STRESS ANALYSIS OF WELDED ELLIPSOIDAL END-TO-SHELL JOINT OF A STAINLESS STEEL TANK

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In the name of Allah, the Most Merciful and the Most Beneficent.

To my beloved son, wife, parent and my siblings.

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ABSTRACT

Welding is most widely used in metal joining. In Tungsten Inert Gas (TIG), defining the process and appropriate values for process is essential in order to control heat-affected zone (HAZ) and get the required effect of residual stress. In this investigation, metallurgical study was carried out on the heat affected zone of weld metal region for SS304 steel joint. Thermal-mechanical analysis was investigated by using finite element (FE) method. Results show that the HAZ has smaller grain size than the base metal and weld metal. FE simulation was performed using uncoupled temperature-displacement analysis with axisymmetric ellipsoidal head-to-shell of welded joint. From the analysis, the distribution of deformation is higher at the weld metal region of axisymmetric model due to the effect of different coefficient of thermal expansion (CTE) between base and weld metal. Subsequently, the distribution of residual stress is localized at the welded zone and Von Mises stress is 558.5MPa at weld metal compared to the grip area, HAZ and base metal. The distribution of equivalent plastic strain shows strains concentration at the toe of weld where the geometrical stress concentration is occurs. However, the highest impact of plastic strain is at the grip holder due to effect of constraints to hold the welded plate during the welding process.

ABSTRAK

Kimpalan digunakan secara meluas di dalam penyambungan logam. Dalam kimpalan jenis TIG, proses dan parameter diselaraskan untuk menentukan dan mengawal kawasan perubahan haba (HAZ) dan mendapatkan nilai tegasan baki yang dikehendaki. Dalam pengkajian ini, kajian permukaan telah dibuat ke atas kawasan perubahan haba (HAZ) pada kawasan besi kimpal bagi sambungan besi SS304. Analisis haba secara mekanikal juga telah dikaji dengan menggunakan kaedah elemen terhingga. Keputusan kajian permukaan menunjukkan bahawa butiran zarah HAZ adalah lebih kecil berbanding dengan zon kimpalan dan kawasan bahan keseluruhan. Simulasi unsur terhingga juga dilakukan dengan menggunakan analisa pergerakan suhu secara berasingan bagi lengkungan kepala kepada badan tangki kimpalan paksi sejajar. Daripada analisa, pergerakan perubahan bentuk adalah lebih tinggi pada kawasan tempat kimpal bagi model paksi sejajar disebabkan kesan perbezaan kecekapan pada haba tambahan di antara tempat kimpalan dan bahan keseluruhan. Tambahan pula, pergerakan tegasan baki adalah bertumpu pada zon kimpalan dan tegasan Von Mises ialah 558.5MPa pada tempat kimpalan berbanding dengan tempat pemegang, HAZ dan bahan keseluruhan. Pergerakan keseimbangan terikan plastik menunjukkan terikan plastik bertumpu pada bahagian utama kimpalan di mana perbentukan tegasan tumpuan berlaku. Walaubagaimanapun, kesan yang paling tinggi terikan plastik ialah pada tempat pemegang disebabkan fungsinya menahan kepingan besi kimpal semasa proses kimpalan.

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LIST OF SYMBOLS

Abbreviation

BM	-	Base Metal
HAZ	-	Heat Affected Zone
WM	-	Weld Metal
CTE	-	Coefficient of Thermal Expansion
FEA	-	Finite Element Analysis

Symbols

q_x, q_y, q_z	-	The heat flow rate per unit area
σ_y	-	Yield Strength
ν	-	Poisson's ratio
E	-	Young's Modulus
ρ	-	Density
c	-	The specific heat
k	-	Thermal conductivity
t	-	Time
T	-	The current temperature
T_1	-	the specified surface temperature which may vary with position and time
q_s	-	The specified heat flow rate per unit area
h	-	The convective heat transfer coefficient as function of the convective exchange temperature
T_s	-	The surface temperature
σ	-	The Stefan-Boltzman constant
ϵ	-	The surface emissivity as function of surface temperature

α	-	The surface absorptivity
q_r	-	The incident radiant heat flow rate per unit area
$[C]$	-	The element capacitance matrix of the time derivative of the nodal temperature
$[K_c]$	-	The element conductance matrices and relate to conduction
$[K_h]$	-	The element conductance matrices and relate to convection
$\{R_T\}$	-	Heat load vector arising from specified nodal temperature
$\{R_Q\}$	-	Heat load vector arising from internal heat generation
$\{R_q\}$	-	Heat load vector arising from specified surface heating
$\{R_h\}$	-	Heat load vector arising from specified surface convection
$\{R_\sigma\}$	-	Vectors arising from surface radiation
$\{R_r\}$	-	Vectors arising from surface radiation
$\{F_b\}$	-	Vectors of force component per unit volume
$\{T\}$	-	Surface traction component per unit area
$[K]^{(e)}$	-	Element stiffness matrix
$\{\delta\}^{(e)}$	-	Element displacement vector
$\{F\}^{(e)}$	-	Element force vector
$[B]$	-	Element strain interpolation matrix
$[L]$	-	Differential operator matrix
$[N]$	-	Interpolation matrix

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CHAPTER 1

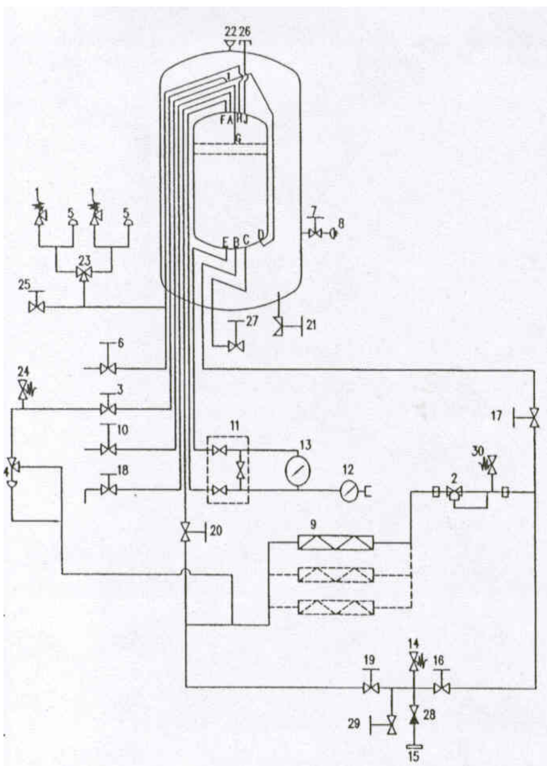
INTRODUCTION

1.1 Background of Axisymmetric Welded Tank

Basically, cryogenic gases are needed to be stored in special containers, which are usually thermally insulated containers, specifically designed to bear rapid temperature changes and extreme differences in temperature. These tanks are suitable for the storage and delivery of liquid oxygen, nitrogen or argon at a maximum allowable working pressure of 18.5 bar. They are also suitable for the delivery of gaseous product with an optional vaporizer. Cryogenic materials include the liquids argon, nitrogen, oxygen and helium, and solid carbon dioxide (dry ice). Carbon dioxide and nitrous oxide, which usually have slightly higher boiling points are also included in the category of cryogenic gas. One of the most commonly used element in cryogenics is liquid nitrogen. Liquid helium is also used. Infact liquid helium allows for the lowest attainable temperature to be reached. It is to be noted that all types of cryogenic liquids are gases at normal temperatures and pressures. These gases are then cooled below room temperature and this should be done before an increase in pressure can liquefy them. Under different conditions of temperature and pressure, different cryogens become liquids. However all cryogen liquids have two common properties, namely very cold and a little quantity of liquid can expand into very large volumes of gas.

Cryogenic gases are very popular and they are used as fuels, oxidizers and refrigerants. These gases are to be stored properly to get their maximum usage. In poorly insulated containers, it is very likely that some cryogenic gases actually condense the surrounding air, forming a liquid air mixture. Cryogenic gas also has some hazards associated with it like as they may be flammable, as in hydrogen, LPG or they may be oxidizers, as in fluorine, oxygen and hence they must be carefully used.

Tank specifications, general and flow diagrams of each tank showing controls and piping are shown in figure 1.1.



Legend:

1-Main safety

2-Pressure building regulator

3-Shut-off valve in pressure building system

4-Pressure reducing regulator (Economizer)

5-Innertank bursting head

6-Vent valve

7-Vacuum probe valve

7-Vacuum probe valve

8-Vacuum probe

9-Pressure building vaporizer

10-Liquid withdrawal/vaporizer inlet

11-Three valve manifold

12-Pressure gauge

13- Liquid level indicator

14- Fill relief valve

15- Fill connection

16- Liquid phase fill valve

17- Liquid phase valve

18- Over flow valve

19- Gas phase fill valve

20-Gas phase valve

21-Evacuation connection

22-Vacuum bursting disc for outer tank

23-Change over valve

24-Economizer relief valve

25-Vent valve

26-Vapor connection

27-Auxiliary product withdrawal

28- Fill over valve

29-Fill drain valve

30-Pressure regulator relief valve

Figure 1.1: Welded tank drawing with piping schematic

The above series tank is a vertical tank with maximum allowable working pressure of 18.5 bar. The pressure vessel is suspended inside a vacuum jacket and insulated with perlite powder under high vacuum. The liquid and gas phase lines to the pressure vessel pass through the lower head of the vacuum jacket. All piping is designed to withstand the stresses caused by expansion and contraction of the pressure vessel, its supports system and piping itself.

The pressure vessel is designed and constructed in accordance with the AD-Merkblatter Code. The inner vessel is constructed of stainless steel 1.4311 or 1.4301 (DIN 17440), and the piping is stainless steel. The vacuum jackets and leg supports are made of structural steel.

The insulation space between the pressure vessel and the vacuum jacket is filled with perlite powder insulation and evacuated to a high vacuum through an evacuation connection, which is permanently sealed at a factory. Insulation space vacuum is measured in the field by connecting a vacuum gauge to the vacuum probe that is located on the lower head of head of the tank. The vacuum probe is isolated from the vacuum jacket by a vacuum probe valve.

In order to reduce and solve the problem of critical point of the cryogenics storage tank, the finite element (FE) method can be used not only to design but to analyze and predict the welding distortion and heat affected zone. For this purpose, this study examines the application of FE method to analyze the deformation behavior and effect of residual stress due to welding on the stress field and under simulated impact loading on the tank. FE models are developed for thermal and mechanical analysis for prediction of welding deformation and residual stresses in the welded structure using FEM.

1.2 Problem Statement

The problem on this field of study can be addressed as follows:

How does the residual stress induced in the welded joint of welded ellipsoidal end-to-shell joint of stainless steel tank?

1.3 Objectives of Study

The objective of this project is to simulate the process-induced residual stress evolution and distribution in welded joint of ellipsoidal end-to-shell joint of stainless steel tank using FE method.

1.4 Scope of Study

The scope of this project includes:

1. Metallurgical study on the welded joint material
2. Develop axisymmetric finite element model of welded joint of ellipsoidal end-to-shell joint of stainless steel tank
3. Simulate process-induced residual stress in welding process
4. Interpret the physics of the thermal-mechanical applied from the welding joint

1.5 Thesis Layout

This thesis consists of five chapters. Chapter 1 will introduces the problem statement, objectives and scopes of work.

In Chapter 2, literature review on pressure vessel steels will be presented. Then the explanation of operating requirements for welded tank and finite elements procedure for simulation of welding deformation behaviour will be reviewed. Including together is thermal-mechanical analysis by finite element (FE) method.

In Chapter 3, summarizes of the methodology executed to complete this field of study. The FE model will be developed to get axis symmetry, elastic-plastic, plastic-strain and uncouple temperature analysis. The axis-symmetry model for the critical area which is top of tank will be developed to evaluate and simulate the FE thermal of residual stress induced by welding process. This chapter also establish with the simulation analysis of temperature and deformation behaviour.

In Chapter 4, the results of finite element model are discussed. The results are including completed temperature displacement analysis and residual stresses.

Conclusions of the work are presented and discussed in the last chapter.

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