International Journal of Offshore and Coastal Engineering
Vol.1 | No. 2 | pp. 64–69 | November 2017
e-ISSN: 2580-0914

Submitted: July 16, 2017 | Revised: August 20, 2017 | Accepted: October 22, 2017

Analysis of the Effect of Welding Sequence Variations on Residual Stresses and Distortions for Welding Pressure Vessels Structures at PT. Petrokimia Gresik using the Finite Element Method

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ABSTRACT

The development of oil and gas industry technology has been very advanced, one of the implementation is to connect material materials to support oil and gas industry facilities. Residual stress may occur due to high temperature differences due to welding and also uneven heat distribution. This causes the material to become hard but brittle so that it may cause structural failure in the connection area. In this final project will be simulated welding pressure vessels to determine the structure of residual stresses that occur as well as the influence of Post Weld Heat Treatment on residual stress itself. The material used is aluminum and WPS data coming from the fabrication company. The simulation is divided into 2 steps: thermal and structural analysis. The value of the residual voltage of 1 to pathline pathline 3 is 189 MPa, 124.8 MPa, 100.76 MPa with distortion value of 40.43 mm. Then analyzed Post Weld Heat Treatment referring to AWS D1.1: 2000 to reduce residual stresses that occur. From the results of the Post Weld Heat Treatment value of the residual stress can be reduced significantly. After being treated Post Weld Heat Treatment with variations of temperatures of 200 C, 300 C The maximum residual voltage reduction occurs in pathline 1 to pathline 3 at 125 MPa, 93 MPa, 100 MPa.

Keywords: Pressure vessels, residual stress, distortion, post weld heat treatment, pathline

1. INTRODUCTION

Welding is widely used in many manufacturing and industrial fields, especially in the maritime shipping and maritime industries. Based on the definition of DIN (Deutsche Industrie Normen) welding is a metallurgical bond at the junction of the metal or metal alloy that is done in a molten or liquid state. From this definition [1] in his book entitled Metal Welding Technology further elaborates that welding is the local connection of some metals by using heat energy.

At the time of welding, the heat source goes on and causes a different temperature distribution on the metal resulting in uneven expansion and shrinkage. The presence of local heating due to welding and rapid cooling or high temperature changes cause energy stored in the weld area is also high resulting in residual stress and distortion.

Residual stress is the voltage acting on the material in the absence of external forces acting on the material. Residual stress is generated due to the non-uniform plastic deformation in the material, inter alia due to the uneven heat treatment or the difference in the cooling rate of the welded material. High residual stresses in the weld region resulting in reduced buckling strength, weld strength, and fatigue life [1].

In welding construction that is left free to move (without getting force or external load), the remaining thermal strain after the weld temperature reaches room temperature (cooling) is called a welding distortion. Distortion is a shape change or deviation caused by heat, which is due to the welding process. Expansion and shrinkage of workpiece will result in curving or drawing parts of the workpiece around the welding, for example during manual arc welding process. The distortion in the parent metal will reduce bending strength. This change will also greatly affect the reliability of the structure.

Residual stress and distortion are inevitable in the welding process. Therefore, this is the biggest challenge for welding practitioners. Although the residual stress and distortion cannot be avoided, but the phenomenon can be minimized by reducing the amount of heat input, heat treatment provision, far corner seam welds, and determine the order of good welding.

In this final project, will be carried out numerical simulations to reduce the magnitude of residual stress and distortion in the structure of the pressure vessels owned by PT. Petrokimia Gresik by varying the order of welding. This study was not conducted experimentally but using finite element method to determine the magnitude of residual stress and distortion.

2. MATERIALS AND METHODS

Method of this research work done with stages as follows:

2.1 The study of literature

Books on welding and distorting effects, national and international journals, theses, and relevant books such as Metal Welding Technology, Las Work Guide and others, codes or standards related to research this.

2.2 Data collection

In the collection of related data can be observation or just by looking at some related data in accordance with the problem to be studied or looking for some data as preparation activities for the implementation of this study. The required data are as follows:

- *Pressure vessels* dimensional data structure PT. Petrokimia Gresik
- Data welding parameters

2.3 Modeling the structure of *pressure vessels* with 3D Autocad *software*

These *pressure vessels* structural modeling using 3D Autocad *software* that refers to the main data dimensional model of the structure of *pressure vessels* taken from PT. Petrokimia Gresik.

2.4 Calculating Expenses *Heat Flux*

The heat transfer at the temperature distribution is influenced by the amount of heat flux in the element, can be calculated by the equation:

$$q_1 = q_e \frac{A_1}{A_f}$$

Where:
$q_{1:}$ heat flux on element (J / mm ^{2})
$q_{e:}$ heat flux produced by the electrode (J / mm ^{2})
$A_{1: \text{The}}$ element surface area (mm ^{2})
Af: flux generated extents electrode (mm ^{2})

After getting *heat flux* values can be *meshing* and analysis of temperature distribution

2.5 *Meshing*

Namely hexahedral meshing element type *(brick elements)* and tetrahedral (prism element) or if the *software* based on the finite element method is called as the elements Shell132 and Shell131. In order to search accuracy at the right size element *meshing* sensitivity of the method used.

2.6 Temperature Distribution Analysis with *software* based on the finite element method

Modelling and running the structure of *pressure vessels* using *software* based on the finite element method. From the results of running illustration obtained simulation of welding and temperature distribution at the beginning to the end of welding.

2.7 Structural analysis with *software* based on the finite element method

Structural analysis is required to perform residual stress analysis and distortion. Reviewed by structural analysis *software* based on the finite element method is necessary to apply a boundary condition, namely the boundary conditions in the form of an object under pedestal weld. Structural analysis was obtained from thermal grinding analysis

2.8 Time Voltage Analysis After PWHT Treatment

The purpose of PWHT is to reduce residual stress, in Table 1 the variation of PWHT treatment for this study is as follows:

Table 2.1. Variation of PWHT Temperature

No.	Temperature (C)	Hold time (hours)
1.	200	4
2.	300	3

3. RESULT AND DISCUSSION

3.1 Structural Dimension Data

In this final project modeled the structure of the pressure vessel *(pressure vessels)* owned by PT. Petrokimia Gresik. Modeling welding pressure vessel structure in this final project using Autocad 2017 software in accordance with the dimensions and geometry shapes contained in Table 3.1.

Table 3.1. Dimension Data Structure of *Pressure Vessels* PT. Petrokimia Gresik

Material	Al-6061-T6
Outer Diameter	2380 mm
Inner Diameter	2086 mm
Total Length	8100 mm
Thickness	13 mm

3.2 Meshing Structure

Before the imposition *of heat flux* on the model needs to be done *meshing*. *Meshing* is to divide the model into small elements. Variation of meshing length will result in different number of nodes. Selection *meshing* shape and size will affect the results, *solving* time, the number of elements, etc

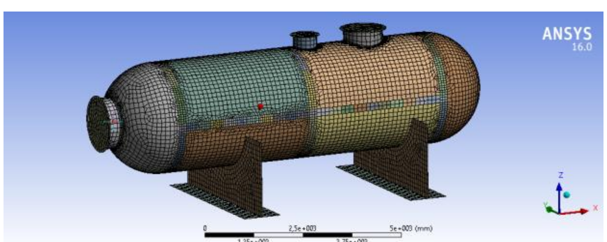

Figure 3.1 The shape of the meshing of the structure of pressure vessels

3.3 Welding Order

To know the amount of residual stress that is formed, then used several variations in welding simulation. In this case the determination of the order of welding. Welding area numbering is to determine the order of welding process as shown in Figure 3.2.

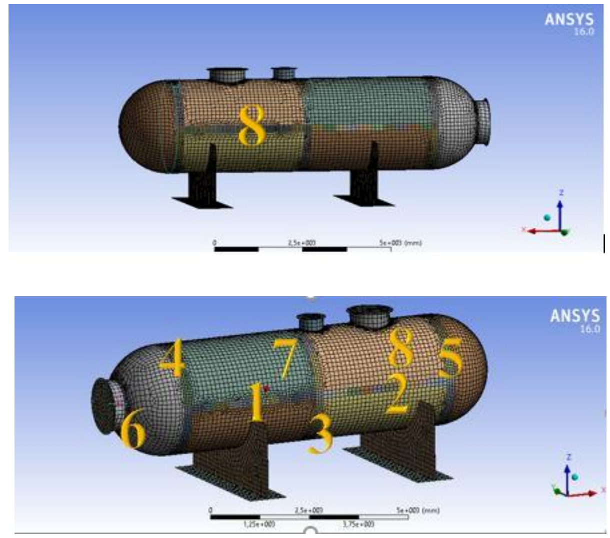

Figure 3.2 The order of welding on the structure of pressure vessel

3.4 Heat Flux Load Calculation

Weld simulation on tubular joints will be provided on each surface of the elements to be transferred into loads. The load is a heat flux where the magnitude is obtained from the cleaner heat input of each element. The weld meters are used to simulate weld connections.

Process: Single Pass GMAW
Type welds: GMAW
Current: 100 A
Voltage: 38 V
Welding speed: 225 mm / min
Diameter of Electrode: 4 mm

1. Heat Flux Heat For Area 1 and 2

Heat input
Q = h UI
Where:
Q: Net heat input (Watt)
h: coefficient of efficiency
U: Voltage (Volt)
I: Electric current (Ampere)
With:
h: 0.75
U: volts
I: 150 Ampere
Q = h UI
= 0.75 x 38 x 100
= 2850 watts

After doing the calculations above, the next is calculating heat flux.

$$q_1 = q_e \frac{A_1}{A_f}$$

$$q_1 = 223.92 \frac{230}{143.745,7}$$

$$q_1 = 0.35 \text{ watt/mm}^2$$

2. Heat Flux Heat For Area 3.4 and 5

After doing the calculations above, the next is calculating heat flux.

$$q_1 = q_e \frac{A_1}{A_f}$$

$$q_1 = 223.92 \frac{230}{165.721,8}$$

$$q_1 = 0.31 \text{ watt/mm}^2$$

3. Heat Flux Heat for Area 6.7 and 8

After doing the calculations above, the next is calculating heat flux.

$$q_1 = q_e \frac{A_1}{A_f}$$

$$q_1 = 223.92 \frac{230}{185.642,7}$$

$$q_1 = 0.26 \text{ watt/mm}^2$$

3.5 Thermal Analysis Results

At the time of welding occurs heat loads that can cause strain and stress on the area affected by welds. In addition, the welding simulation in this final project also produces heat distribution area around the weld. The welding temperature is observed at the start of welding as shown in Figure 3.3.

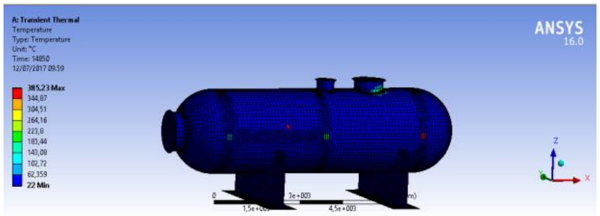

Figure 3.3 The result of thermal analysis using ANSYS workbench software 16.0

3.6 Heat Distribution Results

To determine the maximum temperature at each Regional welding predefined welding can be obtained from the load *Heat Flux.* The simulated welding cycle starts from 1-2-3-4-5-6-7-8 so that each peak of the following graph is the maximum temperature of each welding region as shown in Figure 3.4.

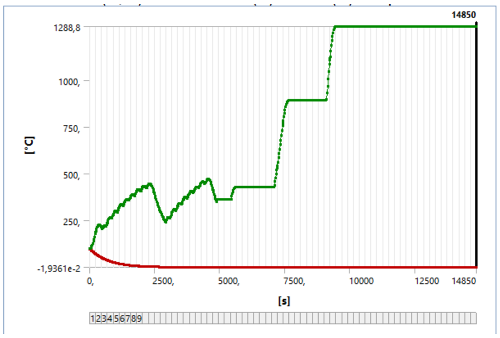

Figure 3.4 Graph Thermal Analysis Heat Distribution Results

3.7 Result of Residual Stress Analysis

The residual stress has axial and tengsial direction, in this analysis only use axial residual stress only. Determination of axial residual stress also based on pathline or axis to know the amount of residual stress. The residual voltage reading is performed on the body of the structure based on the pathline that has been made. In the structure of *pressure vessels* using the assistance of 3 *pathline.*

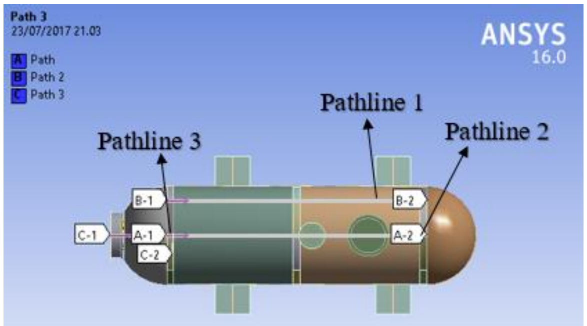

Figure 3.5 Graph Distribution of Residual Stress On *Pathline* 1

3.8 Time Voltage Distribution In Pathline 1

The residual voltage occurring in the area near the welding area is the tensile stress and has the greatest voltage value. While at the point of further distance with weldtoe then the value will be closer to 0 (zero). In *Pathline* 1 maximum residual stress value amounted to 189.5 MPa as shown in Figure 3.6..

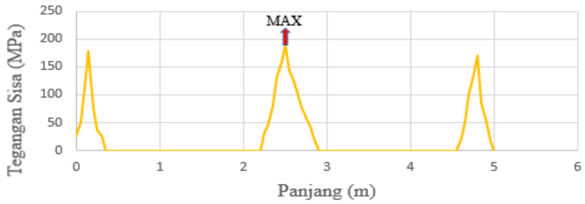

Figure 3.6 Graph Residual Stress Distribution In *Pathline* 1

3.9 Time Voltage Distribution In Pathline 2

The residual voltage occurring in the area near the welding area is the tensile stress and has the greatest voltage value. While at the point of further distance with weldtoe then the value will be closer to 0 (zero). In the second *Pathline* maximum value of the residual voltage is equal to 124.8 MPa. As shown in Figure 3.7.

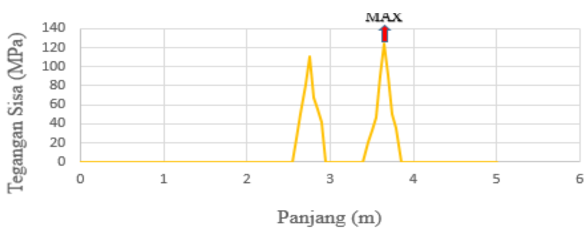

Figure 3.7 Graph Residual Stress Distribution In *Pathline* 2

3.10 DistributionResidual Stress On Pathline 3

The residual voltage occurring in the area near the welding area is the tensile stress and has the greatest voltage value. While at the point of further distance with weldtoe then the value will be closer to 0 (zero). In *Pathline* 1 maximum residual voltage value is equal to 100.76 MPa. As shown in Figure 3.8.

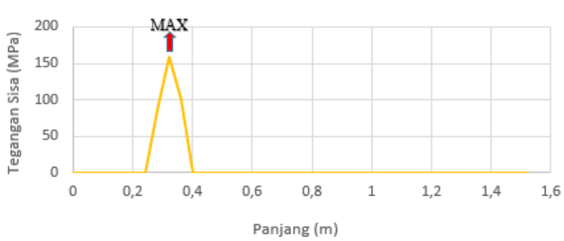

Figure 3.8 Graph Residual Stress Distribution In Pathline 3

3.11 Total Deformation Result Analysi

From the analysis results obtained deformation The total deformation is at the head in the structure of *pressure vessels*. For example in the following figures the total deformation shown in Figure 3.9.

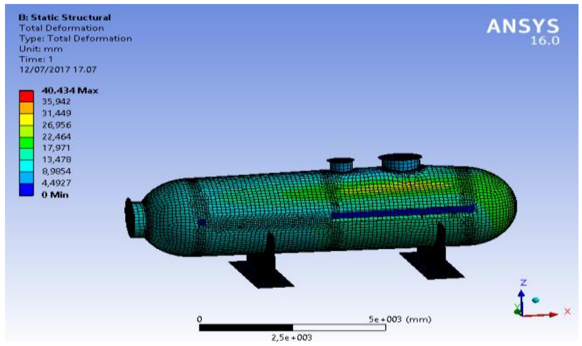

Figure 3.9 Total deformation that occurs in the structure

From the image above the distortion that occurs is equal to 40.434 mm or 4 cm. The value is quite large because the size of the geometry model used is also large.

3.12 Results of Temperature Time After Post Weld Heat Treatment

PWHT simulation was conducted on the model by giving back to the thermal load reaches a certain temperature holding time specified in the welding area. In this final task 2 variations *PWHT* as detailed in Table 2 to see temperature resistant which makes the residual stress is reduced a lot.

Table 2. Variations in temperature and holding time *post weld heat treatment*

Temperature (C)	Hold time (hours)
200	4 hours
300	3 hours

Here is a comparison graph of residual stresses starting from pathline 1 to pathline 3 as shown in Figure 3.10, Figure 3.11 and Figure 3.12.

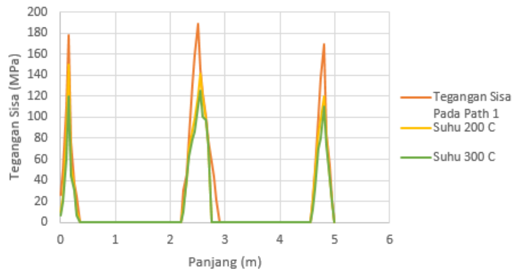

Figure 3.10 Graph Residual Stress After *Post Weld Heat Treatment* on *Pathline* 1.

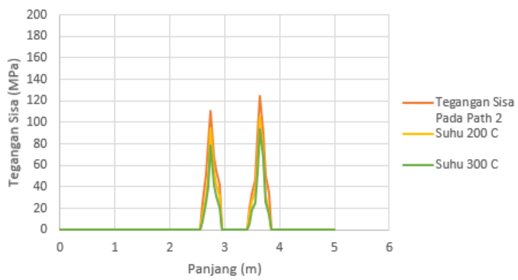

Figure 3.11 Graph Residual Stress After *Post Weld Heat Treatment* on *Pathline* 2.

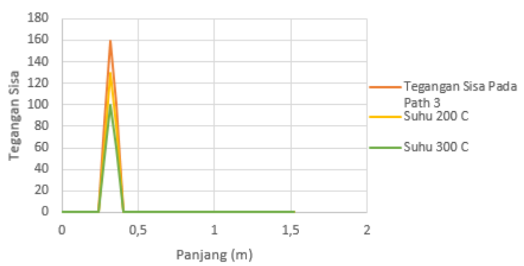

Figure 3.12 Graph Residual Stress After *Post Weld Heat Treatment* on *Pathline* 3.

4. CONCLUSION

From the research that has been done, obtained residual stress value can be reduced after PWHT treatment. Based on the analysis and discussion conducted obtained some conclusions as follows:

1. The maximum residual stress result from pathline 1 to pathline 3 is 189 MPa, 124,8 MPa, 100,76 Whereas for maximum distortion is 40,3 mm. While the residual stress that occurs the smallest of the pathline 1 to pathline 5 is 15 MPa, 20 MPa, 17 MPa.
2. After the PWHT treatment the residual stress continues to decrease as the temperature increases. The largest reduction in maximum residual stress occurs in pathline 1 to pathline 3 of 125 MPa, 93 MPa, 100 MPa, of residual stress before PWHT. Of all the treatments *Post Weld Heat Treatment* PWHT temperature, the higher the maximum residual voltage reduction will be even greater.

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