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Fracture Analysis of Unfired PV by using Finite Element Analysis

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Abstract - *The paper aims to perform fracture analysis of unfired pressure vessel which is subjected to internal pressure and having thickness very low as compared to diameter of cylinder. (i.e. t<<d.) from the fracture analysis the criteria for material selection of pressure vessel is to be verified for three material viz. steel 4340, steel 4335, steel 350 Maraging. The methodology used for analysis this paper is finite element Analysis which carried out in Ansys software and the area of interest is to get the value of stress intensity factor and hoop stress for three given materials with semi elliptical crack. finally comparing the values obtained from Ansys software with theoretical values of unfired pressure and applying criteria for material selection to choose best possible alternative material from given materials for the unfired pressure vessel.*

Key Words: **Stress intensity factor, Hoop stress, Fracture mechanics, Semi elliptical crack**

1. INTRODUCTION

The pressure vessel are the containers or cylinders which are commonly used for loading, storing, receiving or carrying the fluids under pressure, the cylindrical pressure vessel can be divided into two groups – thin wall and thick wall cylinders. The unfired pressure vessel are all vessels, pipelines and the like for carrying, storing steam, gases or liquids at pressure above the atmospheric pressure. Such pressure vessel can be designed according to national and international standard codes.[1]

1.1 Fracture Mechanics:

The term fracture mechanics assumes there is microscopic surface crack in the components. When the localized stress close to tip of crack in the material reaches the yield stress, then there is plastic deformation.
The proper definition of fracture mechanics is study of mechanical behavior of cracked parts in applied load and environment.

1.2 Stress intensity factors:

The stress intensity factor is defined by amount of gathering of stress close crack tip. It is given by
$K=\sigma\sqrt{\pi a}$, where k= Stress intensity factor.

a= crack length.

σ=Nominal Stress.

1.3 Critical stress intensity factor:

The critical Stress intensity factor is the specialty of material by which material can able to bear the fracture failure. It is very important assets of material [2]

1.4 Modes of crack proliferation:

1.4.1 Mode I:

The mode I is called opening mode or tensile mode. It is mostly observed in crack phenomenon.

1.4.2 Mode II:

In this case, the crack faces separate symmetrically with respect to crack plane proliferation. The mode II is characterized by sliding action

1.4.3 Mode III:

In this case the crack proliferation is fundamentally done by shear failure. The mode III is indicated by tearing action

1.5 Crack length:

It is the length of crack which propagates in components resulting growth of fracture with same amount of stress.[3]

1.6 Hoop stress:

It is the crosswise stress or circumferential which is present in the cylinder due to internal pressure acting inside the cylinder.

When the hoop stress exceeds the yield strength of material then there will be break down of cylinder. Also, when the longitudinal stress exceeds the yield strength, then malfunctioning of cylinder will start.

2. LITERATURE REVIEW:

2.1 **Osama et al.** studied the behavior of ductile crack growth in surface cracked pressure vessels. In the study, it was observed that a vastly different crack sequence develops under ductile tearing conditions compared to fatigue and the stress intensity dominated crack growth. The conclusion was that, the crack shapes developed under Linear Elastic Fracture Mechanics conditions would therefore no longer be applicable to ductile tearing scenarios. [4]

2.2 **Mundhe et al.** performed analysis of a cracked cylindrical pressure vessel by using experimental approach. The study applied linear elastic fracture mechanics approach in determination of Stress intensity factor of cracked cylindrical pressure vessel made of brittle epoxy. The authors observed that, the strain gauges they used in the experiment gave good results to calculate the required Stress intensity factors.[5]

2.3 **Salam et al**. carried out a study on crack growth prediction in a thick cylinder under fatigue loading by finite element analysis (FEA) and presented a numerical analysis to predict crack growth under fatigue loading in a thick cylinder made of an aluminum alloy.[6]

3 . PROBLEM STATEMENT:

The proposed paper aims at fracture analysis of pressure vessel by using theoretical and finite element method using software. The problem statement is follows:

A cylindrical pressure vessel with closed ends has a radius R = 1 m and thickness t =40 mm and is subjected to internal pressure p_i. The vessel must be designed safely against failure by yielding (according to the von Mises yield criterion) and fracture. Three steels with the following values of yield stress σ_y and fracture toughness K_{ic} are available for constructing the vessel.[7]

Table 1: Given Data

Steel	σ_y (MPa)	K_{IC} (MPa$\sqrt{m}$)
4340	860	100
4335	1300	70
350 Maraging	1550	55

Fracture of the vessel is caused by a long surface crack of depth a. The pressure vessel should be designed with a fos , S = 2 against yielding and fracture

For each steel we have: (a) Calculate the maximum permissible crack depth ac for an internal pressure P_i = 12 MPa;(b) Calculate the failure pressure Pc for a minimum detectable crack depth a= 1 mm. (c) Select the best material from given different option

4. Methodology

4.1 Theoretical Calculation [8]:

Table no 1 Table of Failure Pressure

Steels	Failure pressure (MPa) when crack length is maximum i.e. a=20mm
4340	5.038
4335	3.53
350 Maraging	2.77

4.2 Finite Element Analysis (FEA) [9]:

The finite element analysis is method which breaks complex shapes into simple shapes by which it can be used to determine solution for partial differential equation. Numerical method, mathematical representation of actual problem approximation method.[8]

4.3 Fracture analysis of unfired PV using Ansys:

The fracture analysis of unfired pressure vessel is carrried out in ansys software with different materials such as steel 4330, 4335 and 350 Maraging. The 3D CAD model is drawn in solid work bench software after which it is imported into ansys 17.2 for frature analysis

4.3.1 Generation of 3D CAD model:

The input value requried for solidwork bench follows

- Dimensional paramater

Table no 2 Dimensional parameter.

Serial nos.	Parameters	Values
1	Outer radius	1 m
2	Inner radius	0.960 m
3	Internal pressure	12 MPa
4	Thickness	0.04 m

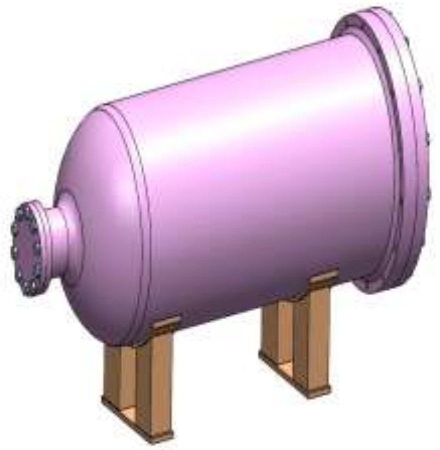

Fig 4.1 3D CAD Mode

4.3.2 Static analysis of unfired pressure vessel without crack conditions:

Table no 3 Input parameter for no crack condition

Parameters	Values
Internal pressure	12 MPa
Fixed Support	Saddle Support
Meshing size	118.50 mm

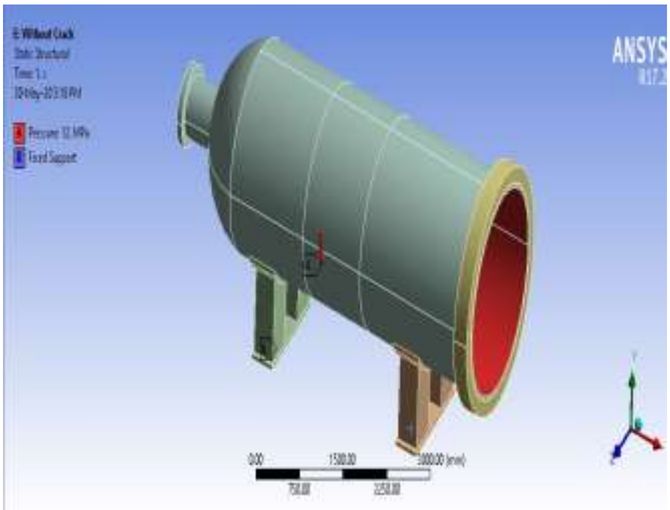

Fig 4.2 Boundary condition for unfired PV

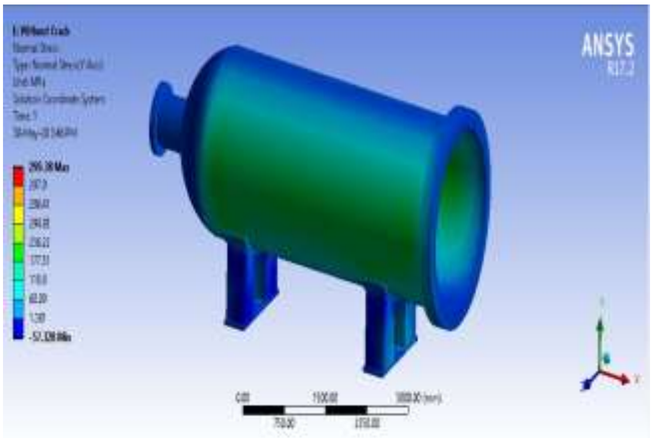

Fig 4.3 Hoop stress for Unfired PV

4.3.3 Fracture analysis of unfired pressure vessel

4.3.3.1 For steel 4340

Table no 4 Simulation software result table

Parameters	Values
Yield Stress	860 MPa
Failure pressure	12 MPa
Fixed Support	Saddles
Semi elliptical crack length	20mm
Meshing size	118.50 mm

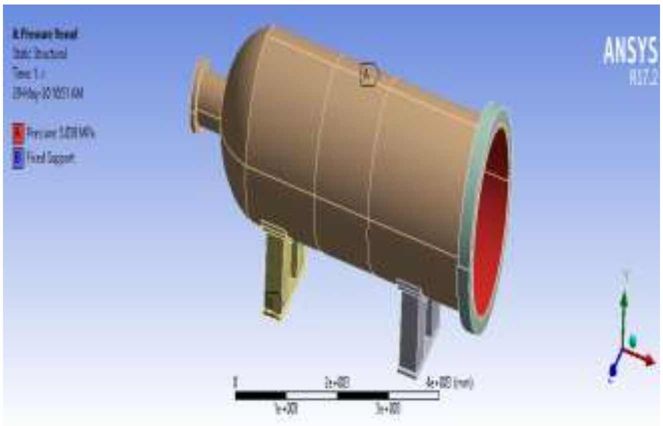

Fig 4.4 Boundary condition with steel 4340

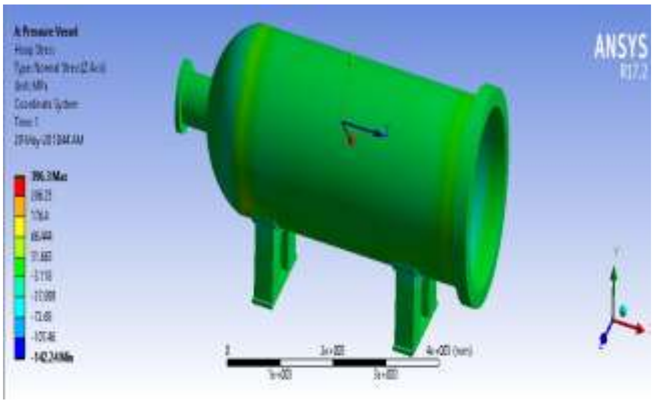

Fig 4.5 Hoop stress with steel 4340

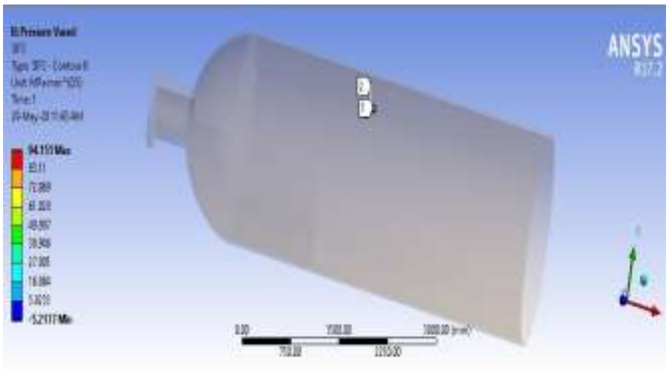

Fig 4.6 Stress intensity factor with steel 4340

4.3.3.2 For steel 4335-

Table no 5 Simulation software result table

Parameters	Values
Yield Stress	1300 MPa
Failure pressure	3.53 MPa
Fixed Support	Saddles
Semi elliptical crack length	20mm
Meshing size	118.50 mm

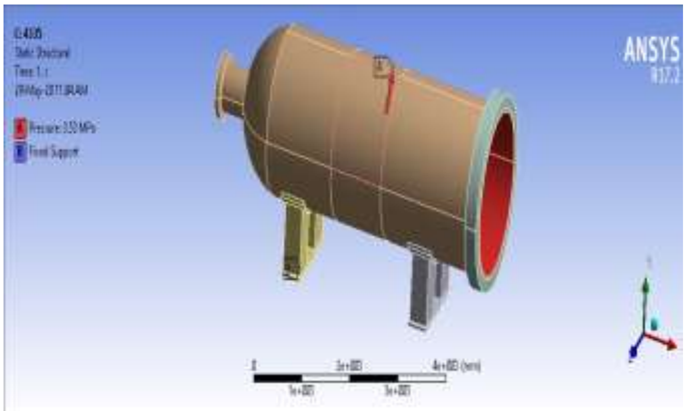

Fig 4.7 boundary condition with steel 4335

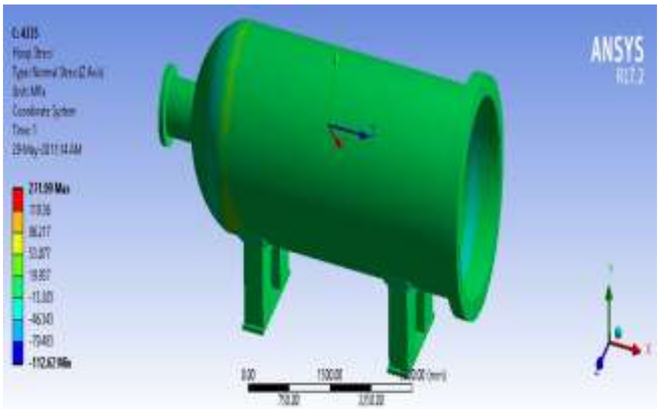

Fig 4.8 Hoop stress with steel 4335

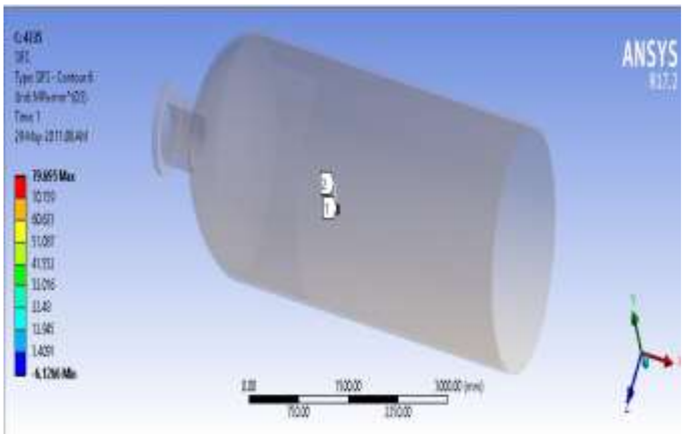

Fig 4.9 Stress Intensity factor with 4335

4.3.3.3 For steel 350 Maraging-

Table no 6 Simulation software result table

Parameters	Values
Yield Stress	1550 MPa
Failure pressure	2.77 MPa
Fixed Support	Saddles
Semi elliptical crack length	20mm
Meshing size	118.50 mm

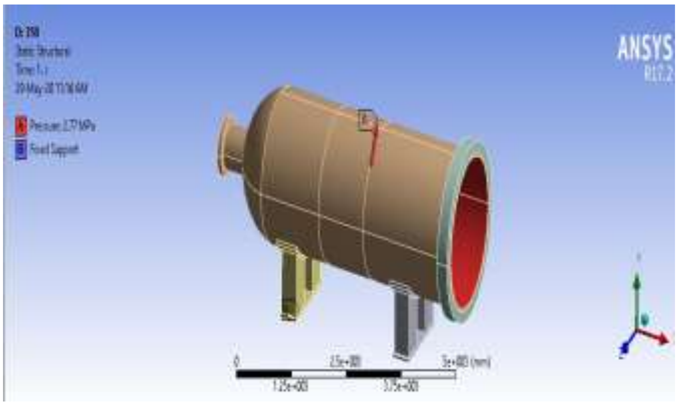

Fig 4.10 boundary condition with steel 350 maraging

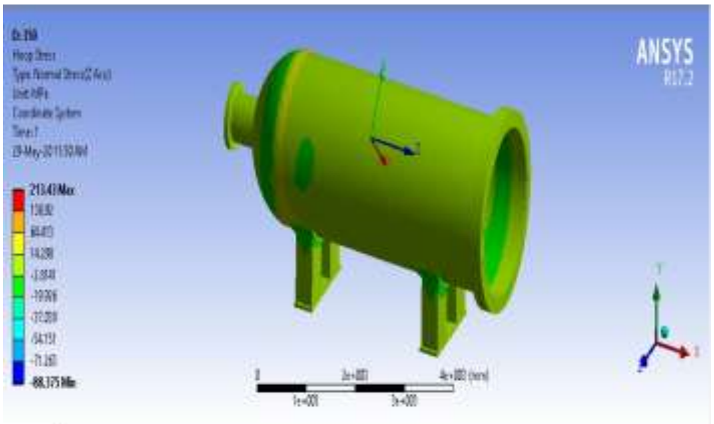

Fig 4.11 Hoop stress with steel 350 maraging

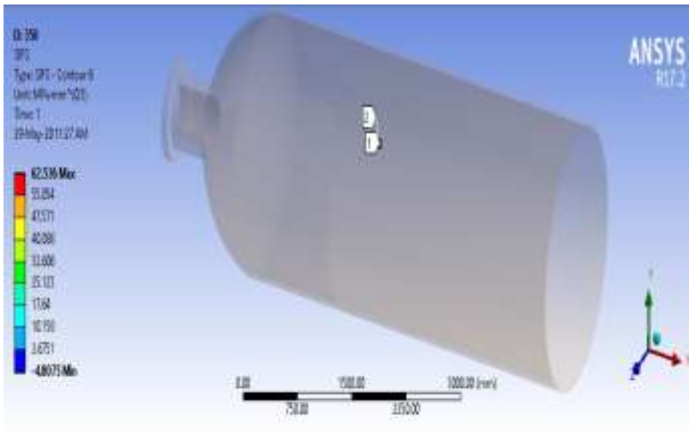

Fig 4.12 Stress intensity factor with steel 350 maraging

5. RESULTS

5.1 Simulation Software Analysis:

Table no 7 Simulation software result table

Steels	Stress intensity factor (K) in MPa/$\sqrt{m}$	Critical Hoop stress σ_{hc} in MPa	Hoop stress σ_h in MPa
4340	94.15	299.38	396.3
4335	79.69	299.38	271.99
350 maraging	62.53	299.38	213.43

5.2 Theoretical Values:

Table 8 Theoretical values Hoop Stress

Steels	Critical stress intensity factor (K_{IC}) in MPa/$\sqrt{m}$	Critical Hoop stress σ_{hc} in MPa	Theoretically calculated hoop stress σ_t in MPa
4340	100	300	400
4335	70	300	280
350 maraging	55	300	220

5.3 Discussion:

According to definition of fracture mechanics when the stress intensity factor of material exceeds the critical stress intensity factor of material than that material undergoes fracture failure. That is symbolically represented as below

$K > K_{IC}$, ……………..(1)

Therefore, in order to prevent the fracture failure of material the stress intensity factor induced in material must be less than critical stress intensity factor, thereby which becomes the criteria for material selection for this project.

That is designated symbolically as $K < K_{IC}$……. (2)

Another point to notice that hoop stress of material should be greater than the critical hoop stress of material which is maximum hoop stress that material can sustained before failure without crack present

The material which has less value of hoop stress induced than the normal material without is definitely fail before reaching the permissible stress. which is very fatal for machine as a whole for people working on machine.

Therefore, the criteria for material selection becomes that material hoop stress should be greater than or equal to permissible stress

It is symbolically represented as

$\sigma_{hc} \leq \sigma_h$ ………………..(3)

Finally, criteria for material selection is

i) Fracture mechanics
$K < K_{IC}$
ii) Steady crack growth [10]
$\sigma_{hc} \leq \sigma_h$

5.4 Validation of results:

Table 9 Table of validation

Steel	Fracture mechanics criteria i.e. $K < K_{IC}$	Steady crack growth criteria i.e. $\sigma_{hc} \leq \sigma_h$	Remarks
4340	94.15 < 100	300 ≤ 396.3	Satisfy the criteria
4335	79.69 < 70	300 ≤ 271.99	Does satisfy the criteria
350 marag ing	62.53 < 55	300 ≤ 213.43	Does not satisfy the criteria

6. CONCLUSIONS

❖ From the Ansys simulation analysis, we accomplish that -

1. The steel 4340 satisfies the condition of fracture mechanics in simulation analysis.
2. It also satisfies the condition of steady crack growth i.e. means the catastrophic failure of pressure vessel will not occurs.
3. In case of material like steel 4335 and 350 maraging does not fulfill the criteria of material selection and which results into an unsteady crack growth which will lead to catastrophic failure of material
4. The steel 4340 will be the proper, suitable, reliable, safe material for unfired pressure vessel

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