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Design and Analysis of Rocket Motor Casing

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ABSTRACT

The work "DESIGN AND ANALYSIS OF ROCKET MOTOR CASING" involves modelling of casing in 'CATIA V5' and performing finite element analysis in 'ANSYS 14.5 'by using two different materials such as MDN250,15CDV6 and by comparing their thickness, length and weight . Mainly case design is usually governed by the combination of motor and vehicle requirements. The shape of the case is usually determined from the grain configuration (or) from geometric vehicle constraints on length (or) diameter. The case configuration range from long and thin cylinders to spherical (or) near spherical geometries. The main purpose of the motor casing is to store the propellant. As soon as the propellant is ignited and rocket starts moving, a high amount of pressure and temperature will act on motor casing which is protected by incorporating an insulating material between propellant and casing.

Keywords: Rocket motor casing, MDN250, 15CDV6, Design, Analysis.

I. INTRODUCTION

Rocket motor is an essential part of rocket which contains the propellant which is used to propel the rocket. Rocket motor consists of casing, insulator, nozzle, and igniter etc., the case of the rocket motor which stores propellant serves as a highly loaded pressure vessel. Case design is usually governed by combination of motor and the vehicular requirements.

Steel alloys are considered for design of casing Casings are usually cylindrical in shape and hence employed cylinder theory in our design for calculating the thickness of the case. Domes are used to close the cylinder at both ends by using welding. Openings are made at both the ends for fixing nozzle and igniter assembly. Welding efficiency and mismatch factors are acknowledge and examined for practical design of Rocket motor casing.[1]

II. METAL CASES

Metal cases have several advantages compared to filament-reinforced plastic cases: they are rugged and will take considerable rough handling (required in many tactical missile applications), are usually reasonably ductile and can yield before failure, can be heated to a relatively high temperature (700 to 1000°C or 1292 to 1832°F and higher with some special materials), and thus require less insulation. High-strength alloy steels have been the most common case metals, but others, like aluminium, titanium, and nickel alloys, have also been used.

STEEL ALLOYS

- MDN250
- 15CDV6

MDN250 [6]

Maraging steels are steels alloys that are known for possessing superior strength and toughness without losing malleability. Aging refers to the extended heat-treatment process. These steels are a special class of low-carbon ultra-high-strength steels that derive their strength not from carbon, but from precipitation of intermetallic compounds. The principal alloying element is 15 to 25 wt.% nickel. Secondary alloying elements, which include cobalt, molybdenum, and titanium, are added to produce intermetallic precipitates.

Table 1: Mechanical properties for MDN250

Tensile strength, Ultimate	1800 MPa
Tensile strength, Yield	1700 MPa

15CDV6

Alloy 15CDV6 is a low carbon steel which combines a high yield strength (superior to SAE 4130) with good toughness and weldability. 15CDV6 can be readily welded with very little loss of properties during welding and without the need for further heat treatment. This alloy finds many applications in the aerospace and motorsports industries in such components as roll cages, pressure vessels, suspensions, rocket motor casings, wish bones and sub frames.

Table 2: Mechanical properties for 15CDV6

Tensile strength, ultimate	1080
Tensile strength, yield	980

SHELLS ARE CLOSED BY USING THREE DOMES

- Ellipsoidal dome
- Torispherical dome
- Hemispherical dome

Note: As shell with hemispherical dome stores the less amount of propellant, so shell with hemispherical dome is not considered for design.

By considering maximum operating pressure thickness of domes and shell are calculated according to BPVC SEC VIII.[2]

THICKNESS OF DOMES

1) TORISPHERICAL HEAD

t_1=PLM/ (2SE-0.2p)

THICKNESS CALCULATIONS FOR MDN250 MATERIAL

Thickness of the shell

T=PR/ (SE-0.6P)

Where

P=internal pressure

S=allowable stress

E= welding efficiency

R= Radius of shell

T=2.69 mm

THICKNESS OF DOMES

1) TORISPHERICAL HEAD

t_1=PLM/(2SE-0.2p)

Where

t_1=thickness of dome [3]

$M=0.25(3+(L/r)^{0.5})$

L=crown radius

r=knuckle radius

r= 10% of crown radius

t_1=4.142mm

2) ELLIPSOIDAL HEAD

t_2=PRK/(S-(0.1)P)

t_2=thickness of dome

$K=(1/6)*[2+(a/b)^2]$

“a” and “b” are semi major and minor axis

t_2=3.46mm

3) HEMISPHERICAL HEAD

t_3= PR/ (2SE-0.2p)

R= radius ofshell

t_3=thickness of dome

t_3= 1.33mm

THICKNESS CALCULATIONS FOR 15CDV6 MATERIAL

Thickness of the shell

T=PR/(SE-0.6P)

T=4.512 mm

t_1=6.9mm

2) Ellipsoidal head

t_2=PRK/(S-(0.1)P)

t_2=5.8mm

3) Hemispherical head

t_3= PR/(2SE-0.2p)
t_3= 2.22mm

THICKNESS OF THE FLANGE (MDN250)

$$T = \frac{7}{4}\,Ri\left[\frac{P(R-Ri)}{R*Se}\right]^{0.5}$$

Where
Ri=opening radius
R=pitch circle diameter
P=pressure
Se=allowable stress

THICKNESS OF THE FLANGE AT HEAD END SIDE:

$$T = \frac{7}{4}\,Ri\left[\frac{P(R-Ri)}{R*Se}\right]^{0.5}$$

Ri=opening radius at head end
Se =1200 $\frac{N}{mm^2}$
T = 3.85 mm

As thickness of the flange is very less, in order to accommodate the bolt taking T=8mm

THICKNESS OF THE FLANGE AT NOZZLE ENDS SIDE:

$$T = \frac{7}{4}\,Ro\left[\frac{P(R-Ro)}{R*Se}\right]^{0.5}$$

Ro=opening radius at nozzle end
Se =1200 $\frac{\mathrm{N}}{\mathrm{mm}^2}$
T = 6.17 mm

FASTNERS SIZING:[4]
FOR HEAD END:
Size of the bolts and No of bolts required are calculated iteratively in order to meet F.O.S
F.O.S considered is 1.5
M8 bolts are considered
No of bolts required at the head end side are 24

FOR NOZZLE END
M10 bolts are considered
No of bolts required at the head end side are 30

Table: 3 MASS OF ROCKET MOTOR CASING FOR MDN250

MDN 250 **THICKNESS OF SHELL = 2.69 mm**			
DOMES	t (mm)	V (m^3)	MASS (Kg)
TORISPHERICAL HEAD	4.14	0.029	235
ELLIPSOIDAL HEAD	4	0.029	235

Table: 4 MASS OF ROCKET MOTOR CASING FOR 15CDV6

15CDV6 **THICKNESS OF SHELL = 4.512 mm**			
DOMES	t (mm)	V (m^3)	MASS (Kg)
TORISPHERICAL HEAD	6.9	0.048	375
ELLIPSOIDAL HEAD	6.45	0.048	375

It is found that 15CDV6 material as more mass compared to mdn250 material. As weight matters more in rocket motor casing, hence 15CDV6 material is not considered for design

Now modelling and analysis is done for shell with ellipsoidal and shell with torispherical dome by considering MDN250 material and the required F.O.S is 1.5 based on UTS.

MODELLING OF ROCKET MOTOR CASE

SHELL WITH ELLIPSOIDAL HEAD

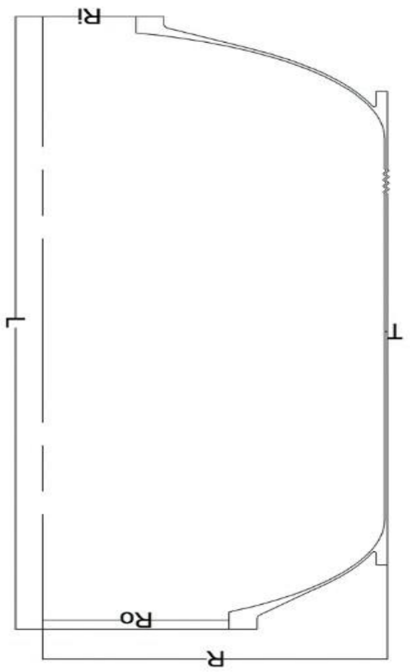


Figure 1. 2D model of rocket motor casing

SHELL WITH TORISPHERICAL HEAD

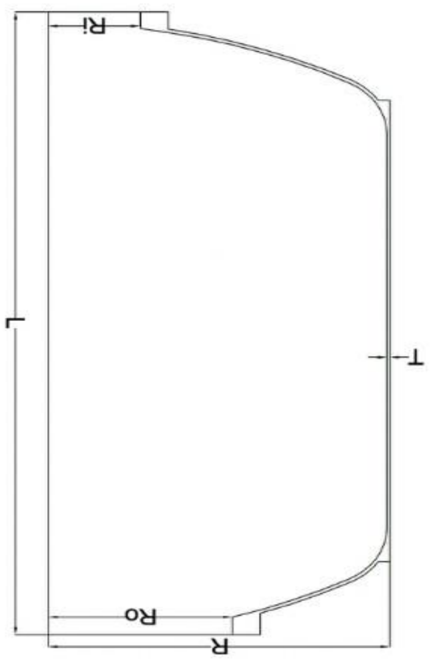


Figure 2. 2D model of rocket motor casing

STRUCTURAL ANALYSIS OF ROCKET MOTOR CASING:

ANALYSIS ON SHELL WITH ELLIPSOIDAL HEAD:

The 2d axisymetric model of rocket motor casing is imported to ANSYS 14.5 in IGES format and area is generated. Meshing is another important step in finite element alalysis.the results are depends on type element used for analysis. Quad elements of size 1are used to mesh the entire geometry. the fixed support is applied at head end skirt.

As the material MDN250 will act as a brittle material So principal stress is considered during analysis[4].

Imported IGES model from AUTOCAD14

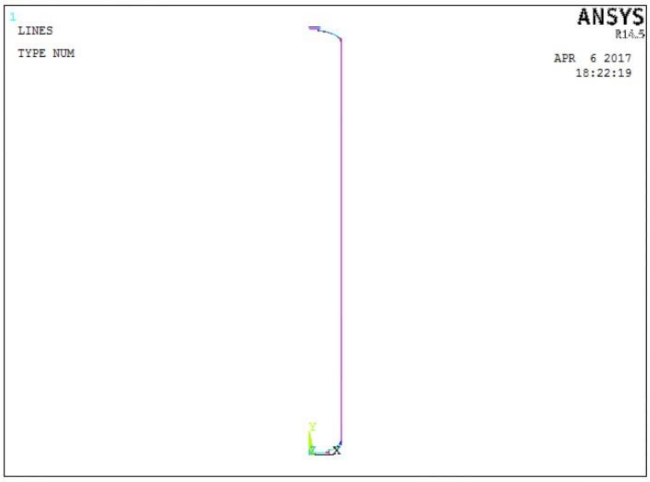


Figure 3. Imported Model of Rocket Motor Casing

CASE 1

Thickness of shell 2.69mm
Thickness of dome 4mm

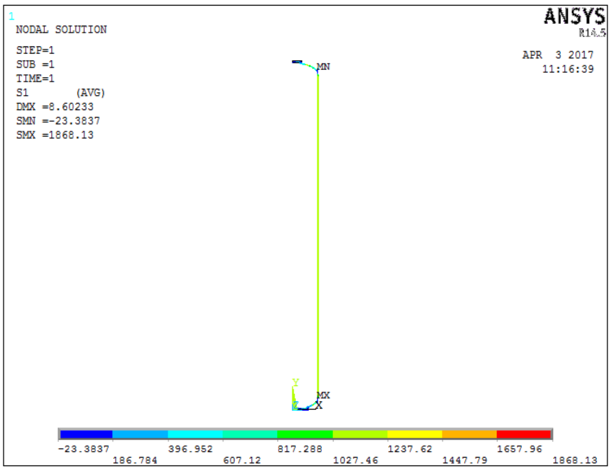
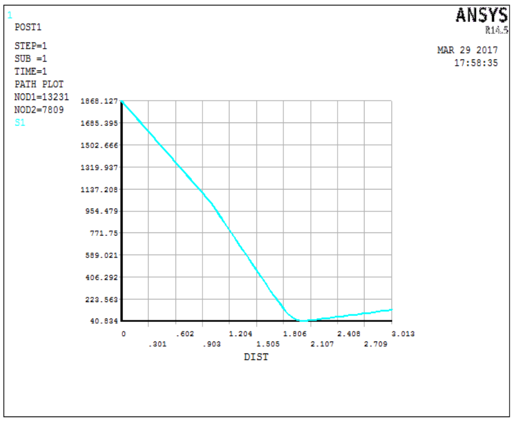


Figure 4. Stress results of rocket motor casing

The max stress found to be 1868 $\frac{N}{mm^2}$ acting on shell region

$$FOS = \frac{1800}{1868}$$
$$= 0.965$$

As the required FOS is not meeting, we can justify it by using graph with stress on Y-axis and thickness on X – axis. If the stresses are acting below 10% of thickness then we can neglect the stress value and considered it as safe for design of motor casing.



Graph: 2 showing the stress values at max stress acting portion

As stress is acting on more than 10% of thickness, so shell with 2.69mm thickness is not safe for design.

As the stresses are acting on the shell region, so analysis is done by increasing the shell thickness till desired FOS is reached.

CASE 2

Thickness of shell 3.4mm

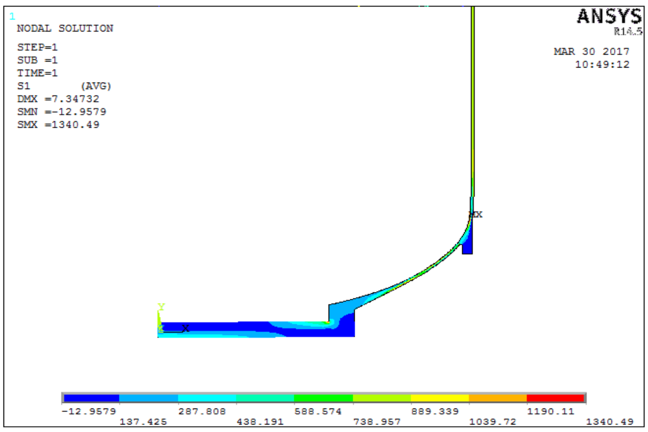
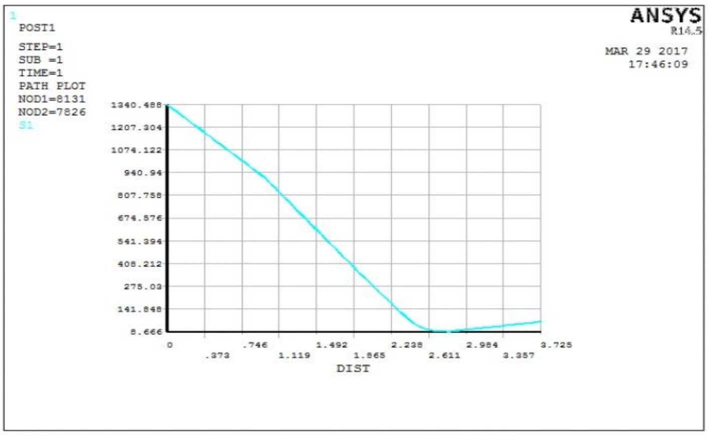


Figure 6. the Max stress value is 1340 N/mm^2

$$FOS = \frac{1800}{1340}$$
$$= 1.35$$



Graph:1 showing the stress values at max stress acting portion

From the graph it is concluded that stress values are acting less than 10% of thickness. So shell with 3.4mm thickness is considered safe for design.

SHELL WITH TORISPHERICAL HEAD

CASE 1

Thickness of shell 2.69mm

Thickness of dome 4.14mm

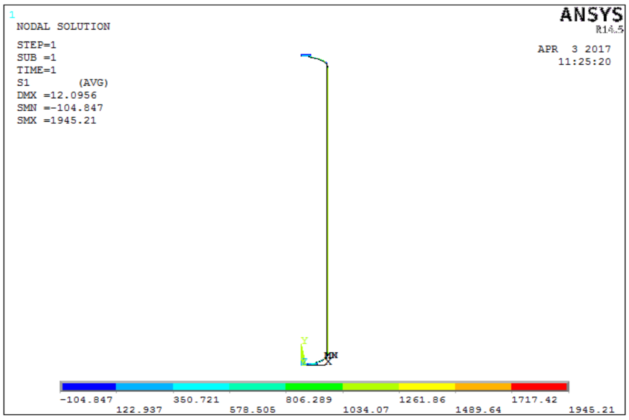


Figure 5. Max stress is acting on knuckle region

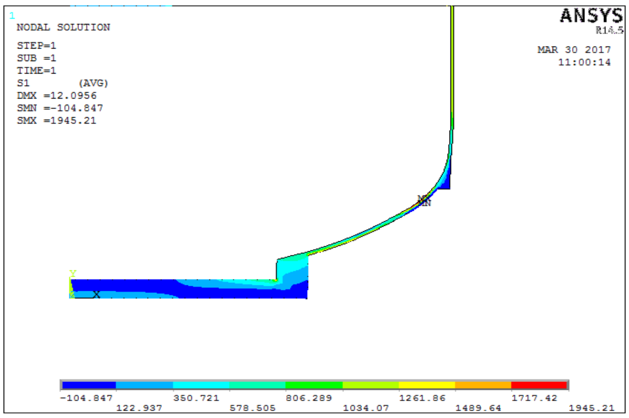
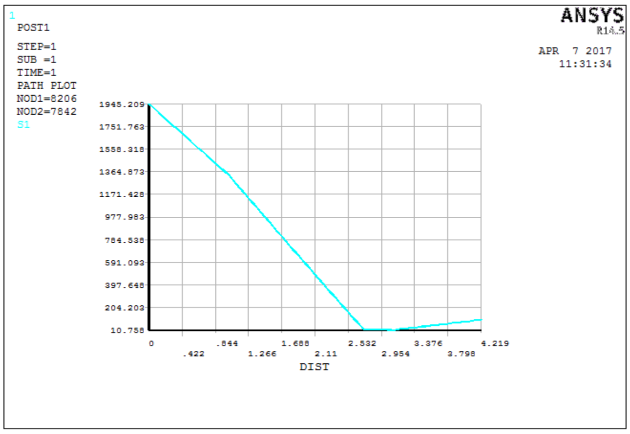


Figure 7. **T**he Max stress value is 1945 N/mm^2



Graph:3 showing the stress values at max stress acting portion

Stress values are acting more than 10% of thickness of dome. Now the dome thickness should be increased to get required F.O.S.

CASE 2

Thickness of dome 4.4mm

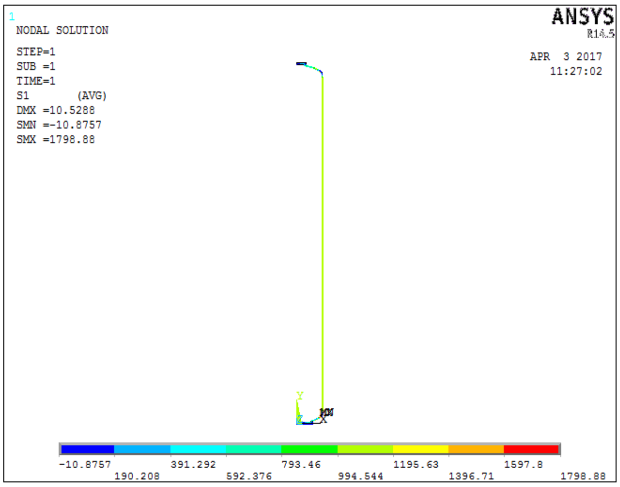
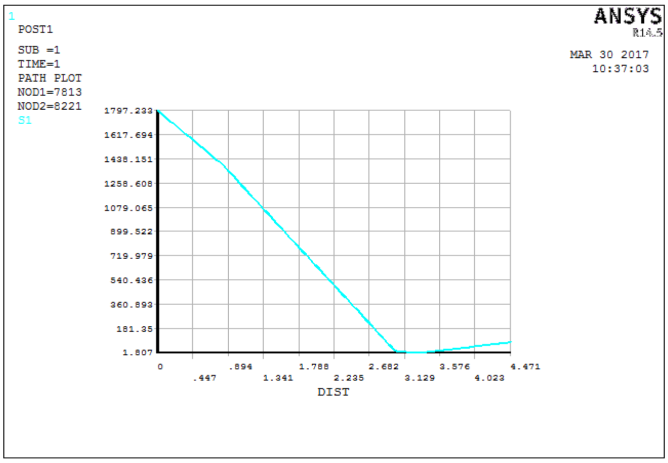


Figure 8. The Max stress value is 1798 N/mm^2



Graph: 4 showing the stress values at max stress acting portion

As the stress is acting on knuckle region even though we increase the thickness of dome to 4.4mm FOS of safety is not meeting. So torispherical dome is not safe for design.

III. RESULTS TABLE

Table: 5 Shell with ellipsoidal head

S.NO	T (mm)	T (mm)	Max principle stress(Mpa)	F.O.S
Case 1	2.69	4	1868	0.96
Case 2	3.4	4	1340	1.35

Table: 6 From graph (neglecting stress acting below 10% of thickness)

S.NO	Max stress at 10% of thickness at Max stress portion	F.O.S
Case 1	1620	1.11
Case 2	1180	1.52

Table: 7 Shell with torispherical head

S.NO	T (mm)	t (mm)	Max principle stress (Mpa)	F.O.S
Case 1	2.69	4.14	1945	0.92
Case 2	2.69	4.4	1798	1.0

Table: 8 from graph (neglecting stress acting below 10% of thickness)

S.NO	Max stress at 10% of thickness at Max Stress portion.	F.O.S
Case 1	1750	1.03
Case 2	1600	1.12

IV. CONCLUSION

The rocket motor casing in designed by considering MDN250 and 15CDV6 material. Thickness calculations for rocket motor casing are done by considering pressure vessel design as per BPVC section VIII.

As the mass of the 15CDV6 material is twice the MDN250 material, so 15CDV6 material is rejected as weight matters more in rocket motor casing. Three types of domes are considered such as, ellipsoidal, torispherical and hemispherical, for closing shell ends. As shell with hemispherical dome stores less amount of propellant, so it is rejected.

Now, modeling and finite element analysis is done by considering shell with ellipsoidal and torispherical dome.

By observing the structural analysis results, by increasing shell thickness the stresses are decreasing for shell with ellipsoidal head. Hence shell of 3.4mm thickness and ellipsoidal dome of 4mm thickness is considered safe for ROCKET MOTOR CASING DSIGN.

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