

Simulation Study of Welding Distortion on Multi pass Welding of the Fillet Joint

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Abstract— This paper investigated the distortion induced by the gas metal arc welding (GMAW) process on the multi pass welding of tubular T joints. Two types of materials used in this study were high strength low alloy steels S355 and S460. In this research, Simufact.Welding 4.0 was used to analyze the distortion behavior of both joints. Goldak's double ellipsoid heat source model was applied since it was a commonly used model for arc welding processes and was readily available within the Simufact.Welding software. Prior to the results and discussions, this paper discussed the procedures to simulate the joining processes, beginning with the creation of the geometry using Catia and meshing in Patran and post processing using Simufact.Welding process. Apart from the comparative analysis, this research was intended to be a baseline study to provide preliminary information on preparing the tools and equipment for further experimental investigation on the multi pass welding.

Keywords— HSLA, s355, s460, distortion, Simufact.welding

I. INTRODUCTION

Tubular T joints are prominently used for bridges and jackets of oil and gas platform because of its efficiency in bearing compression, bending, and torsion. Generally, it is a component of truss joint connection between steel structures mostly joined by an arc welding process such as gas metal arc welding (GMAW) or shielded metal arc welding (SMAW). Most fillet joints are welded by a single pass or a multi pass depending on the diameter and the side wall thickness of the pipe used. As the diameter and wall thickness increase, the amount of welding pass will also increase. This phenomenon influences the amount of distortion and residual stress in the welded joint.

Distortion is the results from the expansion and contraction of the weld metal and the adjacent base metal during the heating and cooling cycle of the welding process. Since the arc welding process is an economical way to join metal parts, this method is generally preferred by industries. The distortions basically cannot be eliminated from welded parts, however, it can be controlled using appropriate control

methods such as clamping or support. Reworking due to distortion is normally associated with additional maintenance costs, project delays and ultimately, decreased structural integrity such as fatigue and toughness of the material [1].

The materials used in this welding simulation were high strength low alloy steel S355 and S460. HSLA is normally used in structural fabrication to reduce the thickness and weight of the steel due to its good weldability, excellent strength and corrosion resistance that made it ideal for many welding applications. Both S355 and S460 steels are widely used in bridges, buildings, offshore, cranes [2]. They typically contain 0.07 to 0.12% carbons, up to 2% manganese and small additions of niobium, vanadium and titanium (usually max. 0.1%) in various combinations. High-strength low alloy (HSLA) steels, or micro alloyed steels, are designed to provide better mechanical properties and greater resistance to atmospheric corrosion than conventional carbon steels [3]. This material is preferably produced by a thermomechanical rolling process that maximizes grain refinement as a basis for improved mechanical properties. Grain refinement and precipitation strengthening are the primary mechanisms to increase yield strength of micro alloyed steels, while maintaining desired levels of ductility and weldability.

Simulating any welding process using Finite Element (FE) is not an easy task due to the interaction of thermal, mechanical and metallurgical phenomena [4]. The FE application has recently gained popularity in the industry and one of the latest FE software available today is SIMUFACT.WELDING. It is a customized software solution for analysis and optimization of welding processes. This software has been extensively used by several researchers and companies such as BMW, Mercedes-Benz, Porsche and Audi to predict the distortion induced by the heat of welding robotic [5-6]. Simufact.Welding offer numerous functions and references and a variety of inputs to allow engineers and production planners to optimize welding applications, including the ability to control the intervals of several robots

by modifying welding sequences, speed, heat input, stop times, or fastening devices [7]. Welding heat source model such as Goldak double ellipsoidal and laser are also available in this software.

There have been a few attempts in the prediction of welding distortion of the tubular T joint for structural jacket fabrication. Most of the welding simulations review publications focused on the plate, bar or sheet of the certain carbon steel group [8-10]. The objective of this study is therefore to compare the distortion and residual stress of multi pass welded on tubular T joint of HSLA S355 and HSLA S460. Apart from the comparative analysis, this research is also intended to serve as the baseline study to provide preliminary information on preparing the tools and equipment for further experimental investigation of multi pass welding.

II. WELDING SIMULATION SETTING

Two types of materials used for this study were S355 and S460. Both materials are high strength alloy steel (HSLA). The chemical composition of these materials is shown below in Table 1 [11].

TABLE 1. CHEMICAL COMPOSITION OF S355 AND S460

	C%	Cu%	Mn%	Si%	Al%	Cr%	Nb%	Ni%	V%
S355	0.17	0.1	1.6	0.5	0.02	0.1	0.012	0.3	0.1
S460	0.19	0.1	1.62	0.6	0.032	0.1	0.012	0.09	0.1

TABLE 2. WELDING PARAMETER FOR WELDING SIMULATION

Material	S355&S460
Modelling component	2
Bearing	1
Fixing	0
Clamp	3
Robot	2
Welding Parameter	
Welding current	150 amps
Voltage	20 v
Travel speed	8mm/s
Clamping sets up	
Activation time	0
Deactivation time	300s
Clamp force	200N
Heat source	Goldak's double ellipsoid

In Simufact.Welding software, there is a predefined material library database of various materials concerning thermal properties and mechanical behaviour data for the simulation purposes. This software also allows users to create new material database. There are some important steps that need to be considered before running the welding simulation in Simufact.Welding as described in step 1 to step 5 below.

A. Step 1. Creating Modelling and Meshing

In this section the geometries of the tubular T joint of both materials were first modelled using Catia software. The diameter and wall thickness of the tubular geometries were

illustrated in Figure 1. Once the geometry modelling processes completed, all geometries were then imported to the Patran software for meshing process and their material properties were also defined. These geometries were then kept as bulk data file format (.bdf). The meshing was carried out in in Patran using a tetrahedron mesh type. Meshing the modelled geometries were very critical in order to be analysed further in Simufact.Welding.

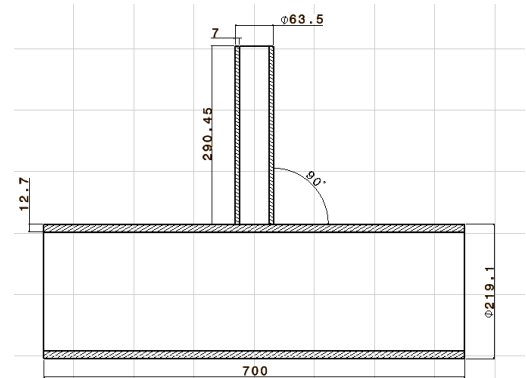


Figure 1. Sketch of joint design of tubular T-joint in CATIA software.

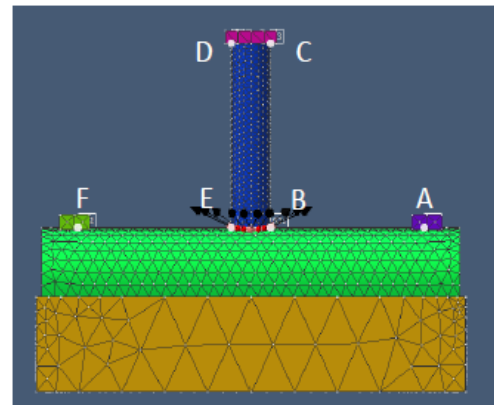


Figure 2. Tracking points of tubular T-joint in simufact.welding

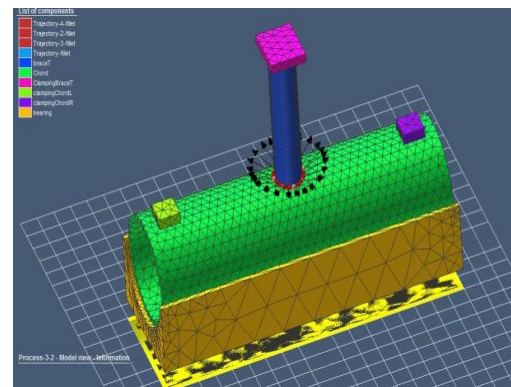


Figure 3. Set up of geometry modelling for welding simulation for tubular T-joint.

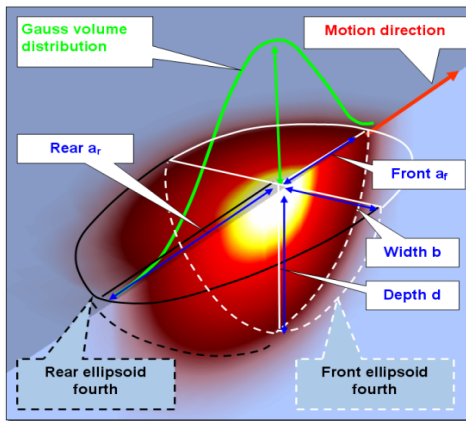


Figure 4 Presentation of Goldak's double ellipsoid heat source model

B. Step 2. Pre-processing in Simufact.Welding

Preprocessing in Simufact.Welding involved several steps that needed to be defined clearly. The first step was to set up the number of components, bearings, fixing, clamps and welding robots. The components referred to the number of geometries of the model, bearing referred to the table used in Simufact.Welding, fixing referred to the holder of the geometry, clamp referred to the number of clamps used, while the welding robot referred to the number of welding robots used to weld the modelled geometry. The second step was to import the bdf file from Patran software. This file contained the modelled geometry of the tubular T joint to be analysed further in the Simufact.Welding. The third step was to select the material used from the materials library by simply drag into the project component. The fourth step was creating node set and trajectories. In this step the nodes set of the mesh corresponding to the trajectory of the weld path were selected carefully and once completed, it was put under the welding robot in the process tree. The fifth step was to set up the welding parameter such as current, voltage and travel speed of the welding robot. Prior to this stage, pause times, lead times and follow up times were also defined. However, this setting was dependent upon the welding method requirement. The sixth step was to set the robot trajectory position that could be placed in the center, left or right of the welding path. The seventh step was to define the size of the fillet representing the actual size of weld metal. The exterior of this fillet could also be modified and visualized into fine, medium and coarse. The eighth step was setting the clamping activation time, deactivation time and force value of the clamps used. The preprocessing variables of the welding simulation in Simufact.Welding are summarized in Table 2. Tracking points could also be set up in Simufact.Welding. By using tracking points, it was relatively easy to determine the total distortion and residual stress on the spotted area of the tubular

fillet joint. For this welding simulation the defined tracking points are A, B, C, D, E and F respectively as shown in Figure 2.

C. Step 3 Heat source calibration

To gain the appropriate distribution of the heat source on the welding path, heat source in Simufact.Welding should be first calibrated. For this welding simulation the heat source used was Goldak's double ellipsoid, a common heat source model for arc welding processes. The heat source in Simufact.Welding is easy to be visualized and modified until an appropriate size of heat source is obtained for the welding simulation as illustrated in Figure 4.

D. Step 4. Welding simulation

The welding simulation in Simufact.Welding began with simulating the thermal analysis without mechanical solution. This was important to ensure the thermal was well disseminated along the weld path and also to make sure that the preprocessing steps were set up properly. Thermal analysis was unable to be performed if something was not correct during the preprocessing set up. As the thermal analysis executed smoothly, then the mechanical simulation analysis could be triggered by simply copying the thermal analysis process and activated its start time and end time analysis. Figure 3 illustrated the complete tubular T joint set up which was ready for welding analysis simulation.

E. Post processing

As the welding simulation analysis completed in the Simufact.Welding all mechanical results such as total distortion, effective stress and total stress could be visualized and compared in the form of figures and graphs as described in the results and discussion section.

III. RESULTS AND DISCUSSION

After the completion of welding analysis in the Simufact.Welding, the mechanical results such as amount of stress, thermal and total distortion was obtained in the section result of the software. In this section the mechanical results of both materials are discussed.

A. Welding simulation analyses result

1) Total distortion of S355 and S460

By referring to the tracking points A to F in the tubular fillet joint; it clearly demonstrated that welding activities induced some sort of distortion. In each tracking points on both materials, it showed different values of distortion as presented in Table 3.

TABLE 3. TOTAL DISTORTION OF S355 AND S460

Type of joint	Tubular T-joint		
	Total Distortion (mm)		% different
Tracking Points	S355	S460	
A	1.82	0.75	83
B	1.93	0.87	76
C	2.13	1.04	69
D	2.13	1.04	69
E	1.93	0.82	81
F	1.62	0.75	73
STDEV	0.194	0.133	37

TABLE 4. TOTAL RESIDUAL STRESS OF S355 AND S460

Type of joint	Tubular T-joint		
	Residual Stress (MPa)		% different
Tracking Points	S355	S460	
A	406	65	145
B	464	86	137
C	580	108	137
D	522	108	131
E	464	86	137
F	290	65	127
STDEV	99.9	19.23	135

Based on the results in Table 3, the tubular T joint of S355 showed a slightly higher total distortion compared to the S460. Among the disseminated tracking points in figure 2, points C and D obtained higher distortion, which is approximately 2mm each. These tracking points located on the tip of the tubular T joint, which is among the area that have a great possibility of shrinkage when welding process took place, especially when no clamps used [12-13]. The percentage differences of the total distortion between the tracking points also showed to be consistent at approximately 73%-83 %. The consistency was due to the welding performed on both sides with the help of clamping that accosted properly on the tubular T joint. During welding, there were many factors affecting the contraction of the metal that lead to distortion, such as physical and mechanical properties that changed whenever heat was applied. For instance, as the temperature of the weld area increased, yield strength, elasticity, and thermal conductivity of the steel plate decreased, while thermal expansion and the specific heat increased [14]. These changes, in turn, affected the heat flow and the uniformity of heat distribution resulting in the difference of distortion values in the tracking points. Based on this literature, the S460 obtained less distortion compared to the S355 due to it had excellent properties and greater resistance to corrosion than S355 [15]. The weldability of S460, with regard to hydrogen-induced cold cracking was also better than S355. Weldability was in contrast related to the hardenability of the steel, which measured the ease of forming martensitic material during heat treatment. The hardenability of steel depended on its chemical composition, where greater quantities of carbon and other alloying elements resulted in a higher hardenability and, therefore, lower weldability.

However, the results of this welding simulation was only the prediction over the total distortion occurred on the multi pass weld of the tubular T joint. Actual experiment needed to be conducted in order to validate this welding simulation results.

2) Residual stress of HSLA S355 and S460

Residual stresses in welded joints primarily developed due to differential heating, peak temperature and cooling at any moment during welding. This was experienced by the weld metal and region closed to the fusion boundary around the heat affected zone (HAZ).

As shown in table 4 the amount of residual stress on both materials after the welding simulation showed vast differences. Point B, C, D and E displayed higher residual stress among the tracking points on both materials. Point C and D obtained the highest residual stresses among the located points in both tubular fillet welds, while the stress in points B and E shows a bit lower. When inspecting the location of these points in figure 2, they were located on the weldment and the tip of the tubular T joint. In welding, the area of weld metal generally acquired higher residual stress compared to the other components of the joint parts. This was due to the heat input during the welding process that concentrated on the area of the weld path. However, the clamp also influence the distribution of the residual stress in both tubular fillet weld due to its hold the expansion of the pipe during the welding progress. Many researchers proved that weld metal and clamp areas had higher amount of residual stress as the welding process completed [16-19]. The differences in percentage of residual stress on the tracking points B, C, D and E were approximately 137 % each tubular fillet joint. The difference indicated that the distribution of the residual stress among these areas were not similar. Other point showed less residual stress due to the areas not being exposed significantly to the heat input of welding process. S460 obtained lower residual stress as indicated in table 4 due to it had an excellent properties compared with S355.

The residual stresses exist in metal as a tensile or compressive stress. Tensile residual stresses in weld joints cause cracking problems, which in turn adversely affected their load carrying capacity. However, the compressive residual stress seemed to be important to the welded joint for its increased the fatigue life of weld joint [20]. The degree of residual stress, increased progressively to the peak value until weld joint cooled down to the room temperature as what actually happened to the tracking points B and E in this welding simulation. However, actual experiment needed to be conducted to validate this welding simulation results in future.

IV. CONCLUSION AND RECOMMENDATION

Based on results of total distortion and residual stress of the tubular T-joint, there were some conclusions that could be drawn as follows:

- The welding simulation result showed that the total distortion occurred at the multi pass weld on tubular T joint did not significantly influence the yield strength of the material.
- The welding simulation result confirmed that the area of weld metal had higher residual stress compared to the other structural parts.
- Further study needs to be done to validate the welding simulation results by doing the actual welding investigation on the material S355 and S460.

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