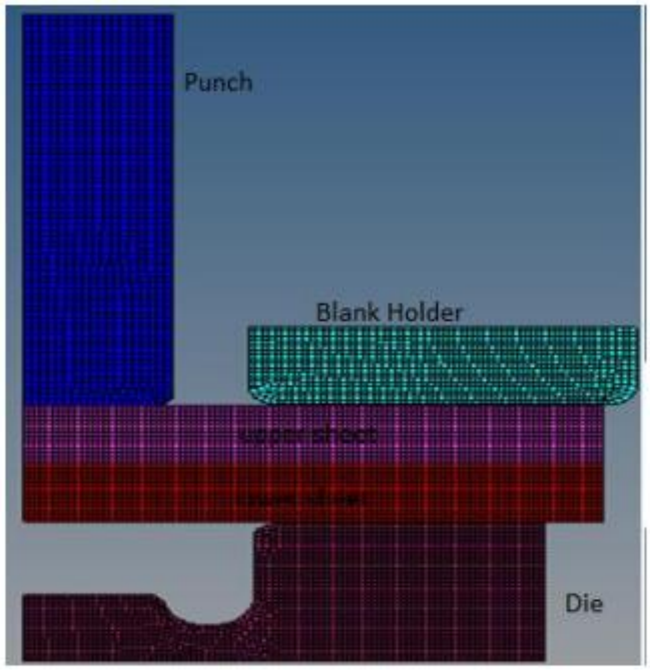

Fig -6: 2-D Axissymetric setup of Clinching Process

1. Punch displacement: Displacement was given to the punch tool using the *BOUNDARY_PRESCRIBED MOTION_RIGID card. A displacement is such that the final bottom thickness of sheets should be 25 % of total thickness. A curve was specified for the motion of the tool. The load curve was defined in *DEFINE_CURVE card

2. Pad force: Desired loading force was applied on the sheets to stay clamped before riveting process starts. Loading force was defined using *LOAD_RIGID_BODY card. The load curve was specified in *DEFINE_CURVE card.

3. Adaptive Remeshing: The Adaptive process is used in Ls-DYNA to obtain the greatest accuracy for a given set of computational resources. In adaptive method the element are subdivided into smaller element whenever an error indicator shows that subdivisions of elements will provide improved accuracy. The user sets the initial mesh size and the maximum level of adaptivity and the programme subdivide those elements in which the error indicator is the largest. The input parameters for the adaptivity process are specified in the *CONTROL_ADAPTIVITY card. For 2D axisymmetry element only r- adaptivity option can be applied and thus used in this study. The adaptive option ADPOPT was given a value of 2 to specify 2D r- adaptive remeshing for axisymmetric and plan strain solid element. When using this r-adaptivity in Ls-DYNA , the user specifies the birth time, tbirth at which the adaptive remeshing begins, the death time, tdeath, at which the adaptive remeshing ends and a time interval delta T, between each remeshing. At each remeshing interval nodal values for all variables to be remapped are generated. A

completely new mesh is generated from the old mesh based on characteristic element size.

4. Element formulation: As the problem is 2D axisymmetric calculations element formulation type 15 axisymmetric solid was used. It is default shell element formulation in Ls-Dyna. It is computationally efficient element formulation used as common for all axisymmetric setup. The type of element formulation for each is specified in the *SECTION_SHELL card under ELFORM option.

5.Contact condition: The *CONTACT _2D_AUTOMATIC_SURFACE_TO_SURFACE_ID card was used to define contact between various parts. The part ID was used to identify master and slave segment. The deformable body was considered as slave because it has to follow the shape of the master. In our setup we have considered the punch, blank holder and die as a master and sheets as a slave. Appropriate static and dynamic friction coefficient were specified.

6. Material Modeling: In practice tools are much stiffer than the blank hence the tools can be treated as rigid bodies. Material model *MAT_20 in Ls-dyna is used to represent the rigid tools. The material properties can be entered in this card. The boundary conditions for the rigid body were also specified in the same card. The material model *MAT_24 in Ls-Dyna is used to represent the deformable parts i.e. sheet metal. The material properties for the parts are input in the *MAT_PIECEWISE_LINEAR_PLASTICITY card.

5. Validation with Experimental Result

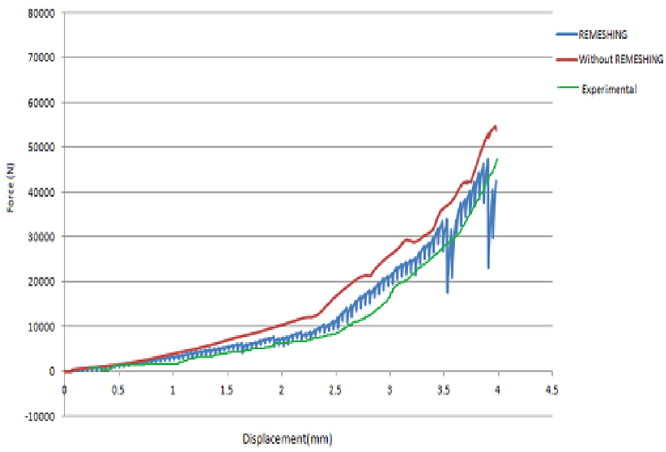

Chart -2: Validation with Experimental Force-Deflection Diagram

Table -3: Comparison of forming force of CAE result with Experimental result aterial

	Experimental	With Remeshing	Without Remeshing
Force(kN)	44.5	46.5	55.5

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we can say that force deflection diagram of CAE with Remeshing gives good correlation with experimental Force-Deflection diagram. Therefore methodology with remeshing technique is adopted.

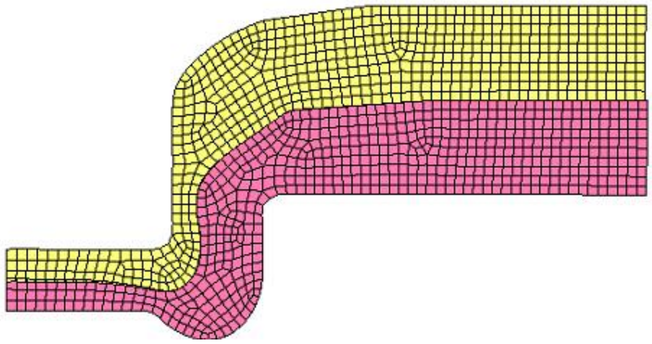

Fig -7: 2-D Axissymetric Clinched Joint

6. Sequence of Strips

In this case we used one aluminum sheet and one steel sheet of 1.5mm thickness. We have tried all six tool combinations for selecting optimum tool combination. With upper aluminum sheet and lower steel sheet joint cannot be formed because upper sheet cracks before the formation of joint.

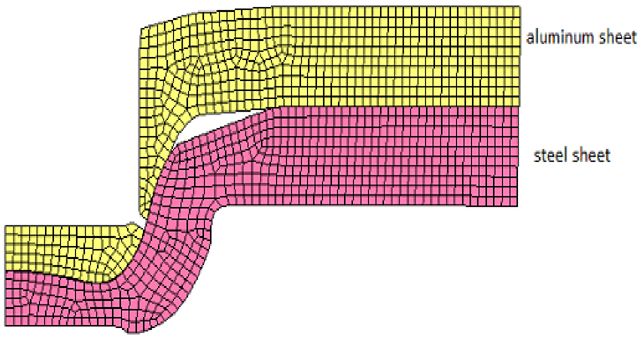

Fig -8: Neck fracture during clinching process

By keeping the Steel sheet on punch side or upper side we can form the Clinched joint.

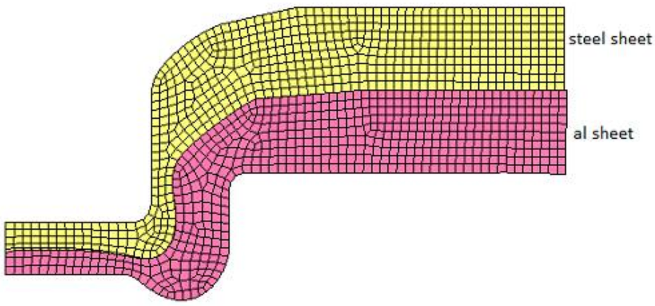

Fig -9: Clinched joint of dissimilar material sheets

7. Parametric study of Clinched Joint

There are several parameters that affect the quality of Clinched joint. For optimum Clinched joint perfect combination of punch & Die is must. There are four main parameters that affect the quality of clinched joint.

1. Die groove diameter.
2. Die diameter.
3. Punch corner radius.
4. Punch stroke.

1. Die groove diameter: For finding the effect of die groove diameter on joint quality we have used different die groove diameter as given in table. From table we can say that with increasing the groove diameter undercut increases and neck thickness decreases.

Table -4: Effect of Die groove diameter on clinched joint

Die Groove Diameter(mm)	Undercut (mm)	Neck Thickness(mm)
0.6	0.08	0.5
0.8	0.1	0.46
1.0	0.11	0.42

2. Die diameter: For finding the effect of die diameter on joint quality we have used different die diameter as given in table. From table we can say that with increasing the die diameter undercut decreases and neck thickness increases.

Table -5: Effect of Die diameter on clinched joint

Die Diameter(mm)	Undercut (mm)	Neck Thickness(mm)
6	0.12	0.42
8	0.09	0.50
10	0.07	0.62

3.Punch corner radius. : For finding the effect of Punch corner radius on joint quality we have used different Punch corner radius as given in table. From table we can say that with increasing the Punch corner radius undercut decreases and neck thickness increases.

Table -6: Effect of Punch corner radius on clinched joint

Punch corner radius (mm)	Undercut (mm)	Neck Thickness(mm)
0.2	0.11	0.42
0.3	0.1	0.48
0.4	0.09	0.54

4.Punch stroke. : For finding the effect of Punch stroke on joint quality we have used different Punch stroke as given in table. From table we can say that with increasing the Punch stroke undercut increases and neck thickness decreases.

Table -7: Effect of Punch stroke on clinched joint

Punch Stroke(mm)	Undercut (mm)	Neck Thickness(mm)
3.8	0.08	0.6
3.95	0.1	0.48
4.1	0.15	0.36

8. CONCLUSIONS

Clinching simulation with remeshing technique gives good correlation about 92% than without remeshing technique. Therefore adaptive remeshing technique is used throughout the project. Parametric study of clinching process is carried out. Effect of Die height, Punch diameter & Punch stroke on clinch joint is studied. We have developed guidelines for Guidelines for clinching process are as follow:

- Optimum tool combination is required to obtain good quality clinched joint.
- With increasing punch stroke quality of joint improves.
- With increasing Die depth Neck thickness decreases and Undercut increases.
- With increasing Punch diameter Neck thickness decreases & Undercut increases.
- For dissimilar metal sheet joining, higher strength material should be at punch side.
- For metal sheets with different thickness, thicker sheet should be at punch side.
- Cinched joint strength directly depends on neck thickness & undercut.

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