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Effect of Welding Speed on Residual Stress and Distortion of AISI 1045 Plate Using the Finite Element Method (FEM)

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ABSTRACT

Welding is one of the metals joining methods to assembly parts which are used in manufacturing, automotive, and aerospace industries. The welding process merely simulated in modelling using finite element method (FEM). Simulation is used to determine how the effect of welding speed on the distribution of temperature, residual stress, and deformation in the V-Butt Joint welding model. The material used in this welding simulation is AISI 1045 plate with a thickness of 8 mm. Variable speed of welding performed in 30 cm/minute, 40 cm/minute and 50 cm/minute. As the result, the residual stress and distortion will be compared in order to find the best welding speed which produces the smallest residual stress and distortion value. Welding simulation based on SMAW with 6.3 mm of E7016 electrode, current of 150 A, voltage of 26 V, and single-pass welding. The finite element method using the ANSYS 2020 R2 software for simulation. Welding simulation uses transient thermal and moving heat flux features, while residual stresses and distortion use static structural features. From this research, the maximum temperature distribution after welding at welding speeds of 30 cm/minute, 40 cm/minute and 50 cm/minute were 295.22 ℃, 240.59 ℃ and 205.94 ℃, respectively. In this study, the welding speed of 30cm/minute has the highest values of residual stress and distortion, which is about 0.00000036965 MPa and 0.090894 mm. Besides, for welding speed of 40 cm/minute and 50 cm/minute, the total residual stress and total distortion valueare 0.00000027744MPa; 0.067248 mm and 0.00000022218 MPa; 0.053419 mm, respectively.

Keywords: Distortion, Finite Element Method, Residual Stress, Welding Speed.

1. INTRODUCTION

Welding has been widely applied for assembly parts in manufacturing, automotive, and even aerospace industries. Welding gives several advantages to guarantee high-strength and small thermal deformation in parts joint. During the welding process, the welding speed is one of the variables to be considered for proper application of welding. Welding speed has various impact on the residual stress and distortion during welding process[1, 2]. This fact has been considered as a pivotal factor in estimating good parameters during the welding process. To determine the proper parameters, welding process-based modelling simulation has been widely developed using finite element method by computer aided engineering software[3]. This simulation gives several merits to determine crucial roles during welding process.

Several studies on the effect of welding parameters on distortion and residual stress of welding. Xie et.al.studied the effects of different welding parameters on residualstresses and distortion of the Cr18Ni90 pipe with thickness of 6 mm andby changing the inserted heat, the most displacement of the pipe obtained[4]. Meanwhile, Fu et.al. observed about the effects of welding sequences on residual stressand distortion of welding by thermo-mechanical finite element method which resulted that welding sequences have asignificant effect on magnitude and distribution of residual stress anddistortion of welding[5]. In addition, Khoshroyanet.al. investigated the distribution of residual stress, temperature, and distortion on stiffened aluminum alloy Al6061-T6 plates by thermo-mechanical finite element simulation. It indicates that the improvement of welding current will enhance residual stress and distortion. From these previous research, it is clearly stated that modelling simulation of finite element method has effectively demonstrated intriguing parameters to investigate various phenomena of residual stress and distortions during welding process[6].

Residual stress and distortions during welding process caused by non-uniform thermal distribution of the welding heat zone and deformation located in the part, which is very crucial to determine welding parameters. Welding speed is considered as a impactful parameter on residual stress and distortion of welding part, which obviously determine the actual time and cost of the welding process[7, 8]. Therefore, in this work, the effect of welding speed on residual stress and distribution of AISI 1045 platehas been studied. The methodology which applied to this work involved the finite element method using computer aided engineering software of ANSYS 2020 R2. The modelling simulation results of less residual stress and distortion were also demonstrated as a consideration of welding process parameters.

2. MATERIALS AND METHODS

Material used in this work is AISI 1045 steel plate and the experimental methodology proposed to set up the simulations consist of the geometry, the implemented mesh, and the boundary condition which undergo in finite element method using ANSYS 2020 R2 software.

2.1. Geometry

The model implemented to run the simulation is depicted in Figure 1. The geometry consists of two plates placed end-to-end, which using V-butt type of welding joint. The center line is the place of arc heat input was developed. The thickness of each plate is about 8 millimeters. The parameter of welding simulation consists of welding speed 6,6 mm/s, current 150 A, voltage 26 V, and shield metal arc welding (SMAW) type with E7016 electrode.

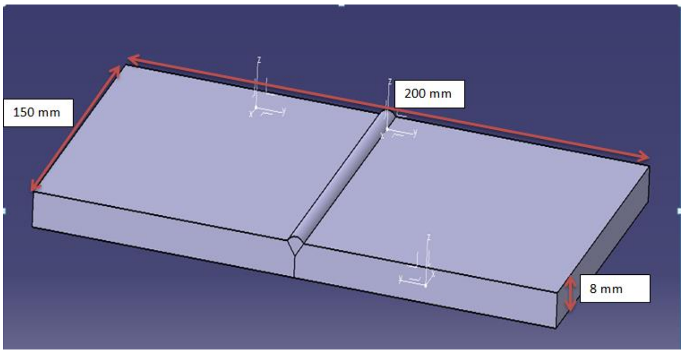

Figure 1. Model of running arc welding simulation

2.2. Mesh

The model designed and meshed by ANSYS 2020 R2 which consist of 406 cubic element and 3028 nodes as demonstrated in Figure 2.In middle line of two AISI 1045 plates are joined, it is observed that the density of elements increases due to higher temperature gradient. The mesh is also built as structural form which capable to minimize error by low quality elements.

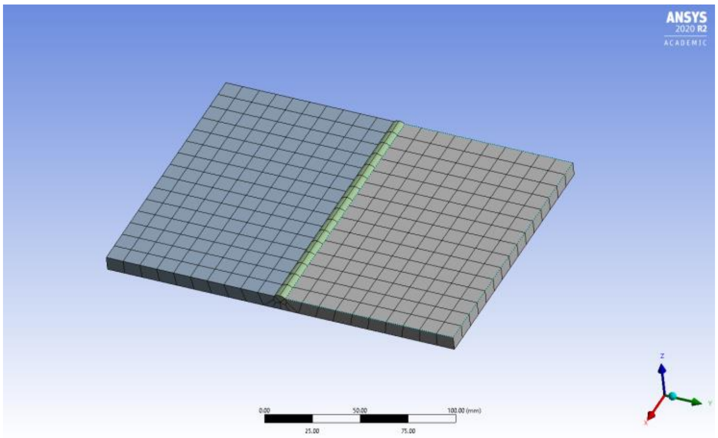

Figure 2. Model meshed by406 cubic element and 3028 nodes.

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2.3. Boundary Condition

Two boundary condition were examined in this simulation. It started by convective heat transfer from the surface to the surrounding air which obtained from ANSYS library. Additionally, the various welding speed was selected in 30, 40, and 50 cm/minute for running the simulation. The whole values related to shield metal arc welding energy were added using the extensive heat source motion.

3. RESULTS AND DISCUSSION

3.1. Thermal Distributions

After welding simulation was carried out, it will depict thermal distribution along with the used welding parameter. Thermal distribution during welding can be seen in Figure 3.

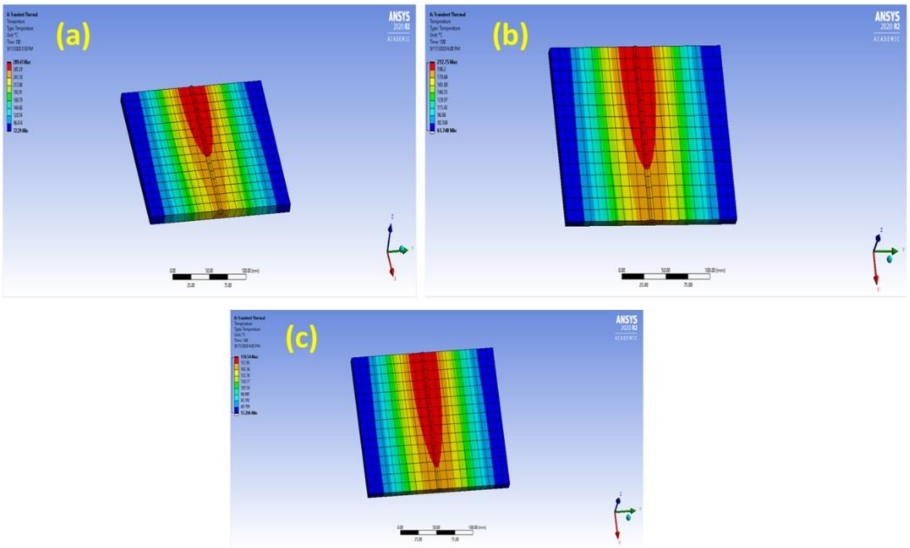

Figure3. Thermal distribution of welding speed of 30 cm/minute

The thermal distribution obtained from 100 seconds transient thermal analysis and welding time from each parameter of this research. The thermal distribution in welding speed of 30 cm/minute possess the highest temperature of 289,41 ^{o}C even in the smallest area. Conversely, the thermal distribution in welding speed of 50 cm/minute resulted in the highest temperature 170,54^{o}C, but in large distribution area. To compare thermal distributions in every welding parameter, it is demonstrated in Figure 4.

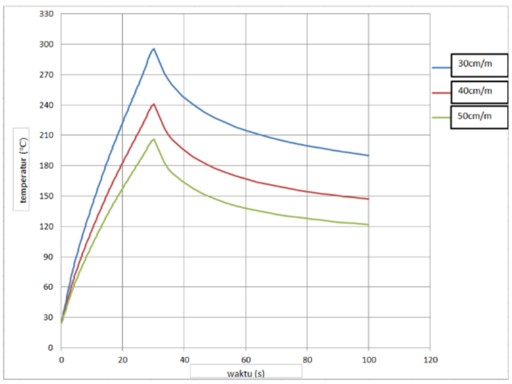

Figure4.Total Thermal Distribution

It can be seen in Figure 4 that the highest temperature occurred in welding speed of 30 cm/minute. It also stated that the smallest welding speed in the welding process of AISI 1045 plate will affect increment of temperature after welding[9]. Besides, the maximum temperature owns the smallest area compared than another parameter, even the resulted temperature is high.

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3.2. Structural Analysis

Structural analysis was examined in this research to determine residual stress and distortion after welding simulation. Welding simulation using welding speed parameter and limitation condition in this analysis was fixed support located in left-right plate which rectified with the welding direction.

3.2.1. Residual Stress

After welding simulation was evaluated, it will be obtained residual stress using static structural workbench. Total residual stress occurred during welding shown in Figure 5.

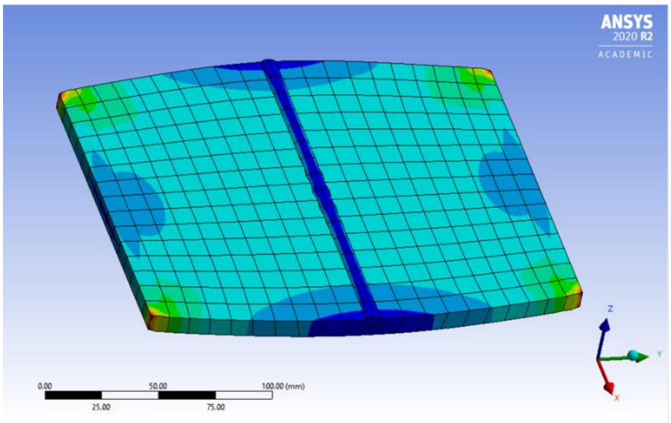

Figure5.Total residual stress

Total residual stress in three parameters have seemed uniform physical and the residual stress value still different with the highest residual stress in welding speed of 30 cm/minute. The result of each parameter can be seen in Table 1.

Table 1. Total residual stress of simulation result

No	Welding Speed (cm/minute)	Min (MPa)	Max (MPa)	Average (MPa)
1	30	0,000000045156	0,0000012351	0,00000036965
2	40	0.000000033912	0.00000093752	0.00000027744
3	50	0.000000027247	0.00000075531	0.00000022218

From table 1, it can be stated that welding speed parameter of 30 cm/minute possess the highest residual stress of 0,00000036965 MPa. Therefore, it can be assumed that lower welding speed will affect to improve total residual stress occurred during welding process. In AISI 1045 plate welding process owns two directional residual stress within longitudinal and transverse direction[10]. Longitudinal residual stress develops in the same direction of welding process which occurred in x-axis. Meanwhile, transverse residual stress can be seen perpendicular with the welding process in y-axis. Longitudinal residual stress in static structural is depicted in Figure 6.

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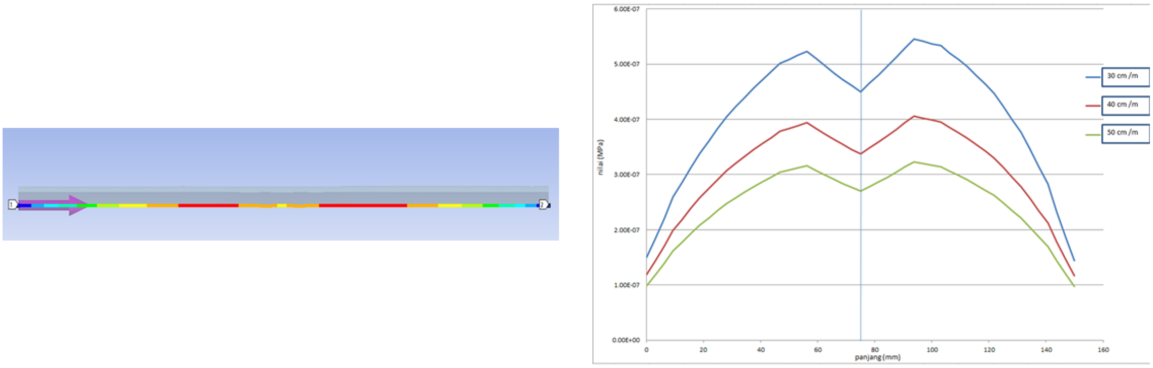

Figure 6. longitudinal residual stress distribution in various welding speed parameter

As in Figure 6, the longitudinal residual stress in welding speed of 30 cm/minute is bigger than another welding speed parameter of 40 cm/minute and 50 cm/minute with the highest residual stress value of 0,00000054536 MPa. Meanwhile,for the welding speed of 40 cm/minute and 50 cm/minute possess residual stress value of 0,00000040573 MPa dan 0,00000032319 MPa. Longitudinal residual stress in every welding speed parameter has taken in the distance of 93,75 millimeters.

Figure 7 depicts the transverse residual stress in every welding speed parameter. It can be seen that transverse residual stress distribution is lower than longitudinal residual stress in welding speed of 30 cm/minute with the value of 0,00000042679 MPa. In addition, for the welding speed of 40 cm/minute and 50 cm/minute own the value of transverse residual stress of 0,00000032004 MPa and 0,00000025606 MPa. Despitetransverse residual stress is smaller than longitudinal residual stress, the area of transverse residual stress is actually larger.

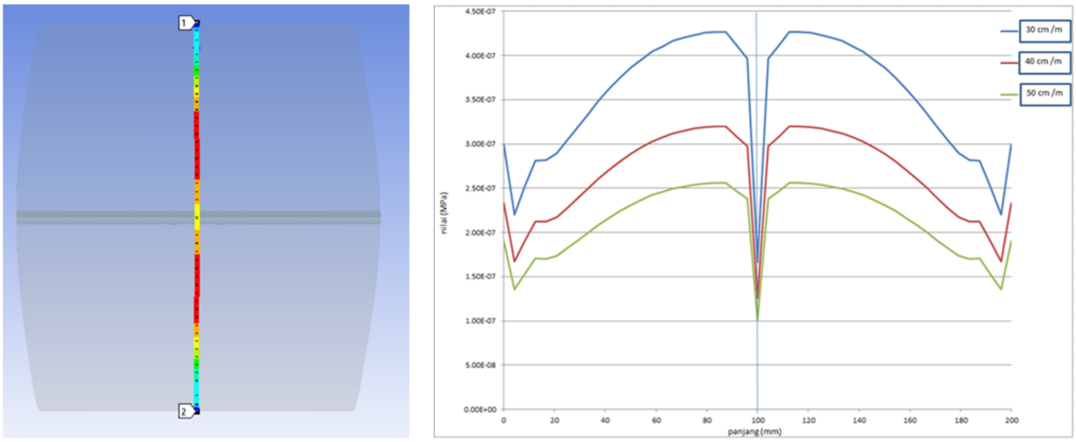

Figure 7. Transverse residual stress distribution in various welding speed parameter

The longitudinal residual stress has the greatest value in the center area of the welding, as well as the transverse residual stress. This fact is influenced by the pedestals which are placed on the right and left sides of the AISI 1045 plate, perpendicular to the welding process on the x-axis. Meanwhile, the transverse residual stress value is smaller than the longitudinal residual stress owing to the shrinkage after welding will be greater in the longitudinal direction which passed by a thermal load[11]. In the transverse direction of welding, there will be greater distortion due to the resistance of the base metal.

3.2.2. Distortion

After the static structural analysis was examined, it obtained that total distortion which is depicted in Figure 8.

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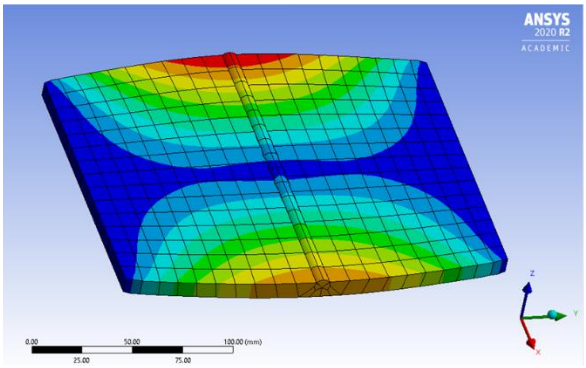

Figure 8. Total distortion

The total distortion occurred in three welding speed parameters which havethe same uniformity in transverse and longitudinal direction. The total distortion value of each welding speed parameter is shown in Table 2.

Table 2. Total deformation

No.	Welding Speed (cm /minute)	Min (mm)	Max (mm)	Average (mm)
1	30	0	0.25728	0.090894
2	40	0	0.18655	0.067248
3	50	0	0.14653	0.053419

The greatest distortion is portrayed in welding speed of 30 cm/minute with 0,090894 millimeters in longitudinal direction. It is clearly stated that lower welding speed in accordance with the improvement of distortion in welding process. The distortion result was obtained from 100 seconds of total simulation involved heating and cooling during welding process.

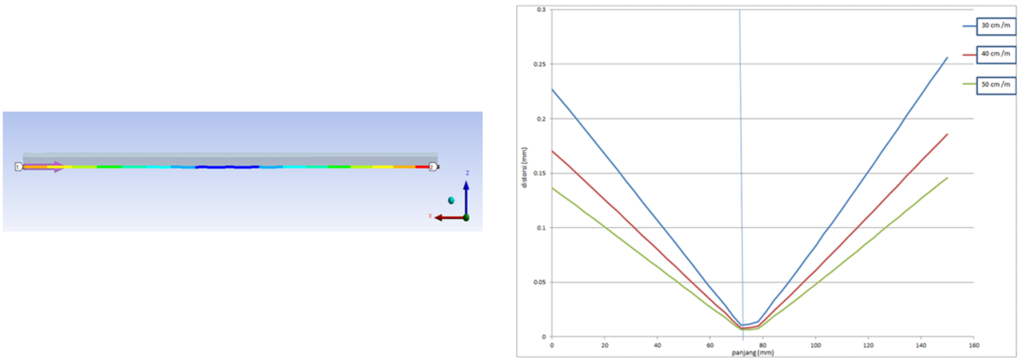

Figure 9. Longitudinal distortion in various welding speed parameter

Distortion in x-axis is longitudinal type which is depicted in Figure 9. The greatest distortion occurred in the starting and end point of welding, meanwhile the smallest distortion occurred in the center area. The comparison of distortion results in longitudinal direction of various welding speed parameterscan also be seen in Figure 9. Longitudinal distortion possesses the highest value in welding speed of 30 cm/minute by the distortion of 0,25609 millimeters shrinkage. However, the distortion value of welding speed 40 cm/minute and 50 cm/minute own 0,18567 millimeters and 0,14584 millimeters. The greatest distortion occurred in the end point of welding.Transverse distortion after welding can be seen in Figure 10.

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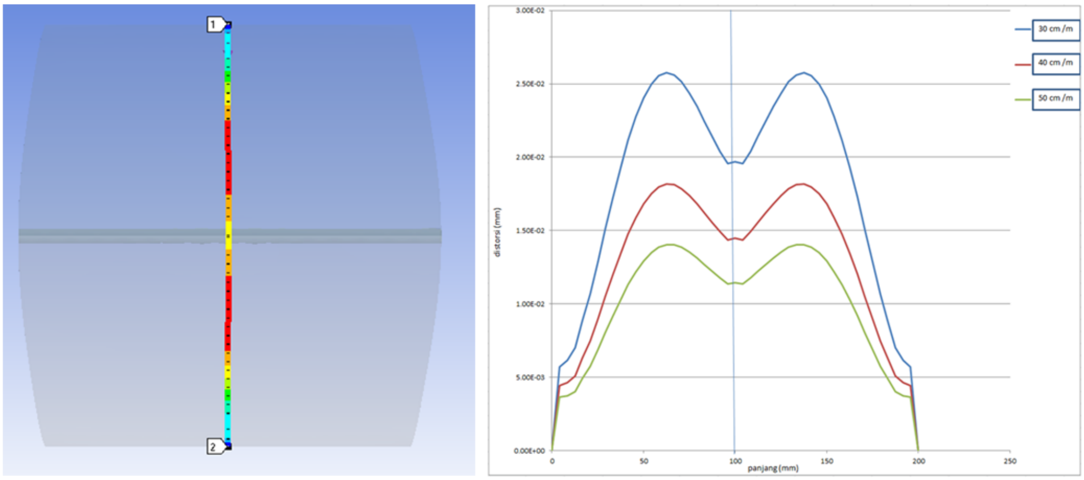

Figure 10. Transverse distortion in various welding speed parameter

In the welding simulation, transverse distortion is retained in the largest area due to the fixed support in left and right side of AISI 1045 plate which maintain the plate in its position and the distortion value is 0. The comparison of various welding speed parameters on transverse distortion is also demonstrated in Figure 10.The graph shows that lower welding speed will influence transverse distortion enhancement. This improvement happens due to transverse distortion of welding speed 30 cm/minute exhibits the highest distortion of 0,025765 millimeters. Moreover, the welding speed of 40 cm/minute and 50 cm/minute exhibit the highest distortion of 0,018168millimeter dan 0,014036 millimeter. The distortion occurred through transverse direction and increase gradually prior to the center area of welding.The greatest distortion occurred in transverse direction by virtue of metal to defend their characteristics and the fixed support part has no effect of heat-affected-zone (HAZ) then it will not occur deformation[12, 13].

4. CONCLUSION

The finite element method (FEM) modeling using ANSYS software of thermal behavior during shield metal arc welding (SMAW) of AISI 1045 plate was successfully simulated. Thermal distribution is observed at the highest of 289,41 ^{o}C in welding speed of 30 cm/minute though on small area. The residual stress and distortion have the strongest value in transverse direction. Therefore, the welding speed observed gives high impact in 50 cm/minute for this simulation to minimize residual stress and distortion during welding process.

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