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Analysis of Rivet Joint for Application of Substation

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Abstract - *This paper deals with the analysis of rivet joint on the basis of Finite Element Method (FEM) simulation. In this research paper we have used four different diameters of rivets for four different materials for analysis purpose. Tensile test on different material such as brass, aluminum, mild steel and stainless steel was done with the help of UTM. 3-D model of the component was made in PTC Creo1.0. The Meshing of the model was done in HyperMesh and the mesh used was tetrahedron. The Dynamic simulation of the model was done in LS-DYNA and the vonMises stresses for different diameters of rivets were found in the same. The data obtained from the test on UTM like material properties and stress vs strain graph was used as input for LS-DYNA and from these properties obtained from UTM of different material. The analysis is done on rivet joint of various diameters for all material and from results of stress obtained, we have selected optimum diameter and check whether the stresses for the same diameter were within permissible limit or not, on the basis of the test results obtained we have selected best diameter for best suitable material on the basis of stresses available, on the basis of results obtained the best material for our purpose was Mild Steel EN 14 and the optimum diameter was 6.05mm.*

Key Words: LS-DYNA, HyperMesh, UTM, vonMises stress etc .

1. INTRODUCTION

A substation is a part of an electrical generation, transmission and distribution system. Substation transforms voltage from high to low or vice-versa. The analysis on the rivets done in this research paper are used in a part which is used in substation, as we know in substation the electrical supply is of very high voltage and when we have to break the circuit it is to be done at high speed. If the breaking of circuits is done slowly then high voltage sparks are generated, this sparks can damage the circuit and the cost to replace the circuit is very high, therefore the part which we are analyzing works at high speed and dynamic forces acts on the rivets. This part is further connected to Vacuum circuit breaker (VCB). A Vacuum Circuit Breaker is a device that interrupts an electric circuit to prevent unwanted current caused by short circuit typically resulting from an overload.

Rivets are considered to be semi-permanent fasteners i.e. they cannot be disassembled without breaking the rivet; non-permanent joints can be assembled and disassembled without damaging the components. Rivets having an application in many large scale industries like shipbuilding, boilers, pressure vessels, bridges, etc.

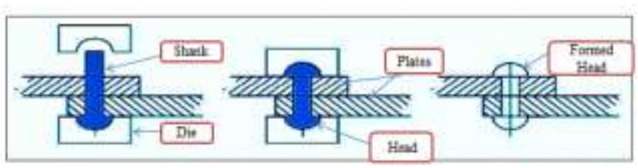

Fig.1.1: Riveting Process

According to Indian standard specifications, there are different types of the rivets heads. Rivet 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).

Riveting is done by placing the rivet in joint, Then the head is used as backing up bar and necessary force is applied on to the tail end with a die until the tail deforms plastically to the desired shape.

Rivet failure in aircraft is a combination of three factors: induced stresses during manufacture, thermal fatigue, and vibration of these, thermal fatigue and vibration are difficult to control.

The fatigue behavior of riveted joints is affected by many variables, often interrelated, associated with the design production and the stress level. Local residual membrane stresses generated due to hole expansion affect the crack initiation location, crack shape development and consequently the fatigue life of a joint. Residual clamping caused by a difference in the elastic spring back of the rivet and the sheets gives rise to friction between the sheets under applied loading. Friction promotes fretting fracture, accounts for some of the load transfer throughout the joint, and also modifies the membrane stress distribution in the rivet hole vicinity.

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Following fig. of component which is going to be analyzed in this project. This component is use for application of substation for breaking the circuit.

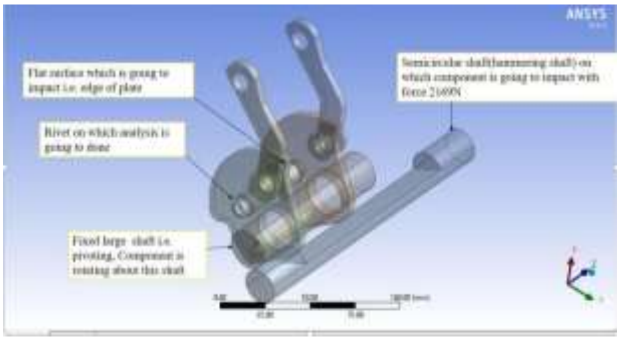

Fig.1.2: Component used in substation

2. Literature Review

"B. Langrand", "Full scale experimental characterization for riveted joint design", 21 June 2002. In this paper design of riveted joints were improved for airframe purposes. This research paper consists of lot of information about material state after the riveting process. The ARCAN test rig. was presented for multiaxial failure criterion for rivets.

Results obtained from ARCAN test in terms of angular maximum position and maximum load which showed failure mode was continue until α= 30˚ and failure propagation was oriented according to this angle. For angular position between 45˚ and 90˚ the rivet counter sank head was sheared. After that they were compared the ratio between maximum tension and shear loads to the ratio of effective shear and they obtained (Fmax/So)tension =~(Fmax/So)shear = 200Mpa. This gave structural effect due to rivet geometry. ARCAN tests were performed which was define experimental failure criterion of rivet by some configuration such as Pure tension (α= 0˚), Mixed shear/Tension (α= 15˚ , 30˚,45˚) and Pure tension (α= 90˚).In future this work was carried out with an ONERA grant.

"ZHANG Kaifu", "Riveting Process Modeling and Simulating for Deformation Analysis of Aircraft's Thin-walled Sheet-metal Parts", 29 October 2002. This paper were simulating to more accurately analyze deformation of thin-walled sheet-metal parts. This paper researches riveting process mathematics model and mechanics model for the elastic deformation, plastic deformation and spring back of the rivet were built. Then the rivet and two thin-walled sheet-metal parts of aluminum alloy used to analyze and simulate the stress and deformation based on ABAQUS system.

They were compared result of analytical and FEM model and proved that two are very approximate by taking the example of hammer which moved to limiting position T=0.50s shift of hammer was S=2.500mm and deflection of rivet δ=2.5mm according to table of deformation value the shift of 10th point calculated by ABAQUS system.

Error between results was calculated by following formula

$$Error = \frac{\delta lp - \delta ls}{\delta ls} = \frac{0.045 - 0.047}{0.0476} = 5.78\%$$

"Wojciech Wronicz", "Numerical Analysis of Riveted Lap Joint Used In Aircraft Structures", February 2006. This paper presents the results of FEM analysis of two rivet lap joints loaded with tension. The joint consists of two sheets with dimensions of 125x60 mm and nominal thickness of 1.2 mm made of 2024-T3 clad alloy Due to its symmetry, only a half of the joint was analyzed.

The article relates the numerical analysis of the riveted lap joint. This kind of joint very often occurs in passenger aircraft fuselages. The study was carried out within the EUREKA-IMPERJA project E! 3496 entitled "Improving the Fatigue Performance of Riveted Joints in Airframes". The project aims at improving fatigue performance of joints by working out the optimal riveting process parameters as well as rivet and joint geometry, and improving accuracy of fatigue estimating methods.

The FEM model was created with linear, solid elements. The MSC MARC solver was used. The preparation of the model as well as post processing were made with the MSC PATRAN and MARC MENTAT software.

During the first calculations, both punches moved simultaneously. Then the shape of the driven heads was unphysical, similar to the reversed cone. At the second stage, the joint was loaded with tension. Pressure of 65MPa was applied to the right end of the upper sheet.
The successful analysis of the riveting process and tension of the joint up to 61MPa was completed with the preliminary model. Above this value of tension stress convergence was not obtained.

"S. A.HASSAN", "Minimizing the Cost of Riveted Joints: A Nonlinear Programming Model", April 2006. In this research paper all satisfying stress and dimensional constraints were developed the terms of unknown variables. They were work on minimum cost of production and maintenance by taking two example and determined the riveted joint design which satisfied the stress, dimensional limitations and in lower possible riveting cost. Minimizing the cost of riveted joints some value criteria or utility function was formulated according to the availability of materials, data and technology in the current riveting industry.

They were examined by selecting the rivet material, diameter and number of rivets and which was decided by solving nonlinear model and by taking two example of brake disc and brake shoe. An optimal solution was found in case of brake was dr =8mm, n=14 rivets, σ=63N/mm² and in case of brake shoe was dr =6mm, n=14 rivets, σ=63N/mm². Their corresponding cost was calculated by following formula

$$C = n(-5.018 + 2.186dr + 0.1846\sigma)$$

In cost of rivet labor cost for making holes, labor cost for riveting and rivet cost was also considered. The calculated solutions result in the minimum cost of riveting.

"M. Skorupa", "Fatigue life prediction model for riveted lap joints", 23 March 2015. In this paper the effect of riveting on the fatigue life of a joint is characterized by measurable quantities, namely rivet hole expansion and the load transfer distribution. A validation of model was performed by comparing fatigue life's and observed over 80 fatigue tests on aluminum alloy, lap joint specimens with three rivets. Various combinations of production variables, such as sheet material and thickness, the squeeze stress and rivet type, were involved.

In this paper, the above mentioned experimental results, most relevant for the model formulation, are outlined first. The computed results are compared with those obtained from the model, in which the effect of riveting is disregarded, and the prediction quality of both approaches was evaluated through comparisons with fatigue test data. The fatigue tests were carried out on an MTS 810 fatigue machine. The specimen connection to the machine effectively prevented an in-plane bending, thus ensuring a homogeneously applied load on the specimen. All specimens were tested under constant amplitude uniaxial loading at a stress ratio of 0.1 with a frequency of about 20 Hz.

For a given sheet thickness and rivet type, hole expansion is closely related to the rivet squeeze stress level. Hence, a similarity of the riveting processes for the reference and actual joint was no longer required, which considerably extends the transferability of the reference results.

"Kale Suresh", "analysis of adhesively bonded single lap riveted joint using LS Dyna", 21 June 2012. In this paper, the analysis of adhesively bond on single lap riveted joints was done. In this paper the work involved the appropriate configuration and characterization of these joints for maximum utilization.

This papper includes the effectiveness of bond line thickness, the bonded layer configuration. This was also applicable to dissimilar thickness joints, but in this project they were placing the adhesives at different places for riveted joints. This improves the efficiency and life time of the riveted joints; this is also applicable to dissimilar thickness and dissimilar metals joints for balancing, uniform distribution of stress and without any effect of corrosion on dissimilar metals.

This was quite commonly used technique for finding the strength of different applications like pressure vessels, aerospace, marine and mostly for leak proof joints like oil tanks, boilers etc.. In this a lap joint of steel plate material having 100mm*1.5mm*20mm and a friction factor of 0.1 is over lapped with the other plate having same dimensions and material were joined by means of a rivet having diameter 4mm, apply a load of 500N on one side and the other end was fixed in the LS Dyna.

"MR. B. C. Huskamuri", "Stress analysis of riveted lap joint using FEM", March 2017. In this paper, for experimentation specimens were prepared and different thickness and configurations were considered. The results of experimental test allowed the influence of various parameters such as plate width and pitch. These results were compared with the LS Dyna result. The experimental test using Universal Testing Machine and shear stress results were calculated. These results were compared with model simulated in FEA software.

The shear strength obtained in single chain riveting by variation of pitch and thickness of plate shows maximum shear strength of 7.2 KN with pitch 21mm and thickness of plate 6mm. This suggest that, while using 5mm rivet diameter for single lap joint pitch 21mm and thickness of plate 6mm is recommended.

Increasing the pitch above 21mm results in poor shear strength and decreasing pitch length below 15mm will also reduce shear strength.

The shear strength obtained in double chain riveting by variation of pitch and thickness of plate shows maximum shear strength of 10.8 KN with pitch 21mm, transverse pitch 16.8mm and thickness of plate 3mm. This suggest that while using 5mm rivet diameter for double lap joint pitch 21mm and thickness of plate 3mm was recommended.

Increasing the pitch and transverse pitch and thickness of plate result in decreasing shear strength and decreasing shear pitch 15mm and transverse pitch 12mm below this plate causes tear and weaken the joint. From this all, it can be concluded that the experimental analysis was the most suitable and easy technique to identify the shear stress.

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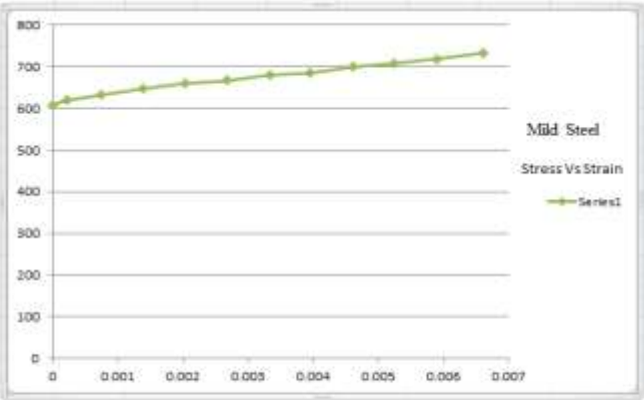
3. Experimental Validation

MS SS AL BRASS

Fig no.2.1: Different material breaking

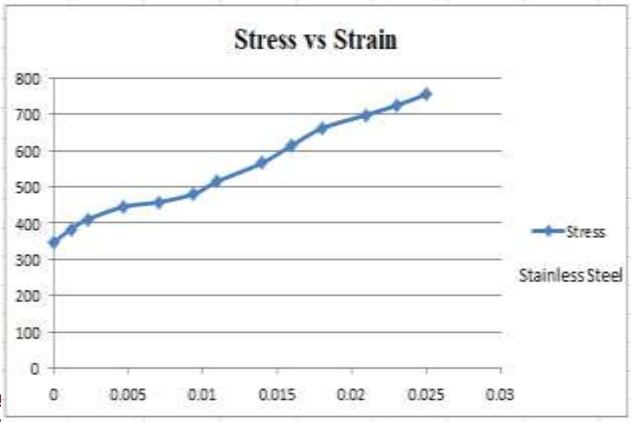
We have done tensile test on different material such as brass, aluminum, mild steel and stainless steel with the help of Universal Testing Machine. The data obtained from the test like material properties and stress vs. strain graph from UTM are used as input for LS-DYNA for simulation purpose.



Following are the results obtained from the UTM.

Materials	Allowable Stresses (MPa)
Mild Steel EN 14	733.04
Stainless steel	755.23
Aluminium	309.48
Brass	565.21

Following are the Stress v/s Strain graph for different materials made from the load v/s Displacement data obtained from UTM.

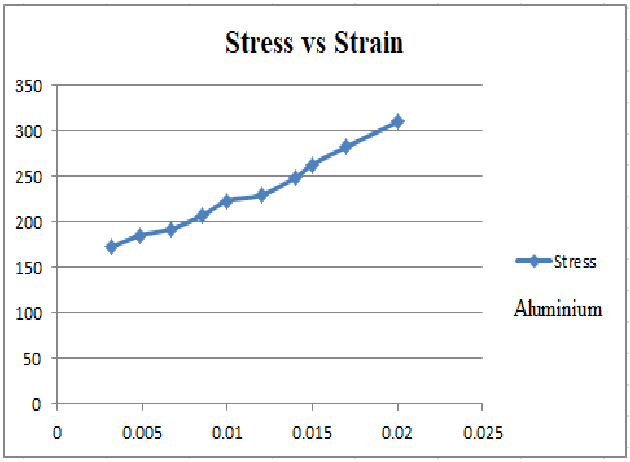


Mild Steel	
Stress (MPa)	733.04
Strain	0.00662

Graph no. 2.2: S.S

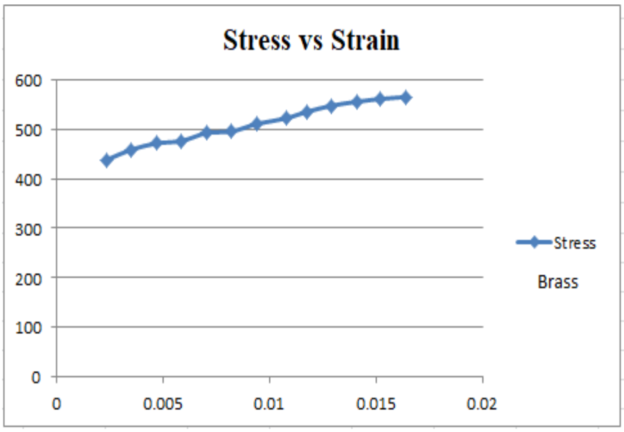
Graph no. 2.1: M.S

Stainless Steel	
Stress (MPa)	755.23
Strain	0.025



Graph no.2.3: Al

Aluminium	
Stress (MPa)	309.48
Strain	0.02



Graph 2.4: Brass

Brass	
Stress (MPa)	565.21
Strain	0.0164

Following are the figures which gives us stresses obtained from simulation for 6.05mm diameter with the help of LS-DYNA.

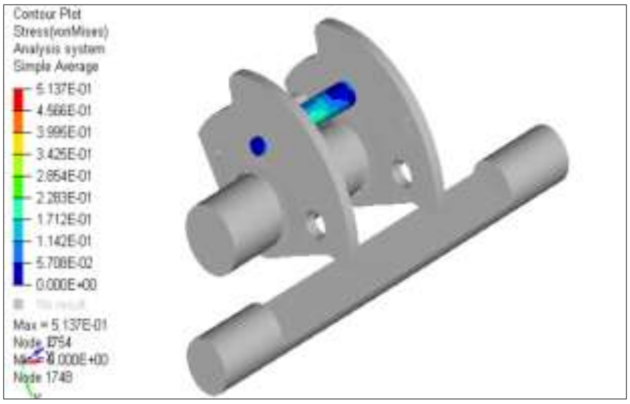


Fig no.2.2: Stresses after impact for M.S.

The above figure shows us the maximum stresses generated after the impact, from fig we can see that the maximum vonMises stress generated in rivet is 513.7MPa for 6.05mm diameter. This stress is less than the allowable stress for M.S. which is 733.04 MPa, also the cost of this material is less than other material selected, therefore we have choose to use mild steel rivet for our purpose.

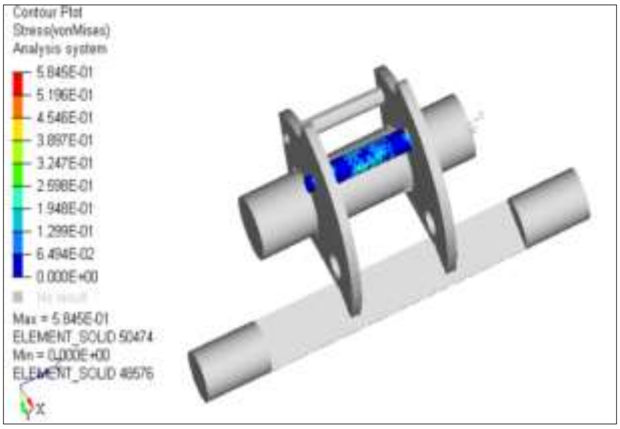


Fig 2.3: Stresses after impact for Stainless steel

The above figure shows us the maximum stresses generated after the impact, from fig we can see that the maximum vonMises stress generated in rivet is 584.5MPa for 6.05mm diameter. This stress is less than the allowable stress for S.S. which is 755.23 MPa, also the cost of this material is less but is more than mild steel therefore we have choose not to use stainless steel rivet for our purpose.

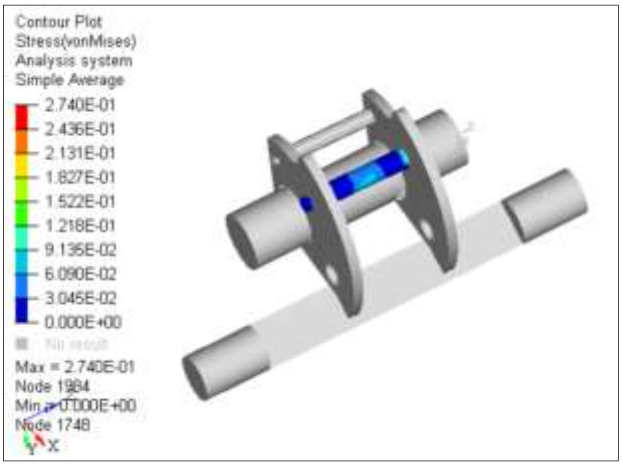


Fig no.2.4: Stresses after impact for aluminium

The above figure shows us the maximum stresses generated after the impact, from fig we can see that the maximum vonMises stress generated in rivet is 274 MPa for 6.05mm diameter. This stress is less than the allowable stress for aluminium which is 309.48 MPa, also the cost of this material is less than other material selected but its hardness is less compared to mild steel therefore we have choose not to use aluminium rivet for our purpose.

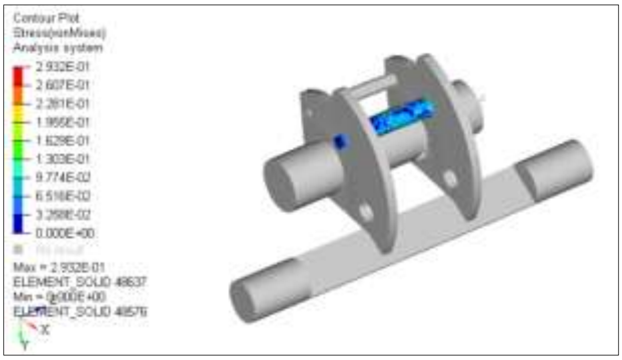


Fig no.2.5: Stresses after impact for brass

The above figure shows us the maximum stresses generated after the impact, from fig we can see that the maximum vonMises stress generated in rivet is 293 MPa for 6.05mm diameter. This stress is less than the allowable stress for brass which is 565.21 MPa, but the cost of this material is more than other material selected therefore we have choose not to use brass rivet for our purpose.

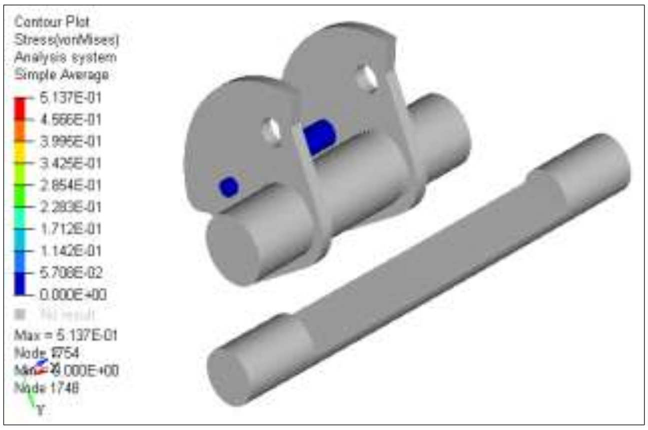


Fig.2.6: Stress analysis in LS-DYNA for 6.05mm diameter for material MS

Mild Steel EN 14 of diameter 6.05mm is best suitable for our project on the basis of cost and maximum stresses developed on rivet.

Following are the results obtained from LS-DYNA by considering a dynamic analysis on the component :

Stresses in MPa				
Dia.(mm) / Mat.	4.05	6.05	7.05	8.05
Mild Steel EN14	810	513.02	506	466.20
Stainless Steel	960	584.5	285.5	266.9
Aluminium	780	236.10	253.7	239.5
Brass	720	287.8	273.9	287.8

From UTM results Allowable stresses should be greater than stresses obtained from LS-DYNA.

Ex. From UTM allowable stress for material MS with 4.05mm diameter is 733.04MPa, which is greater than allowable stress from analysis which is 810MPa, as this is greater than allowable stress so this diameter of rivet is not suitable for our purpose, above condition is satisfied in 6.05mm diameter for all material but as per the cost point of view, we have selected mild steel EN 14 as its stresses are also within permissible limit which satisfies our project needs. Diameters 7.05mm and 8.05mm also suitable for this project but it will cause more cost, so we have selected M.S. EN 14 which is cheap compare to other materials.

4. CONCLUSIONS

In this research, special purpose rivets of various diameters were analyzed in order to select the optimum diameter, also four different materials (Mild Steel EN14, Aluminium, Brass, Stainless steel) were tested on Universal Testing Machine to find their stress strain properties. This stress strain data was given as input to LS-DYNA for simulation purpose. The 3D model was made in PTC Creo. The meshing of the 3D model was done in HyperMesh and the mesh used was tetrahedron. The simulation was done in LS-DYNA and the results obtained were the maximum stresses in the rivet. The Stresses found were vonMises stresses. The vonMises stress for M.S. was 513.02 MPa, S.S was 584.5 MPa, Aluminium was 236.10 MPa and for Brass was 287.8 MPa.

The above results were obtained from LS-DYNA and by analyzing the above results we can conclude that Mild Steel EN14 of diameter 6.05mm is best suitable for our purpose, also it has been observed that as the diameter increases the stress gets reduced. While studying the stresses we have also observed that aluminium has good energy absorption properties. Also Finite element method is found to be the most effective tool for designing and analysis of mechanical components like rivets.

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