# MARAGING STEEL USED IN ROCKET MOTOR CASING

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**Abstract** - Solid-propellant rocket motors are a commonly used mechanism to generate required thrust or impulsive force so as to impart desired velocity in flight vehicles, especially during the initial stages of many space launch vehicles. During the operation of the rocket motor, the motor hardware will be subjected to high temperatures and pressure loads. Structural and thermal analysis has to be carried out for the given input parameters and to check the stress levels and temperatures on the casing. Data from this analysis is used to verify and conclude the nature of maraging steel and its characteristics, being a widely used material for such purposes due to its high strength with retained ductility. The computation design parameters were made with some initial assumptions. A 3D model was developed using CATIA software and structural analysis was carried out in ANSYS.

**Keywords** - Rocket, Motors, Thrust, Maraging Steel, Analysis, CATIA, ANSYS

## I. INTRODUCTION

Every rocket requires a propulsive system to produce thrust to escape Earth's gravity. The rocket engine serves this purpose. A rocket motor is an integral part of a rocket engine which stores propellant (in solid and/or liquid form) which is ignited and ejected at high speed to produce required thrust force.

$$F_{thrust} = \dot{m}\, v_e + (P_e - P_o)A$$

Where, $\dot{m}\, v_e$ is the rate of change of momentum of the escaping gas,

$(P_e - P_o)A_e$ is the high-pressure force acting on the nozzle, due to the escaping gas.

A solid-propellant rocket motor consists of casing, insulator, nozzle, and igniter. The working principle of Rocket motor is based on Newton's 2nd and 3rd laws. Rocket motors are a non-air breathing class propulsion system; hence, they do not require oxygen from the atmosphere for combustion of the fuel.

Casings are usually cylindrical in shape and domes are welded at both ends to close the cylinder. Openings are made for fixing nozzle and ignitor assembly. The casing of the solid rocket motor stores propellant which is a solid-state mixture of the fuel and the oxidizer. During combustion of the propellant, huge amounts of pressure is acted on the motor casing (which forms the momentum change part of the thrust force equation). Hence the motor casing must be of suitable build to resist such high pressures and high temperatures.

Maraging steels are a family of high alloyed steels which possess ultra-high strength and other necessary characteristics which makes these materials suitable for use in critical aviation and space applications, most importantly rocket motor casings. The high strength and toughness of the maraging steel are mainly due to two solid state reactions, martensitic transformation followed by aging.

### 1.1 Main parts of solid-propellant rocket motor

- Motor casing: This is the outer casing of the rocket motor and is the location where combustion of the propellant takes place. It is hence built to withstand huge amounts of pressure and thermal loads with a sufficient safety factor.
- Insulation: A layer of protection between the propellant combustion region and the outer casing against the high temperatures of combustion ranging approximately from 2000-3500 K.
- Igniter: The ignition system gives the energy to the propellant surface necessary to initiate the combustion necessary to produce the thrust.
- Nozzle: Discharge of the high-energy high-temperature products of combustion is through a converging-diverging nozzle where the chemical energy is converted to kinetic energy therefore producing thrust.

## II. IMPORTANCE OF MARAGING STEEL

Maraging steel is the most commonly used material to fabricate solid rocket motor casings. This is due to its high strength while retaining high machinability. Moreover, it is easily available and fabrication technology is also well established.

Most high strength materials are brittle. When such materials fracture, they generally disintegrate in an unsafe manner. However, maraging steel differs from other steel alloys in that it is hardened by the precipitation of a special selection of intermetallic compounds and not by carbon. The absence of carbon and the use of intermetallic precipitation allows maraging steel to achieve combinations of high strength and toughness while maintaining relatively

highductility.Being ductile maraging steel can absorb large amount of energy before undergoing fracture. Maraging steel has a known fracture characteristic i.e. when the material does fracture, it does so in a predictable and safe manner.

### 2.1 Mechanical properties of Maraging steel (250 grade)

| Properties | Values |
|---|---|
| Density | 7916 kg/m$^3$ |
| Ultimate tensile strength | 1776 MPa |
| Yield tensile strength | 1725 MPa |
| Young's Modulus | 210 GPa |
| Poisson's Ratio | 0.3 |

**Table 1: Properties of MDN-250**

## III. STRESSES

The stresses undergone by a rocket motor casing and their location of origin is given in table below:

| Origin of load | Type of load |
|---|---|
| Internal pressure | Axial (tension biaxial) |
| Axial thrust | Axial |
| Motor nozzle | Axial, bending, shear |
| Aerodynamic forces | Tension, compression, bending, shear, torsion |
| Flight maneuvering | Axial, bending, shear, torsion |
| Wind forces on launch pad | Axial, bending, shear, torsion |
| Ground handling and transport | Axial, bending, shear, torsion |

**Table 2 : Loads on the motor casing**

### 3.1 Axial loads

Structurally the motor casing is loaded due to the large internal pressure (up to 4.8 MPa) generated by combustion of the propellant. The case must be capable of withstanding such high pressure. The casing is modelled as a thin-walled cylindrical shell. Employing shell theory for a cylinder:

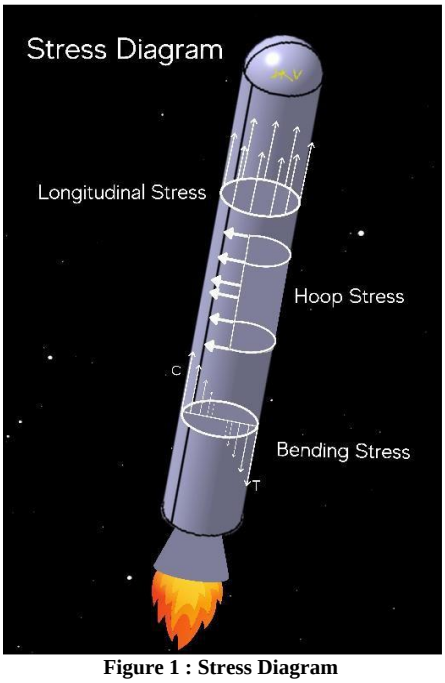



**Figure 1 : Stress Diagram**

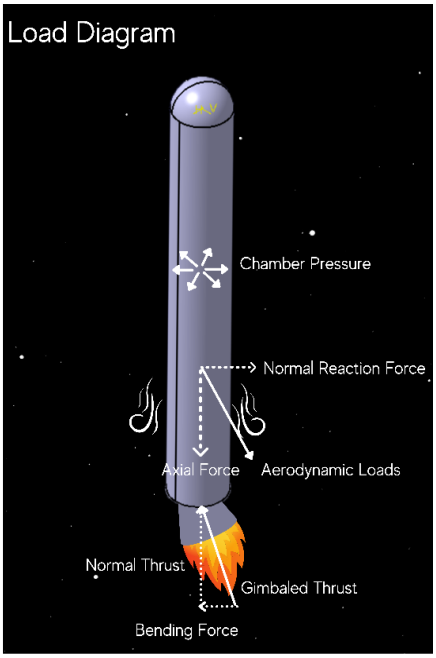



**Figure 2 : LoadDiagram**

$$\sigma_H = \frac{PD}{2t}, \quad \sigma_L = \frac{PD}{4t}$$

The UTS of MDN-250 is 1750 MPa. Taking a safety factor of 1.5 and considering 4.8 MPa to be the maximum pressure that is exerted in the combustion chamber, the minimum thickness of the shell can be calculated. The diameter of a typical high-performance rocket motor casing that produces the considered pressure is 800 mm.

$$t_{min} = \frac{P_{max} D \times S.F.}{2\sigma_{H(max)}}$$

Hence, the minimum thickness is calculated to be 1.7 mm. According to ASME UG-29 standard formula, with the same parameters and a weld efficiency (E) of 0.9, the thickness is found to be 2.44mm.

$$t_{min} = \frac{P_{max} R}{2\sigma_H E + 0.4 P_{max}}$$

The static structural analysis of the generated CAD model loaded due to the pressure forces was carried out on ANSYS and the following results were found:

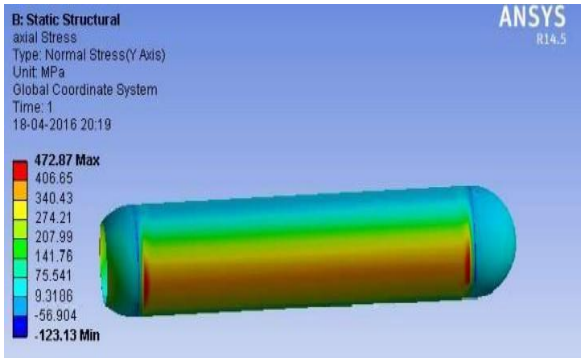
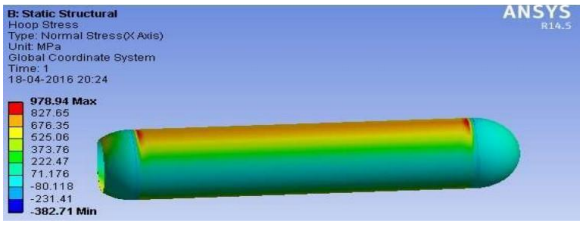



**Figure 3 : Longitudinal stress analysis**

Maximum value of longitudinal stress = 472.87 MPa




Maximum value of hoop stress = 978.94 MPa

The data determined from the analysis is tabulated in the following table along with the values as calculated with the stress equations. Deformation occurred in the casing has also been tabulated.

| Type of stresses | Stress equation | Deformation Equation | Calculated stress | Analytical stress value (ANSYS) | Calculated deformation |
|---|---|---|---|---|---|
| Longitudinal stress | $\sigma_L = \frac{PD}{4t}$ | $\Delta L = \frac{L}{E}(\sigma_L - \mu\sigma_H)$ | 583.33 MPa | 472.87 MPa | 2.22 mm |
| Hoop stress | $\sigma_H = \frac{PD}{2t}$ | $\Delta D = \frac{D}{E}(\sigma_H - \mu\sigma_L)$ | 1166.67 MPa | 978.94 MPa | 3.78 mm |

**Table 3 : Tabulated deformation and stress values**

### 3.2 Bending and shear loads

A rocket is maneuvered by gimballing of the nozzle. This action results in bending and shear loads on the casing of the rocket motor. Secondly a source for shear and bending stresses on the rocket is due to aerodynamic lift forces on the body. Crosswinds that act also induce acceleration in the lateral direction, thus contribution to a bendingmoment.

Bending stress can be calculated by approximating the rocket body as a simply supported beam using the following equation:

Where F is the load, I is the moment of inertia, z is the distance from the neutral axis to a point, L is the length of the beam and x is the axial distance between reference hinge (nose) and each load.

$$\sigma_{Flexure} = \frac{F}{2L(I/z)} \times (L - x)$$

### 3.3 Thermal Loads

Combustion process can generate temperatures of upto 3500 K. Large heat transfer from the chamber to the casing is prevented by the presence of an insulator, which absorbs most of the heat (having a high specific heat). Nevertheless, some amount of thermal stress is induced in the casing due to heating, and thus thermal stresses too are considered for a more accurate analysis.

## IV. CONCLUSION

The various loads that can act on a rocket case due to various forces were analyzed for a rocket motor case using Maraging steel by applying shell theory and beam theory. The stresses produced were well within the limits of the allowable stress for a fixed thickness, considering a suitable safety factor.

Alternatives to MDN-250 for rocket motor cases include Titanium alloys, Steel (D6AC), Stainless steel – 301, and modern composites (carbon fiber and Kevlar epoxy based)

Referring other analyses of rocket motor casings using different materials, and considering factors such as availability, strength, cost, machineability, use of Maraging steel (MDN-250) was found to be most advantageous.

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