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Creep and Fatigue Analysis of Pressure Vessels

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Abstract. **Number of pressure vessels in industries for storing natural gases (like methane, propane etc.) are made from steels. 2¼Cr-1Mo-0.25V steel is used by large no. of industries and works under cyclic loading and operating temperature under creep range. In we have firstly performed thermal analysis by applying loading conditions like temperature of propane gas and outside temperature, then heat transfer coefficient of gas is given as an input to obtain temperature distribution of pressure vessel. Under static study, the temperature distribution and thermal stress obtained from thermal studies are considered and loading conditions are applied and stress is calculated and used this static study as a base for our fatigue analysis. Secondly, creep analysis is performed by giving creep constants at a particular temperature for steel as an input and giving thermal and pressure loading conditions[1]**

Keywords: **creep analysis, fatigue analysis, cyclic loading.**

I. INTRODUCTION

The operating conditions for pressure vessels are not always in the form of static loads. Fluctuations in stresses are always observed and variation in strength of the material is also observed as the operating temperature is increased. Therefore for proper analysis of pressure vessels, these factors must be considered in their designing.

FATIGUE FAILURE:

Fatigue analysis is carried out using fully reversed stress function and using gerber's criteria. S-N chart of the steel is taken to obtain the damage plot and life plot of the pressure vessel. Various stages of fatigue failure are :

(a) Crack initiation – includes the early development of fatigue damage that can be removed by suitable thermal annealing.

(b) Slip band crack growth – involves the deepening of initial crack on planes of high shear stress. This is also known as stage-I crack growth.

(c) Crack growth on planes of high tensile stress – involves growth of crack in direction normal to maximum tensile stress, called stage-II crack growth .Final ductile failure – occurs when the crack reaches a size so that the remaining cross-section cannot support the applied load[2]

Fatigue failures start as small microscopic cracks at some internal flaws and are very sensitive to even minute stress raisers. Considerable research has gone into studying the crack propagation in 2nd stage can be used as fail-safe design considerations.

CREEP FAILURE :

- Based on the variation of creep rate with time, creep curve is considered to be consists of three portions,
- After initial rapid elongation, ε0, the creep rate decreases continuously with time, and is known as primary or transient creep.
- Primary creep is followed by secondary or steady state or viscous creep, which is characterized by constant creep rate. This stage of creep is often the longest duration of the three modes.
- Finally, a third stage of creep known as, tertiary creep occurs that is characterized by increase in creep rate

Creep rate (strain rate) depends on time of loading and temperature of the material. Its equation is given by Norton as:

$$\varepsilon^c = C_o \sigma^{(C_1)} t^{(C_2)} e^{(-C_T/T)} \quad C_1 > 1 \text{ and } 0 < C_2 \le 1 \quad [3]$$

Where :C_T = A material constant defining the creep temperature-dependency
C_0, C_1 and C_2 are the three creep constants
σ = stress , t= time (in hours), T= temperatue in Kelvin)
C_0, C_1, C_2 are obtained from creep curve data at 550 °

II. DESIGN

Pressure vessel is designed using elliptical head because it is more economical to design than spherical head. Dimensions of the vessel are taken from standard ASMI Y14.5-2009 standard calculations as[4]

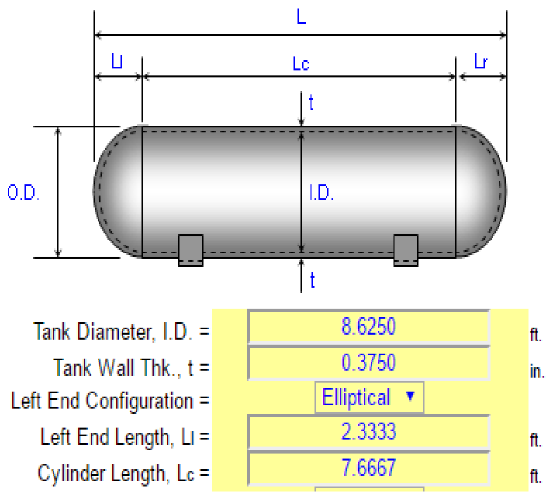


Fig.1 Dimensions of vessel

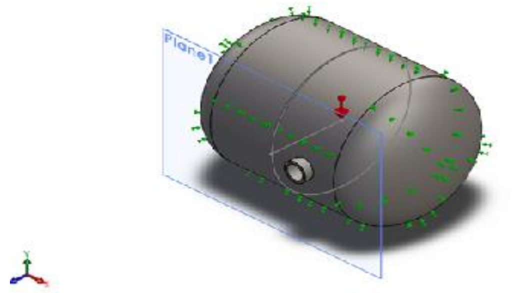


Fig.2 Pressure vessel model

Model of pressure is designed in SOLIDWORKS software and its properties are as follows :

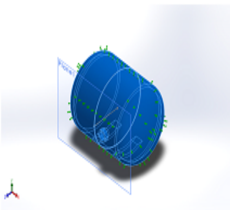
Model Reference	Properties
	Name: AISI 4340 Steel, annealed Model type: Linear Elastic Isotropic Default failure criterion: Unknown Yield strength: 4.7e+008 N/m^2 Tensile strength: 7.45e+008 N/m^2 Elastic modulus: 2.05e+011 N/m^2 Poisson's ratio: 0.285 Mass density: 7850 kg/m^3 Shear modulus: 8e+010 N/m^2 Thermal expansion coefficient: 1.2e-005 /Kelvin

Fig.3 Properties of model

AISI 4340 Steel is used for analysis as it is commonly used in most of the pressure vessel's designing.

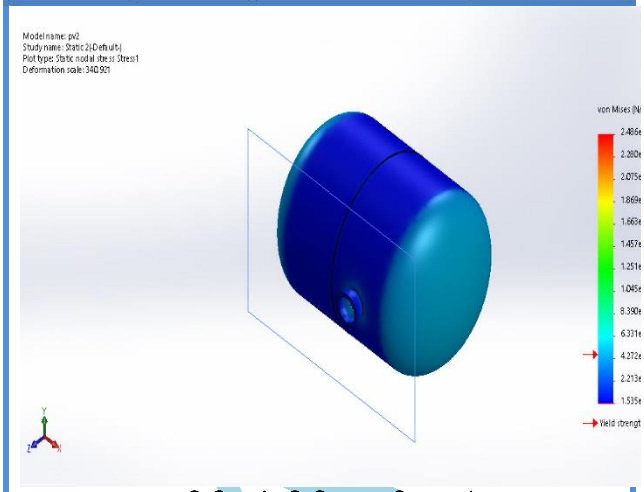
III. ANALYSIS

Firstly convection thermal analysis is carried on pressure vessel to obtain the thermal stress and temperature at 500ºC and pressure is applied to the inner face of cylinder to obtain static study results and its results are directly incorporated into consideration for fatigue analysis under thermal stresses at high temperature. SN curve for AISI 4340 Steel is directly obtained from solidwork database and cyclic load of 100 psi pressure is applied (as 100 psi pressure gas is usually used in practical applications). Fully reversed fluctuating loads are applied for our analysis using gerber's criteria. Also in this study, stress concentration effect will be there due to considering groove in the vessel for stand to pass through. The result obtained from both study are as follows :

STATIC STUDY

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.5348e+007 N/m^2 Node: 23682	2.48634e+009 N/m^2 Node: 16440

Name	Type	Min	Max



pv2-Static 2-Stress-Stress1

Fig.4 Stress under static study

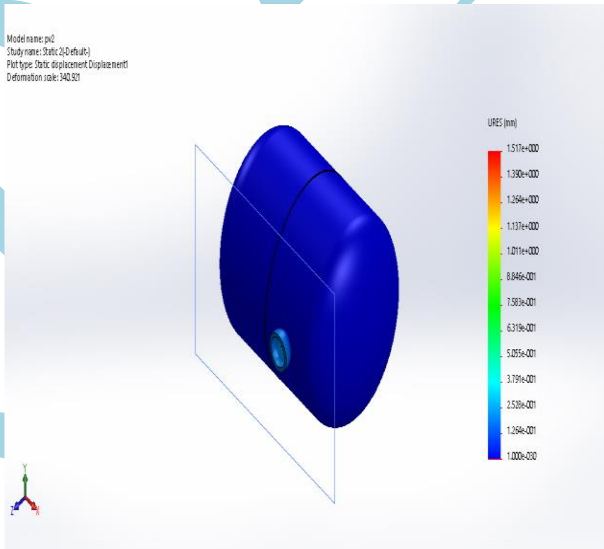


Fig.5 Deformation under static study

FATIGUE STUDY 1

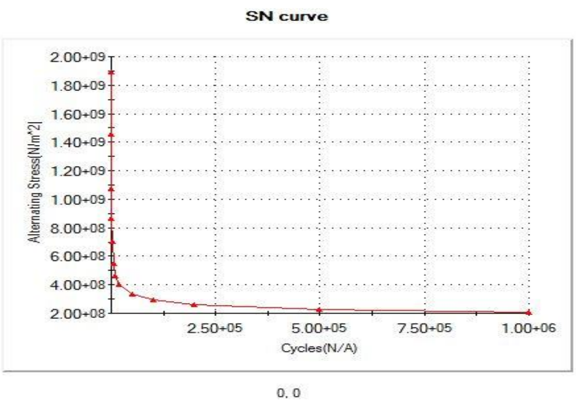


Fig.6 SN curve for AISI 4340 Steel

Name	Type	Min	Max
Results1	Damage plot	0.2 Node: 1005	2000 Node: 16222

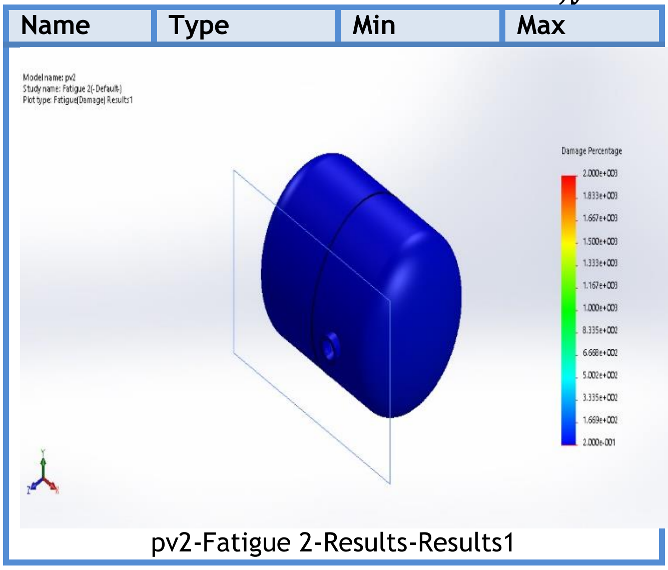


Fig.7 Damage plot under fatigue load

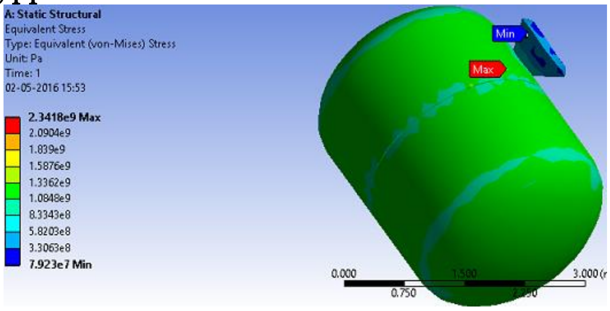


Fig.10 Stress plot under fatigue load under elevated temperature condition

At first analysis cyclic load of 100psi is applied at an surface temperature of 22ºC and goodman's criteria is used. Fully reversed loading is applied as shown below. For second analysis only surface temperature is increased to 400 ºC and results are compared.

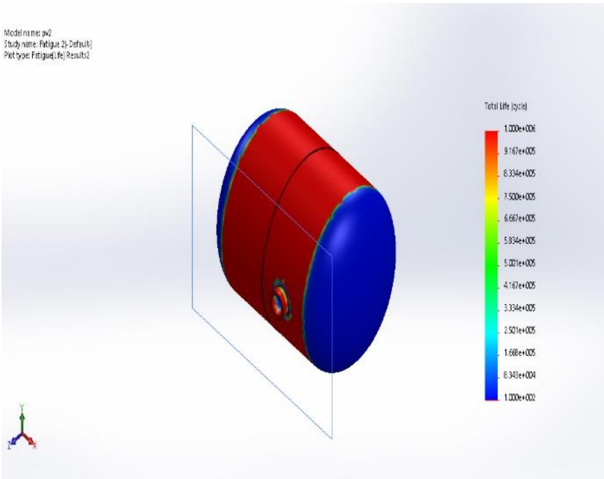


Fig.8 Life plot under fatigue load

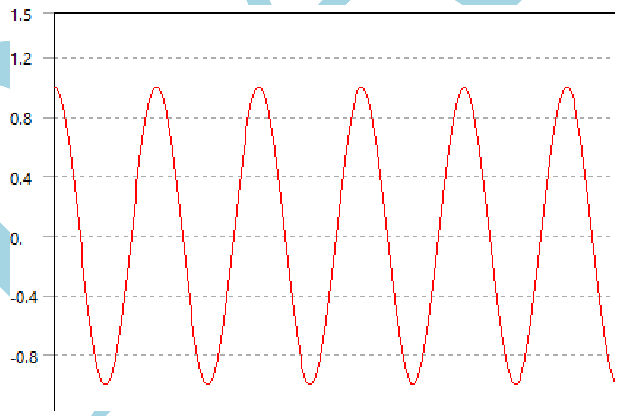


Fig.11 Fully reversed loading

FATIGUE STUDY 2

Another analysis is perfomed in ANSYS software for calculating maximum stress obtained during fatigue load at room temperature and another at higher operating temperature to compare the effect of thermal stresses on pressure vessels and increse in maximum stress. The result of study is as follows:

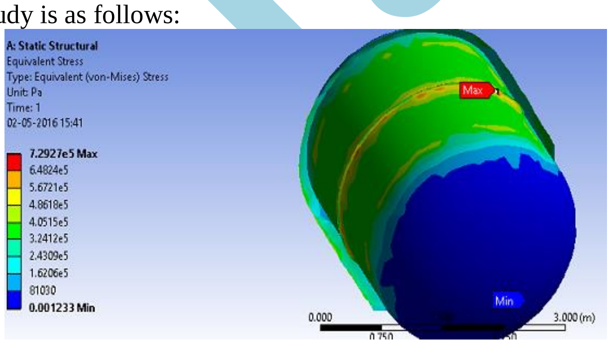


Fig.9 Stress plot under fatigue load under normal condition

CREEP STUDY

Creep study is carried out using nonlinear norton's law equation as described above. Creep constants are taken for structural steel by referring the paper at 500ºC as :

Creep Constant 1	Creep Constant 2	Creep Constant 3	Creep Constant 4
5.e-030	6	0	6

Pressure of 100psi is applied on one of the inner surface of pressure vessel and analysis is performed using norton's law using above creep constant values for structural steel

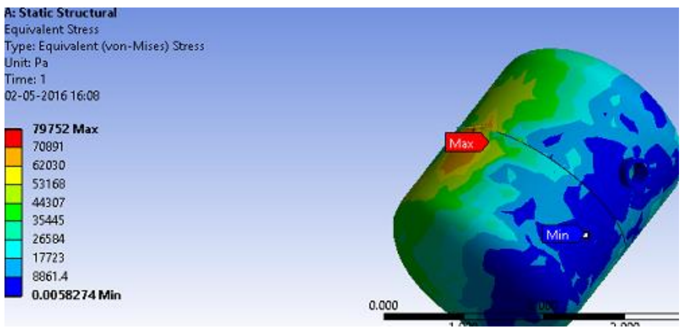


Fig.12 Stress plot for nonlinear creep loading

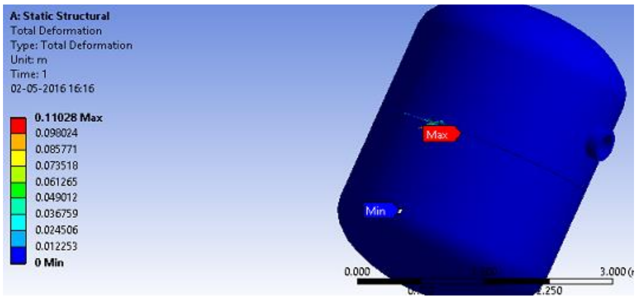


Fig.13 Deformation plot for nonlinear creep loading

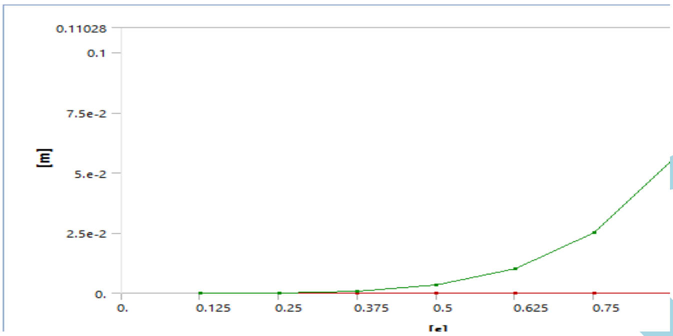


Fig.14 Deformation vs time plot for nonlinear creep loading

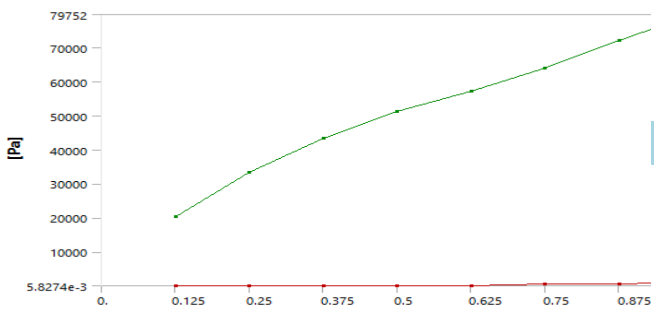


Fig.15 Stress vs time plot for nonlinear creep loading

4. CONCLUSION

From all the analysis and studies we have performed, following conclusions can be made :

1. Comparing the two results of fatigue study 2, it can be said that temperature has an adverse effect on stress and deformation of the pressure vessel. By increasing the temperature from 22ºC to 400º C of the pressure vessel, the stress increases almost 10^4 times and crosses the yield strength of the material. Thus temperature should be maintain as low as possible.

2. From fatigue study 1, we have seen that stress on the pressure vessel surface is in the range of 10^8 Pa and its 10^9 Pa at the groove end where stress concentration is coming. So grooves should must be eliminated in the design to avoid failure.

3. Comparing between creep and fatigue study at low temperatures, fatigue failure is more dominating and its effect is more.

5 FUTURE WORK

Above study can be further extended to more practical situations like considering the combined effect of creep and fatigue on stress and deformation of the pressure vessels. Variable amplitude stress plot can be used in fatigue analysis for more accurate results. Actual stress fluctuation should be given as an input to calculate mean stress and should be use in fatigue analysis.

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