WELDING DISTORTION ANALYSIS ON WELDING JIG/FIXTURE USING FINITE ELEMENT METHOD

Vicky Martin Sianturi[*1], Ir. Hendra Saputra, S.T.,M.Eng[*], Ir. Fedia Restu, S.T., M.Sc.[*]

[*] Politeknik Negeri Batam
Program Studi Teknologi Rekayasa Konstruksi Perkapalan
Jl. Ahmad Yani, Batam Centre, Batam29461, Indonesia
[1]E-mail: svickymartin@gmail.com

Abstract

In the fabrication processes associated with the marine and oil/gas industries, the Indonesian city of Batam is home to numerous welding operations the most frequent of which is SMAW (Shield Metal Arc Welding). The primary disadvantage of this joining process however is that all of these techniques require a high heat to melt the components together and cause distortion. One such material that used are ASTM A36. to counter this problem is making a support to adjust the material prior welding that called Jig/Fixture since welding distortion occur when welding process it made. with the purpose to maintain the material to be adjust in a fixed position so that even after weld its still maintain its designated position. so it need more study for consideration during the tool design phase, and with that a computerized analysis using Finite Element Method (FEM) program to help knowing deformation pattern, thermal response of T-Joint Weld under applied load that can obtain approximated result. The result of the analysis with T-Joint A-36 material with 277.41 MPa is the stress value (von mises). The material type of ASTM A-36 has a deformation value of 0.77 mm. In the meantime, 15 is the safety factor value for the material type of mild steel. Thus, substance with a safety factor value of ≥1, mild steel material is deemed safe to employ as a supporting fixture in this design.

Keyword: welding, distortion, jig, fixture, finite element method

1. Introduction

Batam are the city of Indonesia that have many marine and oil/gas industry related with fabrication processes, in this production itself still relies heavily on welding process, commonly used are SMAW (Shield Metal Arc Welding). However, the main drawback of this joining technology is that all of these methods necessitate a high heat, the heat causes a weld pool of molten material which after undergoing cooling, solidifies as one piece forming a weld in order to melt, the faster-cooling weld metal tries to shrink more than the surrounding area. This creates opposing forces, or stresses within the metal this imbalance of stresses leads to welding distortion in the welded component. Welding distortion refers to the undesired warping, bending, or deformation of a metal workpiece that occurs during and after the welding process due to uneven heating and cooling. When welding, localized heating causes expansion in the heated zone, but as the metal cools, it contracts. Because this expansion and contraction are not uniform across the entire piece, internal stresses develop, leading to distortions. Factors such as the type of welding technique, heat input, the thickness and type of material, and the sequence of welds can influence the degree of distortion. If these stresses exceed the material's yield strength, it can cause permanent deformation of the components together [1]. There are 7 types of different welding distortion that occur on fabrication workpiece such as:

1. Longitudinal distortion: This is the shortening of the workpiece due to the welded area contracting along the weld's length. It frequently occurs in long, straight welds.
2. Transverse Distortion: This distortion happens perpendicular to the weld line, causing the workpiece to contract across the width of the weld. It often results in a narrowing of the welded section.
3. Angular Distortion: This type occurs when there is unequal heating on either side of the weld, causing one side to shrink more than the other, resulting in an angular bend or tilt along the weld axis.
4. Rotational Distortion: Also known as twisting, this happens when different parts of the welded piece rotate or twist relative to each other, often due to asymmetrical heat distribution.
5. Bowing or Bending: This distortion is characterized by a gradual curve or bend along the length or width of the workpiece, often due to longitudinal or transverse shrinkage.
6. Buckling: This severe form of distortion occurs in thin materials when compressive stresses exceed the material's strength, causing the workpiece to buckle or ripple.
7. Warpage: A general term for any irregular or wavy distortions in the flat sections of a workpiece, usually resulting from complex combinations of shrinkage and thermal stresses

One such material is Carbon Steel ASTM A36 that have good mechanical properties often used for structural and with such cheap price it’s the most common material grade that industry used. However, it also has a higher chance of distortion during welding process one such process is fillet welded T-joint on low carbon steel [2].

Significant difficulties arise throughout the fabrication process due to welding distortion, which causes dimensional errors that make pieces fit incorrectly, complicating assembly and requiring rework. Through the introduction of misalignment and residual stresses that weaken joints, this distortion has the potential to jeopardize the assembly's structural integrity. In terms of aesthetics, it can result in ugly finishes that lower customer satisfaction and marketability, particularly in the automobile and architectural industries. Because these distortions need to be repaired, they also result in financial losses, to counter this problem is making a support to adjust the material prior welding that called Jig/Fixture. since welding distortion occur when welding process it made with the purpose to maintain the material to be adjust in a fixed position so that even after weld it still maintain its designated position, achieving sufficient stability during the operation is crucial since any deviation or significant vibration may lower the weld's quality. Many industries are using this solution to save time and are effective to used Type of fixture that are commonly used are tack weld jig using a simple material to use as a support when weld pieces of metal together and clamping jig where it is put on a fixed position to weld. But still effectiveness of a fixture is still in question since there is limited published information on requirement for a fixture [3] [4] [5].

To solve this engineering problem is to develop and analyze a compact welding fixture 3D model that can be utilized appropriately to T-weld joints that will weld together, of course the type of distortion that happen will be likely to happen such as transverse, longitudinal, shrinkage, and transverse [6]. This design is based on the previously described design factors. using analytical, and computational modelling techniques to study the approximate assumption with complex geometry. with this data certain plan for effective fixture as a solution of distortion and also be a good reference for making or research purpose on a better welding fixture.

2. Research Methodology

2.1 Study of Literature

Welding distortion occur by uneven heat on the welded area of parent metal causing a product deviation, Fixture purpose is to maintain its fixed position on a material, so it needs more study for consideration during the tool design phase [7]. as its first step to studying the frame which the jig and fixture will be attached by using pertinent and acceptable references in the problem-solving process. And for that on Figure 1 the process flow of the fixture design and t-joint analysis

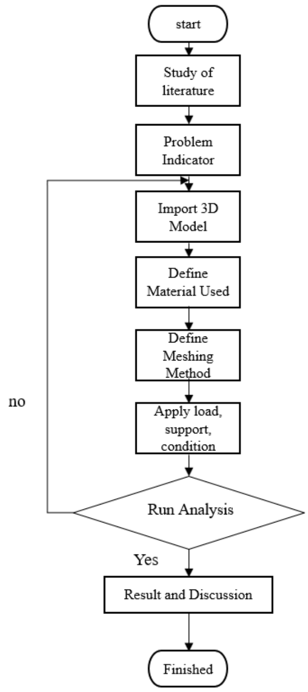

Figure 1 Research Process Flow

2.2 Problem Indicator

Involving phases that range from identifying the problem to analysis and assessing the product. The process of problem identification involves gathering and analyzing all information pertaining to the design of jigs and fixtures There are many factors that a welding distortion can occur from heat input, material properties, welder skill, equipment failure, human error, etc. because of this factor the residual stress reside on the heat when welding and after welding making a deformation that can’t be prevented only can be controlled [8]. To do this the parameter of welding must be in better approach as per Figure 2.

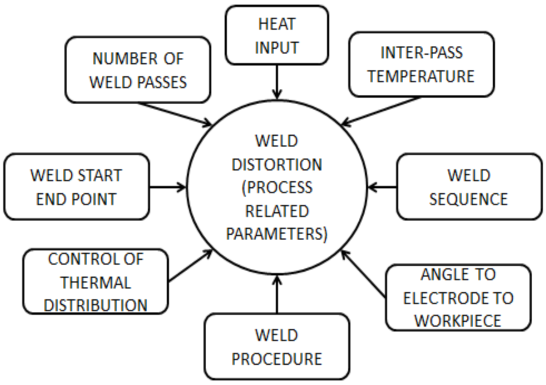

Figure 2 Welding Distortion Parameter [8]

including the material for T-Joint welding. The workpiece will be T-Joint on Figure 3 design, fillet weld where SMAW will be the intended process size of the weld size will be 5 mm and sized of plate for joint are 200 mm x 200 mm x 8 mm preparation method follows EN ISO 15614- 1:2012 [9]. T-joint weld can have a severe distortion after welding such as shrinkage distortion, transverse distortion, longitudinal distortion, and angular distortion because of its geometry, with this data the jig that needed to design need to pay attention on the accuracy of its geometry.

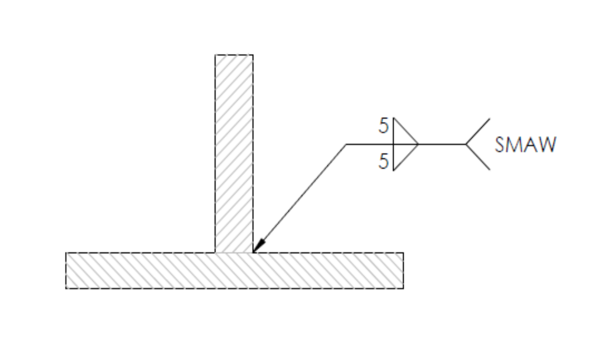

Figure 3 T-Joint Intended Analysis

2.3 Import 3D Model

To accommodate the variances in the workpiece, the fixture must to be reusable and adjustable, in general a fixture consists of three element locators, clamp and support. The locator used to utilize the workpiece in a intended location. Clamp used to exert force that securely holds the workpiece in order to hold it. Support is positioned beneath the workpiece and added to prevent or limit distortion [10]

the effectiveness of the fixture on the workpiece with the following points must be considered [11]:

1. The expansion of a heated workpiece and the distortion that follows shouldn't have an impact on melting, loading, unloading, clamping, or correct placement.
2. Lack of fusion of a welding process to fuse together that creating overlapping need to be plan the solution.
3. Prevent Elastic bulking causes a warping that the metal sheet to be curved when the workpiece is tightened.
4. Misalignment where the edges of the weld joint are not aligned need to properly clamp.

2.3 Define Material Used

The selection of ASTM A36 material is due to the good material properties that shown in Table 1 and adequate to heat. yet research revealed that, depending on the welding parameter settings, distortion in ASTM A36 steel weld might reach 5–10% of the original dimensions [12]. This show that welding fixture must have a durability and strength to maintain its fixed position of the weld workpiece.

Table 1 Material Properties ASTM A36

Material Grade	**ASTM A36**
Density	7.80 g/cc
Elongation	20-23%
Yield Strength	250 Mpa
Tensile Strength	400 Mpa
Coefficient of Thermal Expansion	11.7 x 10^{-6} (°C)

2.4 Define Meshing Method

The Multizone Mesh Method provides an automatic decomposition of geometry into mapped (structured/sweep able) regions and free (unstructured) regions. When feasible, it automatically creates a pure hexahedral mesh; otherwise, it fills in the harder-to-capture areas with an unstructured mesh.

2.5 Setting Condition and Run Analysis

Finite Element Method (FEM) program use to carry out structural analysis using sophisticated solver options such as linear dynamics, nonlinearities, thermal analysis, materials, composites, hydrodynamics, explicit, and more. Static structural is one of the methods to analyze and solution to problem regarding structure form deformation, stress, to factor of safety and Transient Thermal to analyze thermal analysis. This method giving a maximum and minimum value to every problem based on the mathematical formula [13] :

a. Static Structural Non-Linear analysis

   Many Physical processes exhibit non-linear behavior. The relationship between applied forces (input) and resulting deformations or stresses in a structure isn't proportional. And with that express by the equation

$$F = [K]\{x\} \ldots (1)$$

   FEM utilizes various stress formulations, but the most common one is von mises stress with the equation

$$\sigma v = 2(\sigma 1 - \sigma 2)2 + (\sigma 2 - \sigma 3)2 + (\sigma 3 - \sigma 1)2 \ldots (2)$$

   of course on non-linear analysis involves setting up the total deformation to define additional solution control settings related to convergence criteria for non-linear solutions

$$U\ total = \sqrt{U_x^2} + U_y^2 + U_Z^2 \ldots (3)$$

b. Transient Thermal Analysis

   weld process, calculating the temperature profiles under various heat input process circumstances, and analyzing the thermal mapping of the welds' interface zones in order to estimate the heat input and weld process optimization prior to the experiments The heat conduction in solid consists of the internal energy, surface heat flux, and the heat conduction is given by Equation (4) [14]

$$c\rho\frac{\partial^2 T}{\partial x^2} = \ldots (4)$$

$$k\left(\frac{\partial^2 T}{\partial x^2}\right) + k\ \left(\frac{\partial^2 T}{\partial x^2}\right) + k(\left(\frac{\partial^2 T}{\partial x^2}\right) + Q \ldots (5)$$

The heat convection from the surface of weld material by equation (5). Combined heat convection and heat radiation coefficient of the material by equation (6)

$$q_{c=H(T-T_0)} \cdots (6)$$

$$q_r = \epsilon\sigma(T^4 - T_0^4) \ldots (7)$$

Equation (7) is the normal radiation from a surface. Equation (8) is the gaussian surface flux distribution

$$q(r) = q(0)e^{-cr^2} \ldots (8)$$

c. Factor of Safety

To determines, using necessary specifications, how safe a design of fixture is in prior for using Express by the equation

$$Factor\ of\ Safety\ = \frac{Ultimate\ Stress}{Allowable\ Stress} \ldots (9)$$

The intended fillet weld on plate size 200 mm x 200 mm x 8 mm will be welded with table 2 SMAW Parameter. When the plate is joint SMAW process give a high temperature, the surface are assumed clean and free from any layer of scale, rust, and lubricant.

Table 2 SMAW Parameter

Heat Source	Electric Arc
Electrode Type	Consumable
Operation Current	30-300A
Operating Voltage	15-45 V
Max. Temperature	5000ºC
Optimum Welding Speed	75-150 mm/min
Position of Weld	All
Weld Quality	Average

And with that computerized Stress analysis using FEM program to help knowing deformation pattern of design fixture under applied load that can obtain approximated result for T-Joint and thermal analysis to know the effect of heat liberated by the process of welding on the fixture setup.

Evaluation is helpful in identifying the fixture shortcomings and its capacity to bear weights according to the materials used in its design, allowing for future development and improvement of the fixture. Once more in order to verify that the settings are suitable for the production of equipment, evaluation is done by comparing the simulation results with relevant journals so it can possible to be a reference for the upcoming design into a production-ready tool [15].

3. Result

3.1 Jig Design

The fixture concept is to maintain its fixed position with no friction prior and after weld. As per Figure 4 the T-joint are placed on base plate with 15 mm thick, holes are used to assembly the supports on T-Joint Plate vertical using SHS 12 mm to be precisely 90° Angle. While T-Joint plate horizontal is clamp using assembly support tighten using fasteners (Nut and Bolt 4 mm) and SHS 12 mm make it a fixed position on both positions. There are many references that are used when designing the jig but one thing that needed to be certain is to how to maintain it shape after welding, with the SHS that attached on the horizontal plate it will maintain its position and more likely to counter transverse, shrinkage and angular distortion because its attached fixed on the base plate making no friction whatsoever making it a perfect counter. Not to mention also in the vertical plate where it tightens with SHS as the welder weld the vertical plate and the horizontal plate together the SHS jig already making the vertical plate on a fixed position making it frictionless prior, during, and after welding that can counter longitudinal distortion.

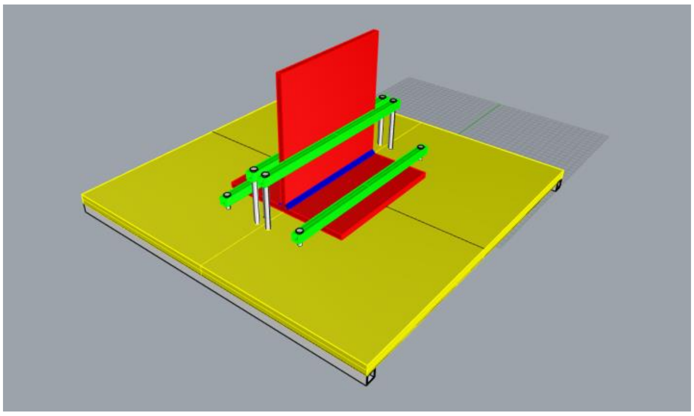

Figure 4 Fixture Design

Part designed description of the intended fixture is shown in Table 3. Material of the jig (exclude fasteners) are using Mild Steel having good material properties to withstand the weight and working procedure.

Table 3 Jig/Fixture Part

No	Component Name	Material	Dimension
1	Base Plate	MS	236 mm x 200 mm x 15 mm
2	Bolt	Grade 8.8	Diameter 4 mm, Length 15 mm
3	Nut	Grade 8.8	4 mm
4	SHS	MS	12 mm
5	SHS	MS	13 mm

3.2 Transient Thermal Analysis

Specimen is analyse using FEM (Finite Element Method) to understanding the heat flow when considering the SMAW Arc is wide range, the 700 °C reference often pertains to the average temperature around the weld area or the Heat-affected zone (HAZ), not the peak temperature in the weld pool. as per Figure 5 visualization resulting maximum temperature of 716.11 °C, and the minimum is 22 °C

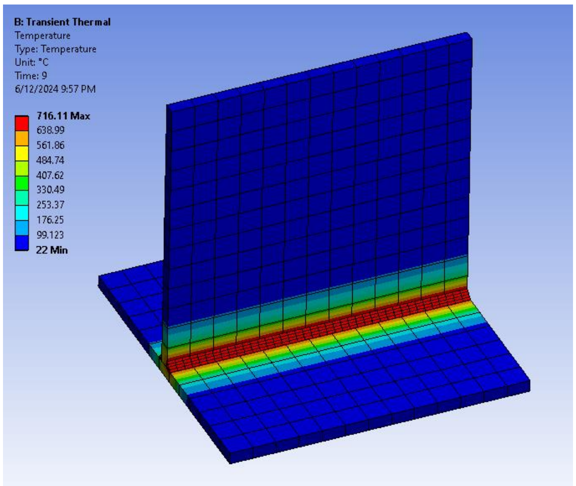

Figure 5 Temperature Result

3.2 Static Structural Analysis (Deformation, Stress)

Analysis is conducted where the condition as per jig design to supress the movement and make it fixed on the vertical and horizontal plate. The visualization per Figure 6 indicates that shrinkage, transverse, longitudinal, angular distortion is countered with the blue colour of the specimen define its fixed position and the deformation is located in start and end weld point with the maximum deformation of T-Joint with designated boundaries are 0.77 mm on the fillet weld. Equivalent stress on the other hand as per Figure 7 visualization the stress can be find in the middle area of the fillet weld with maximum equivalent stress with designated boundaries are 277.41 Mpa.

Table 4 Total Deformation and Equivalent Stress Result on FEM

Maximum Deformation	0.77 mm
Minimum Deformation	0 mm
Maximum Stress	277.41 Mpa
Minimum Stress	0 Mpa

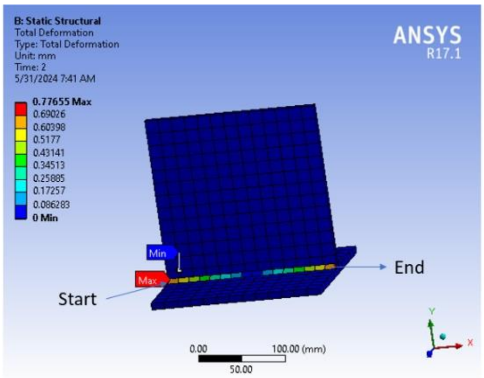

Figure 6 Total Deformation

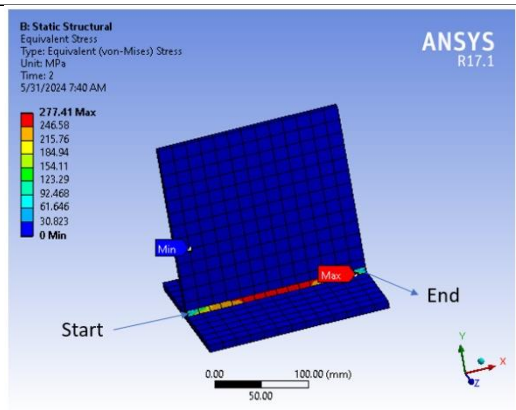

Figure 7 Equivalent Stress

3.4 Factor of Safety

Jig factor of safety is conducted with setting boundary and the load that the jig will withstand maximum 500N, the result of the factor of safety using FEM Analysis are 15. Consider with this value it can be stated safe for the jig

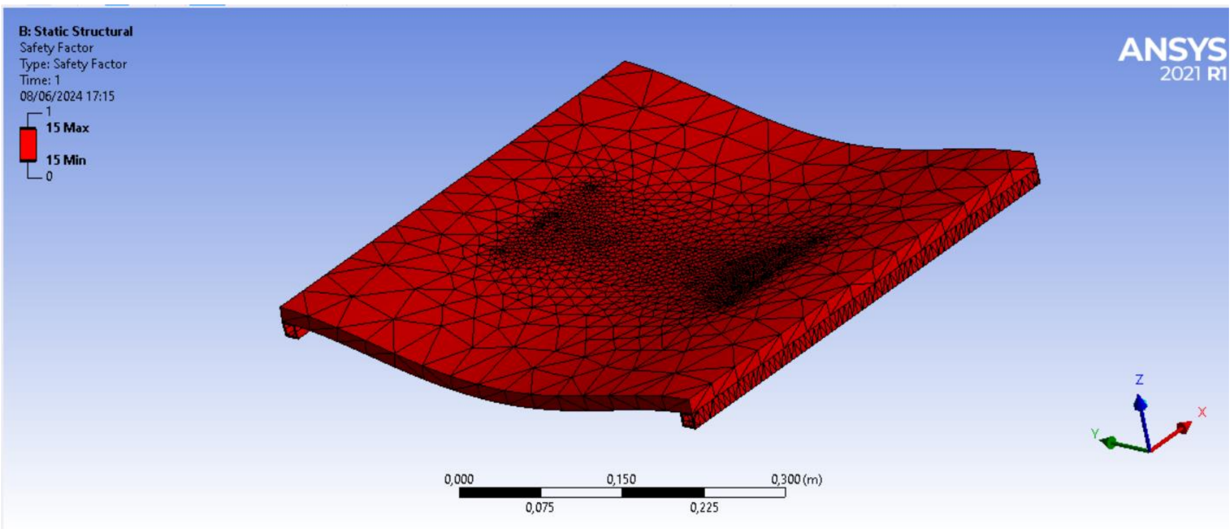

Figure 8 Factor of Safety

4. Conclusion

In order to joint materials together, welding often includes heating the connection. Both contraction and expansion are caused by heat. Distortion may arise from unequal heating and cooling. The distortion is a result of residual stress that is created while welding. Because of it one solution that is necessary is to control the distortion using Jig/Fixture method, this method use to maintain its designated position of the parent material prior, during, and after welding in a fixed position. this study shown and develop a 3D FEM analysis on how the T-Joint weld set on design fixture make it a fixed position with the result of the total deformation on the T-Joint on the Fixture/Jig of minimum value is 0 mm and maximum 0.77 mm with the visualization the maximum total deformation area in the start and end point of fillet weld, Stress Analysis visualize the point of the maximum stress are with the value of 277.41 Mpa, result of thermal analysis pointing that the temperature of maximum 716.11°C on the fillet weld being transfer to the parent material thoroughly and lastly Factor of safety result of the Jig of the value of 15 with 500N Applied load that confirm the Jig/Fixture are safe and with this welding fixture are a valuable investment for any company involved in production welding, their ability to improve accuracy, quality, productivity, and safety. hoping with this study can become a reference into making a better welding fixture.

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