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Analysis of Pressure Vessel for Variable Thermal Load with Different Temprature

Assess their Thermal Properties, Mechanical Strength, and Cost-Effectiveness Compared to Traditional Materials

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Abstract:- Highlighting the importance of understanding failure modes and loadings for effective design and optimization, it emphasizes the role of design parameters like thickness, design pressure, and allowable stresses in influencing performance, efficiency, and safety. The incorporation of commonly used codes, especially the ASME pressure vessel code, adds a practical dimension to the discussion, emphasizing industry standards in the design and analysis of pressure vessels.

Keywords:- *Pressure Vessel, Design, Fabrication & ANSYS Introduction.*

I. INTRODUCTION

Pressure vessels are integral components in various industrial processes, and any failure could lead to catastrophic consequences. Leakage from pressure vessels can result in accidents, environmental hazards, and loss of life. Pressure vessels must undergo a certification process by recognized legislative organizations to verify their compliance with industry standards. Standards specify the criteria for designing pressure vessels, including factors like material selection, thickness, and geometry. Fabrication processes must adhere to strict guidelines to maintain the integrity of the vessel.

II. LITERATURE REVIEW

➢ *First Study: Stress Analysis and Comparison with ANSYS:*

- *Approach:*

✓ Stress analysis of a pressure vessel considering internal pressure, self-weight, and fluid weight.
✓ Manual calculations for design.
✓ Comparison of computed stress values with ANSYS software results.

- *Conclusion:*

✓ Stresses on the vessel shell are much less than the allowable stress of the material.
✓ Concluded that the pressure vessel is safe for usage.

➢ *Second Study: Pressure Vessel for Marine Substation Applications:*

- *Approach:*

✓ Investigation for marine substation applications considering different materials.
✓ Stress analysis performed using MATLAB software.
✓ Consideration of internal and external pressure at various depths in the ocean.

- *Conclusion:*

✓ The pressure vessel is designed to handle external pressure from seawater at different depths.
✓ Concluded that the vessel is suitable for marine applications.

➢ *Third Study: Design and Analysis Using Finite Element Method:*

- *Approach:*

✓ Research on the design and analysis of a pressure vessel using the finite element method.
✓ Sub-division of the vessel into smaller elements.
✓ Application of internal pressure for analysis.

- *Conclusion:*

✓ Used finite element method for a more detailed analysis.
✓ The design and analysis approach using finite elements.

- *General Observations:*

✓ The first study relies on a direct comparison of manual calculations with ANSYS, a widely used finite element analysis tool.
✓ The second study focuses on marine applications, considering external pressure due to seawater at different depths.
✓ The third study utilizes the finite element method for a more detailed and comprehensive analysis of the pressure vessel.

- *Recommendations for Project:*

- ✓ Consider incorporating finite element analysis tools like ANSYS or MATLAB for a more detailed and accurate stress analysis.
- ✓ Depending on your project's scope, you might explore the effects of different environmental factors, materials, and loading conditions on the pressure vessel.
- ✓ Ensure that your study aligns with industrystandards and regulations governing pressure vessel design and analysis.
- ✓ These studies collectively highlight the importance of rigorous stress analysis in ensuring the safety and reliability of pressure vessels acrossdifferent applications and conditions."

➢ *Validation through Principal Stress and Distortion Energy Theories:*

- *Approach:*

- ✓ Utilized Principal Stress Theory And Distortion Energy Theory For Validating The Pressure Vessel Design.
- ✓ Compared Calculated Results With Fea Software.

- *Conclusion:*

- ✓ Maximum principal stress from manual calculations aligned with FEA results.
- ✓ Concluded that the pressure vessel design was safe.

➢ *Analysis of Pressure Vessel Considering ASME Standards and Multilayer Design:*

- *Approach:*

- ✓ Analysis of a pressure vessel following ASME standards for material selection, design, and stress calculation.
- ✓ Exploration of multilayer pressure vessels to withstandhigher internal pressure.
- ✓ Consideration of different materials for cost reduction.

- *Conclusion:*

- ✓ Maximum stress in the pressure vessel was within theyield stress of the material.
- ✓ Suggested That Multilayer Pressure Vessels Can Withstand Higher Internal Pressure.

- *General Observations:*

- ✓ Both studies involve a thorough analysis of pressure vessels using a combination of theoretical methods and FEA software.
- ✓ The second study not only adheres to ASME standards but also explores innovative design approaches such as multilayer structures for enhanced pressure resistance.
- ✓ Consideration of different materials for cost reduction indicates a practical and economic perspective in the design process.
- ✓ Continue to validate your pressure vessel design using both theoretical stress analysis methods and FEA software.
- ✓ Consider exploring innovative design approaches, such as multilayer structures, especially if it aligns with the specific requirements and safety standards of your project.
- ✓ Ensure that your material selection aligns with industry standards like ASME to guarantee the safety and reliability of the pressure vessel.

III. METHODOLOGY

Ensure that the material properties and specifications align with industry standards and regulations, especially when dealing with pressure vessel applications.

Validate the results obtained from ANSYS by comparing them with theoretical calculations or experimental data if available.

Consider exploring different materials and configurations to optimize the design for factors like weight, cost, and performance.

➢ *Design Calculations :-*

When designing a pressure vessel to meet ASME standards, determining the minimum thickness of the shell is a critical step to ensure structural integrity and safety. The minimum required thickness can be estimated using the applicable ASME code section. ASME Boiler and Pressure Vessel Code (BPVC) is typically used for pressure vessel design. Different sections of the code may apply depending on the type of pressure vessel and the materials use.

For cylindrical shells with longitudinal joints, one commonly referenced section is ASME Section VIII, Division 1. Here's a simplified outline of the process to estimate the minimum required thickness:

➢ *Minimum Thickness of the Shell (Equation 1):*

t=SE/PR+Corrosion Allowance

- Where:
- t is the minimum thickness of the shell.
- P is the internal design pressure.
- R is the inner radius of the shell.
- S is the maximum allowable stress value of the material.
- E is the joint efficiency of the vessel.

➢ *Minimum Thickness for External Pressure (Equation 2):*

Pa=Factor × B × t / Do

- Where:
- Pa is the external pressure on the pressure vessel.
- Factor is a constant.
- B is the factor for the maximum design metal temperature.
- Do is the outside diameter of the pressure vessel.

- t is the thickness of the shell for external pressure.

- *Minimum Thickness of the Dished End for Internal Pressure (Equation 3):*
  t= PD /2S(1−E) +Corrosion Allowance

- Where:
- t is the minimum thickness required for the dished end.
- P is the internal design pressure.
- D is the inner diameter of the shell.
- S is the maximum allowable stress value of the material.
- E is the joint efficiency.

- *Minimum Thickness of the Dished End for External Pressure (Equation 4):*
  P4=5/2 X t / RoWhere:

- P4 is the minimum thickness for the dished end due toexternal pressure.
- t is the minimum thickness for the dished end.
- Ro is the equivalent radius of the dished end (Ro=k×diameter).

These equations provide a systematic way to calculate the minimum thickness for different components of a pressure vessel, considering various design parameters and constraints. Ensure that all the constants and variables are appropriately defined and consistent with the units used in your design.

- *Thermal Stress Analysis of Pressure Vessel*

- *Minimum Required Thickness:*

The minimum required thickness for the pressure vessel, including corrosion allowance, is calculated to be 10.92 mm based on design calculations.

- *Considered Thickness Range:*

Thicknesses ranging from 8 mm to 25 mm are considered for analysis purposes.

- *Ambient Temperatures:*

Analysis is performed for different ambient temperatures: 0°C,25°C, and 50°C.

- *Convection on Internal Surface:*

Convection is applied on the internal surface of the pressure vessel using stagnant air with a temperature of 150°C.

- *Support Conditions:*

The saddles of the pressure vessel are assumed to be fixed supports.

- *Applied Pressure:*

A pressure of 1.034 MPa is applied to the internal surface of the pressure vessel.

- *Analysis Scope:*

- *Objective:*

The primary objective of the thermal stress analysis is to obtain deformation and thermal stresses developed in the pressure vessel under the specified conditions.

- *Thickness Variation:*

Analyzing the pressure vessel for a range of thicknesses provides insights into how different thicknesses impact the vessel's behavior under thermal and pressure loading.

- *Temperature Variation:*

Considering different ambient temperatures helps assess the effects of temperature variations on the pressure vessel's thermal stress and deformation.

- *Fixed Support and Applied Pressure:*

The fixed support conditions at the saddles and the applied internal pressure contribute to the overall structural response.

- *Steps in Thermal Stress Analysis:*

- *Geometry and Material Properties:*

Define the geometry of the pressure vessel and the material properties for the analysis.

- *Mesh Generation:*

Create a finite element mesh for the pressure vessel model todiscretize the structure for analysis.

- *Boundary Conditions:*

Apply fixed support conditions at the saddles and simulate theinternal pressure.

- *Temperature Loading*

Apply convection on the internal surface based on the specified ambient temperatures.

- *Analysis and Results:*

Perform the thermal stress analysis using appropriate software (such as ANSYS) to obtain deformation and thermal stress distribution in the pressure vessel for each thickness and ambient temperature.

- *Evaluation and Comparison:*

Evaluate the results for different thicknesses and temperatures, and compare them to determine the impact on the structural behavior.

- *Optimization:*

On the analysis results, optimize the design to meet safety andperformance criteria.

- *Documentation and Reporting*

Document the analysis methodology, assumptions, and resultsin a comprehensive report.

This thermal stress analysis provides valuable information for ensuring the structural integrity and safety of the pressurevessel under various operating conditions.

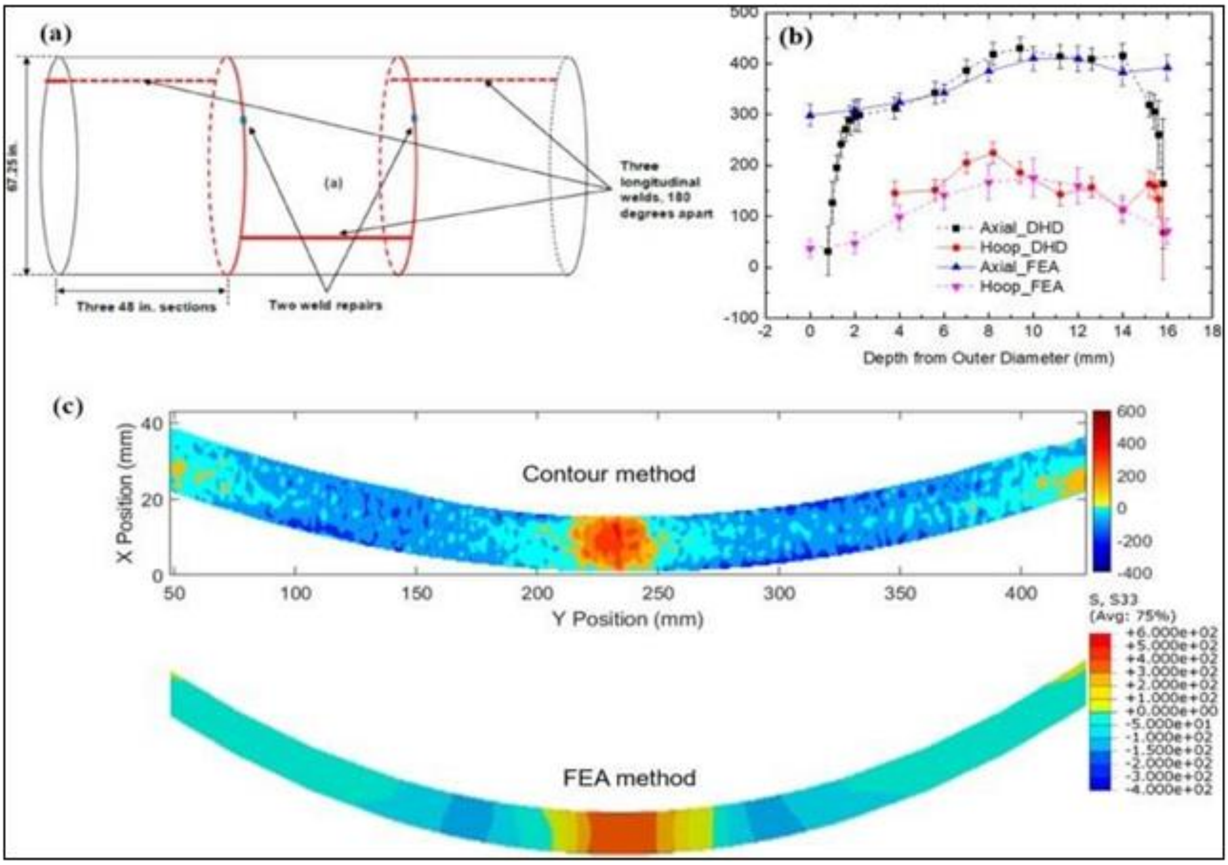


Fig 1 Thermal Stress Analysis of ASME Material for 14 mm Thickness (a) Mesh with Element size of 100 mm (b) Total Deformation (c) Thermal Stress Analysis

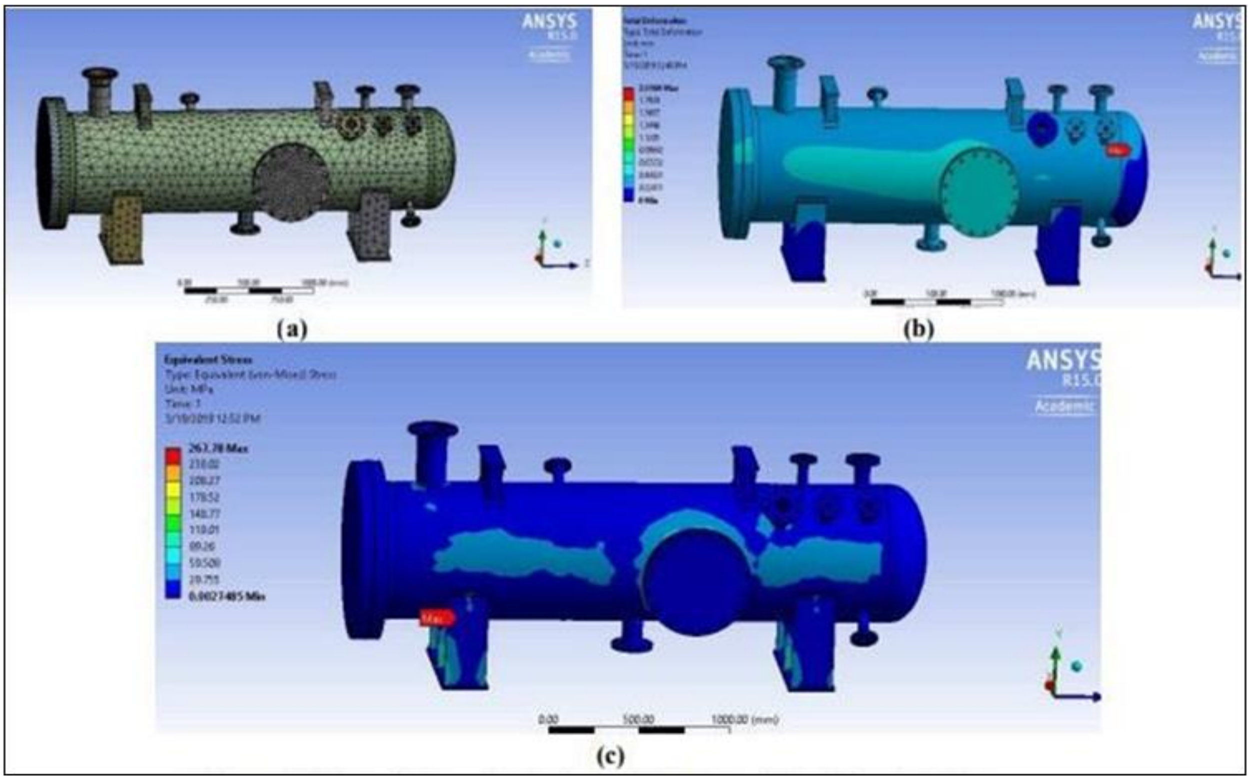


Fig 2 Thermal Stress Analysis of ASME Material for 14 mm Thickness (a) Mesh with Element size of 100 mm (b) Total Deformation (c) Thermal Stress Analysis.

IV. RESULTS AND DISCUSSIONS

- *Optimal Thickness:*

As the thickness increases up to 25 mm, the thermal stress becomes very low, indicating that the pressurevessel can be used for an extended period.

- *Diminishing Returns with Increased Thickness:*

Beyond a certain thickness (25 mm in this case), further increasing the shell thickness does not significantly change the thermal stress.

This suggests that a thickness of 25 mm is sufficient for the given conditions.

- *Material Choice and Longevity:*

The choice of ASME material and the observed low stress at 25 mm thickness imply that the pressure vessel is suitable for long-term use.

- *Temperature Considerations:*

The consideration of different temperatures reflects the versatility of the pressure vessel, making it applicable in various regions worldwide, from thelowest to the highest temperature zones.

- *Safety in Cold Regions:*

A precautionary note is provided regarding the use of the pressure vessel in colder regions (below 0°C). In such cases, it is recommended to conduct impact testing on the material to ensure the safety and resilience of the pressure vessel under low-temperature conditions.

- *Conclusion of Thermal Analysis:*

The thermal stress analysis has been concluded by selecting a thickness of 25 mm. This decision is supported by the low thermal stress observed and the diminishing returns in stress reduction with further increases in thickness.

Table 1 Thermal Stress Analysis Results

Material	Thickness (mm)	0 Deg C		25 Deg C		50 Deg C	
		Deformation (mm)	Thermal Stress (Mpa)	Deformation (mm)	Thermal Stress (Mpa)	Deformation (mm)	Thermal Stress (Mpa)
ASME Material	8	2.10	181.42	1.47	145.90	0.91	129.39
	10	1.94	172.47	1.24	137.41	0.81	114.65
	12	1.79	157.01	1.17	129.33	0.75	101.90
	14	1.64	102.40	1.10	98.31	0.69	92.45
	20	0.42	78.23	0.40	70.27	0.32	62.33
	25	0.38	57.47	0.36	52.44	0.27	46.59
Stainless Steel	8	5.09	1359.90	4.29	1135.60	3.46	911.34
	10	5.06	1340.70	4.27	1116.30	3.49	891.83
	12	5.06	1252.80	4.25	1046.10	3.45	839.35
	14	5.03	1145.70	4.25	956.60	3.45	767.36
	20	4.12	987.42	3.87	814.49	3.01	689.40
	25	3.05	823.67	2.97	694.82	2.12	569.42
Aluminium	8	7.29	695.09	6.23	581.69	5.18	468.30
	10	7.22	674.49	6.15	561.00	5.09	447.51
	12	7.19	635.24	6.11	531.49	5.05	427.74
	14	7.16	575.39	6.08	481.29	5.01	387.18
	20	6.48	442.89	4.98	386.11	3.74	293.47
	25	5.83	328.38	4.31	273.47	2.88	173.44
Copper	8	5.59	846.69	4.75	708.06	3.92	569.24
	10	5.54	825.73	4.70	686.99	3.86	548.26
	12	5.52	779.19	4.68	649.58	3.84	519.96
	14	5.51	711.69	4.66	591.10	3.82	470.68
	20	4.89	603.40	4.08	453.44	3.38	378.94
	25	4.43	488.97	3.74	378.31	2.97	302.56
Gray Cast Iron	8	3.67	498.78	3.16	417.89	2.71	337.00
	10	3.61	480.40	3.11	399.45	2.61	318.51
	12	3.58	463.67	3.07	388.39	2.57	316.48
	14	3.55	428.56	3.04	358.89	2.54	295.96
	20	3.17	368.31	2.64	291.64	1.83	240.87
	25	2.78	309.82	2.32	238.77	1.47	183.34
Titanium	8	3.28	401.02	2.95	336.77	2.68	272.53
	10	3.22	378.69	2.80	314.37	2.47	250.06
	12	3.19	366.15	2.76	305.40	2.34	252.53
	14	3.16	331.28	2.73	274.03	2.21	232.53
	20	2.82	285.45	2.32	238.75	1.98	186.34
	25	2.47	224.78	2.04	174.34	1.74	141.13

V. DESIGN AND ANALYSIS OF PRESSURE VESSEL

➢ *Deformation graphs*

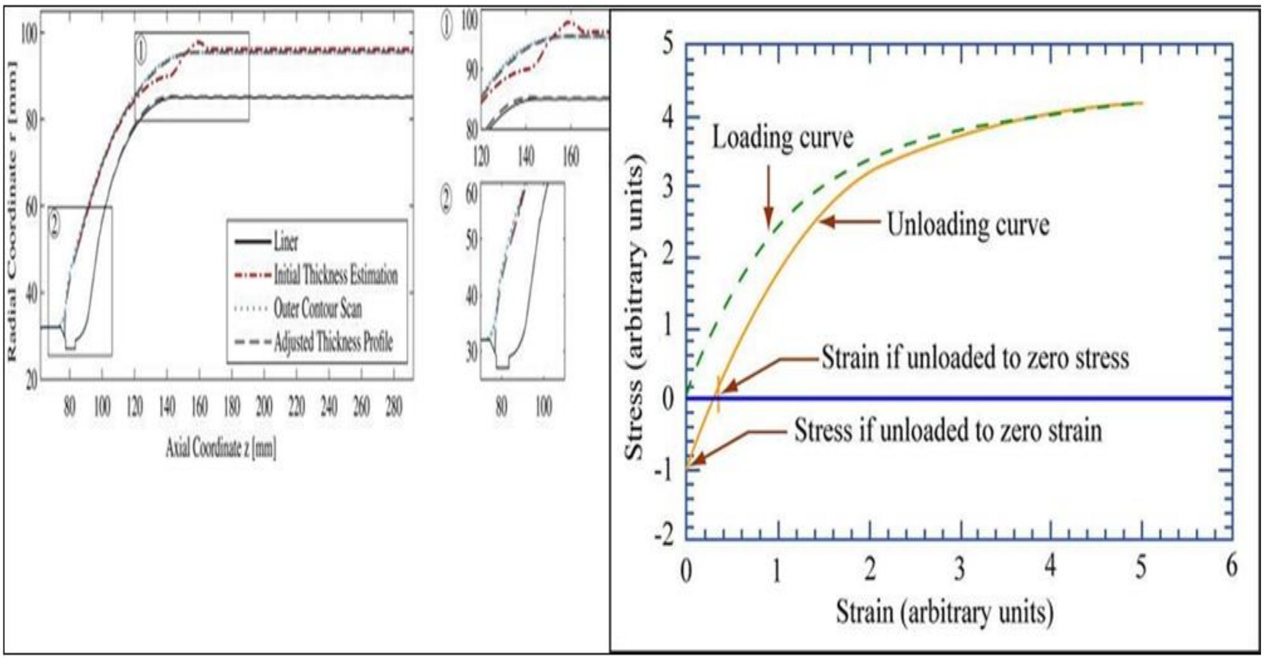
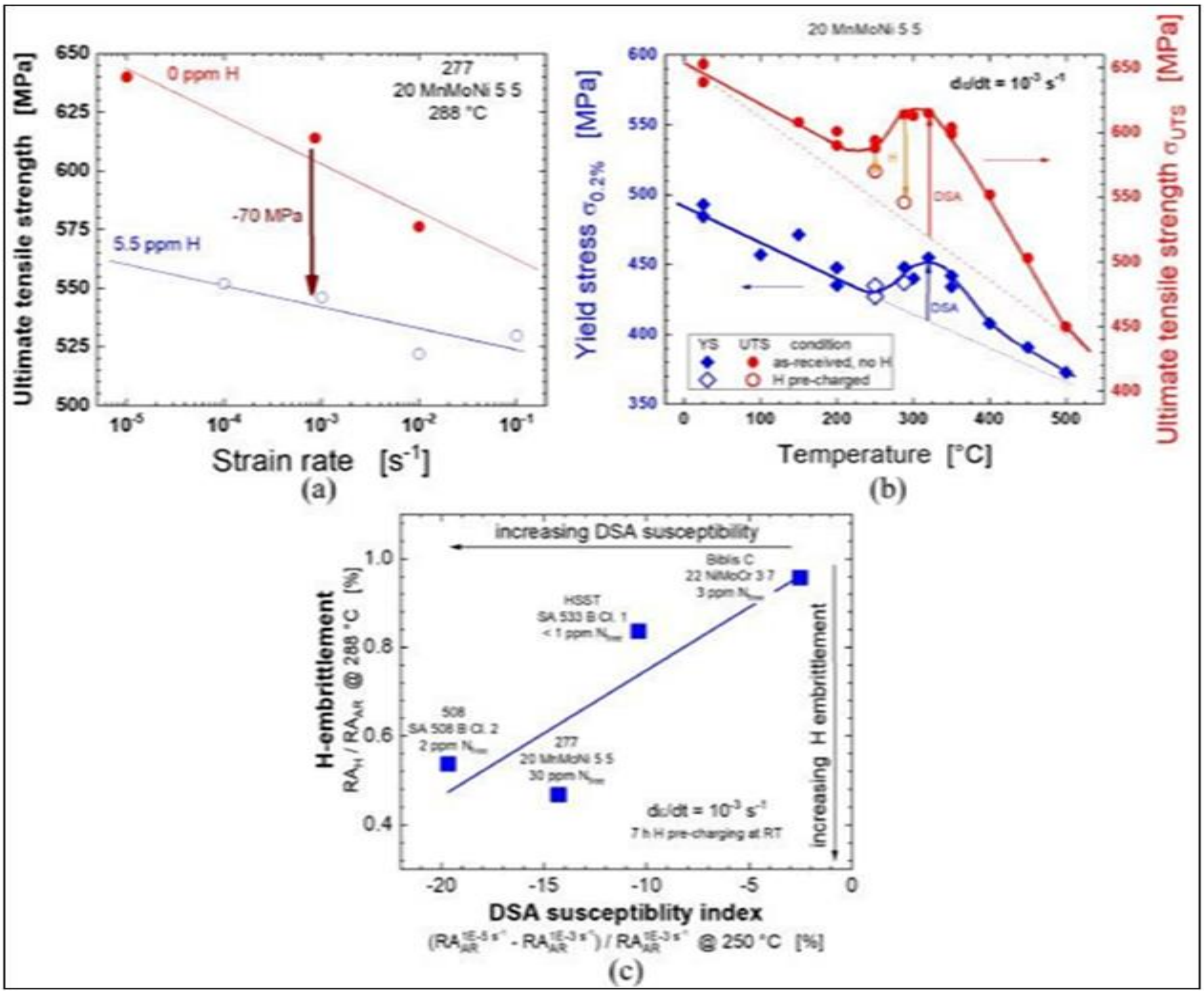


Fig 4 Deformation Graphs of Different Materials atDifferent Ambient Temperatures



Graph 1 Deformation of Graph

VI. CONCLUSIONS

It was found that from the design calculation, the minimum thickness required for the shell and dished end are about 10.99 mm including the corrosion allowance of 3 mm.

It was found that the pattern of the graphs for the different materials are similar for the different ambient temperatures. This is due to difference in property of thermal expansion for different types of materials.

The fracture analysis is done for different types of material using 14 mm thickness specimen. We found that the maximum crack tip deformation is found in case of Aluminium due to its high elastic properties and the lowest in the case of ASME material.

It is found that the stress intensity factor increases initially with the increase in the depth of.

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