Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 4, Issue 2; April-June, 2017 pp. 103-108

http://www.krishisanskriti.org/Publication.html

Modeling and Structural Analysis of Boiler Shell with Riveted Joints

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Abstract—*Pressure vessels, boilers or steam generators with riveted joints are the closed vessels and generally used for storing pressurized fluids in the severe pressure and temperature conditions. This paper studied the finite element analysis of the boiler shell with riveted joints under static condition when shell is subjected to internal pressure along with analytical method. In the present work design and analysis of boiler shell with riveted joints using ANSYS software has been carried out using structural steel and aluminium alloy. The model of boiler shell has been developed in CATIA V5 and SOLID-WORKS. Then, model is saved in parasolid x_t file in solid works and imported in ANSYS workbench. Static analysis of boiler shell has been carried out. The result for equivalent and maximum shear stress has been compared with analytical results. Then stress value compared for structural steel and aluminium alloy for same working conditions.*

Keywords*: FEA, finite element modeling, ASME codes and standards, ANSYS*

1. INTRODUCTION

Universally Pressure vessels have been used in power plants, nuclear power sectors and military as well as in petroleum industries for many years. These vessels contains fluids (liquid or gas) which are subjected to high pressure, high thermal stresses and various types of loads which may be in static or dynamic conditions during services. Various factors viz. the shape, material used, chemical composition, environment conditions of vessels and physical substances etc. effects vessels and are used while designing the pressure vessels. Each of the factors has different effects on the performance of the pressure vessels. The fluid being stored may undergo a change of state inside the pressure vessel as in the case of steam boiler or it may combine with other reagents as in chemical plants. So, the pressure vessels should be designed with utmost care as per ASME or IBR norms and specifications otherwise rupture of the pressure vessels means an explosion which may cause loss of life as property. Generally, pressurized fluid or gas storing vessels are made of uniform thickness and known by the maximum circumferential stresses due to internal pressure, but the stress along the length is 1⁄2 of the circumferential stress So, the longitudinal joints makes more strong than circumferential joints. Pressure vessels and boilers with welded joints or riveted joints should be fabricated and designed as per ASME standards of the design of pressure vessels. It's necessary to design these vessels to sustain such types of load. Due to this reason, the pressure vessels are designed on the basis of lap joint. But at the recent time, due to advancement in technology, CAD and FEA tools are used for modeling and analysis purpose of pressure vessels.

2. LITERATURE REVIEW

Farah et al. [1] developed software for automating the design analysis of rivets for boiler shells. The aim of development of this software was to present a method of effective use of general purpose programs in the design analysis.

Heckman David [2] studied the FEA result of pressurized vessel and analysis is had been made on a three dimensional, symmetric and asymmetric models, than the primary conclusion was made that finite element analysis is the extremely powerful tool for the analysis purposes when used in a correct manner.

William Barnet Le Van [3] studied the riveted joints in boiler shell and concluded that it is familiar to have the rivets hole one sixteen of an inches in diameter larger in rivet in order to allow their expansion when rivet is hot, however the difference between diameter of rivet hole and the rivet diameter should vary with size of rivet.

Nidhi et al. [5] studied pressure divination of pressure vessel with the help of finite element analysis. The main motto of the study was to suggest different type of finite element methods to find out the burst strength of pressure vessel.

Kale et al. [4] studied the riveted joints with the use of adhesive using the Finite Element Analysis method. This work involved the appropriate design and characterization of such type of joints for extreme utilization. This study involves the usefulness of bend line thickness and bonded layer configuration

Gutman et al. [6] studied suitability of thin wall high pressure vessels under corrosion. The researcher proposed a method to determine the critical time of loss in stability of thin wall high pressure vessels prone to uniform corrosion on the inside surface. This method is established on proposed thin elastic cylindrical shell model.

Masayuki et al. [7] Investigated failure pressure of straight pipe having thinning of wall subjected to internal pressure. FEM analysis has been done to analyze the burst pressure. Three types of materials have been used for this analysis purpose i.e. steel, stainless steel and carbon steel. .

3. DESIGN OF ANALYTICAL PROBLEM

A problem is introduced for the purpose of validation and completion of the presented work.

Inner diameter of the boiler shell (D) = 1500mm

Inner steam pressure (P) = 2N/mm^2

The following permissible stress values are used.

Tensile stress (σ_t) = 90MPa

Shear stress (τ) = 75MPa

Crushing stress (σ_c) =150MPa

Thickness of boiler shell (t) = 22mm

Rivet diameter (d) = 28.37mm

Rivet diameter (d_1) = 27mm

Pitch (p) $\approx$105mm

Margin (m) = 42.56mm

Cover plate thickness (t) = 13.75mm

Maximum principle stress (σ_1) = 90 MPa

Minimum principal stress $(\sigma_3) = 2$ MPa (pressure at inner surface)

Von-Mises stress $(\sigma_e) = [\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}\ ]$ /2 = 87.64 MPa

Maximum Shear Stress = $(\sigma_1-\sigma_3)/2$ = 44 MPa

4. CAD MODELING

CAD modeling is done with the help of CATIA V5 and SOLID WORKS compactable design software.

Figure 1: 3-D CAD model of boiler shell

5. FINITE ELEMENT MODELING AND BOUNDARY CONDITIONS

After designing 3-D symmetric model, it is imported in ANSYS workbench. Then meshing is done with the help of patch conforming method. Mesh refinement is carried out until the radial stresses at the most of the inner surface and outer surface of the boiler shell is closely match with 2MPa and zero respectively. Then three displacement and one pressure force of 2MPa at the inner surface of boiler shell is applied as the boundary conditions.

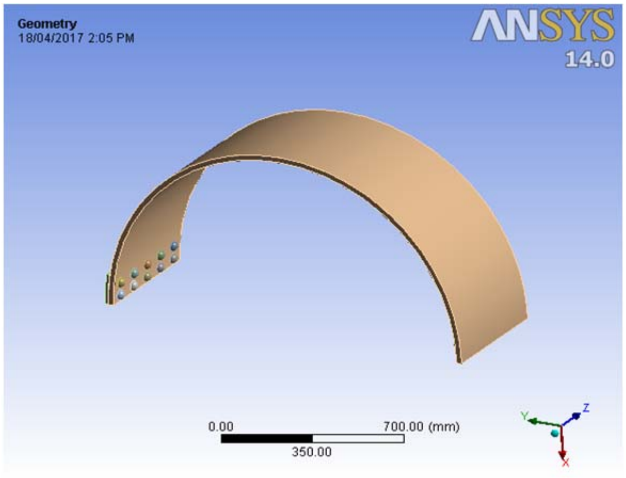

Figure 2: Symmetric boiler shell in ANSYS work bench

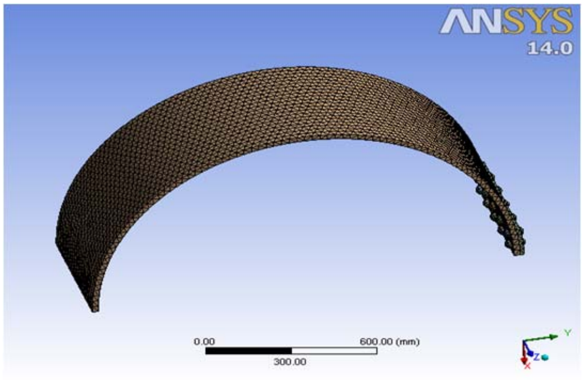

Figure 3: Meshing of symmetric boiler shell

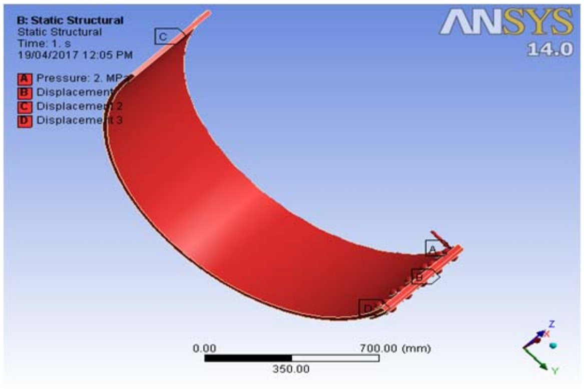

Figure 4: Pressure and displacement supports on the model

6. MATERIAL PROPERTY FOR BOILER SHELL ANALYSIS

Static structural analysis has been done for boiler shell. For analysis purpose two ductile materials structural steel and aluminium alloy has been used under same working conditions.

Table No.1.1: Material Properties of Structural Steel and Aluminium Alloy

Property	Structural Steel	Aluminum Alloy
Young's Modulus, (E)	$2 \times 10^5 \mathrm{MPa}$	$7.1 \times 10^4 \mathrm{MPa}$
Poisson's Ratio	0.30	0.33
Tensile Ultimate strength	460MPa	310MPa
Tensile Yield strength	250MPa	280MPa
Compressive Yield strength	250MPa	280MPa
Density	$7850 \mathrm{kg/m^3}$	$2770 \mathrm{kg/m^3}$
Behavior	Isotropic	Isotropic

7. STATIC STRUCTURAL ANALYSIS OF BOILER SHELL FOR STRUCTURAL STEEL

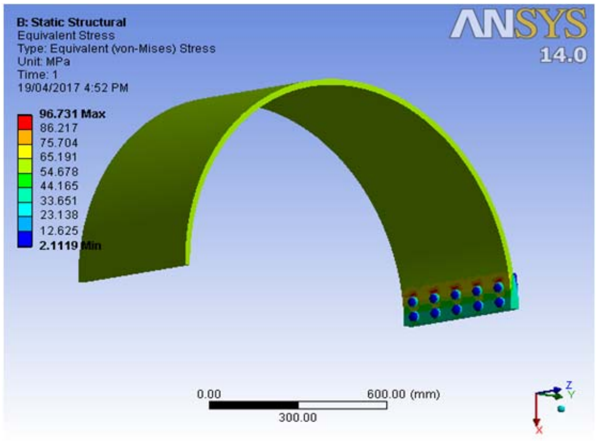

Figure 5: Equivalent (Von-Mises) stress for each element in the boiler shell

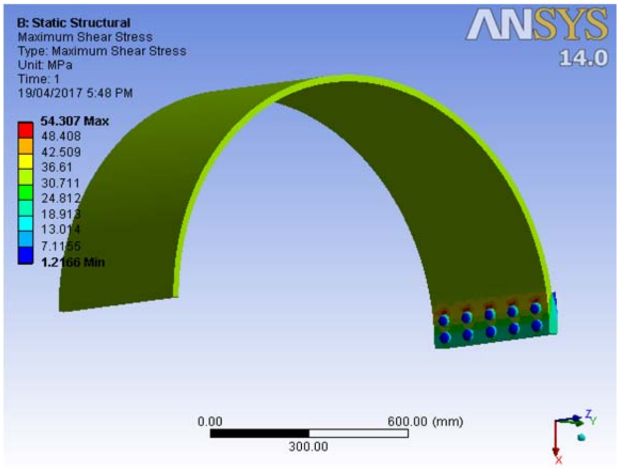

Figure 6: Maximum shear stress for each element in boiler shell

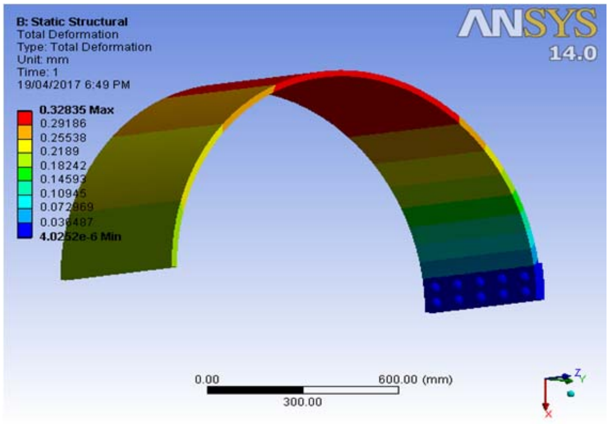

Figure 7: Total deformation for each element in boiler shell

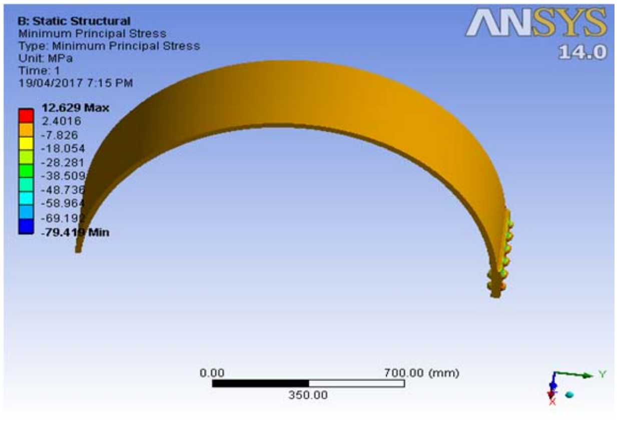

Figure 8: Minimum principal stress for each element in boiler shell

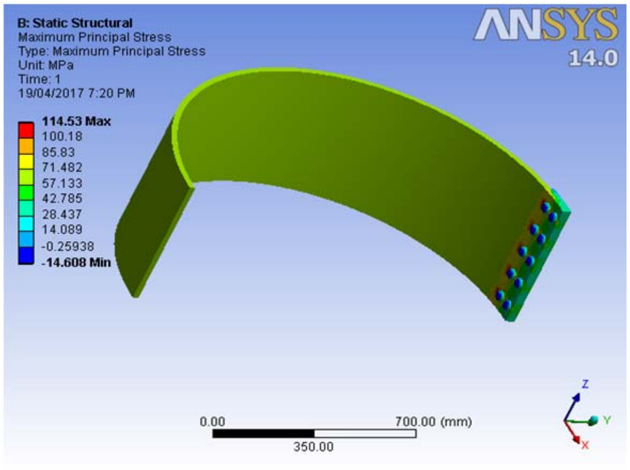

Figure 9: Maximum principal stress for each element in boiler shell

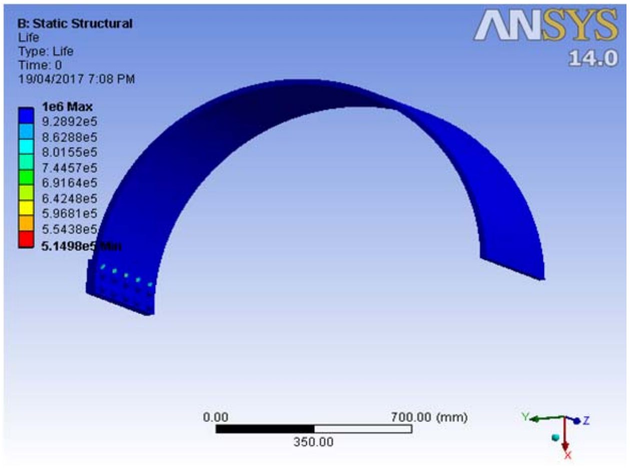

Figure 10: Fatigue life for each element in boiler shell

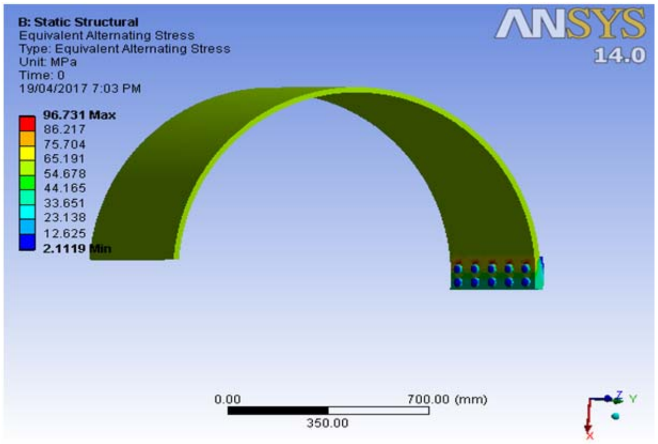

Figure 11: Equivalent alternating stress for each element in boiler shell

Table 1.2: Comparison of theoretical results with FEM results

S.No.	Stress	Analytical Results (MPa)	FEA Results (MPa) (Excluding local stress)
1.	Maximum principal stress	90	100.18
2.	Minimum principal stress	2	2.40
4.	Von-Mises stress	87.64	86.217
5.	Maximum shear stress	44	48.408

8. STRUCTURAL ANALYSIS OF BOILER SHELL FOR ALUMINIUM ALLOY

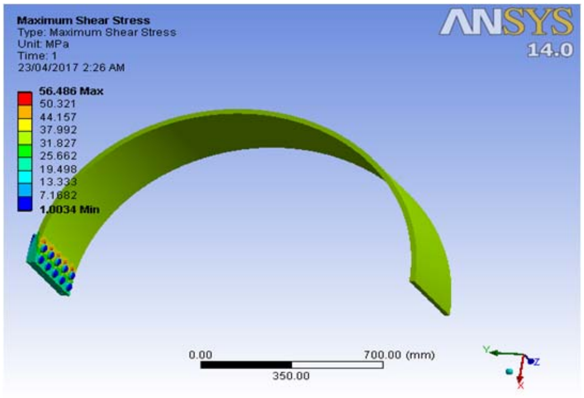

Figure 12: Maximum shear stress for each element in boiler shell for aluminum alloy

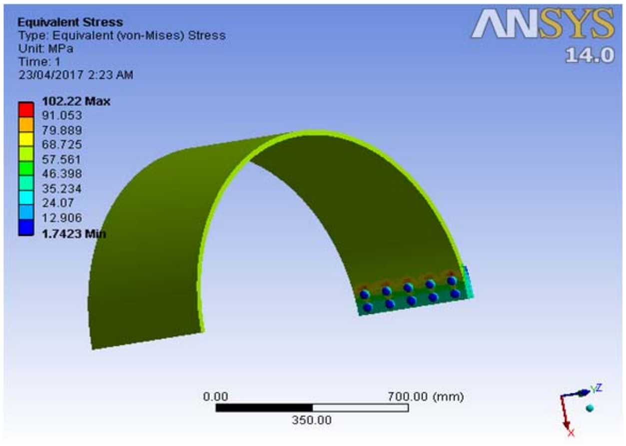

Figure 13: Equivalent (Von-Mises) stress for each element in boiler shell for aluminum alloy

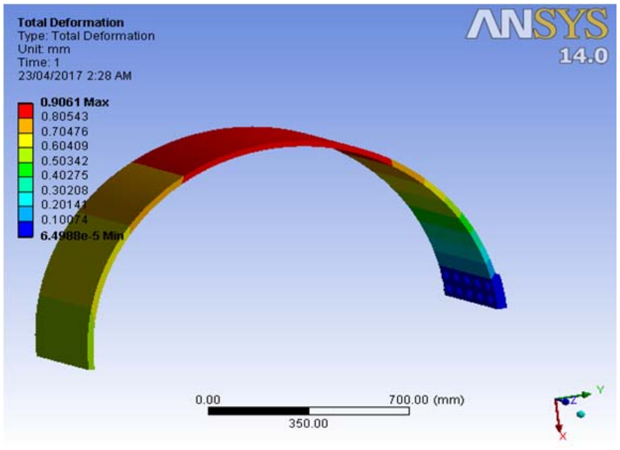

Figure 14: Total deformations for each element in boiler shell for aluminum alloy

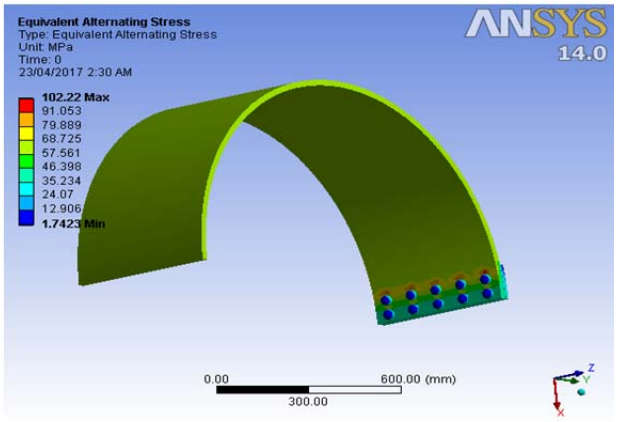

Figure 15: Equivalent alternating stresses for each element in boiler shell for aluminum alloy

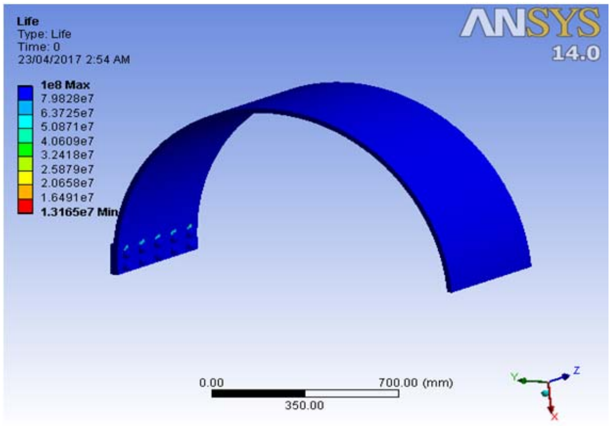

Figure 16: Fatigue life for each element in boiler shell for aluminum alloy

Table 1.3 Analysis result comparison of structural steel and aluminium alloy

S.No.	Parameters	FEA results for structural steel	FEA results for aluminum alloy
1.	Equivalent Von-Mises stress	96.731MPa	102.22MPa
2.	Maximum shear stress	54.307MPa	56.486MPa
3.	Total deformation	0.32835mm	0.9061mm
4.	Equivalent alternating stress	96.731MPa	102.22MPa
5.	Fatigue life	5.1498e5 cycles	1.3165e7cycles

9. S-N CURVES FOR STRUCTURAL STEEL AND ALUMINIUM ALLOY

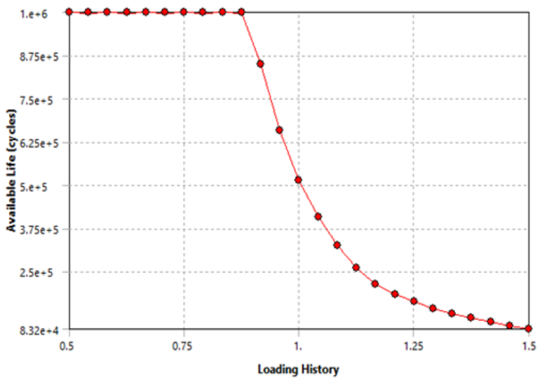

Figure 17: S-N curve for structural steel

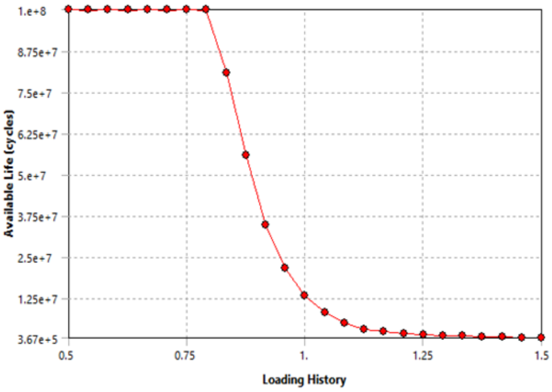

Figure 18: S-N curve for aluminium alloy

10. COMPARISONS OF VON-MISES STRESSES AT INCREASING INNER PRESSURE

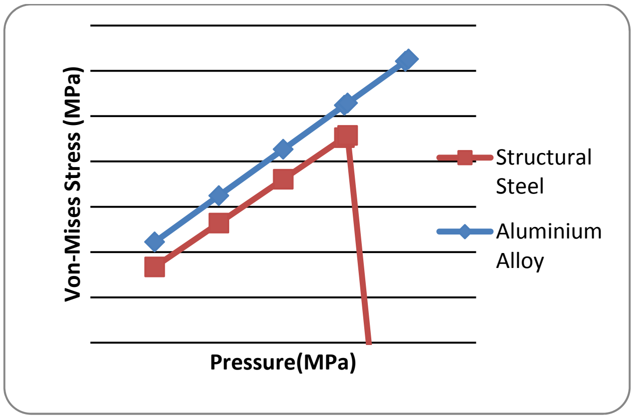

Figure 19 : Von-Mises stresses values for steel and aluminium alloy at incresing inner pressurein boiler shell

11. RESULTS AND DISCUSSIONS

Figure 8 shows the minimum principal stress at most of the inner boiler shell surface is 2.40MPa which is closely match with the applied pressure. Figure 5 shows the equivalent stress of 96.731MPa (include local stress) for 2MPa boiler shell pressure and act at inner surface near to rivet hole shown in red color. Its value is 86.517MPa (excluding local stress) and closely match with the analytical result. Maximum principal stress and maximum shear stress shown in figure 5and 2 has values 100.18 and 48.408 which is excluding the local stress and closely match with analytical results. Figure 7, 11 and 10 shows total deformation, alternating stress and fatigue life for structural steel respectively. Table 1.2 shows the comparisons of analytical and FEM results. Figure 12-16 shows the FEM analysis results for aluminum alloy. Table 1.3 shows the comparison of analysis results for steel and aluminium alloy. S-N curves for steel and aluminium and Von-Mises stress value for at increasing inner pressure is also shown in graphical forms.

12. CONCLUSIONS

The maximum Von-Mises stress value excluding local stress value in structural steel and aluminium is less than the as compared to their yield strength and tensile strength value. So, the presented model is safe under the permissible values of stresses. Boiler shell with riveted joints made with structural steel is safe as compare to aluminium alloy under same working conditions.

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