Stress Analysis Of Riveted Butt Joint

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Abstract

Riveted joints are used in many structural works like ship buildings, in bridge structure and in manufacturing of boiler shells etc. The failures of riveted joint takes place by tearing of the plate, shearing of rivet and crushing of rivet and plate under the action of overloading. Hence the stress pattern in riveted butt joint by varying parameters like thickness of plate, linear pitch, transverse pitch and method of riveting is studied. In this research, analytical, numerical and experimental stress analyses are carried out. For analysis purpose virtual model of riveted butt joint is prepared in Pro-E. And this CAD model is imported in ANSYS software where stress analysis is done by FEM. This analysis shows that, to have safe joint it is better to increase the thickness of main plate and linear pitch instead of increase in transverse pitch. Also the analysis shows that von-mises stresses obtained in chain riveting are lesser as compared to diamond and zig-zag riveting. From this, it can be concluded that chain riveting is the most safe method of riveting. From the analysis, it is revealed that the analytical results obtained are in good agreement to F.E.A results.

Keywords: *FEM, Riveted Joints, Shearing stress, Tearing stresses*

1. Introduction

For nearly a century, rivets are used for permanent joints between plates of boiler shell, structural members of bridges and part of railway wagons and coaches. For making a riveted joint, a hole has to be drilled in the plate to be connected. Riveting is used in many applications, such as cold riveting of thin sheets, riveting sheets of aeroplane structures, etc. Riveting is much faster and also the cheapest process of producing a permanent joint. There are two types of riveted joints, butt joint and lap joint. A butt joint is that in which the main plates are kept in alignment butting (i.e. touching) each other and a cover plate (i.e. strap) is placed either on one side or on both sides of the main plates. The cover plate is then riveted together with the main plates. The failures of riveted joint takes place by tearing of the plate, shearing of rivet and crushing of rivet and plate under the action of overloading. Hence the stress pattern in riveted butt joint by varying parameters like thickness of plate, linear pitch, transverse pitch and method of riveting is studied.

2. Introduction to Problem, Scope and Methodology

In this research riveted joints using different elements under static load conditions are analyzed. For this purpose single rivet double strap joint is considered under static loading conditions. Due to riveting process complex residual stress state is introduced for the riveted joint (both for the rivet and the plates). During the installation process the plates are pressed together by the deformed rivet. This causes surface contact stresses between the joined plates. The stresses are obtained analytically. Then a 3-D model is prepared in Pro-E software and its stress analysis is done by F.E.M. using ANSYS by varying parameter such as thickness of main plate (t), linear pitch (p) and transverse pitch (pt). Also the analysis is done for chain, diamond and zig-zag riveting using same number of rivets in each main plate. The experimental test model is prepared using aluminium alloy plate and rivet. The test is carried out in universal testing machine to determine shearing strength of rivet by applying tensile load on main plate. The plate and rivet are made up of aluminium alloy and its mechanical properties are tabulated in Table.1.

ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

Table 1 Properties of Material

Modulus of Elasticity (Mpa)	E	71000
Poisson's ratio	ν	0.33
Density of material (Kg/mm^3)	ρ	2.77e^{-006}

3. Analytical Stress Analysis of Riveted Butt Joint

The analytical stress calculations for riveted butt joint are performed using following relations [1].

- Tearing stress in a plate per pitch length

$$\sigma t = \frac{f}{n(p-d)*t}$$

Stress concentration factor (k_t = 2.35) is consider for the tearing of plate

- Shearing stress on rivet

$$\tau = \frac{f}{n*2*(\frac{\Pi}{4})*d2}$$

- Crushing stress on rivet and plate

$$\sigma c = \frac{f}{n*d*t}$$

- Maximum shear stress

$$\tau_{max} = \frac{1}{2}[\sqrt{\sigma t^2 + 4\tau^2}$$

- Maximum principal stress

$$\sigma_1 = \frac{\sigma t}{2} + \frac{1}{2}[\sqrt{\sigma t^2 + 4\tau^2}]$$

- Equivalent stress (Von-mises stress)

$$\sigma_{eq} = \sqrt{\sigma^2 + 3\tau^2}$$

4. Finite Element Analysis of Riveted Butt Joint

In this chapter, three-dimensional stress field solutions are obtained in the single riveted double strap joint geometric configuration under both the residual stress field and external tensile loading. Three-dimensional finite element models of riveted butt joints have been developed using a commercial finite element program ANSYS (Workbench). Nonlinearity arising from the interaction (frictional contact condition) between the rivet and Plates was incorporated in the model. The local stress state in a riveted butt joint is very complex due to the residual stress (clamping stress applied by rivet heads and radial pressure applied by rivet expansion) resulting from rivet installation process, surface shear within the contacting zone due to load transfer through friction, pin loading at hole due to load transfer through rivet shear, secondary bending effects of the joint, and biaxial tension in plates due to the applied tensile load.

Thus the results obtained from finite element analysis are shown in table 2 and fig. 1 to 5.

Table 2 Finite element analysis results

Sr. no.	Stress in single riveted double strap butt joint	F.E.A. stresses	Analytical stresses
1	Tearing stress (σ_t) in plate (Mpa)	276-390	322.02
2	Shear Stress (τ) in rivet (Mpa)	11-70	67.85
3	Max. shear Stress (τ_{max}) in rivet (Mpa)	53-102	96.52
4	Max.Principal Stress (σ_1) in rivet (Mpa)	87-166	165.07
5	Von-mises stress (σ_{eq}) in rivet (Mpa)	90-188	180.49

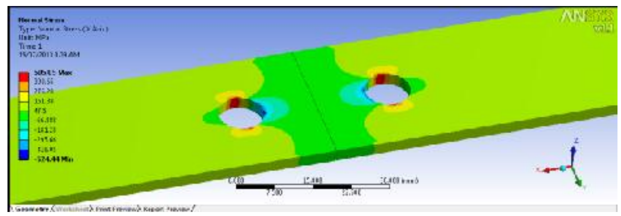

Fig. 1 Tearing stress contour on main plate with 3 mm thickness

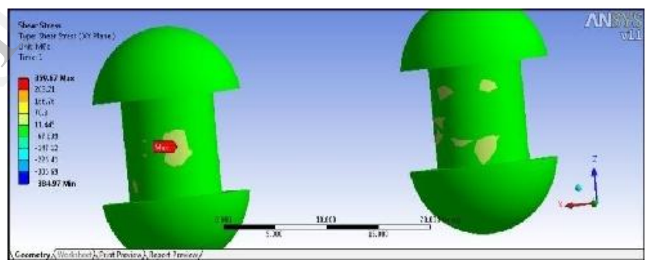

Fig.2. Shear stress contour on rivets with 3mm thickness of main plate

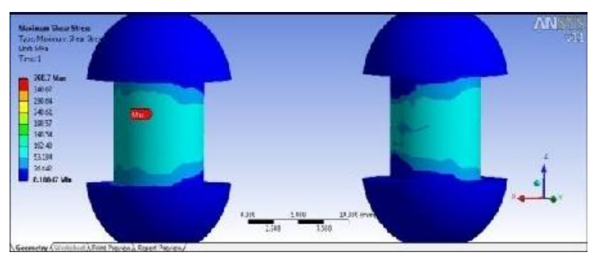

Fig.3. Maximum Shear stress contour on rivets with 3mm thickness of main plate

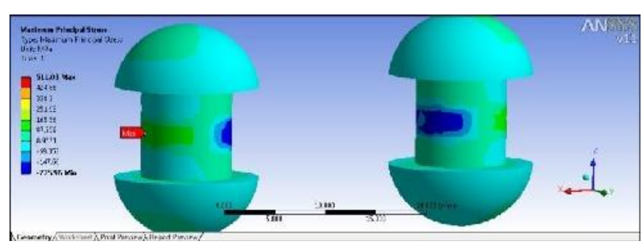

Fig.4. Maximum principal stress contour on rivets with 3mm thickness of plate

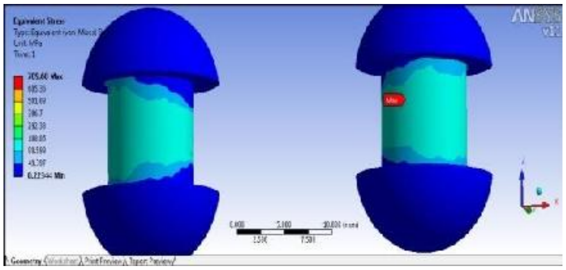

Fig.5. Von-mises stress contour on rivets with 3mm thickness of plate

5. Experimental Stress Analysis of Riveted Butt Joint

A single riveted butt joint as shown in fig.6 is considered for determination of shearing strength. A prototype of rivet joint is prepared and it is tested on universal testing machine (UTM). The photograph of experimentation is shown in fig. 7. And the shearing stress thus determined is 67.85 MPa.

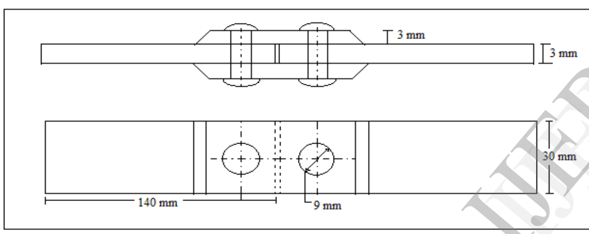

Fig.6 Dimension for test specimens

Fig. 7 Failure of test specimen

6. Results and Discussions

The comparison between finite element analysis and analytical analysis result are as shown in table 3 and fig.8 to 12.

Table 3 Observation between FEA and analytical values by varying thickness of main plate

Stresses in riveted butt joint (MPa)	FEA stresses			Analytical stresses		
	Thickness of main plate (t) in mm			Thickness of main plate (t)(mm)		
	3	4	5	3	4	5
Tearing stress (σ_t)	280-393	190-290	171-245	322	242	193
Shear Stress (τ)	10-71	11-71	11-71	67.8	67.8	67.8
Max. shear Stress (τ_{max})	56 – 108	56-91	53-90	97	85	79
Max.Principal Stress (σ_1)	87 – 169	92-157	85-146	165	136	120
Von- mises stress(σ_{eq})	112-195	98-163	94-154	181	156	143

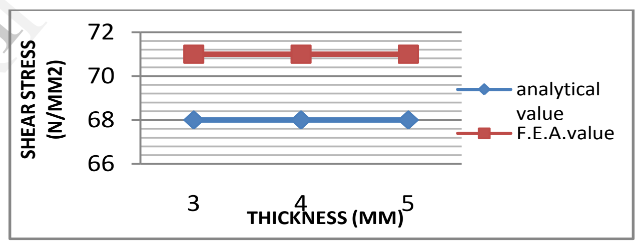

Fig. 8 Variation of shear stress w.r.t. thickness of main plate

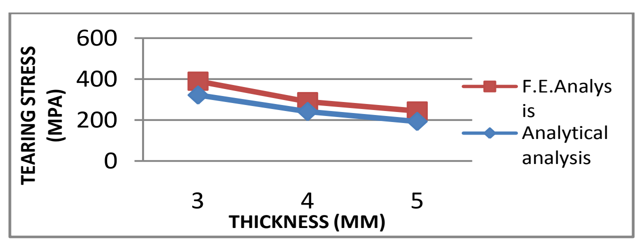

Fig. 9 Variation of tearing stress (normal stress) in plate w.r.t. thickness of plate.

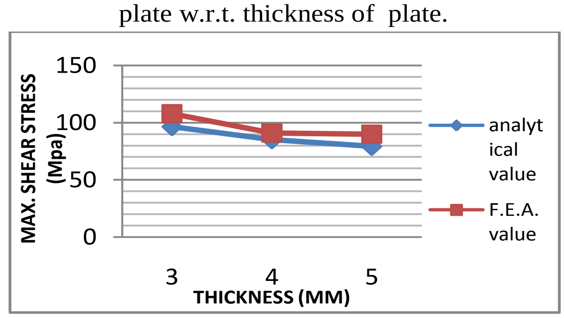

Fig. 10 Variation of maximum shear stress in rivet w.r.t. thickness of main plate.

ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

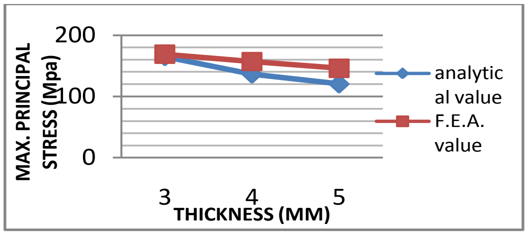

Fig.11 Variation of maximum principal stress in rivet w.r.t. thickness of main plate.

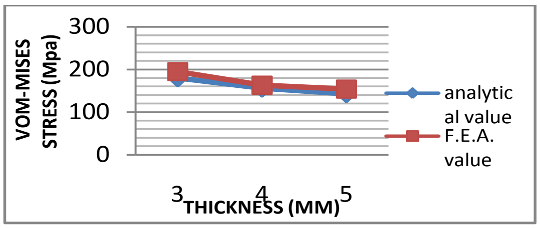

Fig.12 Variation of von-mises stress in rivet w.r.t. thickness of main plate

From table 3 and fig. 8 to 12 it is observed that good agreement is obtained between analytical and F.E.A results. The following observations are obtained.

- From fig.8, it is observed that there is no effect of thickness of the main plate on shear stress in rivet.
- From fig.9, it is observed that there is decrease in normal stress (tearing stress) in plate with increase in thickness of main plate.
- Fig.10 shows that there is decrease in maximum shear stress in rivet with increase in thickness of main plate.

- Similarly fig.11 and fig.12 depicts that decrease in maximum principal stress and von-mises stress in rivet with increase in thickness of main plate.

Table 4 Observation between FE and analytical analysis values by varying linear pitch of rivet

Stresses in riveted butt joint(MPa)	FEA Values			Analytical Values		
	Linear Pitch of Rivet (p) in mm			Linear Pitch of Rivet (p) in mm		
	54	58	62	54	58	62
Tearing stress(σ_t) in plate	514 - 670	528 - 670	415 - 531	555	499	454
Shear Stress (τ) in rivet	17 – 69	13 - 6	9– 69	66.8	66.8	66. 8
Max. shear Stress τ_{max}) in rivet	78 – 139	65– 128	61 – 120	135	125	117
Max.Principal Stress (σ_1) in rivet	104 - 230	97 – 209	42 – 194	254	232	214
Von- mises stress (σ_{eq}) in rivet	169 - 269	106 - 246	114 - 227	263	242	225

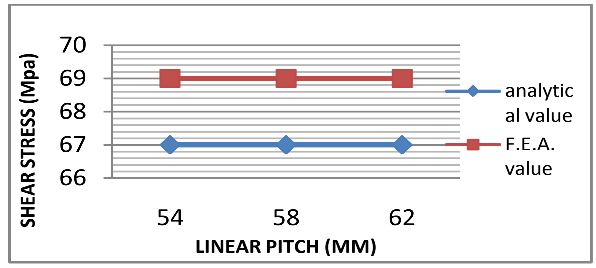

Fig. 13 Variation of shear stress w.r.t. linear pitch of rivet

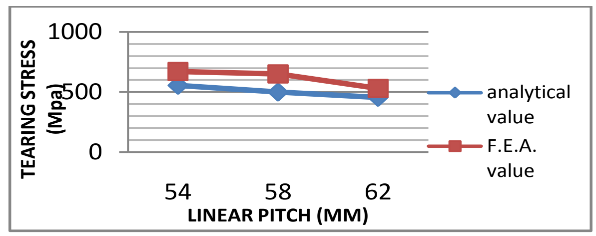

Fig.14 Variation of tearing stress w.r.t. linear pitch of rivet

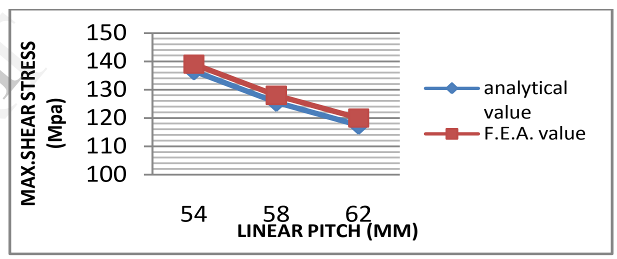

Fig.15 Variation of maximum shear stress w.r.t. linear pitch of rivet

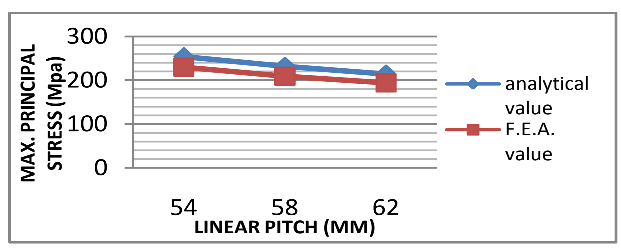

Fig. 16 Variation of maximum principal stress w.r.t. linear pitch of rivet

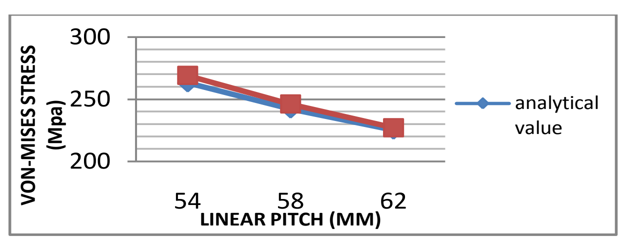

Fig. 17 Variation of von-mises stress w.r.t. linear pitch of rivet

From the table 4 and fig 13 to fig.17, it is seen that

- There is no effect of linear pitch of the rivet on the shear stress in the rivet.
- There is decrease in tearing stress (normal stress) in the main plate with increase in linear pitch of rivet.
- There is decrease in maximum principal stress, maximum shear stress and von-mises stress in rivet with increase in linear pitch of rivet.

Table 5 Observation between FE and analytical analysis values by varying transverse pitch of rivet

Stresses in riveted butt joint (MPa)	FEA Values			Analytical Values		
	transverse Pitch of Rivet(p)in mm			transverse Pitch of Rivet (p) in mm		
	18	20	22	18	20	22
Tearing stress (σ_t) in plate	514-670	545-690	544-689	555	555	555
Shear Stress (τ) in rivet	17–69	10-69	4–69	66.8	66.8	66.8
Max.shear Stress (τ_{max}) in rivet	78–139	72–139	70–139	135	135	135
Max.Principal Stress (σ_1) in rivet	104-230	94 – 230	101-231	254	254	254
Von- mises stress (σ_{eq}) in rivet	169-269	149-267	132-264	263	263	263

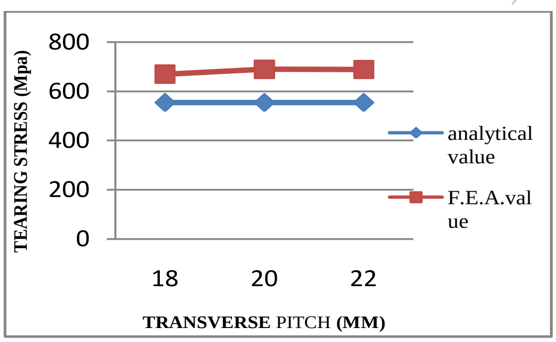

Fig. 18 Variation of tearing stress w.r.t. transverse pitch of rivet

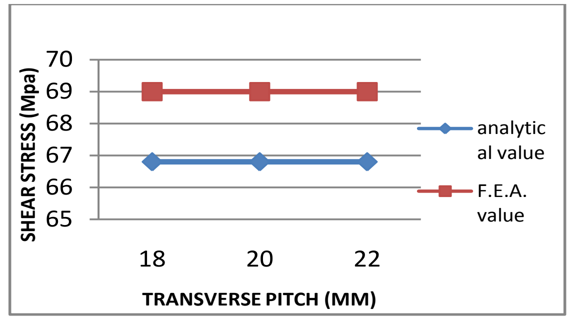

Fig. 19 Variation of shear stress w.r.t. transverse pitch of rivet

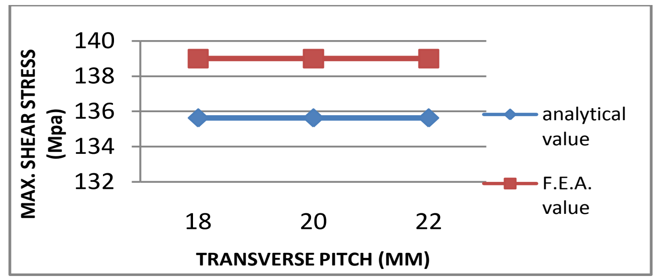

Fig. 20 Variation of maximum shear stress w.r.t. transverse pitch of rivet

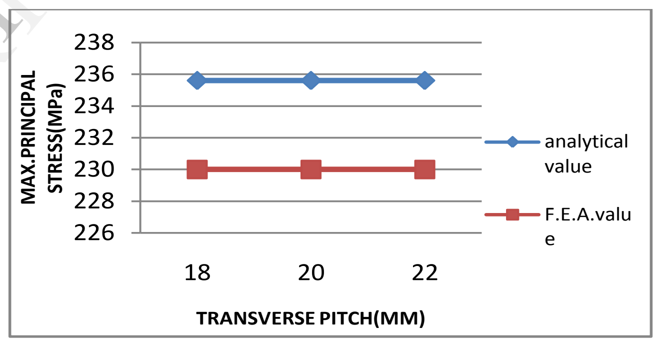

Fig. 21 Variation of maximum principal stress w.r.t. transverse pitch of rivet

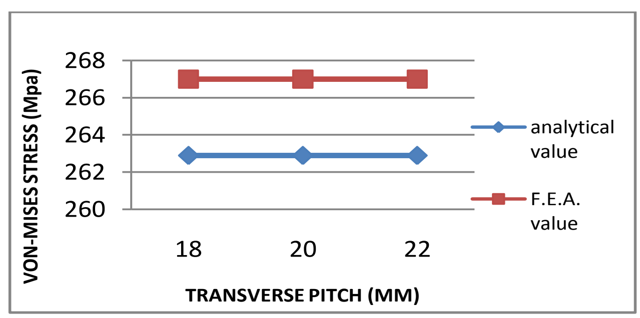

Fig. 22 Variation of von-mises stress w.r.t. transverse pitch of rivet

From the table 4 and fig.18 to fig.22 it is observed that there is no effect of variation in transverse pitch on the stresses developed in main plate and rivet.

Table 5 Observation between FE and analytical analysis values by varying riveting method.

Stresses in riveted butt joint (MPa)	FEA Values			Analytical Values		
	Method of reveting			Method of reveting		
	Diamond riveting	Zig-zag riveting	Chain riveting	Diamond riveting	Zig zag riveting	Chain riveting
Tearing stress (σ_t) in plate	522 - 656	507 - 657	497 - 634	554.9	634.	555
Shear Stress (τ) in rivet	14 – 69	6 - 69	17 – 69	66.80	66.8	66.8
Max. shear Stress (τ_{max}) in rivet	60 - 141	97 - 154	78 – 139	135.5	151	135
Max.Principal Stress (σ_1) in rivet	105 - 259	46 - 288	104 - 230	253.5	285	254
Von-mises stress (σ_{eq}) in rivet	149 - 297	183 - 298	169 - 269	262.8	294	263

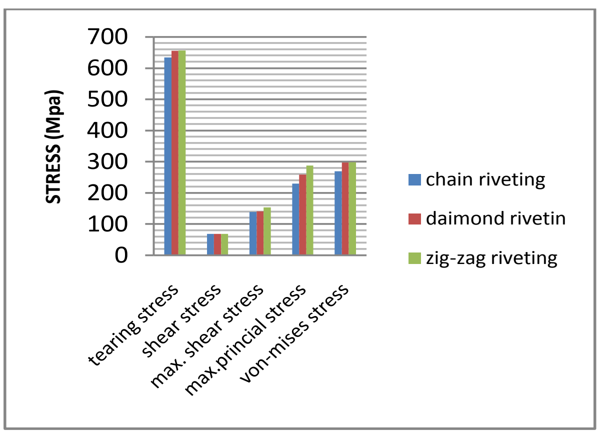

Fig.23 Variation of stresses w.r.t. method of riveting

From table 5 and fig.23 it is found that minimum stresses are induced in chain riveting as compared to other method of riveting. Hence the chain riveting produces 10 % to 11 % more safe joint as compared to diamond and zig-zag riveting.

7. Conclusion

The experimental determination of breaking strength of riveted butt joint revealed the shearing strength of rivet 8633 N (i.e. 67.85 MPa) .The F.E analysis of riveted butt joint for same geometry revealed the shear stress of 70 MPa. This investigation confirmed that shearing stress in the rivet determined by experimentation and F.E. analyses are in close agreement. Analytical and F.E. static stress analysis of riveted butt joint is performed by varying parameters like thickness of main plate, linear pitch of rivet, transverse pitch of rivet and method of riveting, from which it is revealed that the result obtained are in good agreement to each other. Looking at variation of von-mises stress with respect to thickness of main plate (t) and linear pitch (p) it is found that the stresses decreases with increase in value of these parameters. There is no effect of transverse pitch on the stress. Hence to have safe joint, it is better to increase the thickness of main plate and linear pitch instead of increase in transverse pitch. Also the analysis shows that von-mises stresses obtained in chain riveting are lesser as compared to diamond and zig-zag riveting. From this, it can be concluded that chain riveting is the most safe method of riveting.

8. References

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