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PRESSURE VESSEL DESIGN BY FEA

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ABSTRACT

This paper aims to Finite Element Analysis for the Pressure vessel design using ANSYSand ASME Code Book. The Pressure Vessel which is evaluated by manual calculations with Code book and on Ansys. The critical parameters of pressure vessel that are taken into account includes internal pressure, thickness, length, diameter and stress. The stress variation with respected to thickness is noted. A Mathematical relation (Regression Analysis) is developed for all cases. This equation refers to the stress value from ANSYS 14.5 APDL.If the ANSYS value is less than the allowable stress value, then the design is safe. Also, if the induced stress value is greater than code allowable value, then it can be taken as a factor while designing pressure vessel in ANSYS 14.5 APDL.

Keywords: Pressure Vessel, Stress, ASME code book, ANSYS 14.5 APDL, Regression Analysis.

I. INTRODUCTION

The act of storing any type of product is called as storage. Usually, the storages are in different types of vessels. The importance of storage is given as follows. Storage is very necessary for preserving the material it may be food, good or even petroleum products that are to used later. Storage prevents ignition due to heat in case of petrol. Practically, without storage a product cannot be transported from one place to another place. Direct transportation may lead to the risk of explosion in case of expansion. Thus, the storage plays a vital role in our day-to-day life. The storage of petroleum products is mostly preferred in storage barrels or as pressure vessel. The leakage of product can be identified very easily when stored. That is reason for selecting pressure vessel field of study.

Depending on the process condition and to maintain the fluid property stored medium may need to be in pressurized condition like LPG. This pressurized medium can only be stored in the pressure vessels. Thus, pressure vessel is definedas vessel that is used to store any substance where internal pressure and external pressure are not same.These pressure vessels are designed as per the guidelines provided in ASME codes.

B.S.Thakkar, S.A.Thakkar, [1] stated that due to its simplicity, better sensitivity, higher reliability, low maintenance, compactness for the same capacity Pressure vessel is selected for storing fluids.

II. LITERATURE SURVEY

Digvijay Kolekar, Jewargi S.S.,[2] worked on FEA of different types of pressure vessel heads including elliptical head, spherical head, flat head and conical head. The crux from [1] is that the displacement value of spherical head is least than other head when designed in Ansys Workbench.

Apurva R. Pendbhaje, Mahesh Gaikwad, Nitin Deshmukh, RajkumarPatil,[3] performed FEA of pressure vessel with saddle support and validated their design with MAWP of pressure vessel. Also, they have suggested that selection of material for pressure vessel design is critical, even a small change in material will lead to deviated result.

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III. PROBLEM STATEMENT

The pressure vessels are designed as per ASME rules. The obtained thickness value is to fed as input parameter to ANSYS. The stress value from ANSYSis to be compared with the allowable stress value from the code book. The deviation is to be found.

IV. MATERIALS

The two materials for study considered are SA 516 Gr 70 and S A240 316 L (16Cr-12Ni-2Mo). According to Henry H.Bednar, P.E[4]the first material is carbon steel and the second material is stainless steel.The property of these material that are used in design calculation.

V. DESIGN CALCULATION

A. Carbon steel material - SA 516 Gr 70

Assumptions

The following parameters are assumed for the pressure vessel design,
Internal Pressure, P = 145.08 psi (1N/mm^2)
Internal Diameter, D = 2000 mm (Hemi-spherical head)
Internal Radius, R = 1000 mm
Allowable stress value, S = 20015psi (138 N/mm^2)
Joint Efficiency, E = 1
Poisson's Ratio, μ = 0.3
Density, ρ = 7.70085 x 10^{-5} N/mm^3
Length of the vessel, L = 10000 mm

SHELL THICKNESS CALCULATION FOR SA516 Gr 70

As per [5], the thickness for circumferential stress acting on the vessel is calculated by equation (1),

$$t = \frac{PR}{(SE-0.6P)} \qquad (1)$$

$$t = \frac{1 * 1000}{(138 * 1 - 0.6 * 1)}$$

t = 7.278 mm
Approximately,
t = 7.3 mm

HEAD THICKNESS CALCULATION FOR SA 516 Gr 70

As per[5], the thickness of hemi-spherical head is calculated by the by equation (2),

$$t = \frac{PR}{(2SE-0.2P)} \qquad (2)$$

$$t = \frac{1 * 1000}{(2 * 138 * 1 - 0.2 * 1)}$$

t = 3.626 mm

Approximately,
t = 3.6 mm
In similar way, by varying the pressure value the following cases are calculated and tabulated below in TABLE 1.

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TABLE 1. THICKNESS CALCULATION FOR SA516Gr 70

CASE NO.	D	P		S		t_{shell}	t_{head}
	mm	psi	N/mm^2	psi	N/mm^2	mm	mm
1	2000	73	0.5	20015	138	3.6	1.8
2	2000	145	1.0	20015	138	7.3	3.6
3	2000	218	1.5	20015	138	10.9	5.4
4	2000	290	2.0	20015	138	14.6	7.3
5	2000	363	2.5	20015	138	18.3	9.1
6	2000	435	3.0	20015	138	22.0	10.9
7	2000	508	3.5	20015	138	25.8	12.7
8	2000	580	4.0	20015	138	29.5	14.5
9	2000	653	4.5	20015	138	33.3	16.4
10	2000	725	5.0	20015	138	37.0	18.2

B. Stainless steel - SA240 316 L (16Cr-12Ni-2Mo)

Assumptions

The following variables are assumed for the pressure vessel design,
Internal Pressure, P = 145.08 psi (1N/mm^2)
Internal Diameter, D= 2000 mm (Hemi-spherical head)
Internal Radius, R= 1000 mm
Allowable stress value, S =16679.3 psi (115 N/mm^2)
Joint Efficiency, E = 1
Poisson's Ratio, μ = 0.3
Density, ρ=7.8676 X 10^{-5} N/mm3
Length of the vessel, L = 10000 mm

SHELL THICKNESS CALCULATION FOR SA240 316 L

As per [5], the thickness for circumferential stress acting on the vessel is calculated by the by equation (3),

$$t = \frac{P*R}{(SE-0.6P)} \quad (3)$$

$$t = \frac{1 * 1000}{(115 * 1 - 0.6 * 1)}$$

t = 8.74 mm
Approximately,
t = 8.7 mm

HEAD THICKNESS CALCULATION FOR SA240 316 L

As per [5], the thickness of hemi-spherical head is calculated by the by equation (4),

$$t = \frac{PR}{(2SE-0.2*P)} \quad (4)$$

$$t = \frac{1* 1000}{(2 * 115 * 1 - 0.2 * 1)}$$

t = 4.352 mm
Approximately,
t = 4.4 mm
In similar way, by varying the pressure value the following cases are calculated and tabulated below in TABLE 2.

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TABLE 2. THICKNESS CALCULATION FOR SA240 316 L (16Cr-12Ni-2Mo)

CASE NO.	D	P		S		t_{shell}	t_{head}
	mm	psi	N/mm^2	psi	N/mm^2	mm	mm
11	2000	73	0.5	16679	115	4.4	2.2
12	2000	145	1.0	16679	115	8.7	4.4
13	2000	218	1.5	16679	115	13.1	6.5
14	2000	290	2.0	16679	115	17.6	8.7
15	2000	363	2.5	16679	115	22.0	10.9
16	2000	435	3.0	16679	115	26.5	13.1
17	2000	508	3.5	16679	115	31.0	15.3
18	2000	580	4.0	16679	115	35.5	17.5
19	2000	653	4.5	16679	115	40.1	19.6
20	2000	725	5.0	16679	115	44.6	21.8

VI. ANSYS DESIGN

The following are the steps involved in designing of pressure vessel in ANSYS 14.5 APDLusing [7],

The step to be followed in Ansys are as follows,
Step 1: Preferences -> structural.
Step 2: Pre-processor -> Element type -> Add/Edit/Delete -> Add -> Solid -> 8 Node 183 -> ok -> Option -> K1->Triangle ->K3->Axisymmetric-> ok -> close.
Step 3: Material properties-> material models->structural -> linear -> elastic -> isotropic-> E=respective Youngs Modulus ->PRXY=poisson's ratio as per material -> ok-> Density = As per material property.
Step 4: Modelling -> Create ->Area -> Rectangle -> By-Dimension-> Give respective values.
Step 5: Similarly, create circle with By-Dimension for respective values.
Step 6: create -> polygon -> By vertices -> Create a triangle at weld region of vessel.
Step 7: Pre-processor -> modelling ->operate -> Boolean -> add -> areas ->pick all.
Step 8: Meshing -> Mesh tool -> Smart size -> 5 -> Mesh:Tri -> set-> pick all -> Element edge length = 10 ->ok -> Raise Hidden -> Mesh -> pick all.
Step 9: Load -> Define load -> Apply -> Structural ->Displacement -> Symmetric B.C -> on-line -> select two points of pressure vessel -> on-line -> select all the external line -> expansion of 0.5 (Y axis) ->on-line -> outer side of weld triangle (all DOF) -> on-line -> curves -> expansion of 0.5 (X-axis).
Step 10: Load -> Define load -> Apply -> Structural -> Pressure -> give respective pressure values.
Step 11: Solution -> Solve -> Current LS -> ok.
Step 12: General Postproc -> plot results -> contour plot -> nodal solution (for vector sum displacement) -> element solution -> stress -> Von Mises -> ok.
Step 13: Generate the report and save them.

VII. ANSYS OUTPUT

For the above cases the Von-Mises Stress (Element) and Vector sum displacementoutput are given below at ¾ th expansion of pressure vessel for case 1 and 11, from ANSYS 14.5 APDL.

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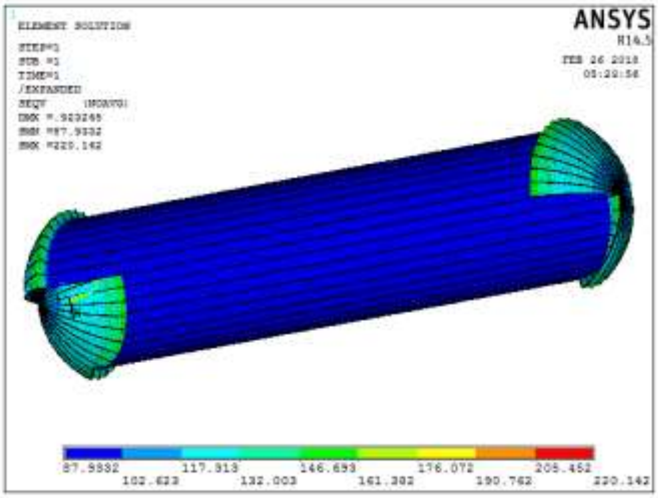

Fig. 1 Von-Mises Stress for case 1

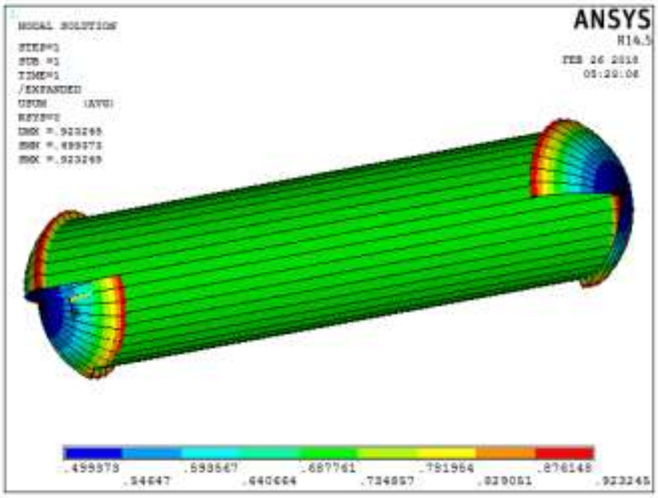

Fig. 2 Displacement for case 1

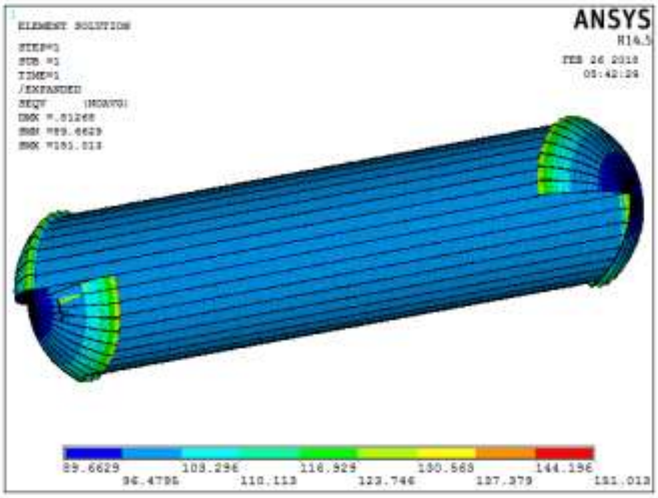

Fig. 3 Von-Mises Stress for case 11

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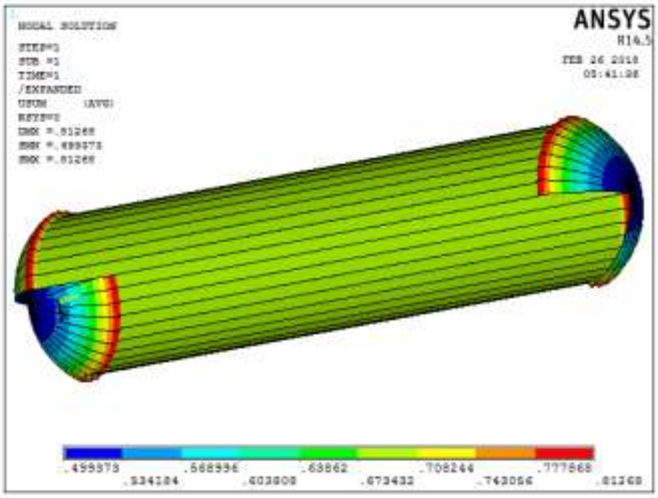

Fig. 4 Displacement for case 11

From Fig.1 and Fig.3 it is clear that the maximum stress value of shell side of pressure vessel is 117.313 $N/mm^2$and 103.296 N/mm^2.Based on the output obtained from all 20 cases, it is pertinent that the shell side of the vessel is safe. Fig.2 and Fig.4 shows the maximum displacement for case 1 and case 11, which lies in the weld region.

VIII. INTERFERENCE FROM OUTPUT

Based on the ANSYS output for all the 20 cases, we interfere that the stress value induced in ANSYS is more than the Allowable Stress value of material at weld location (thickness transition).However, the maximum stress acting on the shell side of the vessel is taken into consideration, and regression analysis is performed.

IX. REGRESSION ANALYSIS

The ANSYS value for the maximum stress acting on the shell side of pressure vessel is considered for regression analysis using [8]. The equation obtained after performing regression for SA 516 Gr 70 is (5)

$$y = 42.8X_1 + 6.63X_2 - 342.55X_3 + 119.5 \qquad (5)$$

The Normal probability curve given in Fig.5 shows that the values from ANSYS are Normally Distributed.

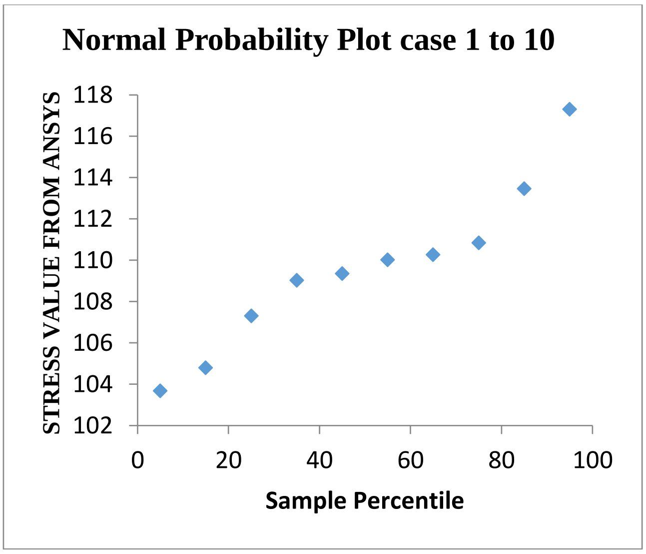

Fig. 5 Normal Probability Plot case 1 to 10

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The equation obtained after performing regression for SA240 316 L is (6)

$$y = 15.36X_1 + 4.53X_2 - 157.43X_3 + 105.01 \quad (6)$$

The Normal probability curve given in Fig.6 shows that the values from ANSYS are Normally Distributed.

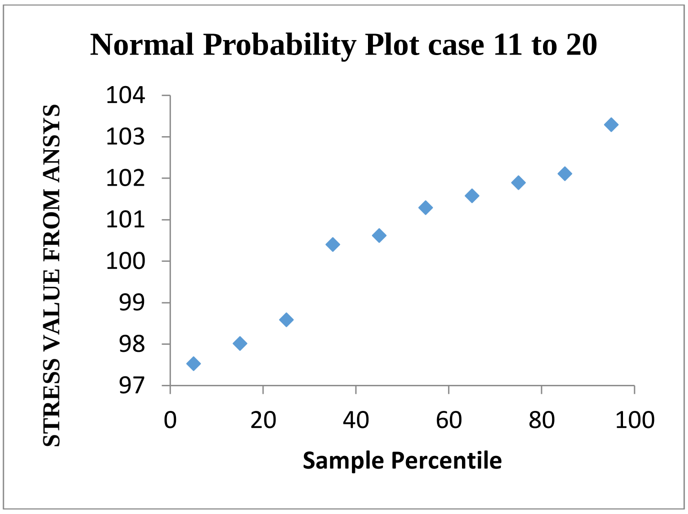

Fig. 6 Normal Probability Plot case 11 to 20

Here,
y = stress induced from Ansys in N/mm^2
X_1 = thickness of shell in mm
X_2 = thickness of head in mm
X_3 = internal pressure of Pressure vessel in N/mm^2

The equation (5) and (6) represents the output of ANSYS Elemental Von-Mises Stress with fractional deviation, this should be less than the code allowable stress value. Also, maximum stress value acting on the shell side of the pressure vessel falls below the allowable stress value of the material. Hence, the design of shell side of the vessel is safe. The above two equations are valid only for the unit system followed in the above table, that is Pressure and Stress in N/mm^2 and Thickness and Diameter in mm.

X. STATISTICAL CONCLUSION

A. SA516Gr 70

Null Hypothesis (H_o): All means are same

Alternate Hypothesis (H_1): At least one mean is different.
From ANOVA table of Regression Analysis,
Calculated F value (F) is 2.2964
Tabulated F value (F_o) is 0.1776.

Since, $F_o$is less than F, reject null hypothesis (H_o). In other words, At least there is one mean which is different. Also, the p-value of shell thickness, head thickness and pressure are 0.0439, 0.8677 and 0.1071 respectively.

If P-value is less than 0.05 then the variable has no significant impact on the output (resultant stress value) and if P-value is greater than the 0.05 then the variable has significant impact on the output.

Result:
Shell thickness has no impact on the stress value from ANSYS.
Head thickness has maximum impact on the stress value from ANSYS.
Pressure has impact on the stressvalue from ANSYS.

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B. SA240 316 L

Null Hypothesis (H_o): All means are same

Alternate Hypothesis (H_1): At least one mean is different.
From ANOVA table of Regression Analysis,
Calculated F value (F) is 3.6506
Tabulated F value (Fo) is 0.08304

Since, F_o is less than F, reject null hypothesis (H_o). In other words, At least there is one mean which is different. Also, the p-value of shell thickness, head thickness and pressure are 0.0176, 0.7684 and 0.0894 respectively.

If P-value is less than 0.05 then the variable has no significant impact on the output (resultant stress value) and if P-value is greater than the 0.05 then the variable has significant impact on the output.

Result:
Shell thickness has noimpact on the stress value from ANSYS.
Head thickness has maximum impact on the stress value from ANSYS.
Pressure has impact on the stress value from ANSYS.

XI. FUTURE SCOPE

This paper was briefly dealt with FEA of Shell side of Pressure Vessel. However, the future scope, includes the FEA of head and the weld region of thePressure Vessel.

XII. CONCLUSION

It is noted that the formulas provided in the code books are used for arriving the Shell and Head thickness of Pressure Vessel. Since the welding of dissimilar thickness is not handled by the direct formulas, the FEA results are not compared against the stress induced in the Shell and Head junction. Hence this effect was not considered for evaluation. The induced stress is more by 26% than the code allowable for SA 516 Gr 70 and for SA 240 316L the induced stress is greater by a factor of 34%, even then the pressure vessels are safe due to the Material yield point. Thus, this ANSYSsoftware can be used for any pressure vessels design with some correction factors.

ANSYS software can be utilized for Pressure vessel modelling with due consideration of correction factors for respective material and the arrived equation can be utilized for equating the design codes allowable stresses. Iteration process may be applied in case of ANSYS software used for fixing the Pressure vessel thickness rather applying the code formulas to arrive the required thickness.

XIII. REFERENCES

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