Liquid Hydrogen Storage

Team Protium

Presents to You

Simulation of Hydrogen Tank in Ansys

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What is Hydrogen ?

Hydrogen, is the lightest and most abundant element in the universe, exhibits unique properties when in its liquid state. Liquid hydrogen is produced through cryogenic liquefaction. Liquid hydrogen is a key component in rocket propulsion due to its high energy content and efficiency. It has been used in various space missions, powering rockets and serving as a crucial element in the exploration of outer space. While hydrogen itself is not toxic, it is highly flammable, demanding strict safety protocols in storage and transportation.

Liquid Hydrogen

- Liquid hydrogen is the cryogenic state of the chemical element hydrogen (H_2).
- At standard atmospheric pressure, hydrogen exists as a gas.
- Still, when cooled to very low temperatures, it undergoes a phase transition and becomes a colorless, odorless, and highly flammable liquid.
- The change from gaseous to liquid hydrogen occurs at its boiling point, approximately -252.87 degrees Celsius.

It's important to note that the handling and storage of liquid hydrogen require specialized equipment and safety precautions due to its extremely cold temperature and flammability. Proper safety measures are crucial when working with this cryogenic substance.

Liquid Hydrogen Storage

The cryogenic hydrogen is to be stored in specially insulated vessels at (-) 252.880C.The energy required to liquefy hydrogen (gas at 300oK and 1 bar pressure) is about 47 MJ / kg of hydrogen.

Cryogenic Storage

Liquid hydrogen is stored in cryogenic tanks at 21.2 K at ambient pressure. Because of the low critical temperature of hydrogen (33 K), the liquid form can only be stored in open systems, as there is no liquid phase existent above the critical temperature.

Pressure Vessel

Hoop Stress/ Circumferential Stress

total force developed by the pressure P,

$$F = \text{stress} \times \text{Area}$$

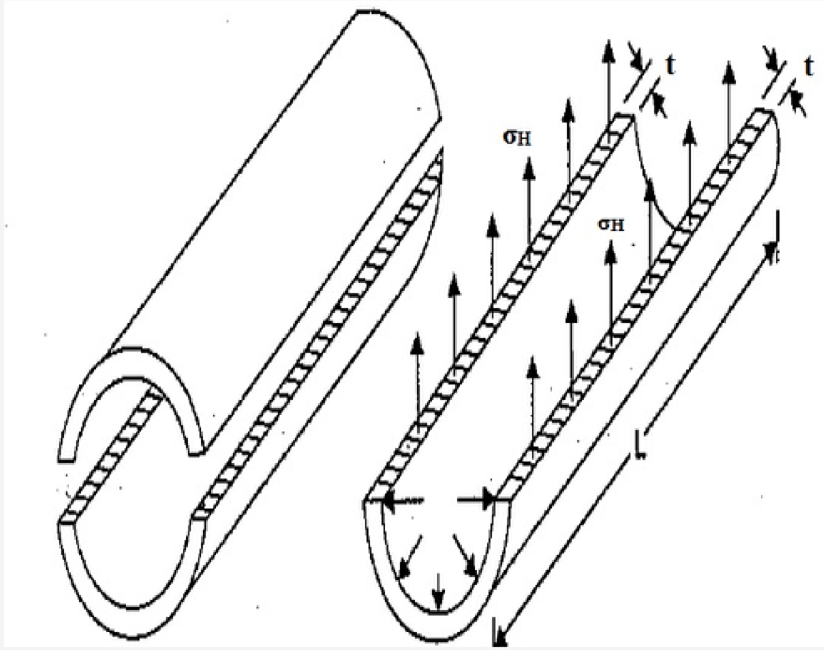
$$F = PdL$$

Hoop stress is given by,

$$\sigma_h = \frac{F}{\text{cross sectional area}}$$

$$\sigma_h = \frac{PdL}{2Lt}$$

$$\sigma_h = \frac{Pd}{2t}$$



Assuming thin pressure vessel

Longitudinal Stress

total force developed by the pressure P,

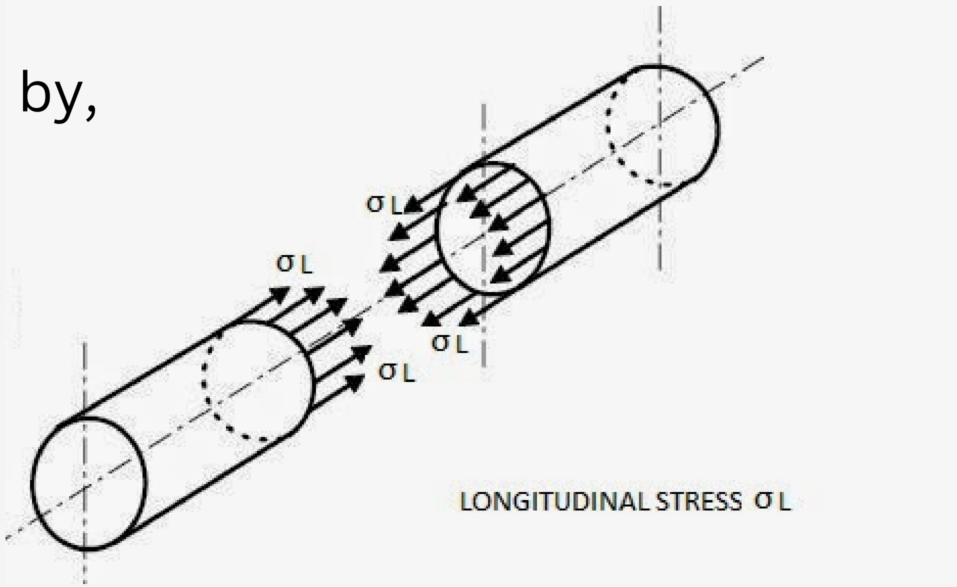
$$F = P \times \frac{\pi}{4} \times d^2$$

Longitudinal stress is given by,

$$\sigma_l = \frac{F}{\text{cross sectional area}}$$

$$\sigma_l = \frac{P \times \frac{\pi}{4} \times d^2}{\pi \times dt}$$

$$\sigma_l = \frac{Pd}{4t}$$



Assuming thin pressure vessel

Tangential Stress

Area of rectangle,

$$A = dL$$

$$T = \sigma_t \times tL$$

pressure can be given as,

$$P = \frac{F}{dL}$$

$$F = PdL$$

$$\sigma_t = \frac{T}{tL}$$

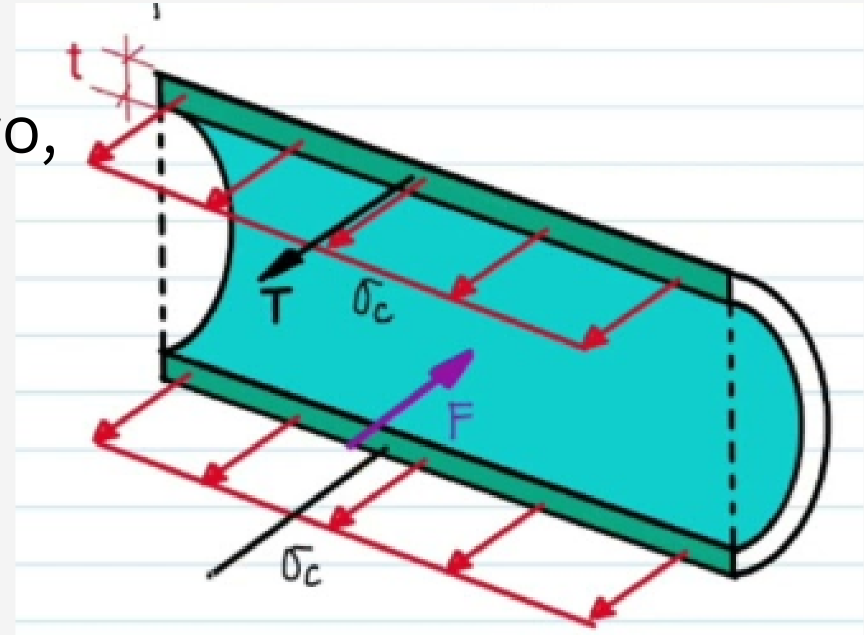
Net force along x direction is zero,

$$\Sigma x = 0$$ --> $$F - 2T = 0$$

$$F = 2T$$

$$PdL = 2(\sigma_t \times tL)$$

$$\sigma_t = \frac{Pd}{2t}$$



Assuming thin pressure vessel

Thick Pressure Vessels

Lame's Equations:

Hoop stress (σ_h)

$$\sigma_h = \frac{\beta}{r^2} + \alpha$$

1

Pressure at any r:

$$Pr = -\alpha + \frac{\beta}{r^2}$$

2

Where α and β are Lamé's constants

Using eq. 2 to find α and β,

at, r = R_i and P = P_i

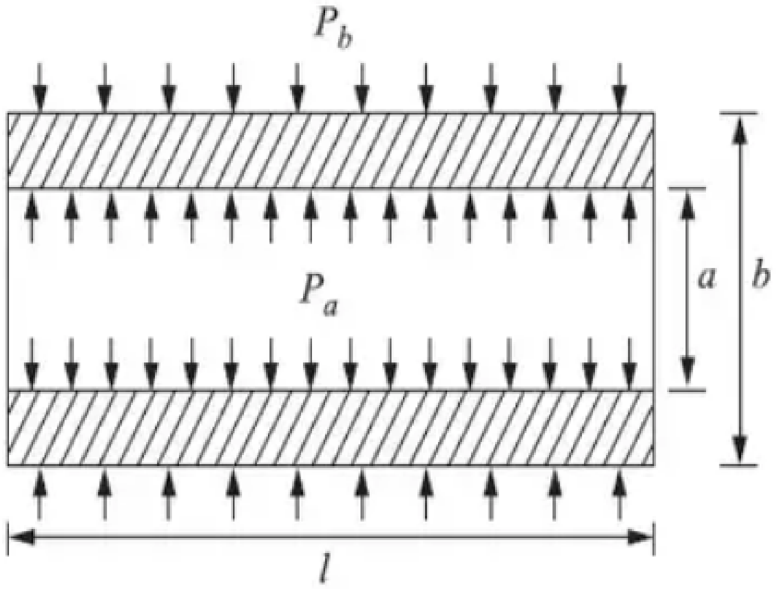
$$P_i = -\alpha + \frac{\beta}{R_i^{\,2}}$$

3

at, r = R_i and P = P_i

$$P_0 = -\alpha + \frac{\beta}{R_0^{\,2}}$$

4



Solving 3 and 4:

$$\alpha = \frac{\beta}{R_i^{\,2}} - P_i$$

5

$$\beta = \frac{(P_i - P_0)R_i^{\,2}R_0^{\,2}}{R_0^{\,2} - R_i^{\,2}}$$

6

at r = R_i and r = R_o,

$$\sigma_{h,R0} = \alpha + \frac{\beta}{R0^2}$$

$$\sigma_{h,Ri} = \alpha + \frac{\beta}{Ri^2}$$

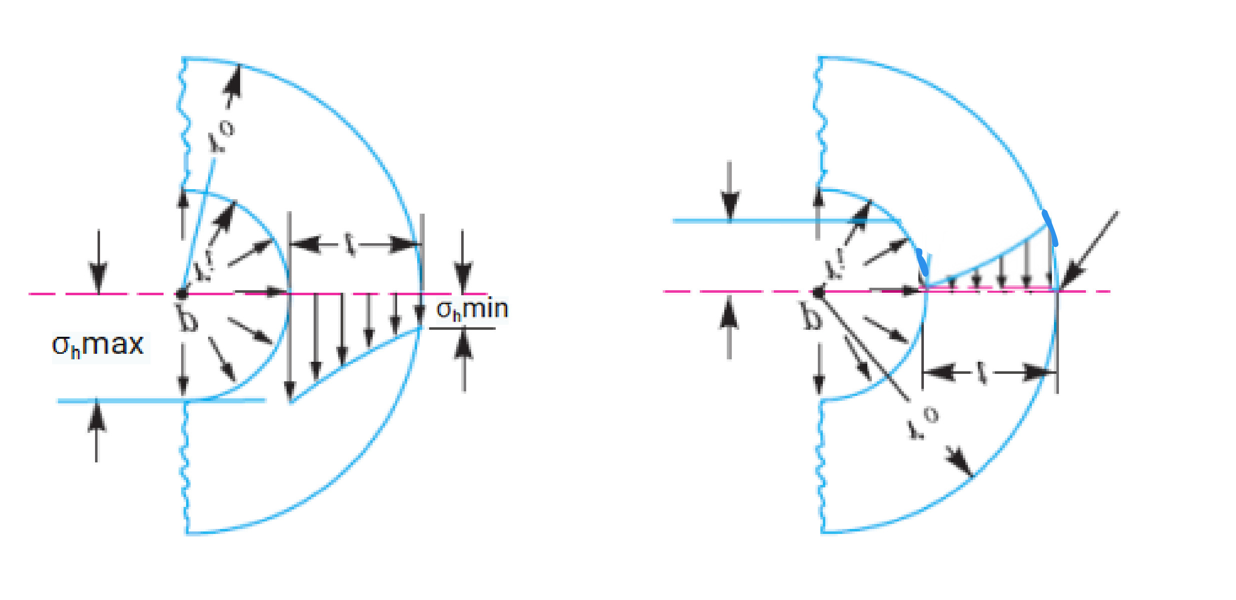
Substracting them,

$$(\sigma_{h,R0}) - (\sigma_{h,Ri}) = \beta \times \left(\frac{1}{Ri^2} - \frac{1}{R0^2}\right)$$

using eq. 6,

$$(\sigma_{h,R0}) - (\sigma_{h,Ri}) = Pi - Po \quad *$$

Case 1: Only external pressure, Pi = 0:



Radial and hoop stress distribution

Case 2: Only internal pressure, $P_o = 0$

$$P_o = 0 = -\alpha + \frac{\beta}{R0^2}$$ --> $$\alpha = \frac{\beta}{R0^2}$$

Putting it in P_i,

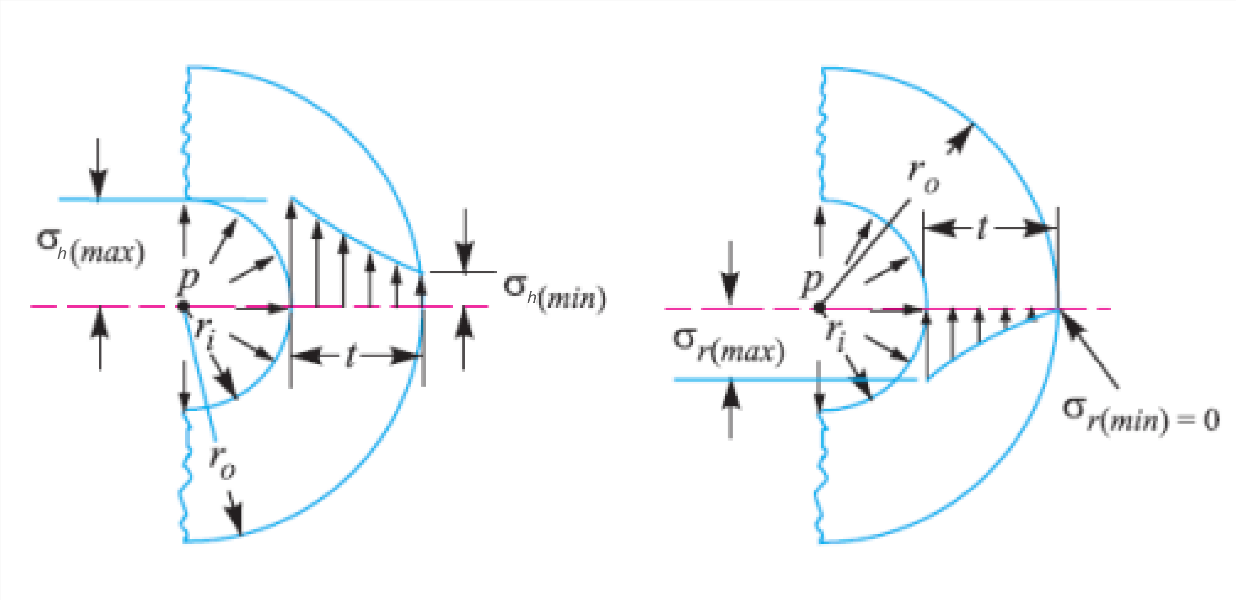
$$Pi = \frac{\beta}{Ri^2} - \frac{\beta}{R0^2}$$

$$\beta = \frac{Pi \times Ri^2 \times R0^2}{R0^2 - Ri^2}$$ and $$\alpha = \frac{P_i {R_i}^2}{{R_0}^2 - {R_i}^2}$$

putting it in 1 and 2 :

$$\sigma_h = \frac{P{r_i}^2\left(1 + \frac{{r_i}^2}{x^2}\right)}{{r_0}^2 - {r_i}^2}$$

$$\sigma_r = \frac{P{r_i}^2\left(1 - \frac{{r_0}^2}{x^2}\right)}{{r_0}^2 - {r_i}^2}$$



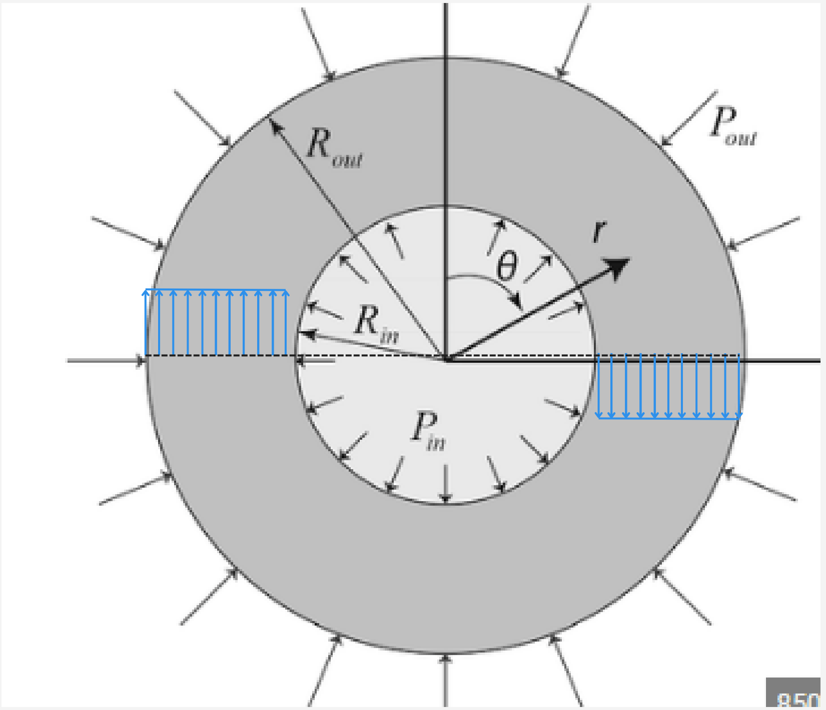
Radial and hoop stress distribution

Case 3: Pi = P_o=P:

$$P_o = 0 = -\alpha + \frac{\beta}{R0^2} = -\alpha + \frac{\beta}{{R_i}^2}$$

β = 0 and P = -α

$$\sigma_{h}, x = -P$$ → Independent of radius and constant through out radius



PARAMETERS CONSIDERING FOR DESIGN

Circumferential or Hoop Stress :

Hoop stress resists internal pressure, analyzed in cylinder equilibrium. It's the circumferential force on particles, perpendicular to the axis and radius. Excess stress may split the pipe, allowing failure along any diameter-axis plane. Elements resisting this are stressed along the circumference.

Longitudinal Stress:

A closed-ended cylinder containing fluid under gauge pressure experiences both longitudinal and circumferential stresses in its walls. Under internal pressure 'P,' the pipe may fail, with elements resisting this failure subjected to stress parallel to the longitudinal direction.

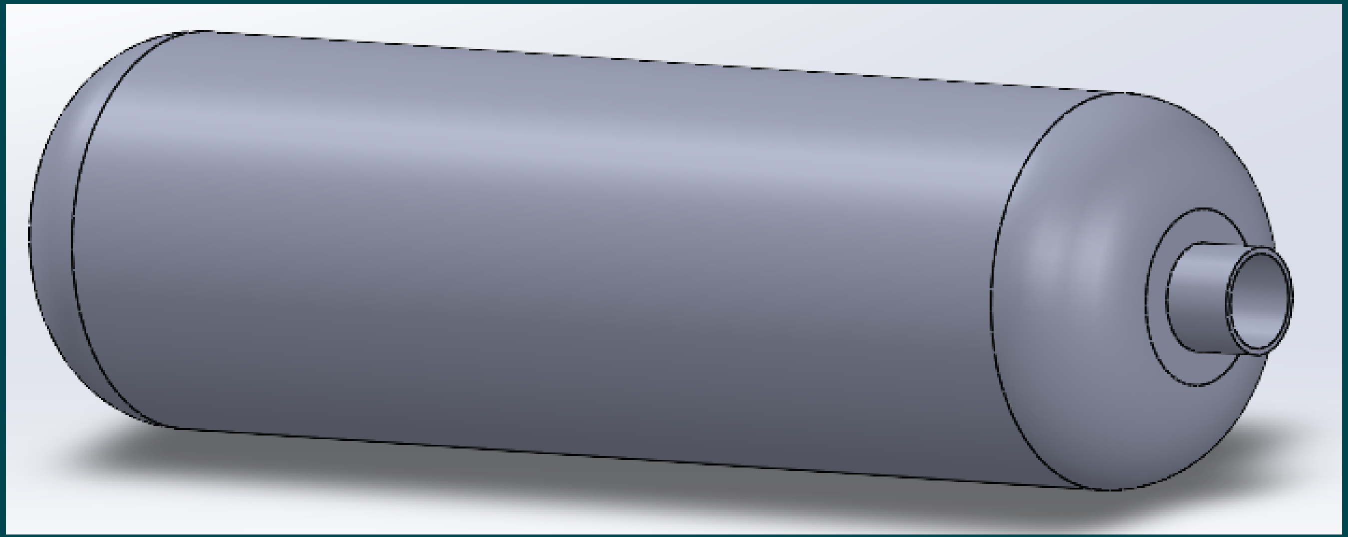
Radial stress:

Radial stress can also be a factor in thick-walled pipe. It is stress in directions coplanar with, but perpendicular to, the symmetry axis. The radial stress is equal and opposite to the gauge pressure on the inside surface, and zero on the outside surface.

Designing of Hydrogen Storage Tank

Length - 8270mm **Thickness - 39mm**

Diameter - 2300mm **Pressure - 35MPa**



We made this pressure vessel shown above with the mentioned dimensions

Simulation conditions

Internal Pressure - 35MPa

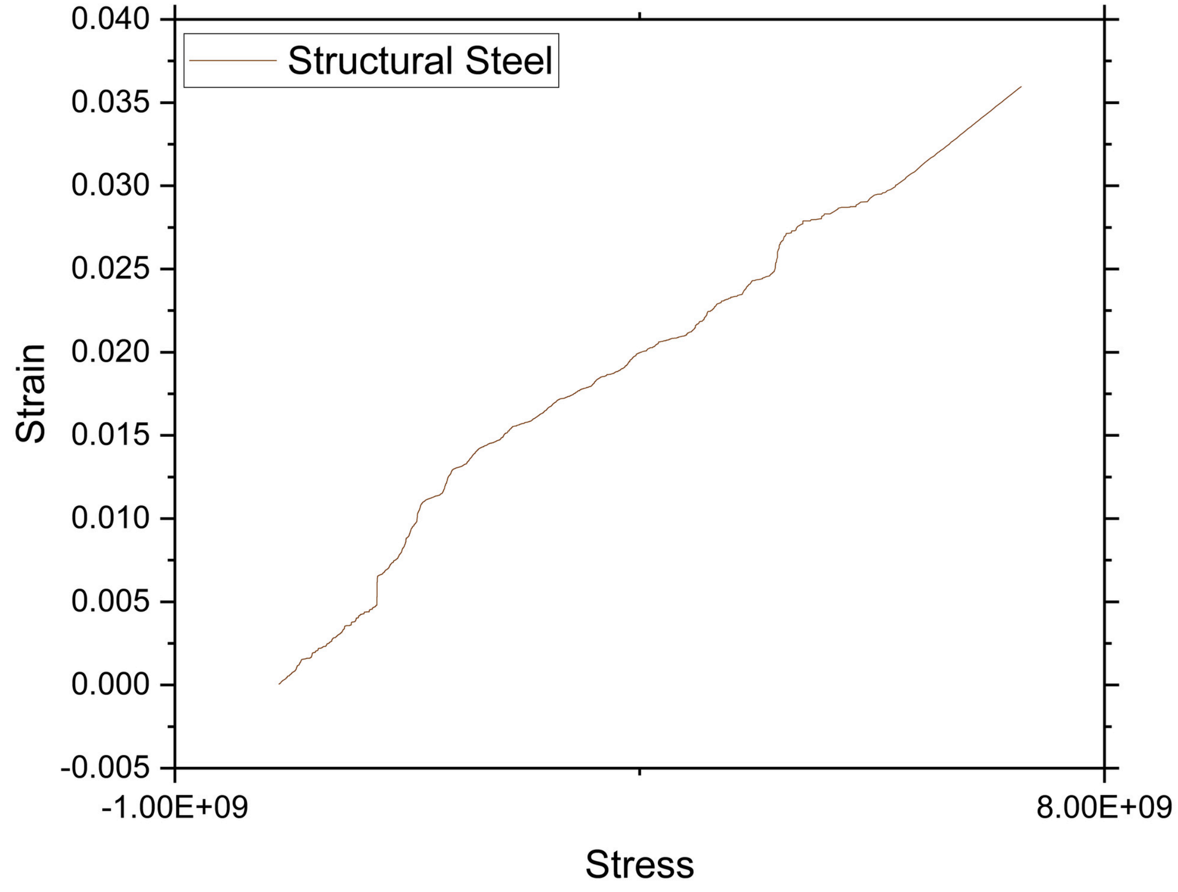
Environment Temperature - -250C

One fixed support at the mouth of this vessel

Materials Used:

- Structural Steel
- Magnesium
- AL7075-T6 (Aluminium alloy)
- Ti-6Al-4V (Titanium alloy)

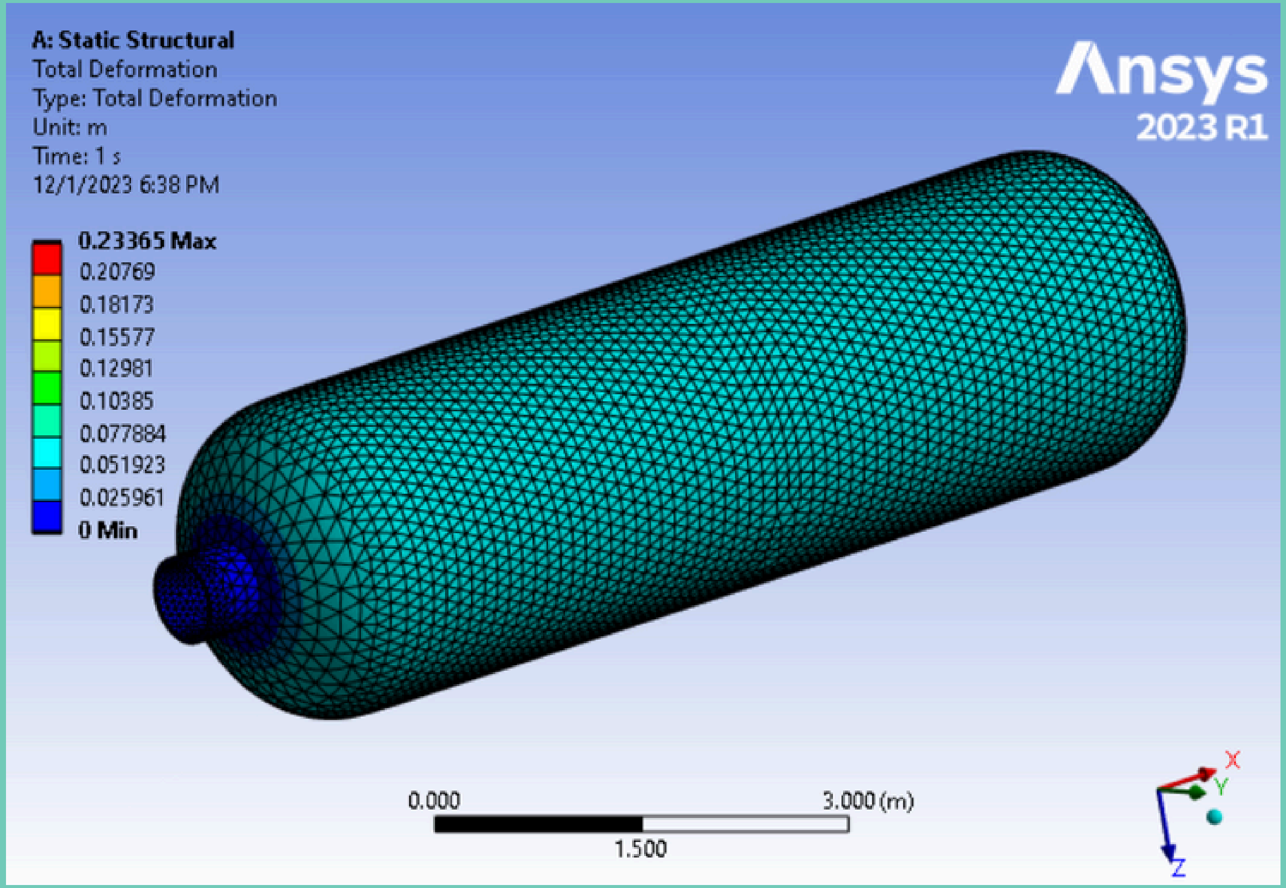
Structural Steel



Proprieties	Value	**Units**
Density	7850	Kg/m^3
Young Modulus	2,07E+11	Pa
Poisson's ratio	0.3	
Shear Modulus	7.9615E+10	Pa
Bulk Modulus	1.725E+11	Pa
Tensile yield strength	2.5E+08	Pa
Tensile ultimate strength	2.5E+08	Pa
Limit rupture in traction	4.6E+08	Pa

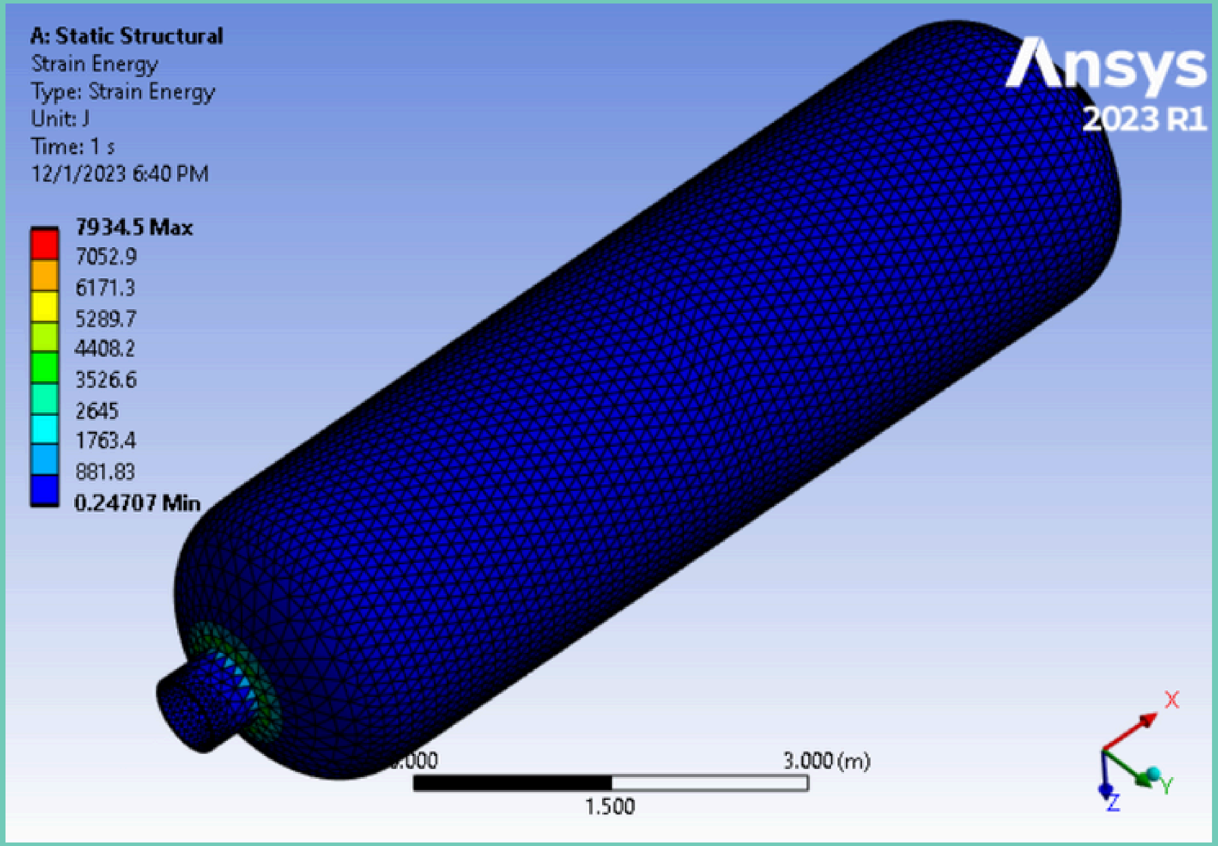
Structural Steel

Deformatation



Shows maximum deformation of 0.23365 m

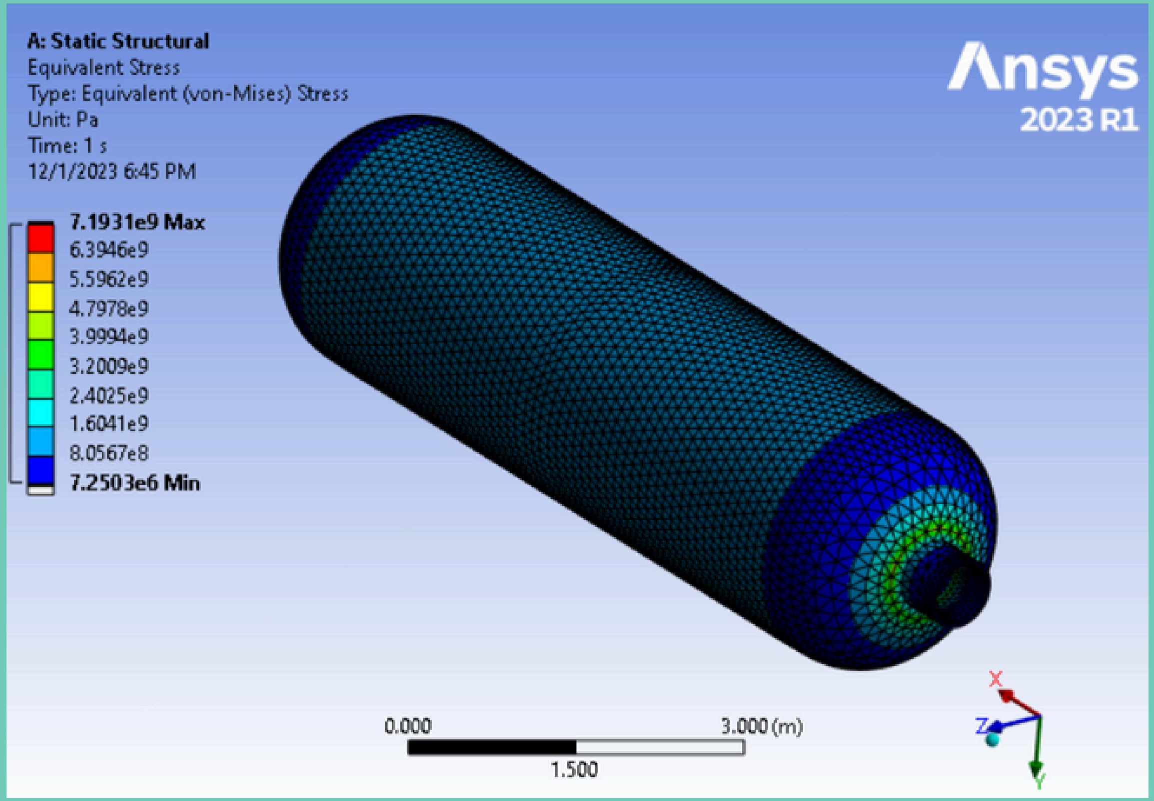
Strain Energy



Maximum strain energy came out as 7934.5 J

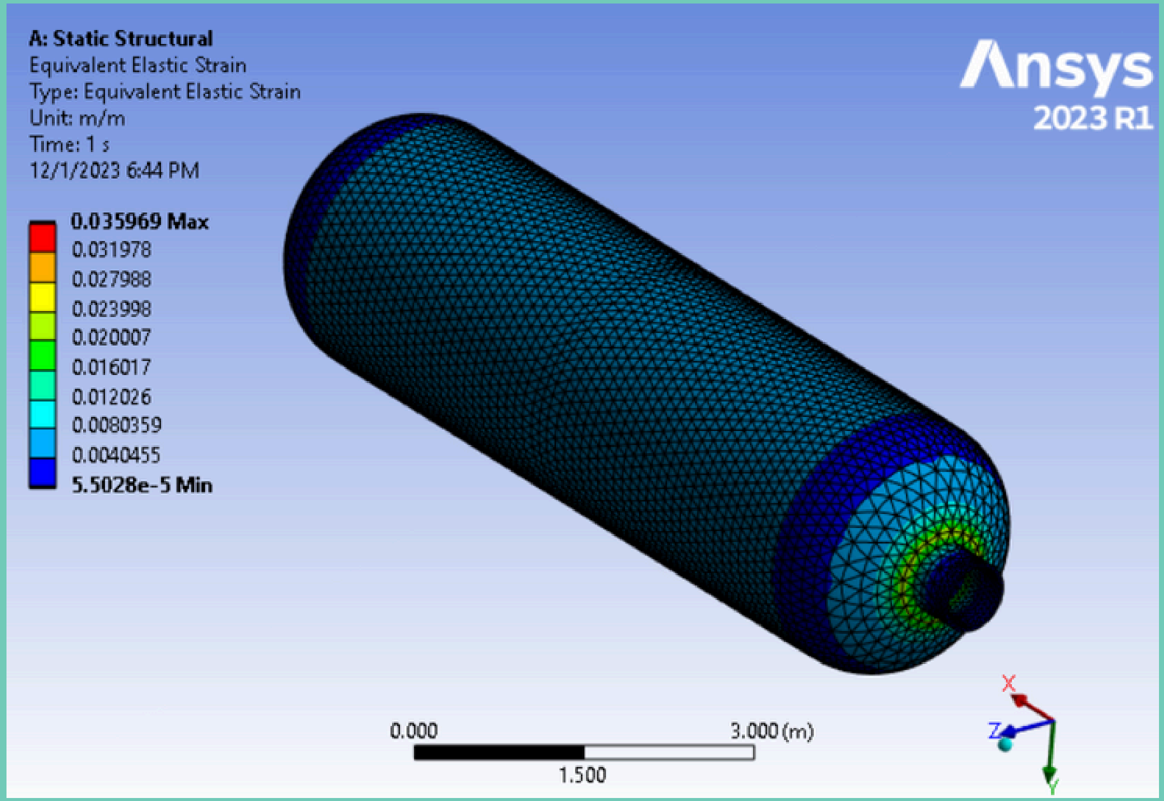
Structural Steel

Stress

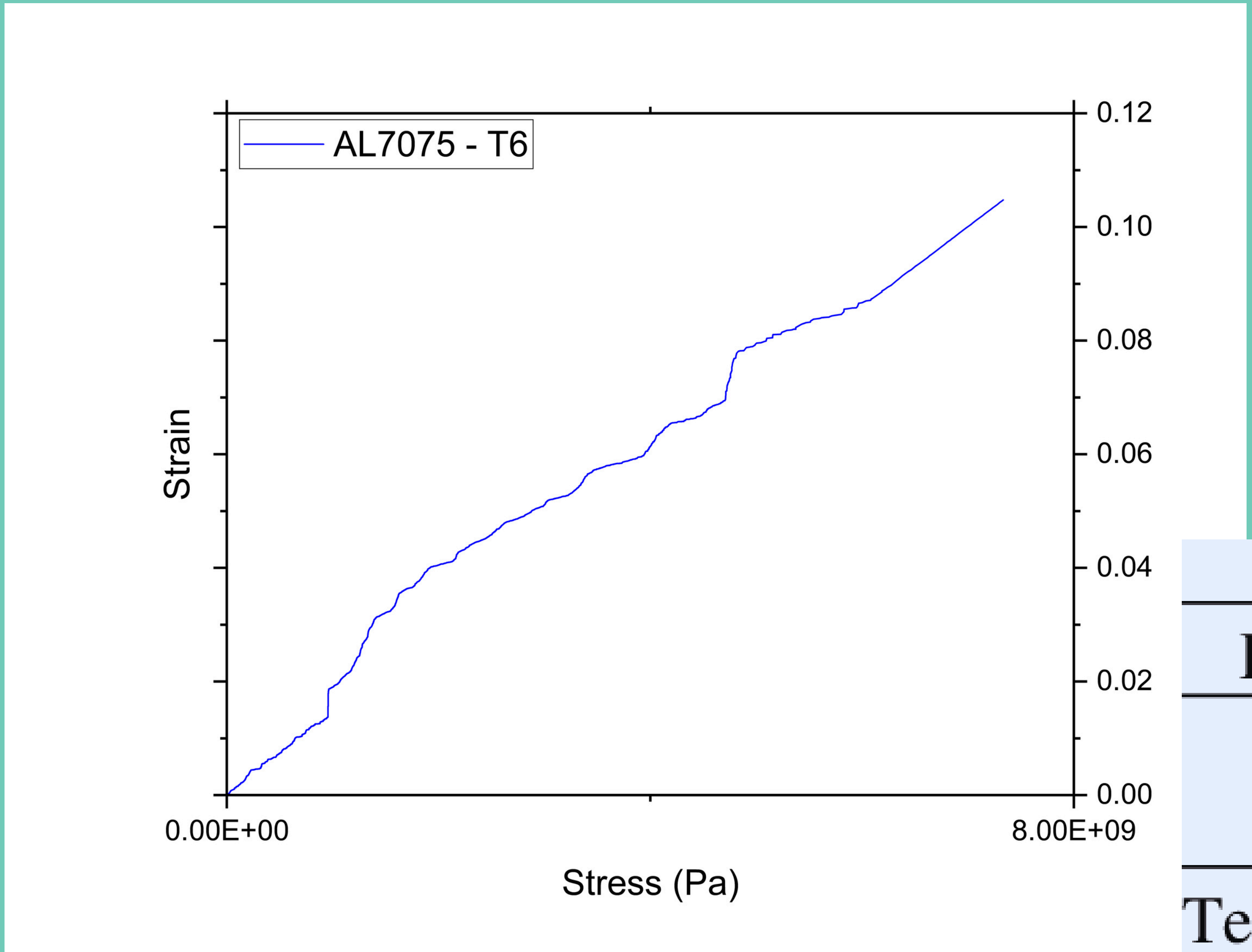


The maximum stress experienced by the material is 7.1931e9 Pa

Strain



The maximum strain experienced is 0.035969.

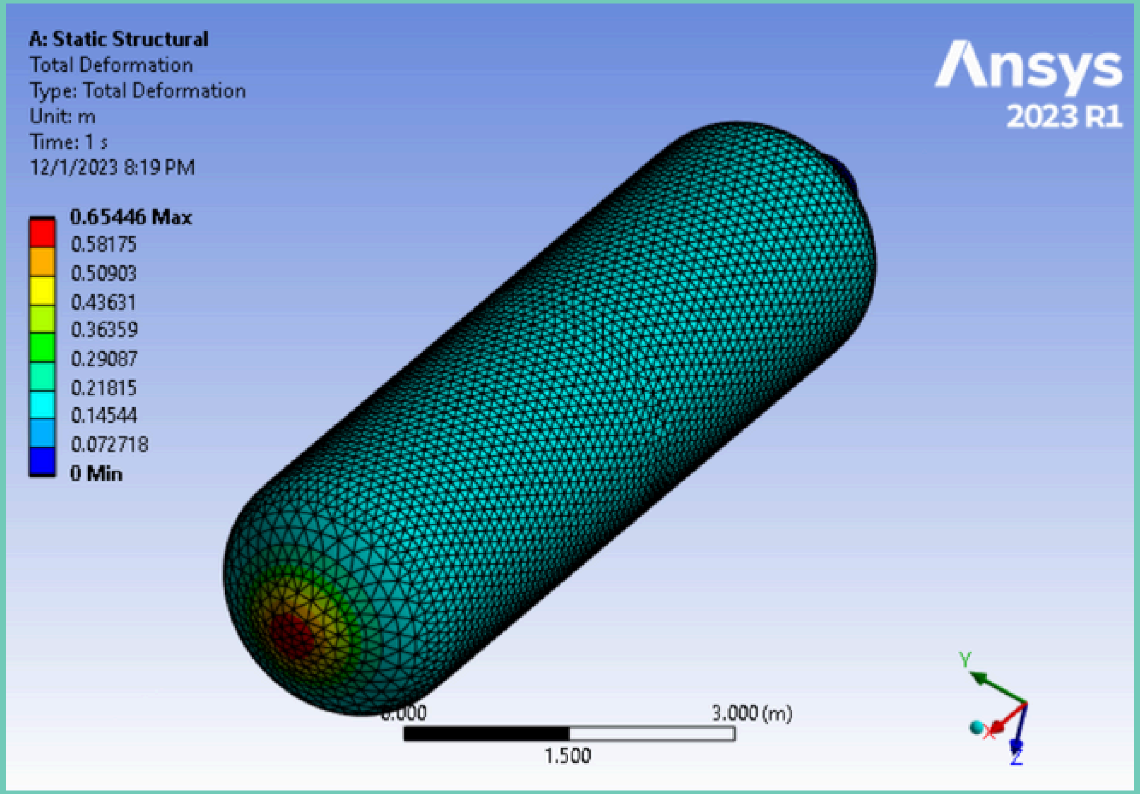


AL7075-T6 : Aluminium Alloy

Density	2.81g/cc
Hardness, Vickers	175 HV
Ultimate Tensile Strength	572MPa
Tensile Yield Strength	503MPa
Modulus of Elasticity	71.7GPa
Thermal Conductivity	130 W/m-K
Melting Point	477-635°C

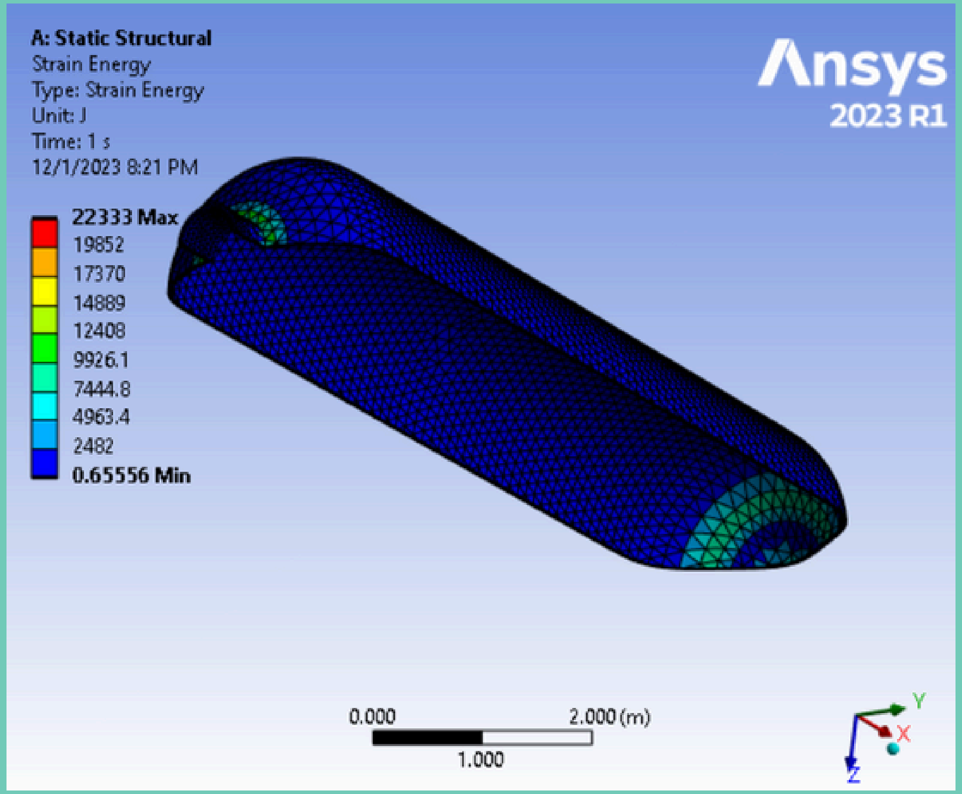
AL7075-T6 : Aluminium Alloy

Deformatation



Shows maximum deformation of 0.65446 m

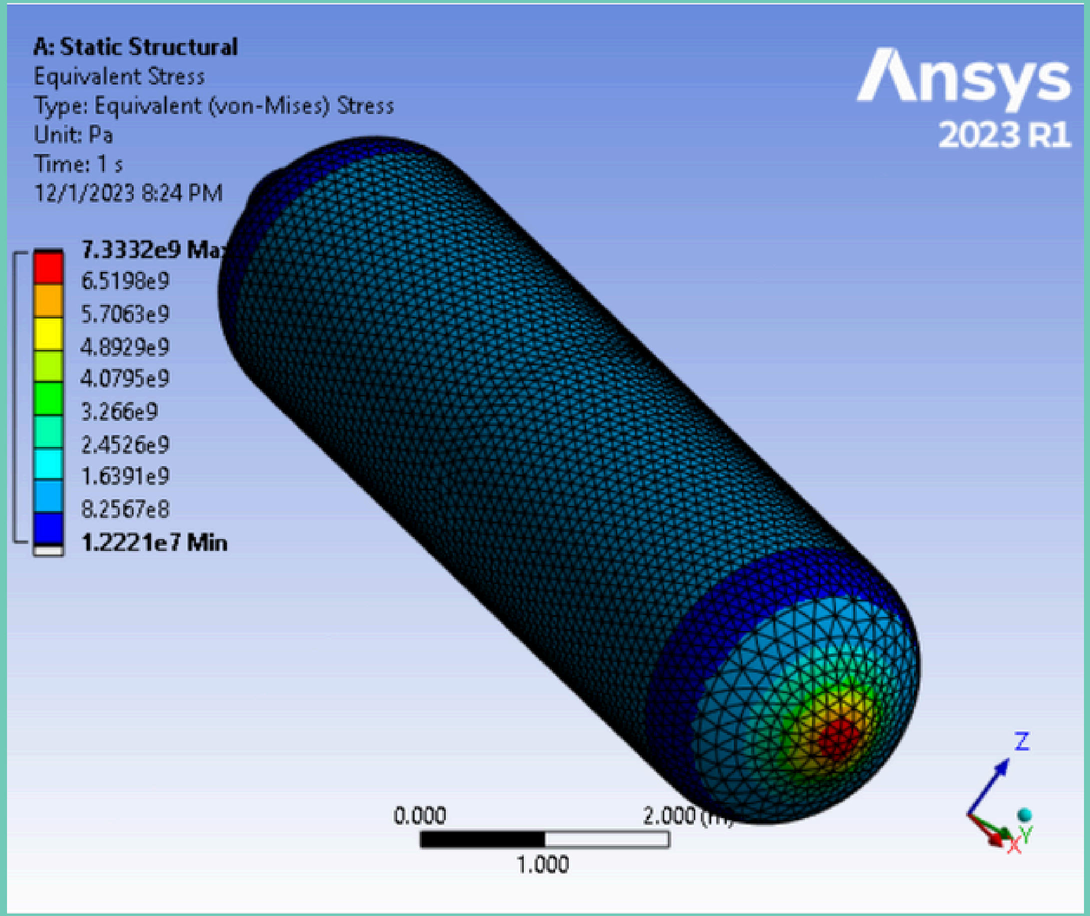
Strain Energy



Maximum strain energy came out as 22333 J

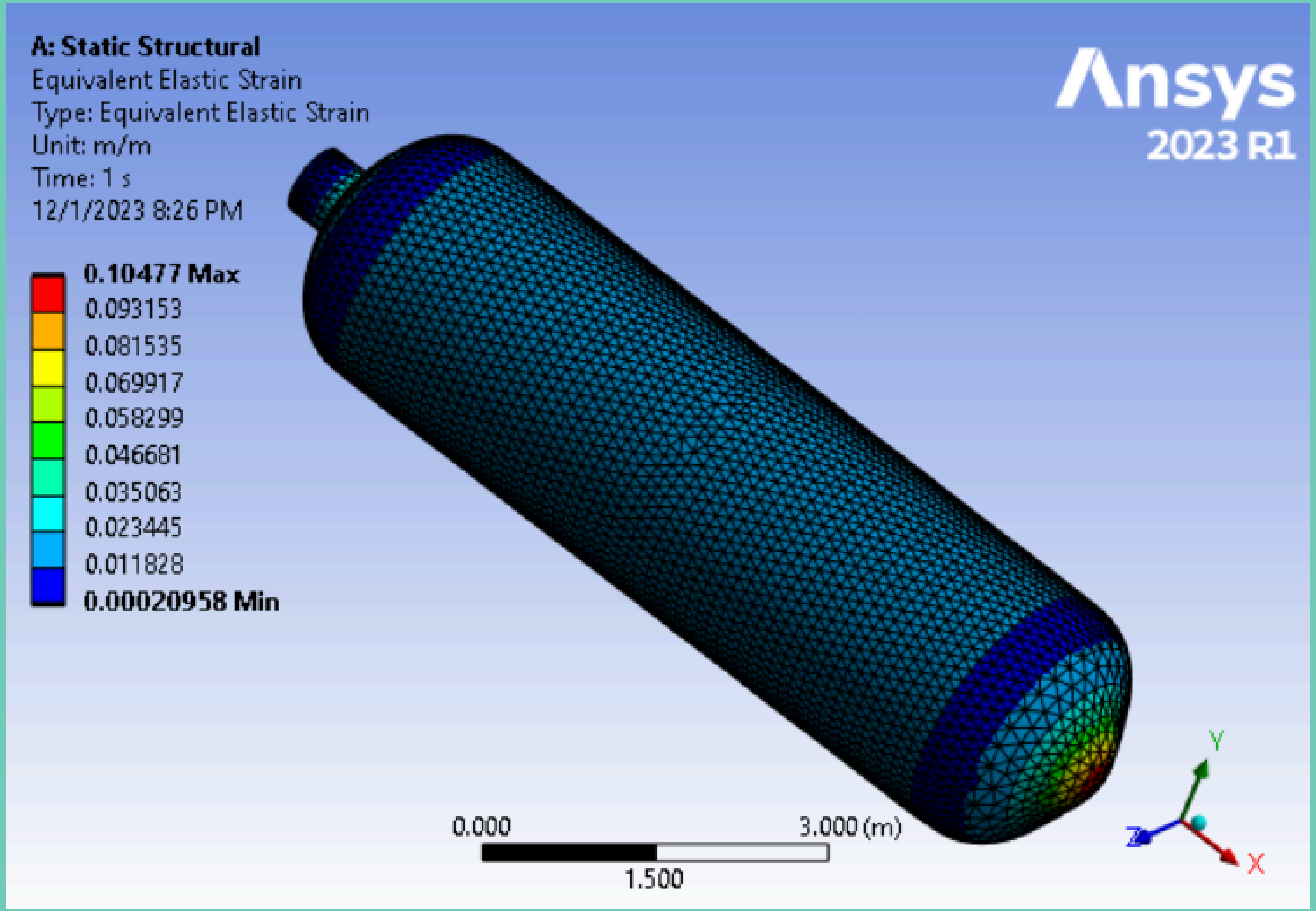
AL7075-T6: Aluminium Alloy

Stress



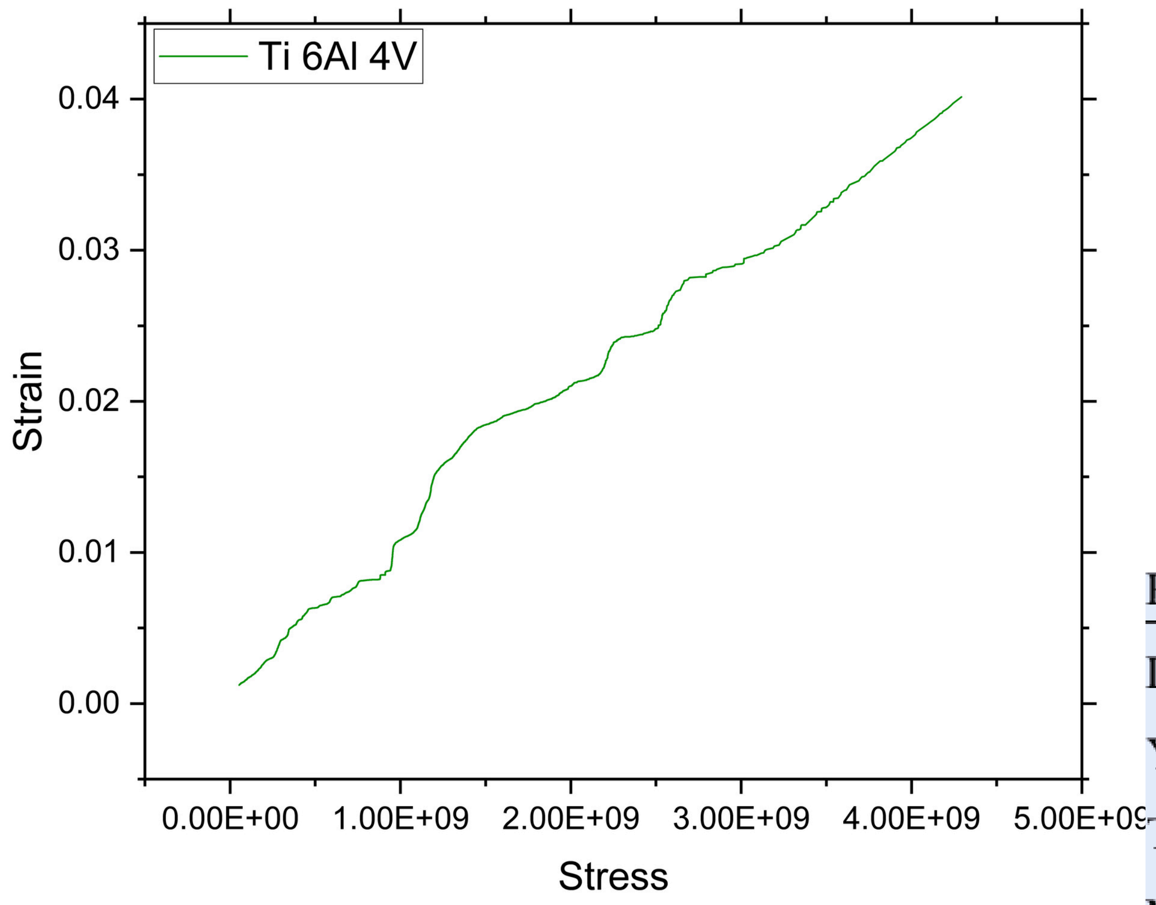
The maximum stress experienced by the material is 7.3332e9 Pa

Strain



The maximum strain experienced is 0.10477.

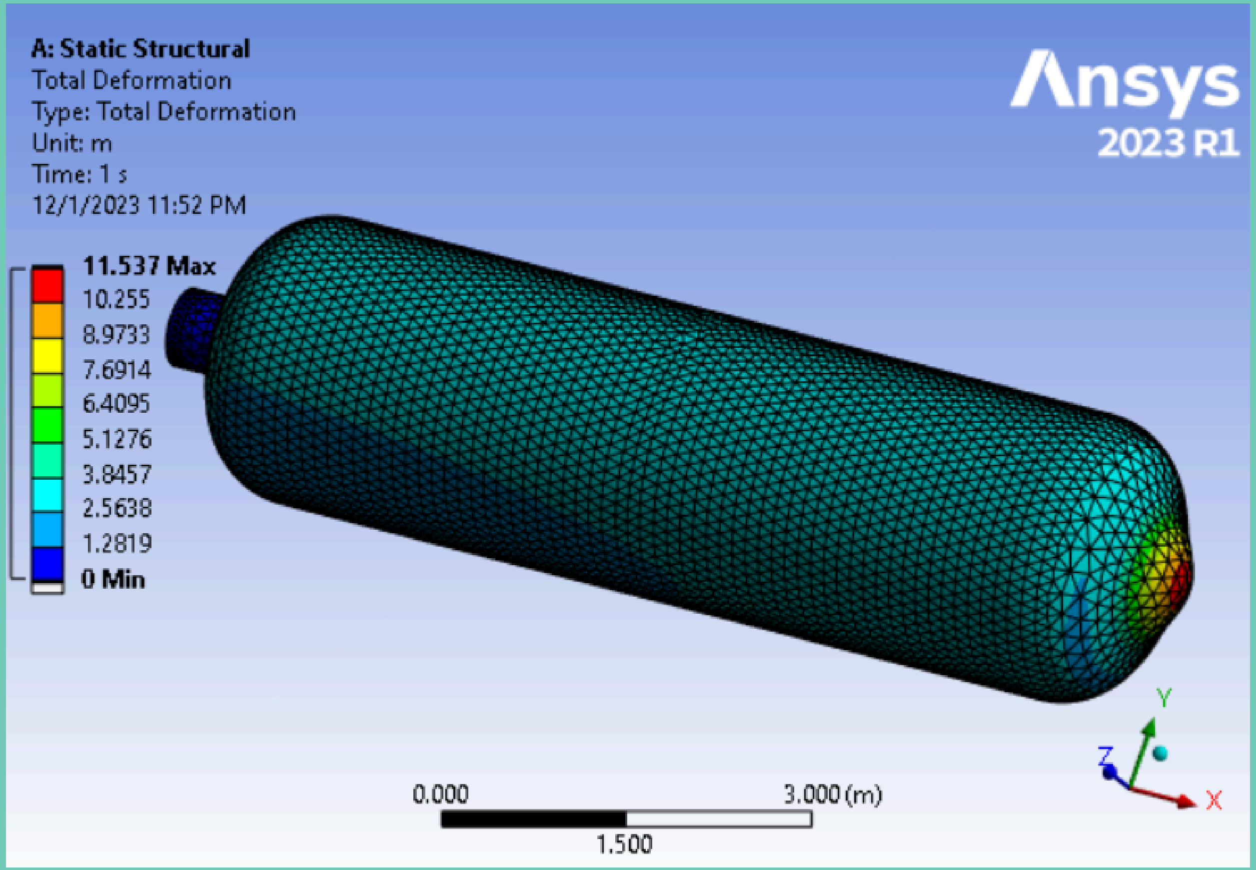
Ti-6Al-4V : Titanium Alloy



Property	Value
Density (ρ)	4.43 x 10^3 kg/m^3
Yield strength (R_e)	880 MPa
Tensile strength (R_M)	950 MPa
Modulus of elasticity (E)	113.8 GPa
Shear modulus (G)	44 GPa
Poisson ratio (ν)	0.342
Longitudinal velocity of sound (c_l)	5068.4 m/s
Transversal velocity of sound (c_t)	3151.6 m/s

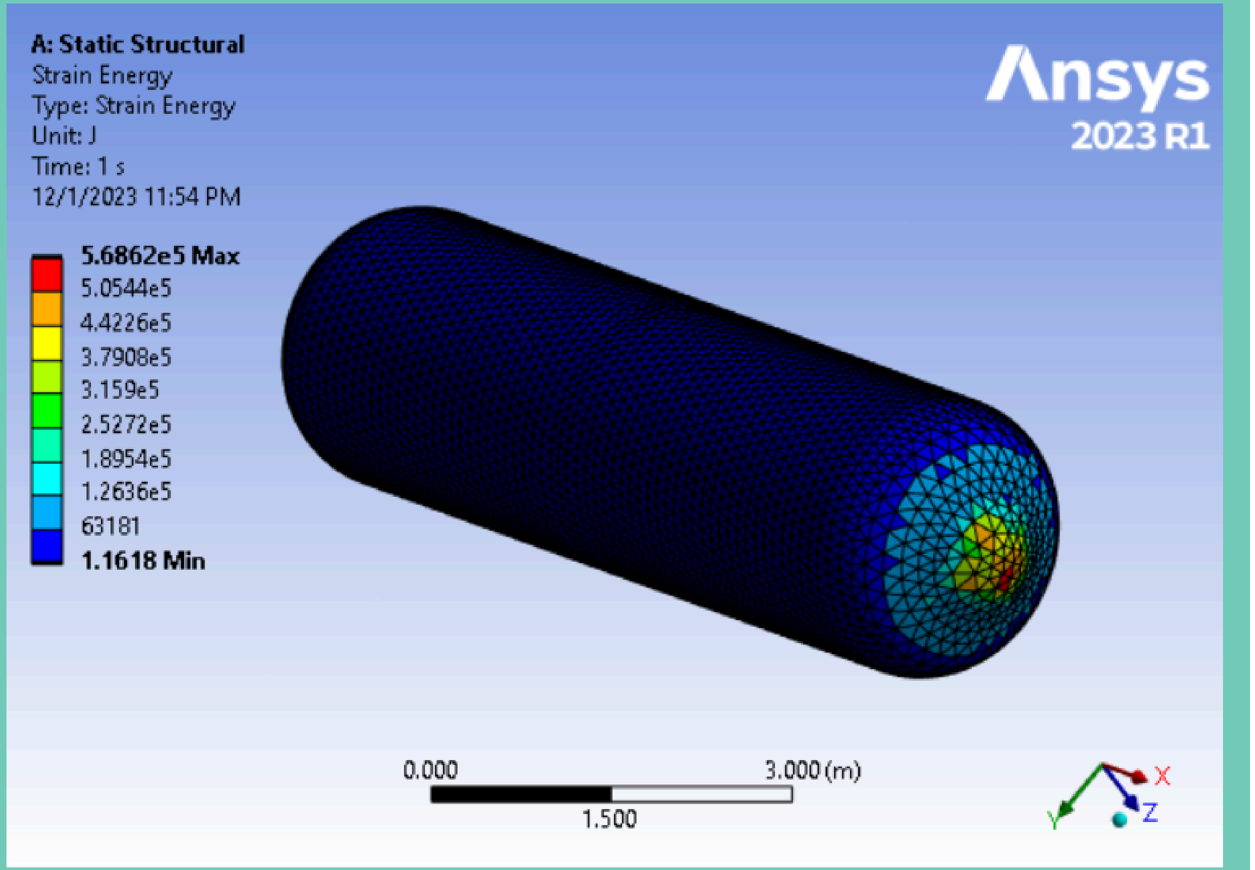
Ti-6Al-4V : Titanium Alloy

Deformatation



Shows maximum deformation of 11.537 m

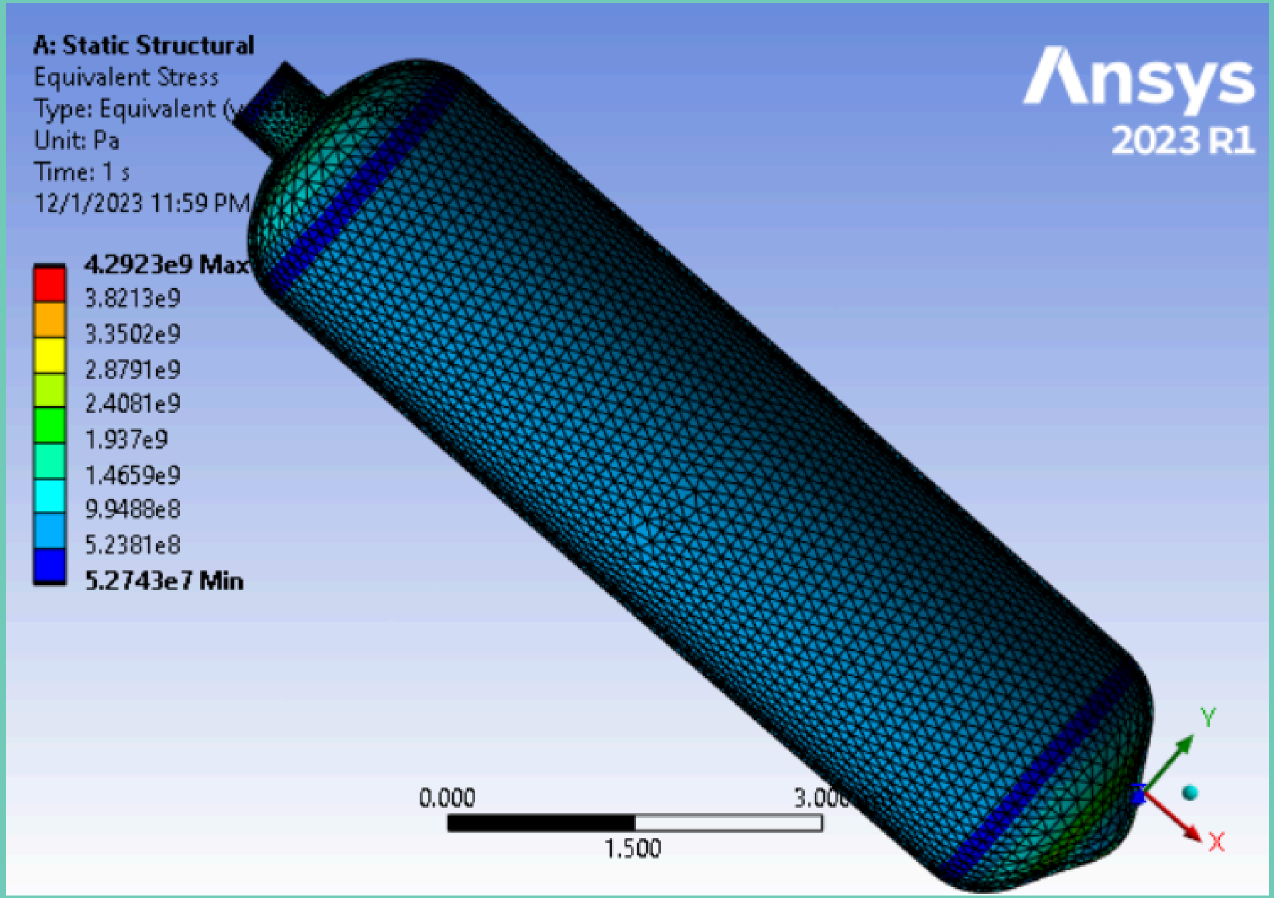
Strain Energy



Maximum strain energy came out as 5.6862e5 J

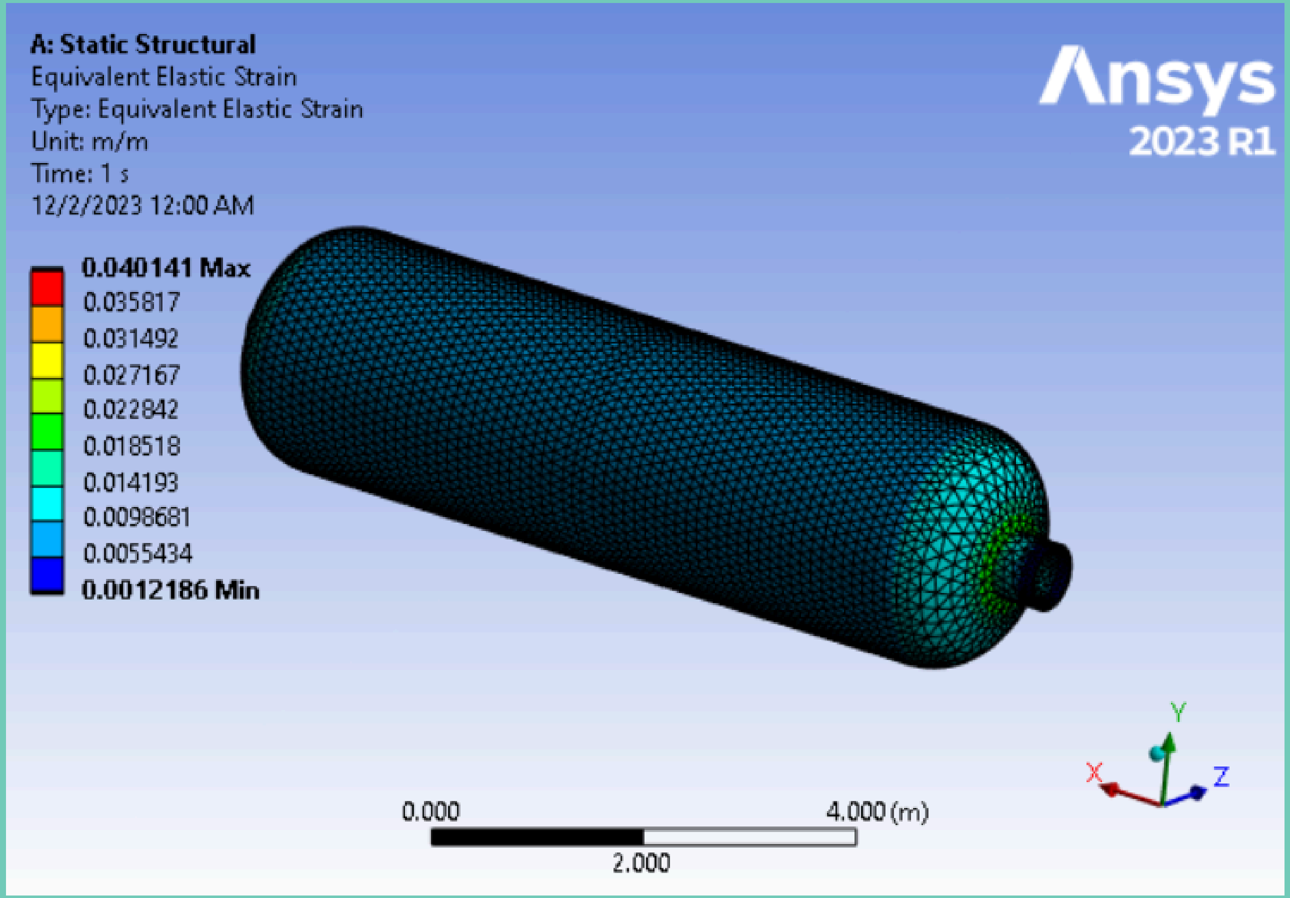
Ti-6Al-4V : Titanium Alloy

Stress



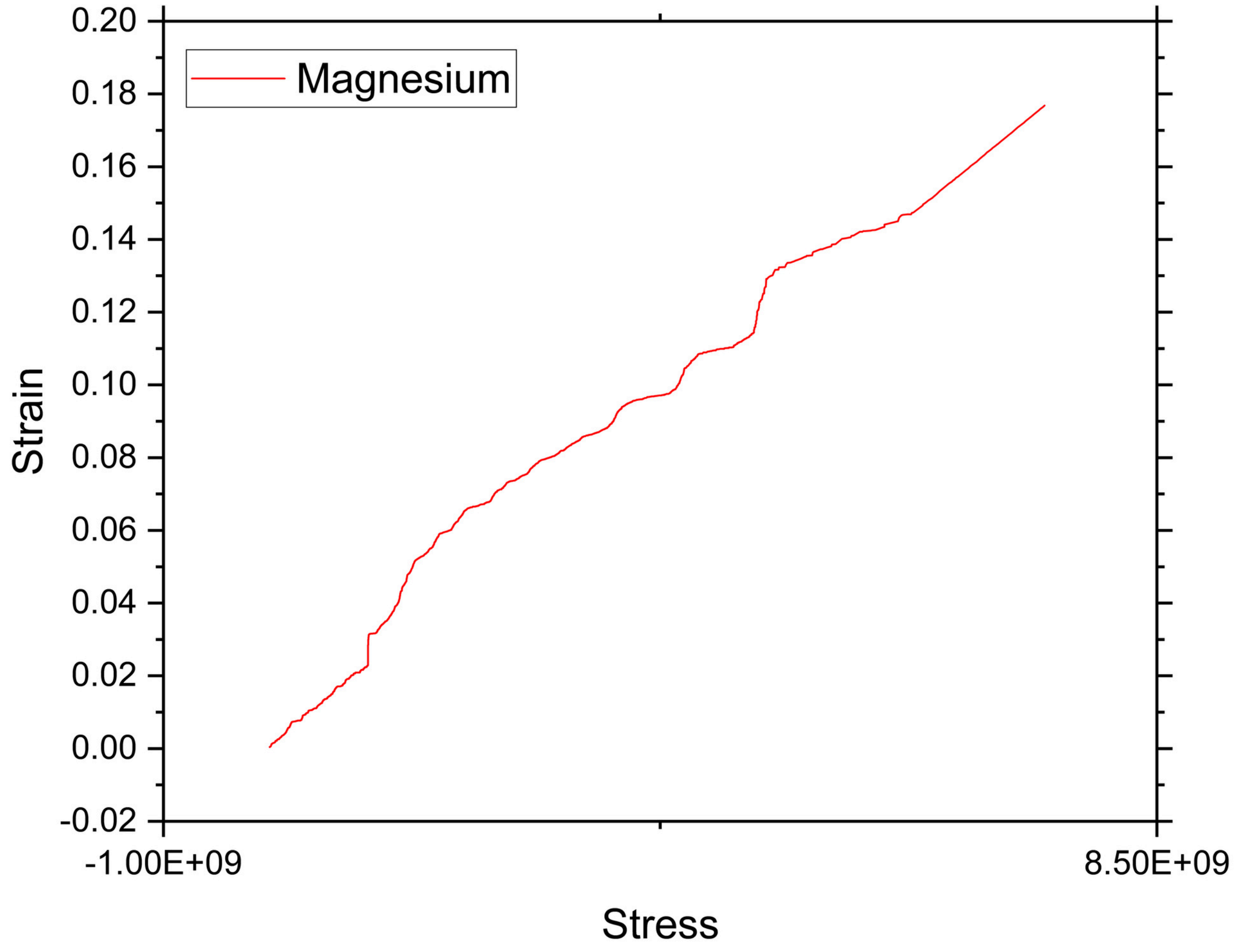
The maximum stress experienced by the material is 4.2923e9 Pa

Strain



The maximum strain experienced is 0.040141.

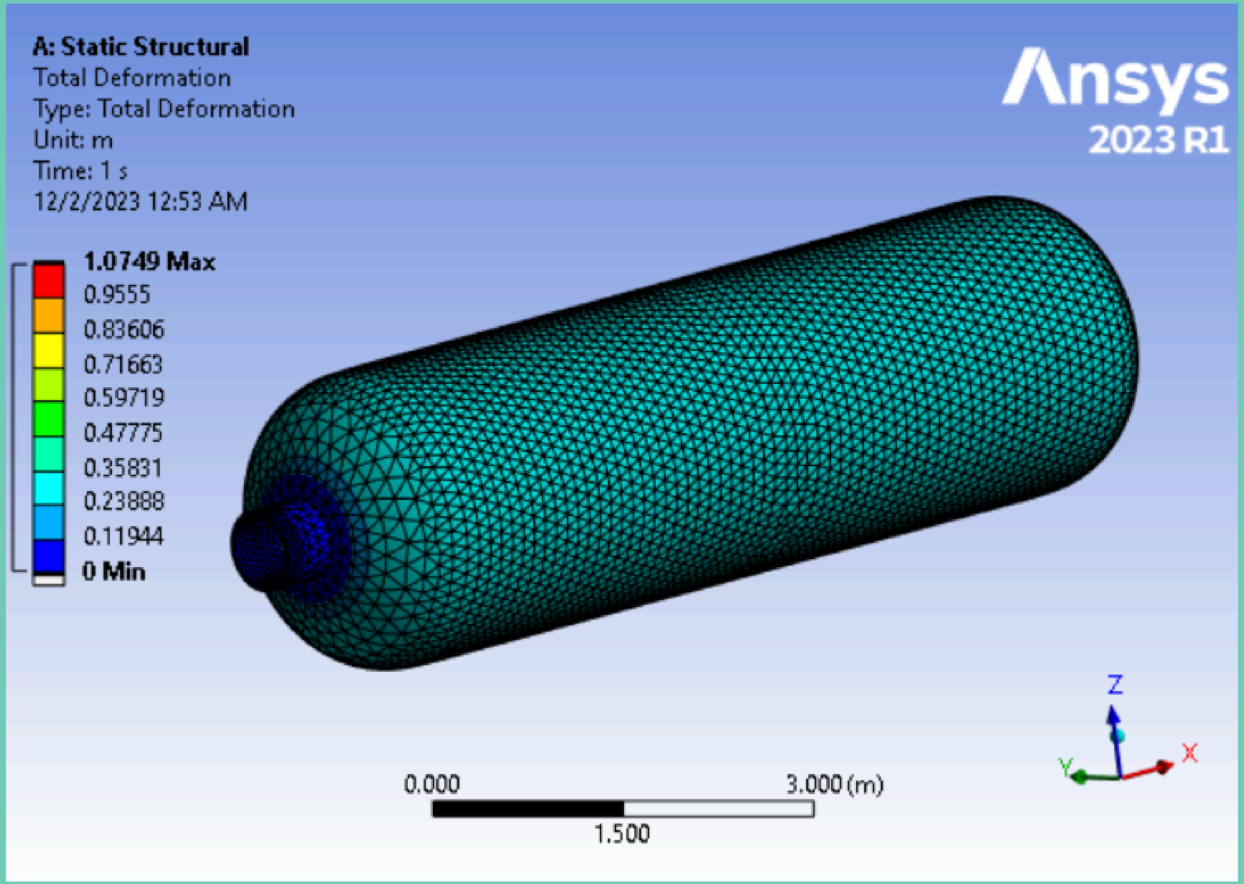
Magnesium



Density [kg/mm^3]	1.77×10^{-6}
Young's Modulus [kN/mm^2)	45,000
Possion's ratio	0.35
Melting temperature [K]	891
Thermal Conductivity [W/(mK)]	77+0.096 T
Specific heat capacity [J/(kgK)]	1000+0.666T
Thermal expansion coefficient [K^{-1}]	2.48×10^{-5}

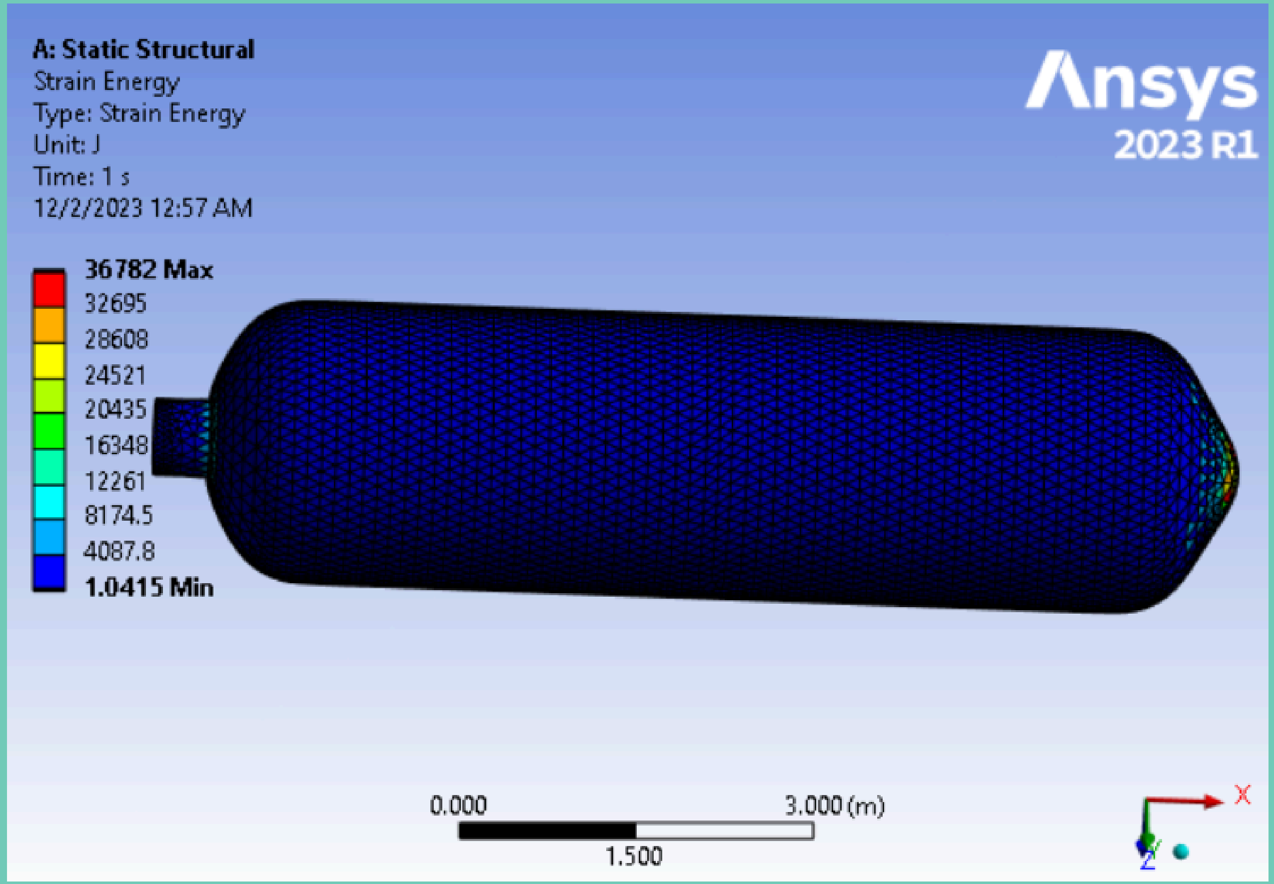
Magnesium

Deformatation



Shows maximum deformation of 1.0749 m

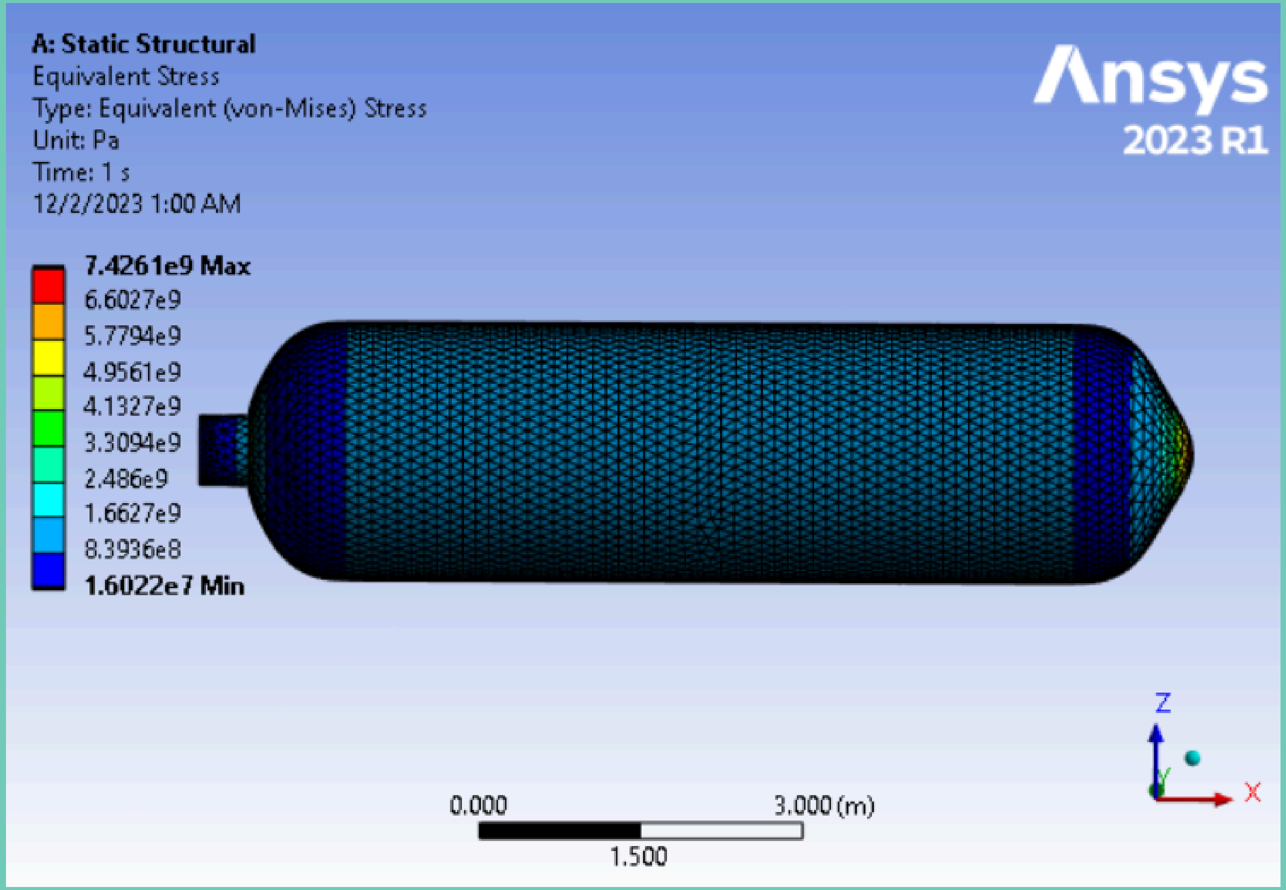
Strain Energy



Maximum strain energy came out as 36782 J

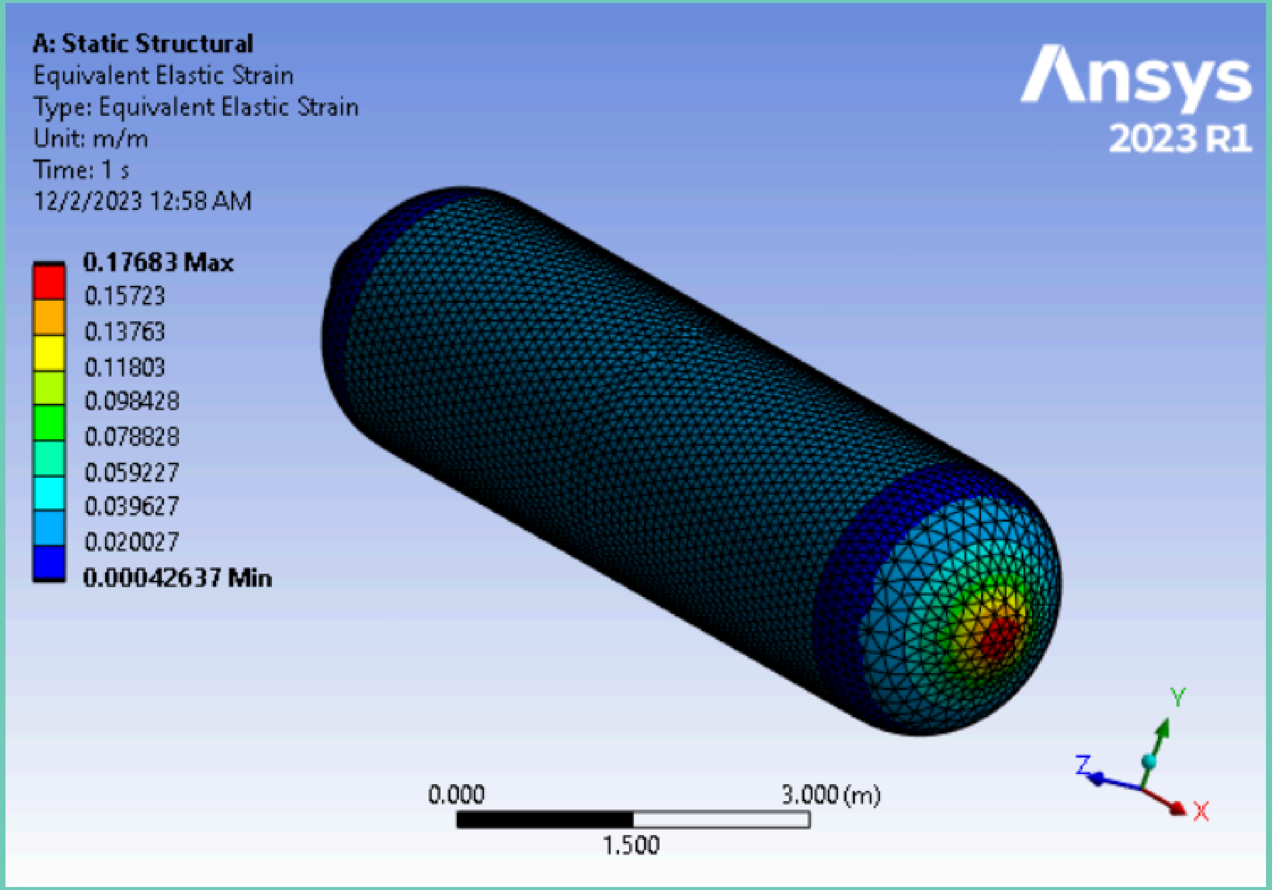
Magnesium

Stress



The maximum stress experienced by the material is 7.4261e9 Pa

Strain

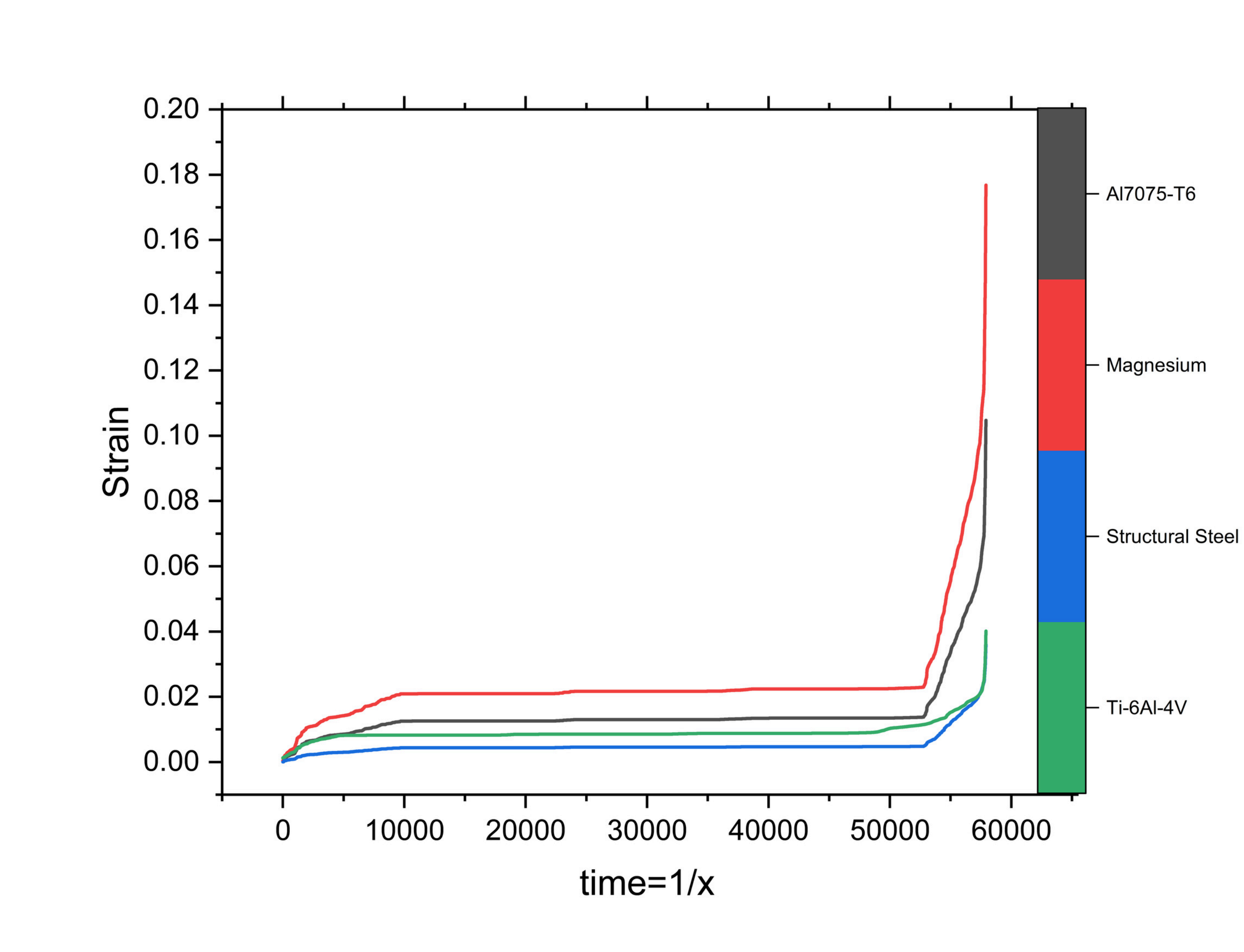


The maximum strain experienced is 0.17683.

Strain Plot

Peak values of strain:

AL7075-T6: 0.10477
Magnesium: 0.17683
Structural Steel: 0.035969
Ti-6Al-4V : 0.040141



Stress Plot

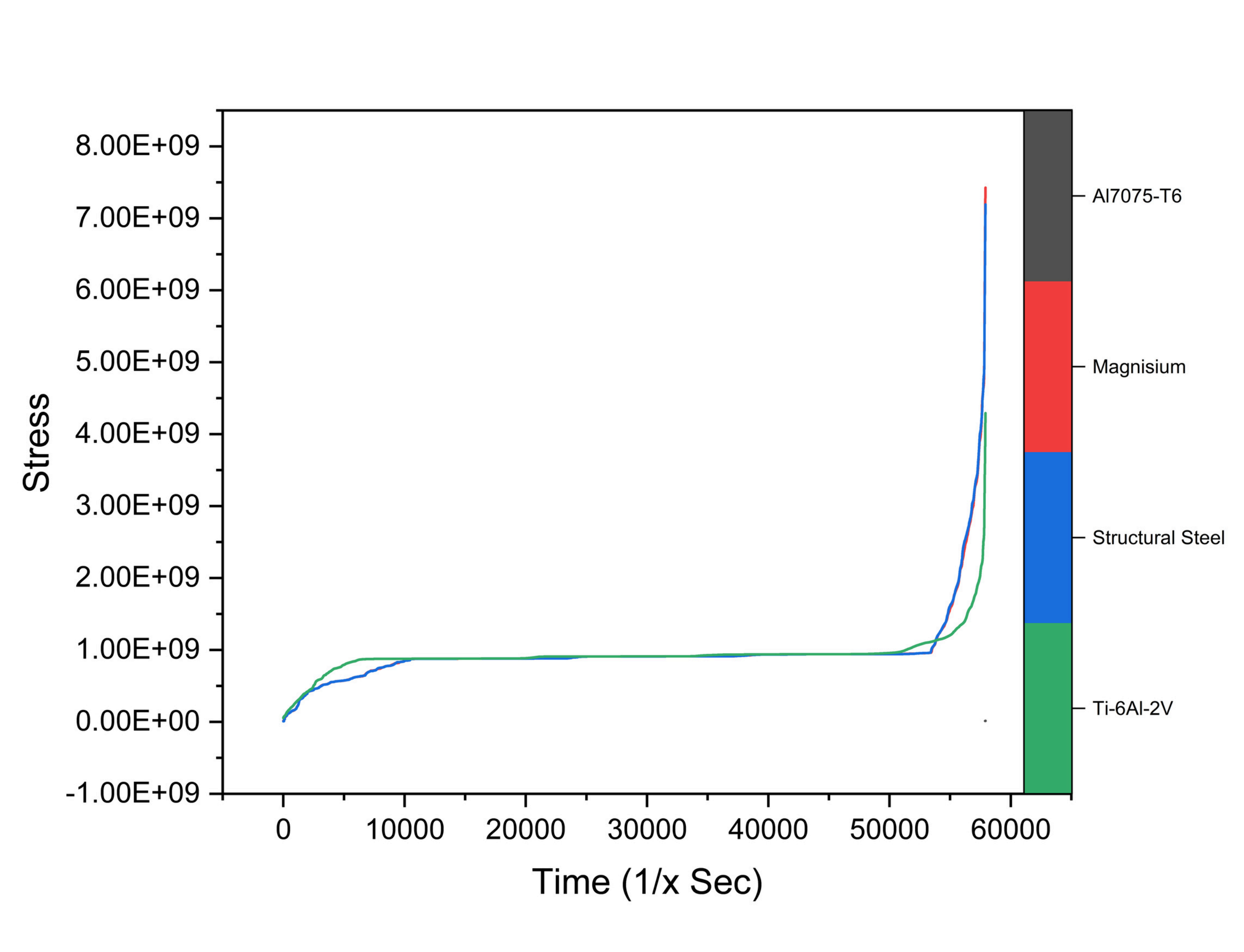
Peak values of strain:

AL7075-T6: 7.3332e9 Pa

Magnesium: 7.4261e9 Pa

Structural Steel: 7.1931e9 Pa

Ti-6Al-4V : 4.2923e9 Pa



Strain Energy

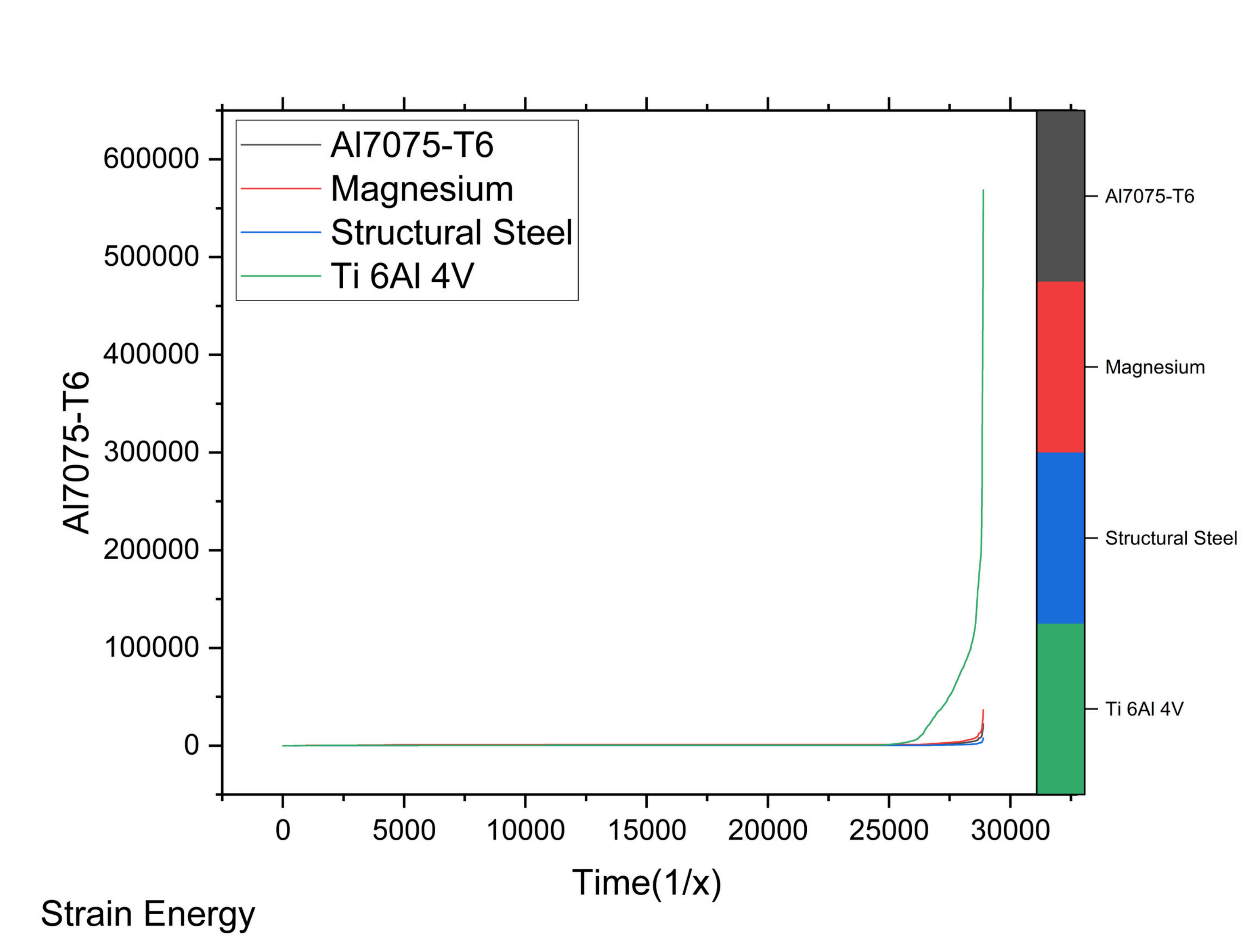
Peak values of strain:

AL7075-T6: 22333 J

Magnesium: 36782 J

Structural Steel: 7934.5 J

Ti-6Al-4V : 5.6862e5 J



Deformation

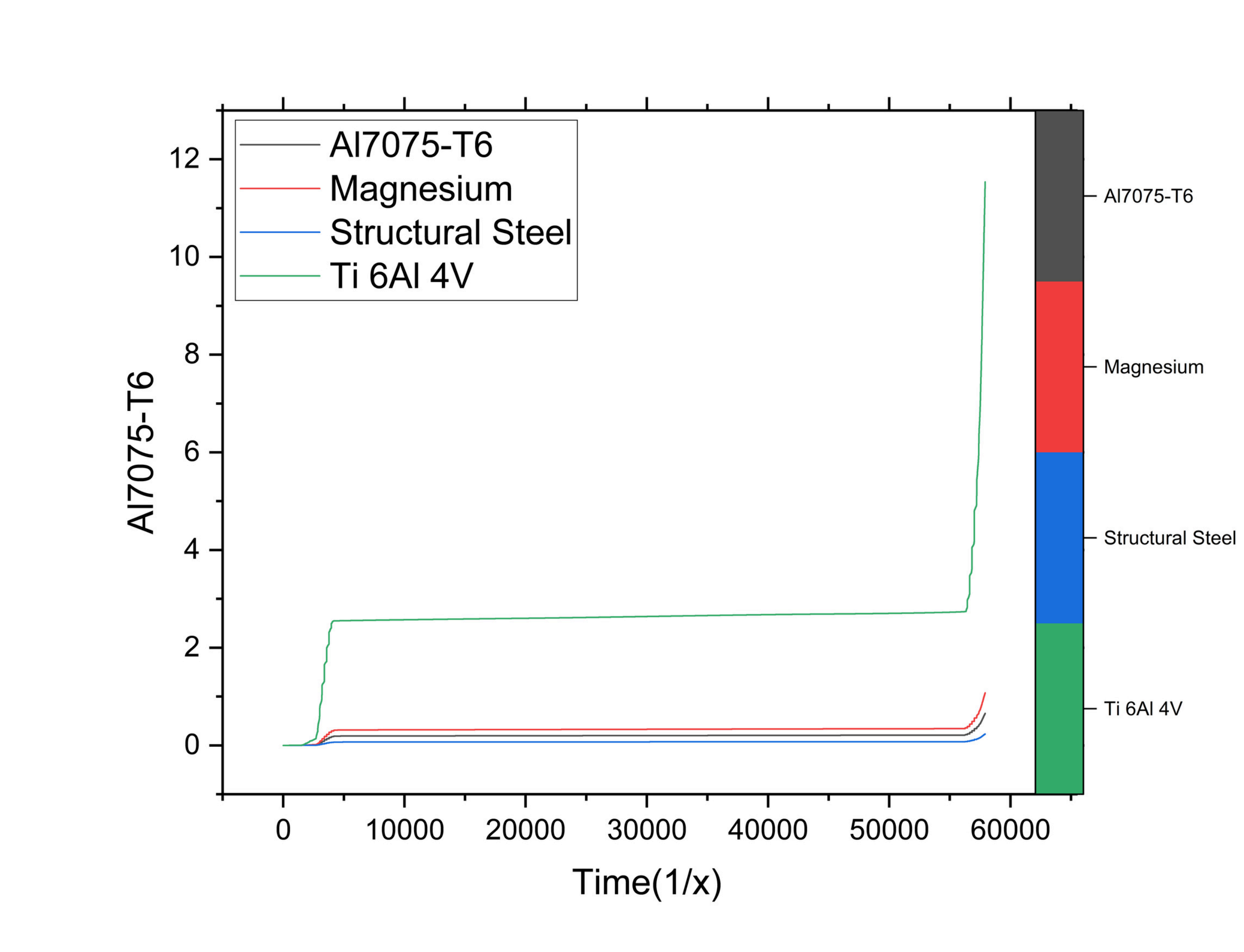
Peak values of strain:

AL7075-T6: 0.65446 m

Magnesium: 1.0749 m

Structural Steel: 0.23365 m

Ti-6Al-4V : 11.537 m



Thank You

Team Protium