AEMA3302 Strength of Materials - 1

Group Project: Pressure Vessel Design

Group 2
Mohamed Abdulkarim - 60104560
Mohamed Abdulshafie - 60087589
Mohammed Al Shaikh - 60102109
Abdulwadood Fathah – 60104538
Shehban Aiyub – 60102657

Instructor: Mr. Rizwan Choudhry

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Introduction

When designing and constructing pressure vessels, safety, cost, and environmental impact must all be carefully considered, especially when dealing with hazardous materials like ammonia. The primary goal of this project is to design and construct an ammonia tank following standard methods such as ASME Boiler and Pressure Vessel Code and using hand calculations and Finite Element Analysis (FEA) to ensure the tank can safely withstand the specified pressures and environmental conditions while considering cost-effective and sustainable material selection.

Background

The case study "Fast Fracture of an Ammonia Tank" demonstrated a catastrophic failure resulting from a crack in a circumferential weld, leading to the explosive discharge of ammonia. During the unloading of liquid from the tank, a fast fracture occurred in one of the circumferential welds, causing the cap to be blown off the end of the shell. The space above the liquid had been pressurized with ammonia gas using a compressor to facilitate the decanting process. The explosive discharge of a large volume of highly toxic vapor had severe implications for nearby individuals. This incident underscored the critical importance of selecting materials with appropriate fracture toughness and ensuring stringent manufacturing and testing procedures.

Design Requirements

Maximum operating pressure: 2.07 MN/m² gauge.

Shape: Cylindrical shell with hemispherical end caps.

Vessel Volume and Dimensions:
Cylindrical shell: 6 m long.
Radius: 1067 mm.
Wall thickness: 7 mm.
Vessel Volume = 2.655e10 mm^3

Operating Conditions:
The tank must function as a pressure vessel at a temperature up to 50°C

Method of Manufacture:
The tank will be manufactured through welding. Non-destructive testing (NDT) methods like Radiographic testing are employed to detect any signs of stress corrosion cracking.

Constraints:
- L = 6000 mm
- r = 1067 mm

Design Calculations

From the case study
$Normal\ Operating\ Pressure\ of\ Compressor\ \ P_C = 1.83\ MPa$
$r = 1067\ mm$
$t = 7\ mm$
$So, \sigma = \frac{1.83\ MPa \times 1067\ mm}{2 \times 7\ mm} = 139.47\ MPa$

According to ASME standards:

- $Design\ Pressure = 10\%\ more\ than\ Maximum\ Operating\ Pressure$

  $Maximum\ Operating\ Pressure\ P_{max} = 2.07\ Mpa$
  $\therefore\ Design\ Pressure\ P_D = 2.07\ MPa + (0.1\ + 2.07MPa) = 2.277MPa$

- $Minimum\ Wall\ thickness\ t = \frac{P_D D}{4\sigma E + 0.8 P_D}$

  $where\ D = Diameter\ of\ Pressure\ Vessel$
  $E = \ Welded - Joint\ Efficiency = 1$

  $\Rightarrow t = \frac{2.277MPa \times (1067\ mm \times 2)}{(4 \times 139.47MPa) + (0.8 \times 2.277\ MPa)} = 8.65\ mm$

- $Maximum\ stress\ \sigma_{max} = \frac{P_D r}{2t} = \frac{2.277\ MPa \times\ 1067\ mm}{2 \times 8.65\ mm} = 140.43\ MPa$

  $Yield\ Stress\ \sigma_y = Maximum\ stress\ \sigma_{max} \times F.O.S$

  $For\ a\ Factor\ of\ Safety\ of\ 1.5$
  $Yield\ Stress\ \sigma_y = \ 140.43\ MPa \times 1.5 = 210.66MPa$

- $Fracture\ Toughness\ K_{IC} = \sigma_y Y \sqrt{\pi a}$

  $From\ case\ study,$
  $Dimensionless\ Geometry\ factor\ Y = 1.92$
  $depth\ of\ crack\ a = 2.5mm$

  $\Rightarrow K_{IC} = 210.66\ MPa \times 1.92 \times\ \sqrt{\pi \times\ 2.5 \times\ 10^{-3}} = 35.844\ N/m^{3/2}$

Material Indices for Material Selection

- **Strength Index**: $M1 = \frac{\sigma_y}{\rho}$, Maximize for strong, lightweight materials
- **Cost Index**: $M2 = \frac{Cost}{\sigma_y}$, Minimize for cost-effective design
- **Fracture Toughness Index**: $M1 = K_{IC}$, Maximize to avoid brittle failure

Material Selection – CES

Using Granta CES Edu Pack, we conducted a detailed material selection process that meets the design requirements of the ammonia tank while also being cost-effective. The software allowed us to filter materials based on yield strength, fracture toughness, and cost per unit strength.

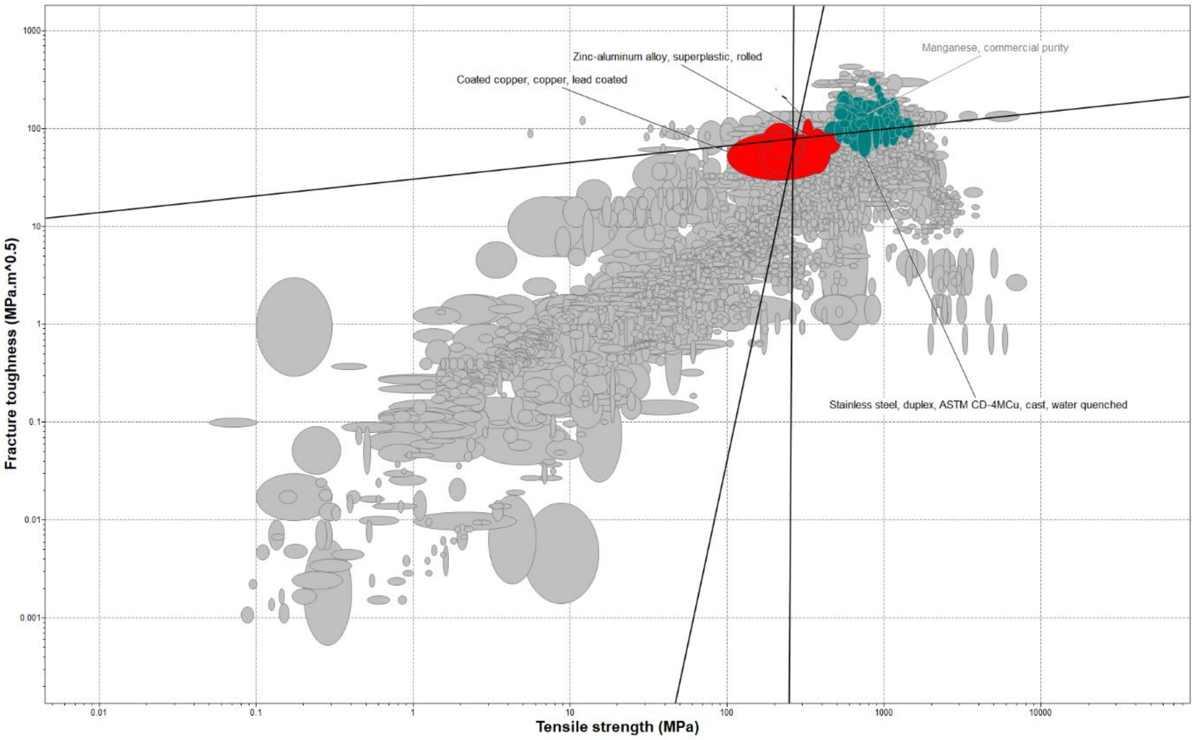


Figure 1: CES Stage 1 Graph, Tensile strength (MPa), Fracture toughness

In Figure 1 CES Stage 1 Graph, we plot tensile strength (MPa) against fracture toughness (MPa·m^0.5). The x-axis represents tensile strength, indicating the maximum stress a material can endure before breaking, crucial for pressure vessels under high internal pressure. The y-axis shows fracture toughness, measuring a material's resistance to crack propagation, essential for preventing catastrophic failure in high-stress environments.

Using calculated material indices, we filtered out unsuitable materials. The graph's upper right quadrant shows ideal candidates with high tensile strength and fracture toughness, suitable for the ammonia tank. Conversely, the lower left quadrant contains materials with low tensile strength and fracture toughness, unsuitable for this application. This visual representation simplifies material selection by highlighting those that effectively balance both properties, ensuring safety and durability.

In Stage 2 of the CES material selection process, we use the LIMIT function to filter materials based on a cost constraint of 4 to 8 USD/kg, which is standard cost considerations for an ammonia tank.

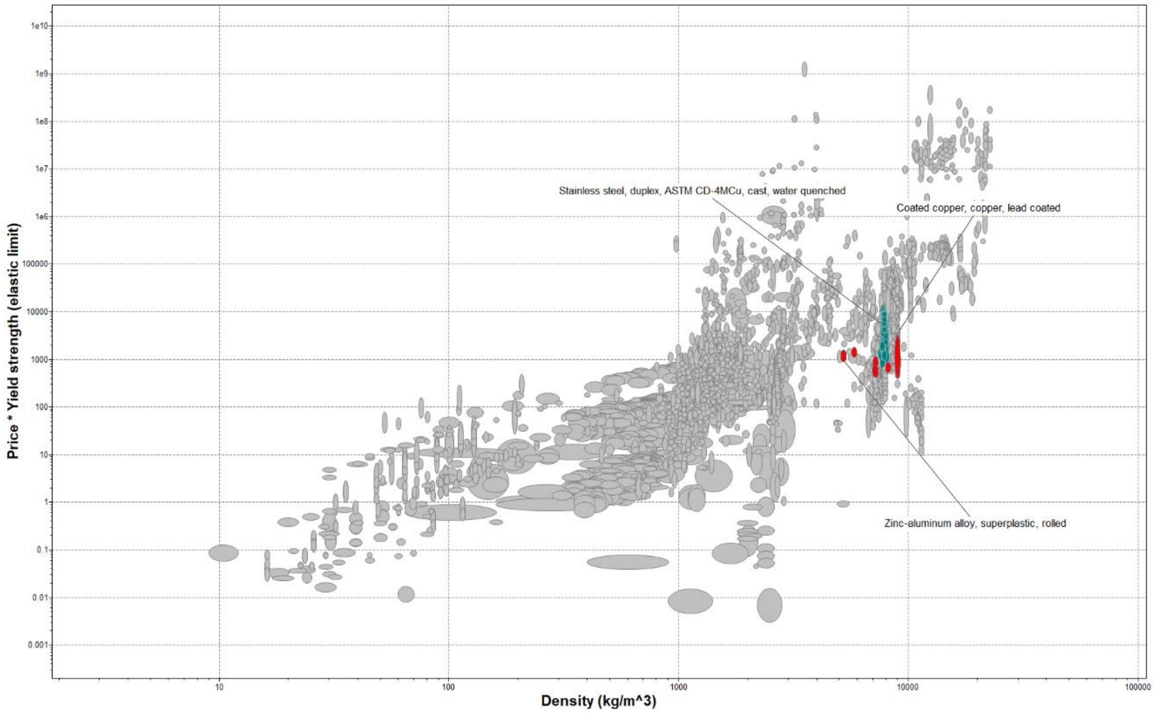


Figure 2: CES Stage 3 Graph, Density (kg/m^3), Price * Yield strength (elastic limit)

In Figure 2, CES Stage 3 Graph, we plot density (kg/m^3) against the product of price and yield strength (elastic limit). The x-axis represents density, indicating the material's mass per unit volume, which impacts the overall weight of the pressure vessel. The y-axis shows the product of price and yield strength, reflecting the cost-effectiveness and mechanical performance of the material. We filter out materials that are too heavy or too costly relative to their yield strength.

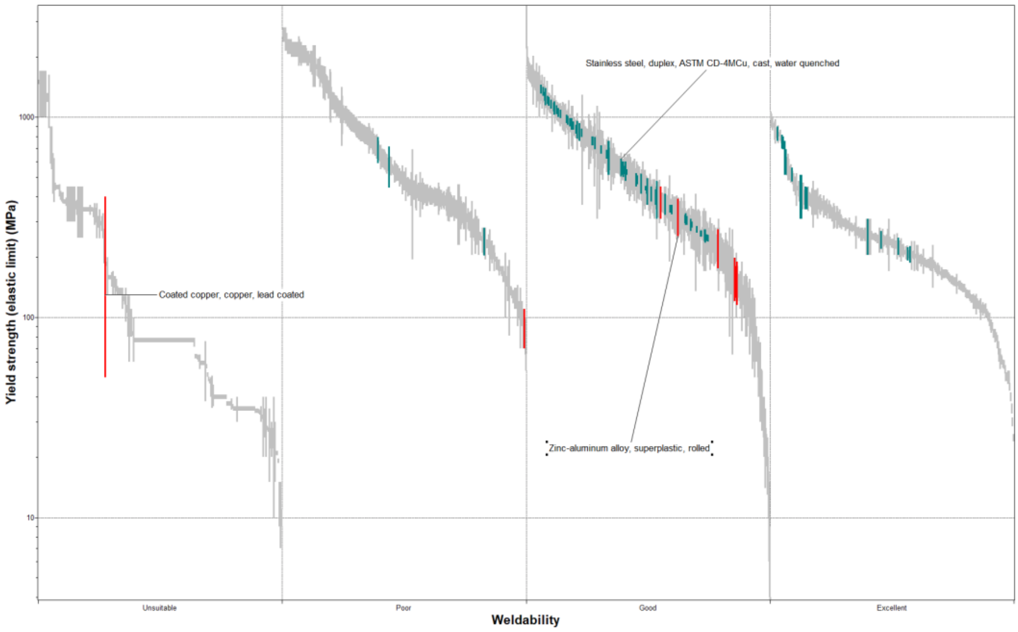


Figure 3: CES Stage 4 Graph, Weldability, Yield strength (elastic limit) (MPa)

Figure 3, CES Stage 4 Graph, plots Weldability against Yield Strength (elastic limit) (MPa). Weldability, crucial for manufacturing pressure vessels, is represented on the x-axis, while Yield Strength (elastic limit) (MPa) is shown on the y-axis, indicating the material's ability to withstand stress without permanent deformation.

Table 1: Comparison of Materials Based on Different Factors

No.	Material	Yield Strength (MPa)	Fracture Toughness (MPa.m^0.5)	Cost (USD/kg)
1.	Coated copper, copper, lead coated	50 - 400	30 - 90	7.85 - 8.23
2.	Stainless Steel, duplex, ASTM CD-4MCu, Cast, water quenched	505 - 620	51 - 112	7.81 - 10
3.	Zinc-aluminum alloy, superplastic, rolled, wrought (Zn-Al alloy)	255 - 390	35 - 100	3.28 - 4.38

Comparing multiple materials based on these CES graphs using Table 1, which evaluates them based on Yield Strength (MPa), Fracture Toughness (MPa·m^0.5), and Cost (USD/kg), provides a structured approach to selecting the most suitable material. In this context, Stainless Steel is chosen for the ammonia tank pressure vessel design due to its excellent fracture toughness and ability to withstand operational stresses. Despite its higher cost compared to other materials in the table, the durability and corrosion resistance of stainless steel justify its selection, ensuring longevity and reliable performance over the vessel's operational lifetime.

FEA analysis

To ensure the safety of the ammonia tank design, it is essential we validate our hand calculations with SolidWorks Finite Element Analysis (FEA) design because it allows for a more detailed analysis of stress distribution throughout the pressure vessel under varying loading conditions. Unlike hand calculations that simplify assumptions, FEA considers the geometric complexity, material properties, and boundary conditions with greater accuracy. FEA helps validate the calculated values of yield strength (σ_{max}) and fracture toughness (K_{IC}) by providing stress and strain distributions across the vessel. This validation ensures that the chosen material and calculated parameters meet safety margins and performance requirements as per ASME standards.

The use of simplified geometry in FEA, excluding welds, joints, internal components like baffles or nozzles, and focusing on a basic cylindrical and hemispherical structure, impacts the results by potentially underestimating stress concentrations at these critical points. However, it provides a baseline assessment of the overall structural integrity and strength of the main vessel body. Importing material properties from CES ensures that FEA simulations use accurate material data for Stainless Steel, duplex, ASTM CD-4MCu, Cast, water quenched. This consistency aligns FEA results with the material's actual behavior and performance characteristics. Fixturing the bottom face of the legs in the FEA simulation stabilizes the vessel's base, mimicking its support conditions in real-world applications. This fixture choice affects stress distribution and ensures realistic boundary conditions for accurate simulation. Choosing a finer mesh in FEA enhances accuracy by capturing local stress concentrations and variations more precisely. It helps in refining stress predictions and ensuring that critical areas are adequately analyzed for potential failure points.

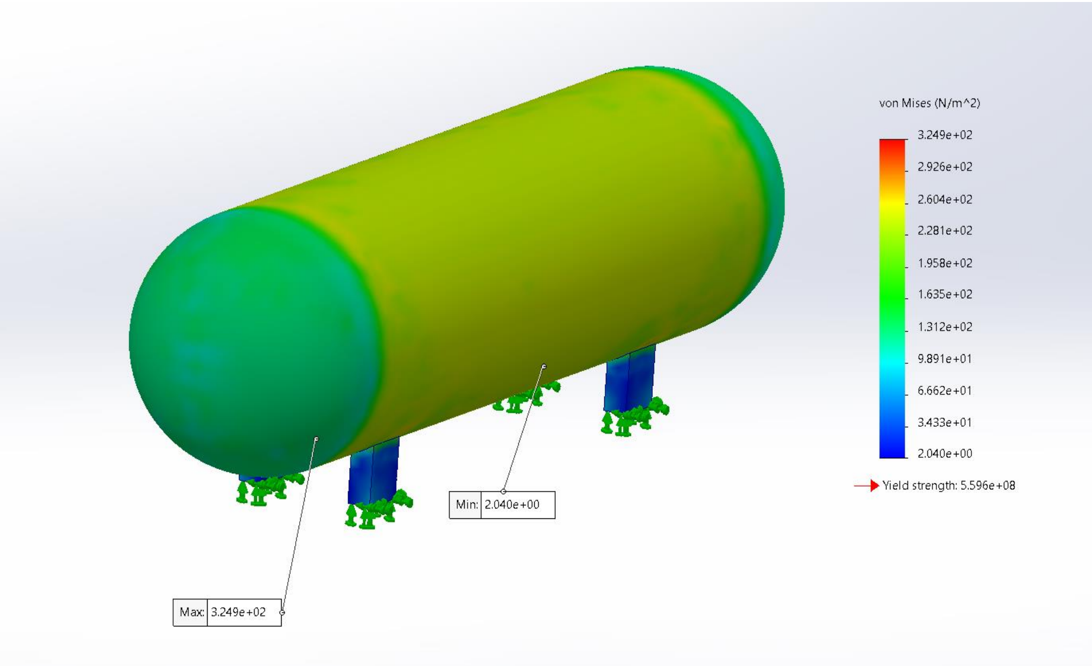


Figure 4: SolidWorks FEA Analysis

Von Mises stresses are used because they represent the equivalent stress that combines both shear and normal stresses, offering a comprehensive indicator of material yielding and potential failure. This stress criterion is preferred for its conservative estimation of potential compared to principal stresses failure compared to principal stresses.

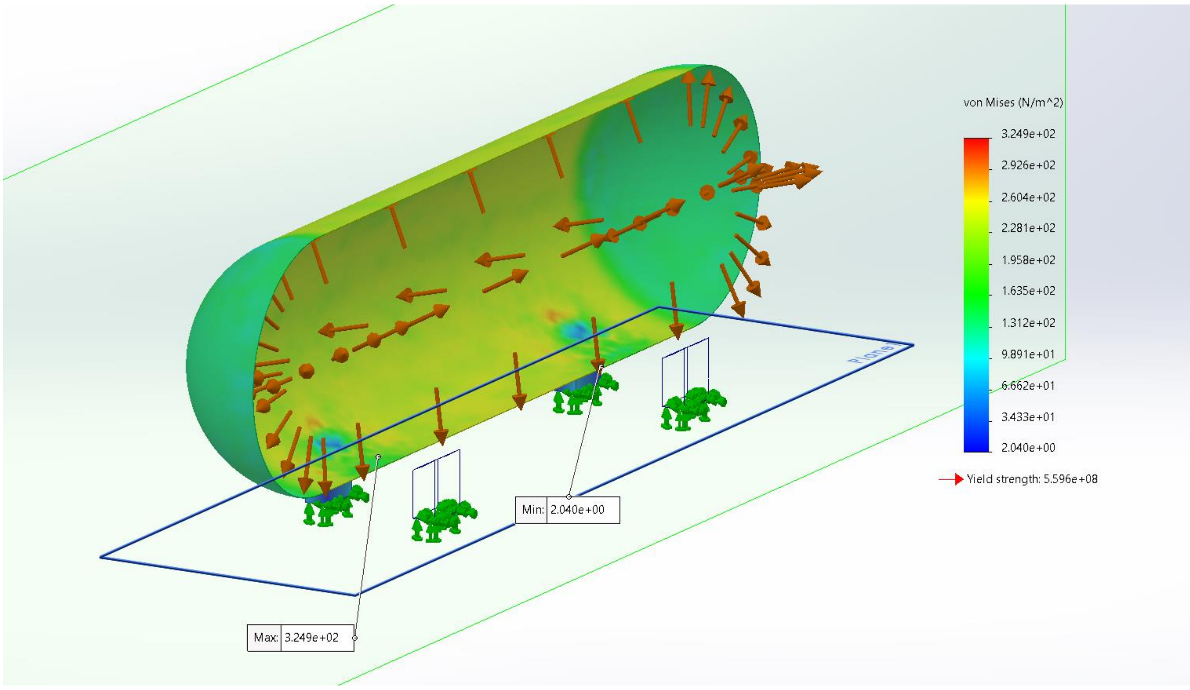


Figure 5: SolidWorks FEA Analysis (Section Clipping)

The color gradient on different parts of the 3D model indicates varying levels of Von Mises stresses. By using section clipping in the analysis, we were able to view stress distributions inside the vessel, providing insights into how stresses propagate throughout the structure under applied loads. Areas of cylinder showed yellow-green coloration which had moderate Von Mises stress ranging from approx. 2.1e02 MPa to 2.3e02 MPa. The hemispheres showed green coloration which had lesser Von Mises stress ranging from approx. 1.4e02 MPa to 1.9e02 MPa. This shows how different shapes behave when affected by applied pressure.

In conclusion, FEA plays a critical role in validating the pressure vessel design by providing detailed insights into stress distribution and structural behavior. It ensures that the design meets safety standards, validates material selection, and identifies potential areas for design optimization or reinforcement to ensure long-term reliability and safety of the ammonia tank.

Eco – Audit

Environmental considerations were addressed using the Granta Edu Pack Eco Audit tool, which allowed us to assess the ecological impact of various material choices. This tool provided insights into the lifecycle environmental impact of materials, from extraction to disposal.

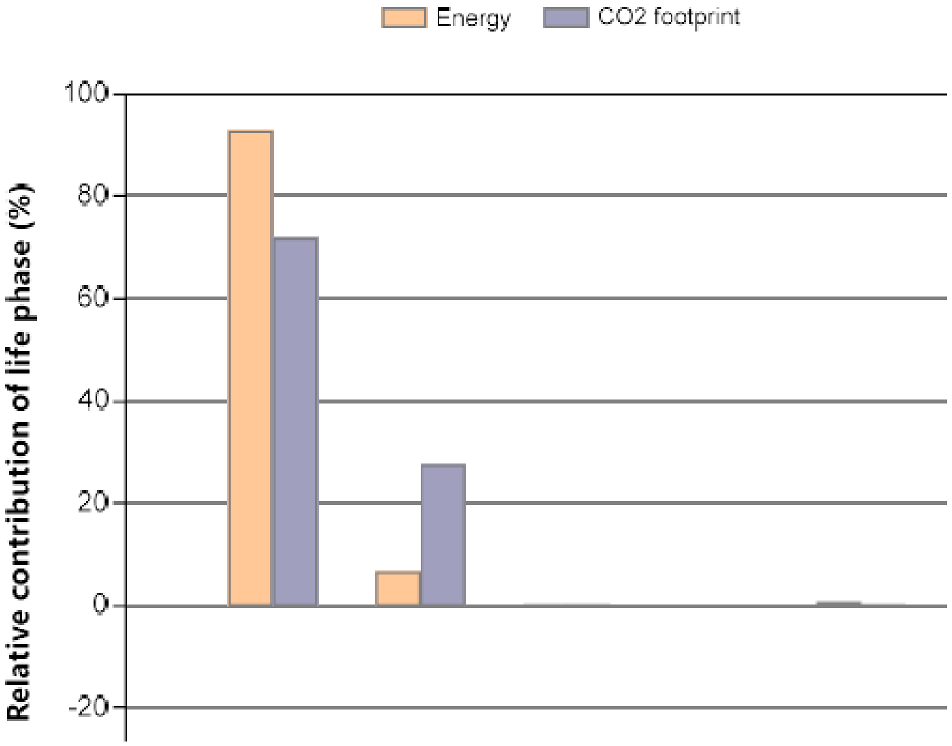


Figure 6: Eco Audit of Stainless-Steel Pressure Vessel

Table 1: Energy and CO2 Footprint

Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	2.65e+05	92.9	2.38e+04	71.8
Manufacture	1.85e+04	6.5	9.19e+03	27.8
Transport	66.1	0.0	5.14	0.0
Use	0	0.0	0	0.0
Disposal	1.84e+03	0.6	129	0.4
Total (for first life)	**2.85e+05**	**100**	**3.31e+04**	**100**
End of life potential	-1.03e+05		-9.63e+03	

The eco audit results for Stainless Steel, duplex, ASTM CD-4MCu, Cast, water quenched, reveal that most of the energy consumption and CO2 footprint occur during the material production phase. By considering these findings, we should explore alternative materials or manufacturing methods that reduce its significant environmental footprint, promoting sustainability throughout the lifecycle of the pressure vessel.

Conclusion

In conclusion, the design and analysis of the ammonia tank pressure vessel were carried out, aligning with ASME standards and insights from the case study "Fast Fracture of an Ammonia Tank" by Ashby and Jones. Design specifications, including a cylindrical shell with hemispherical end caps, 6 meters long, 1067 mm radius, and 7 mm wall thickness, were meticulously validated through detailed hand calculations and ASME code compliance. We utilized advanced tools like CES for material selection and SolidWorks FEA for validation. The material, Stainless Steel, selected based on criteria like Yield Stress (σ_y) and Fracture Toughness (K_{IC}), demonstrated robust performance in withstanding operational stresses and ensuring safety. its higher initial costs is justified by its durability and corrosion resistance. However, there significant environmental impact of material production, urging consideration of alternative materials or sustainable manufacturing methods to reduce carbon footprint and enhance long-term sustainability.

Recommendations for future work

Future work should focus on further refining the material selection process by exploring advanced composite materials that offer enhanced strength-to-weight ratios and superior corrosion resistance. Expanding the use of FEA to simulate more complex loading conditions and incorporating fatigue analysis can provide deeper insights into the long-term durability of the pressure vessel.

References

1. ASME codes- Pressure Vessels Mechanical Design
2. Case Study - Fast Fracture of an Ammonia Tank
3. Case Study - Safe Pressure Vessel Material Selection using CES

Appendix

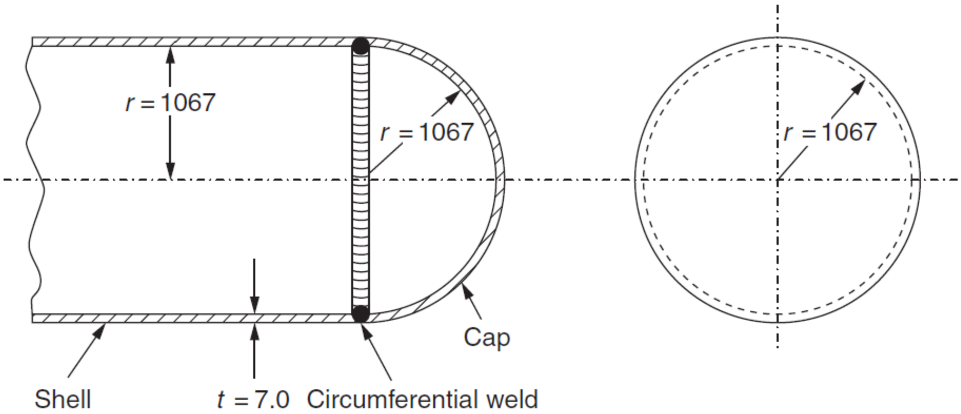


FIGURE 17.1
The weld between the shell and the end cap of the pressure vessel (dimensions in mm).

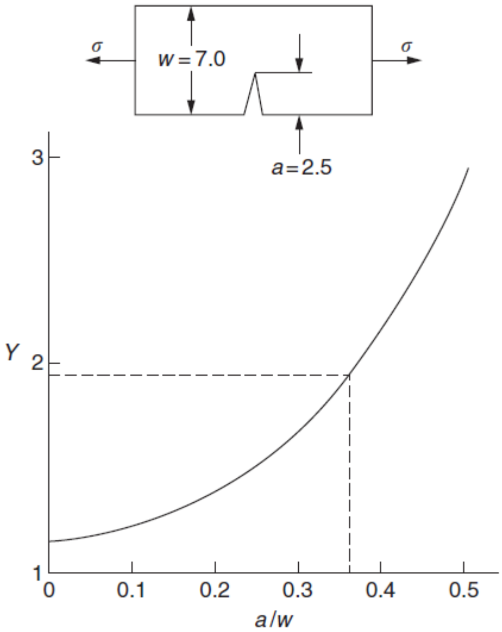


FIGURE 17.3
Y value for the crack (dimensions in mm). See Chapter 14 (*Y* values), Case 4.

13.4.1. Design Pressure

A vessel must be designed to withstand the maximum pressure to which it is likely to be subjected in operation.

For vessels under internal pressure, the design pressure (sometimes called maximum allowable working pressure or MAWP) is taken as the pressure at which the relief device is set. This will normally be 5 to 10% above the normal working pressure, to avoid spurious operation of the relief valve during minor process upsets. For example, the API RP 520 recommended practice sets a 10% margin between the normal operating pressure and the design pressure. When deciding the design pressure, the hydrostatic pressure in the base of the column should be added to the operating pressure, if significant.

13.4.4. Maximum Allowable Stress (Nominal Design Strength)

For design purposes it is necessary to decide a value for the maximum allowable stress (nominal design strength) that can be accepted in the material of construction.

This is determined by applying a suitable safety factor to the maximum stress that the material could be expected to withstand without failure under standard test conditions. The safety factor allows for any uncertainty in the design methods, the loading, the quality of the materials and the workmanship.

The basis for establishing the maximum allowable stress values in the ASME BPV Code is given in ASME BPV Code Sec. II Part D, Mandatory Appendix 1. At temperatures where creep and stress rupture strength do not govern the selection of stresses, the maximum allowable stress is the lowest of:

1. the specified minimum tensile strength at room temperature divided by 3.5
2. the tensile strength at temperature divided by 3.5
3. the specified minimum yield strength at room temperature divided by 1.5
4. the yield strength at temperature divided by 1.5.

TABLE 13.3. Maximum Allowable Joint Efficiency

Joint Description	Joint Category	Degree of Radiographic Examination		
		Full	Spot	None
Double-welded butt joint or equivalent	A, B, C, D	1.0	0.85	0.70
Single-welded butt joint with backing strip	A, B, C, D	0.9	0.8	0.65
Single-welded butt joint without backing strip	A, B, C	NA	NA	0.60
Double full fillet lap joint	A, B, C	NA	NA	0.55
Single full fillet lap joint with plug welds	B, C	NA	NA	0.50
Single full fillet lap joint without plug welds	A, B	NA	NA	0.45

13.4.8. Minimum Practical Wall Thickness

There will be a minimum wall thickness required to ensure that any vessel is sufficiently rigid to withstand its own weight, and any incidental loads. The ASME BPV Code Sec. VIII D.1 specifies a minimum wall thickness of 1/16 in (1.5 mm) not including corrosion allowance, and regardless of vessel dimensions and material of construction. As a general guide the wall thickness of any vessel should not be less than the values given below, which include a corrosion allowance of 2 mm:

Vessel Diameter (m)	Minimum Thickness (mm)
1	5
1 to 2	7
2 to 2.5	9
2.5 to 3.0	10
3.0 to 3.5	12

13.5. THE DESIGN OF THIN-WALLED VESSELS UNDER INTERNAL PRESSURE

13.5.1. Cylinders and Spherical Shells

For a cylindrical shell the minimum thickness required to resist internal pressure can be determined from equations 13.7 and 13.8.

If D_i is internal diameter and t the minimum thickness required, the mean diameter will be (Di + t); substituting this for D in equation 13.7 gives

$$t = \frac{P_i(D_i + t)}{2S}$$

where S is the maximum allowable stress and P_i the internal pressure. Rearranging gives

$$t = \frac{P_i D_i}{2S - P_i} \qquad (13.39)$$

If we allow for the welded-joint efficiency, E, this becomes

$$t = \frac{P_i D_i}{2SE - P_i} \qquad (13.40)$$

The equation specified by the ASME BPV Code (Sec. VIII D.1 Part UG-27) is

$$t = \frac{P_i D_i}{2SE - 1.2 P_i} \qquad (13.41)$$

This differs slightly from equation 13.40 as it is derived from the formula for thick-walled vessels.

Similarly, for longitudinal stress the code specifies:

$$t = \frac{P_i D_i}{4SE + 0.8P_i} \qquad (13.42)$$

The ASME BPV Code specifies that the minimum thickness shall be the greater value determined from equations 13.41 and 13.42. If these equations are rearranged and used to calculate the maximum allowable working pressure (MAWP) for a vessel of a given thickness, then the maximum allowable working pressure is the lower value predicted by the two equations.

For a spherical shell the code specifies:

$$t = \frac{P_i D_i}{4SE - 0.4P_i} \qquad (13.43)$$

Stainless steel, duplex, ASTM CD-4MCu, cast, water quenched

Datasheet view: All attributes | Show/Hide | Find Similar

Price

Price	* 7.81	-	10	USD/kg
Price per unit volume	* 6.01e4	-	7.8e4	USD/m^3

Physical properties

Density	7.7e3	-	7.8e3	kg/m^3

Mechanical properties

Young's modulus	195	-	205	GPa
Specific stiffness	25.1	-	26.5	MN.m/kg
Yield strength (elastic limit)	505	-	620	MPa
Tensile strength	670	-	820	MPa
Specific strength	65.2	-	80	kN.m/kg
Elongation	30	-	40	% strain
Tangent modulus	1.28e3			MPa
Compressive strength	* 505	-	620	MPa
Flexural modulus	* 195	-	205	GPa
Flexural strength (modulus of rupture)	505	-	620	MPa
Shear modulus	75	-	82	GPa
Bulk modulus	138	-	159	GPa
Poisson's ratio	0.265	-	0.285	
Shape factor	42			
Hardness - Vickers	245	-	270	HV
Hardness - Rockwell C	* 21	-	26	HRC
Hardness - Brinell	* 228	-	258	HB
Elastic stored energy (springs)	643	-	953	kJ/m^3
Fatigue strength at 10^7 cycles	* 323	-	373	MPa
Fatigue strength model (stress amplitude)	* 282	-	427	MPa

Parameters: Stress Ratio = -1, Number of Cycles = 1e7cycles

Impact & fracture properties

Fracture toughness	* 51	-	112	MPa.m^0.5
Toughness (G)	14.5	-	56.1	kJ/m^2

Coated copper, copper, lead coated

Datasheet view: All attributes | Show/Hide | Find Similar

Price

Price	* 7.85	-	8.23	USD/kg
Price per unit volume	* 7.01e4	-	7.36e4	USD/m^3

Physical properties

Density	* 8.93e3	-	8.94e3	kg/m^3

Mechanical properties

Young's modulus	* 112	-	148	GPa
Specific stiffness	* 12.5	-	16.6	MN.m/kg
Yield strength (elastic limit)	* 50	-	400	MPa
Tensile strength	* 100	-	450	MPa
Specific strength	* 5.6	-	44.8	kN.m/kg
Elongation	* 3	-	50	% strain
Tangent modulus	387			MPa
Compressive modulus	112	-	148	GPa
Compressive strength	* 30	-	400	MPa
Flexural modulus	112	-	148	GPa
Flexural strength (modulus of rupture)	* 50	-	400	MPa
Shear modulus	45	-	52	GPa
Bulk modulus	* 120	-	155	GPa
Poisson's ratio	* 0.34	-	0.35	
Shape factor	30			
Hardness - Vickers	44	-	180	HV
Elastic stored energy (springs)	* 16.7	-	362	kJ/m^3
Fatigue strength at 10^7 cycles	* 49.2	-	133	MPa
Fatigue strength model (stress amplitude)	* 24.1	-	271	MPa

Parameters: Stress Ratio = -1, Number of Cycles = 1e7cycles

Impact & fracture properties

Fracture toughness	* 30	-	90	MPa.m^0.5
Toughness (G)	* 8.48	-	51.8	kJ/m^2

Zinc-aluminum alloy, superplastic, rolled

Datasheet view: All attributes | Show/Hide | Find Similar

Price

Price	* 3.28	-	4.38	USD/kg
Price per unit volume	* 1.7e4	-	2.29e4	USD/m^3

Physical properties

Density	5.18e3	-	5.22e3	kg/m^3

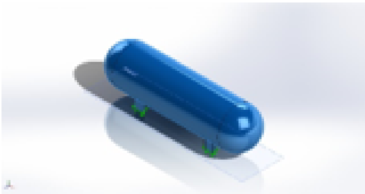
Mechanical properties

Young's modulus	68	-	93	GPa
Specific stiffness	13.1	-	17.9	MN.m/kg
Yield strength (elastic limit)	255	-	390	MPa
Tensile strength	310	-	445	MPa
Specific strength	49	-	75	kN.m/kg
Elongation	9	-	27	% strain
Tangent modulus	606			MPa
Compressive strength	* 255	-	390	MPa
Flexural modulus	* 68	-	93	GPa
Flexural strength (modulus of rupture)	* 255	-	390	MPa
Shear modulus	* 25	-	40	GPa
Bulk modulus	* 55	-	90	GPa
Poisson's ratio	* 0.305	-	0.325	
Shape factor	20			
Hardness - Vickers	* 90	-	155	HV
Elastic stored energy (springs)	416	-	940	kJ/m^3
Fatigue strength at 10^7 cycles	* 50	-	120	MPa
Fatigue strength model (stress amplitude)	* 45.9	-	131	MPa

Parameters: Stress Ratio = -1, Number of Cycles = 1e7cycles

Solid Bodies		
Document Name and Reference	Treated As	Volumetric Properties
Boss-Extrude1 	Solid Body	Mass:4,789.95 kg Volume:0.618071 m^3 Density:7,749.84 kg/m^3 Weight:46,941.5 N

Material Properties

Model Reference	Properties	
	Name:	Stainless steel, duplex, ASTM CD-4MCu, cast, water quenched
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	5.59553e+08 N/m^2
	Tensile strength:	7.41215e+08 N/m^2
	Compressive strength:	5.59553e+08 N/m^2
	Elastic modulus:	1.99937e+11 N/m^2
	Poisson's ratio:	0.274818
	Mass density:	7,749.84 kg/m^3
	Shear modulus:	7.84219e+10 N/m^2
	Thermal expansion coefficient:	1.09545e-05 /Kelvin

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	153.285 mm
Minimum element size	153.285 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	36858
Total Elements	19228
Maximum Aspect Ratio	194.59
% of elements with Aspect Ratio < 3	2.21
Percentage of elements with Aspect Ratio > 10	94.7
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:07
Computer name:	U9214-23

Detailed breakdown of individual life phases

Material:

Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed** (kg)	Energy (MJ)	%
Pressure Vessel	Stainless steel, duplex, ASTM CD-4MCu, cast, water quenched	Virgin (0%)	3.7e+03	1	3.7e+03	2.6e+05	100.0
Total				1	3.7e+03	2.6e+05	100

*Typical: Includes 'recycle fraction in current supply'

**Where applicable, includes material mass removed by secondary processes

***User-defined material

Manufacture:

Summary

Component	Process	% Removed	Amount processed	Energy (MJ)	%
Pressure Vessel	Rolling*	-	3.7e+03 kg	1.8e+04	99.5
Pressure Vessel	welding*	-	0 kg	0	0.0
	Welding, electric	-	40 m	97	0.5
Total				1.8e+04	100

*User-defined process

Transport:

Summary

Breakdown by transport stage

Stage name	Transport type	Distance (km)	Energy (MJ)	%
	Sea, bulk carrier	2e+02	66	100.0
Total		2e+02	66	100

Breakdown by components

Component	Mass (kg)	Energy (MJ)	%
Pressure Vessel	3.7e+03	66	100.0
Total	3.7e+03	66	100

Use:

Summary

Relative contribution of static and mobile modes

Mode	Energy (MJ)	%
Static	0	
Mobile	0	
Total	0	100

Disposal:

Summary

Component	End of life option	% recovered	Energy (MJ)	%
Pressure Vessel	Downcycle	100.0	1.8e+03	100.0
Total			1.8e+03	100

EoL potential:

Component	End of life option	% recovered	Energy (MJ)	%
Pressure Vessel	Downcycle	100.0	-1e+05	100.0
Total			-1e+05	100

Detailed breakdown of individual life phases

Material:

Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed** (kg)	CO2 footprint (kg)	%
Pressure Vessel	Stainless steel, duplex, ASTM CD-4MCu, cast, water quenched	Virgin (0%)	3.7e+03	1	3.7e+03	2.4e+04	100.0
Total				1	3.7e+03	2.4e+04	100

*Typical: Includes 'recycle fraction in current supply'

**Where applicable, includes material mass removed by secondary processes

***User-defined material

Manufacture:

Summary

Component	Process	% Removed	Amount processed	CO2 footprint (kg)	%
Pressure Vessel	Rolling*	-	3.7e+03 kg	9.2e+03	99.9
Pressure Vessel	welding*	-	0 kg	0	0.0
	Welding, electric	-	40 m	6.8	0.1
Total				9.2e+03	100

*User-defined process

Transport:

Summary

Breakdown by transport stage

Stage name	Transport type	Distance (km)	CO2 footprint (kg)	%
	Sea, bulk carrier	2e+02	5.1	100.0
Total		2e+02	5.1	100

Breakdown by components

Component	Mass (kg)	CO2 footprint (kg)	%
Pressure Vessel	3.7e+03	5.1	100.0
Total	3.7e+03	5.1	100

Use:

Summary

Relative contribution of static and mobile modes

Mode	CO2 footprint (kg)	%
Static	0	
Mobile	0	
Total	0	100

Disposal:

Summary

Component	End of life option	% recovered	CO2 footprint (kg)	%
Pressure Vessel	Downcycle	100.0	1.3e+02	100.0
Total			1.3e+02	100

EoL potential:

Component	End of life option	% recovered	CO2 footprint (kg)	%
Pressure Vessel	Downcycle	100.0	-9.6e+03	100.0
Total			-9.6e+03	100