25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

THERMAL ANALYSIS FOR A MULTIPLE WELDING PASSES WITH MATERIAL DEPOSITION

Douglas Silva Marques Serrati
Tarcila Rocha França
Douglas Bezerra de Araújo
Federal University of Uberlândia
douglasserrati@gmail.com
tarcilarochafranca@gmail.com
dbaraujo@ufu.br

Abstract. *The necessity to develop a welding holdfast to avoid warping of the plates during a multiple passes welding process caused that the computational analysis was approached in order to obtain the necessary parameters. The welding processes used as well as their parameters and samples sizes were defined by Welding Process Specifications (EPS). The finite element study was carried out through a transient analysis of the stainless steel AISI304, using its temperature-dependent properties. Birth and death functions were applied to represent the deposition of the addition metal through a Gaussian heat source.*

Keyword: *Welding, residual stresses, multiple passes, finite element*

1. INTRODUCTION

The structural integrity of the samples and welding holdfast will be affected by the residual stress levels in the vicinity of the welded region. Knowing that arc welding processes inputs a huge quantity of heat that will melt and bond the materials being welded. Because it is a localized source of heat, will occur uniform plastic deformations, dilations and contractions, which will cause deformations and residual stresses. These can play a significant role in accelerating or slowing down many failure processes, and if may unfeasible the use of the plates. Because of that, it is important to study what is the impact of the residual stresses and how the distortions occur. This work is based on computational simulation, using the finite element technique.

2. FINITE ELEMENT ANALYSIS

2.1 Model

To provide the data of how much strain does the welding process should cause, it was used the finite element technique, a computational tool used to solve complex engineering problems. The simulation was based on a stainless steel AISI304 plate with dimensions shown in Figure 1, with 250 mm of length, and a heat source of Gaussian type. For the welding process with deposition of material, there are two weld beads geometry, one is for the roots passes of Tungsten Inert Gas (TIG) process and the other is for Shielded Metal Arc Welding (SMAW) process.

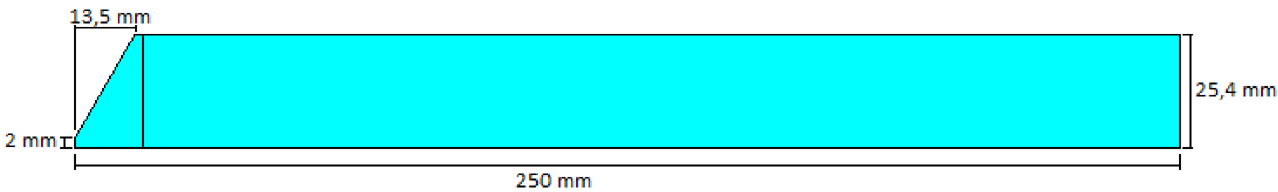

Figure 1. Plate dimensions

This is a case of unsymmetrical problem, because there are eleven welding passes, being those two firsts the root passes. Plates are positioned at a distance of 5 mm between each other. The model is shown in figure 2. The stresses generated by multiple passes welding process are thermo-structural analyzed. The thermal and mechanical properties are temperature-dependent used by Venkatkumar (2016). To also simulate the process with material deposition was used functions of elements birth and death. Dead elements don't have influence, only after being activated by element birth function.

For the case approached above, a transient analysis was used considering data given by EPS as in table 1, and an efficient in welding process of 0,6 for TIG and 0,7 for SMAW, used by Marques (2014). So, the heat of the welding arc was modeled by a distribution of a heat source with a Gaussian distribution. Therefore, the heat flux distribution on the surface of the solid is related to the radial position *r* (whose origin is the arc center), given by Eagar and Tsai (1983):

$$q_r = \frac{\eta U i}{2\pi\sigma^2} e^{-\left(\frac{r^2}{2\sigma^2}\right)} \tag{1}$$

Where q_r is the surface flux at radius r, η is the thermal efficiency arc welding coefficient, U is the voltage, I is the current and σ is the radial distance from the center. In this study, the value for a σ was equal to 1,2 mm.

Table 1. Welding parameters from EPS

Passes	Process	Inicial temperature	Current (A)	Voltage (V)	Velocity (cm/s)
Root	TIG	Minimum of 15°C	80 – 180	10 – 14	5 -15
Others	SMAW	Maximum of 150°C	80 – 180	20 – 28	10 - 30

To get the critical situation, it is considerate the condition that impose more energy to the plates during the process. Because, it is the critical condition that following equation 1:

$$E = \frac{V * I}{v} \tag{2}$$

Where, V is the voltage, I the electrical current and v is velocity. It means that, to get the highest welding energy during simulation, it is necessary to get the smallest velocity and biggest amperage and voltage.

For the thermal analysis, the SOLID70 element with 8 nodes per element with a single degree of freedom, which is the temperature, was used. And for the thermal analysis of the surface with the natural convection and radiation, those two plates, the element SURF152 was used. This element is coupled to the outer surfaces of the solid elements and an extra node. For the structural analysis, the element SOLID185, which has the same characteristics as SOLID70, was used, with degree of freedom of translation in the x, y and z directions. This element also has the capacity of plasticity and large deformations.

The structure was meshed with an unstructured mesh size of 2 mm in the region of the weld bead and chamfer, and a mesh with size of 3 mm in the distal region between 0.023 m, in x direction, to the end of the plate. And between the two regions was used an unstructured mesh of size of 4 mm, placed in (0.018<x<0.023 m). The complete model is represented in Figure 2.

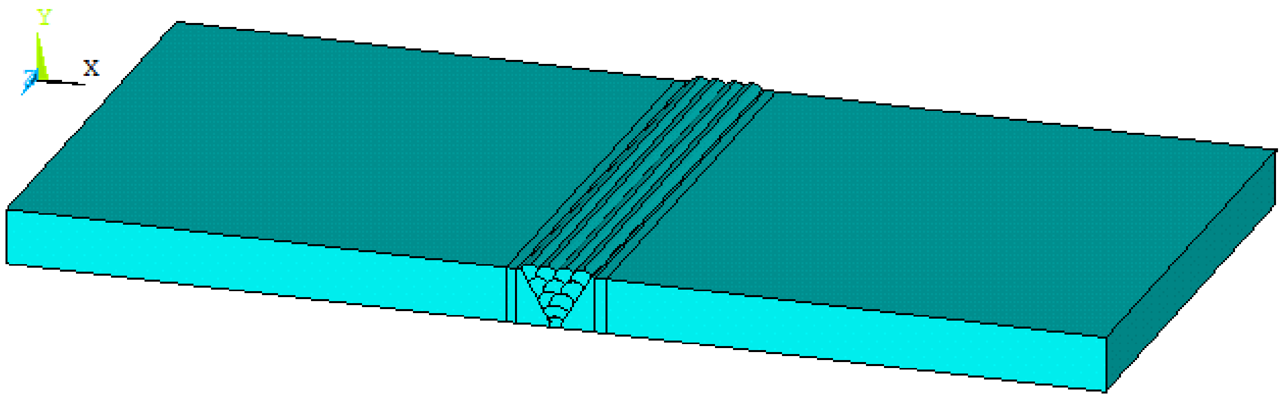

Figure 2. Plates and weld beads

2.2 Thermal analysis

To simulate the eleven passes of welding, the two firsts passes was TIG process and the others nine passes are made by SMAW process, both of them were use the slowest velocity and higher current and voltage showed in table 1. Between these welding passes were considered ten minutes of cooling.

For the thermal analysis is necessary to define two material properties: specific heat and thermal conductivity. As shown in table 2.

Table 2. Material properties for thermal analysis

Temperature (°C)	Conductivity (W/m°C)	Specific Heat (J/Kg°C)
0	14.6	462
100	15.1	496
200	16.1	512
300	17.9	525
400	18.0	540
600	20.8	577
800	23.9	604
1200	32.2	676
1300	33.7	692
1500	120	700

The thermal field is governed by the heat conduction equation given by:

$$\frac{\partial}{\partial x}\left(k(T)\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k(T)\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k(T)\frac{\partial T}{\partial z}\right)+Q_v=\rho(T)C_p(T)\frac{\partial T}{\partial t} \tag{3}$$

where, T is the temperature, $k(T)$ is the thermal conductivity, $\rho(T)$ is the specific mass, $C_p(T)$ is the specific heat and Qv is the rate at which energy is generated per unit volume of the medium (in this study, Q_V is null).

The thermodynamic boundary conditions on the external surfaces of the solid comprise heat transfer for convection and radiation.

The heat flow density for convection (q_c) is Newton's law. Newton's law of cooling states that the rate of heat loss of a body is directly proportional to the difference in the temperatures between the body and its surroundings temperature, and is given by:

$$q_c = h_c(T - T_0) \tag{4}$$

Where, T is the temperature of the external surface, T0 is the temperature of gas and h_c is the coefficient of convective heat transfer. The convection coefficient of the surface depends on many factors. It is calculated as a local coefficient, given by:

$$h_c = \frac{i * U * \eta}{L * c * (T_S - T_\infty)} \tag{5}$$

Where η means the efficiency of the welding process, L is the width of the plate, c is the length of the plate, T_s means the surface temperature of the plate that defaults to the melting temperature of the stainless steel that is 1500°C, because it is the local that will have the biggest flux of heat, and T_∞ is the room temperature that was considered 25°C.

The radiation heat transfer (q_r) is governed by Stefan-Boltzmann's law, given by:

$$q_r = \varepsilon_r \sigma_r (T^4 - T_0^4) \tag{6}$$

Where, ε_r is the emissivity of the material surface and σ_r is the Stefan–Boltzman constant (5.67×10^{-8} W·m^{-2}·K^{-4}). The value of the emissivity depends on the temperature in the welding process, however, in this study, this value was invariable, with a value of 0.80. To include radiation heat transfer, was necessary to create a node above the plates to simulate a surface, so the radiation heat transfer could happen.

3. RESULTS

The result obtained was the thermal analyzes with material deposition processes. The Figure 3 shows the temperature distribution over the entire plate during a moment of welding. The maximum temperature was limited to 1500 °C considering the melting temperature of the material. In figure 4 can be seen the beginning of the welding. The figure 5 shows the moment during weld of the third pass and figure 6 is about the end of the cooling time between the third and fourth welding pass.

The stainless steel have a low thermal conductivity, it causes the material to retains a lot of heat. It means that even the cooling time being thirty-five minutes, the material always starts the next welding pass in a greater temperature that started the welding pass before. The simulation was carry out through the extreme values for equation 2 from table 1, that make these fact more evident.

The "Birth and death" technique was used in thermal analysis. In the thermal analysis, a technique was used to activate the dead elements previously in front of the Gaussian heat source, because it is not possible to apply heat to the elements due to their almost zero thermal conductivity. This causes the temperature to rise to very extreme values by diverting the solution from the problem.

Granted the thermal results, next step is to build the structural model for simulation. So, it will be possible to know how much strain should the welding holdfast support, and then select the correct commercial one.

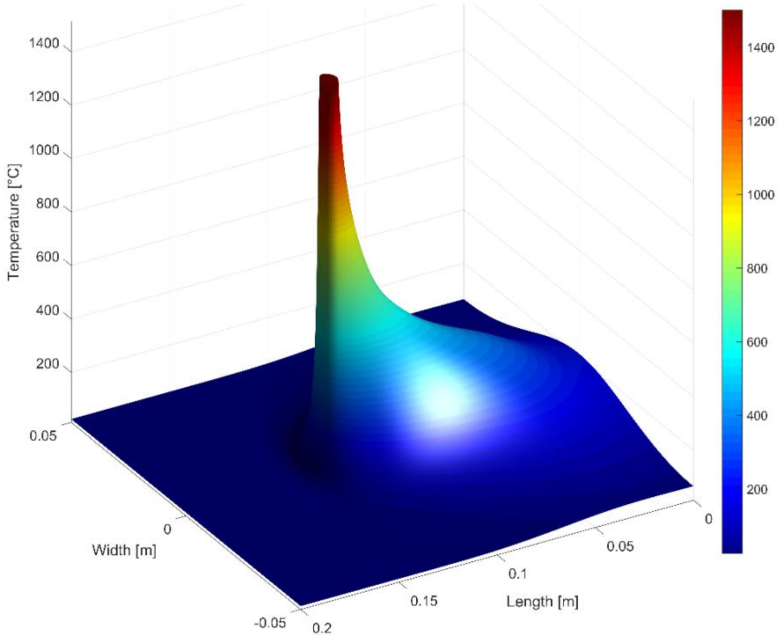

Figure 3. Isotherms during welding

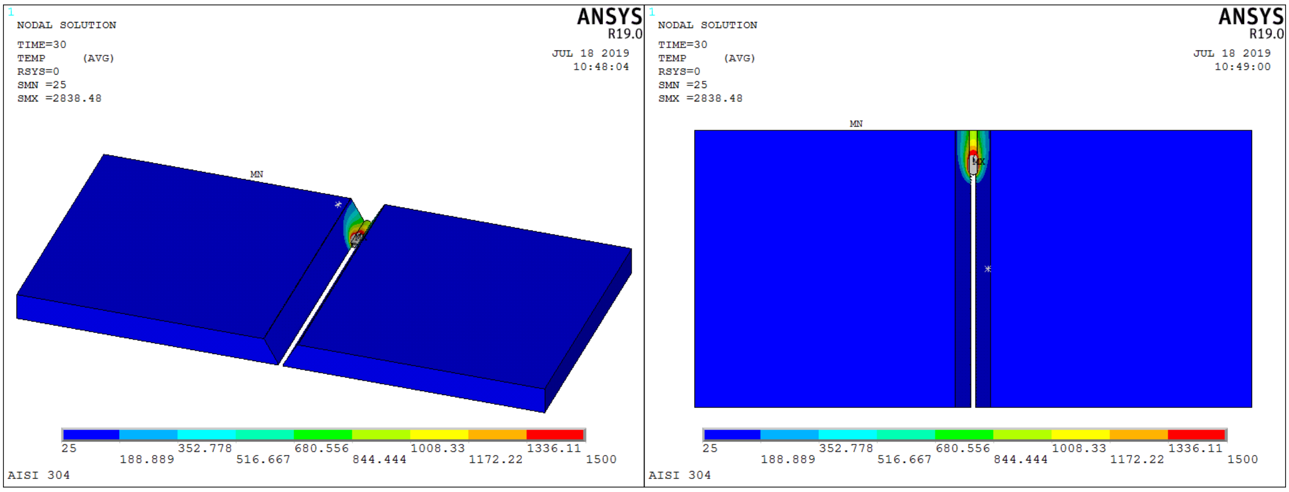

Figure 4. Beginning of welding

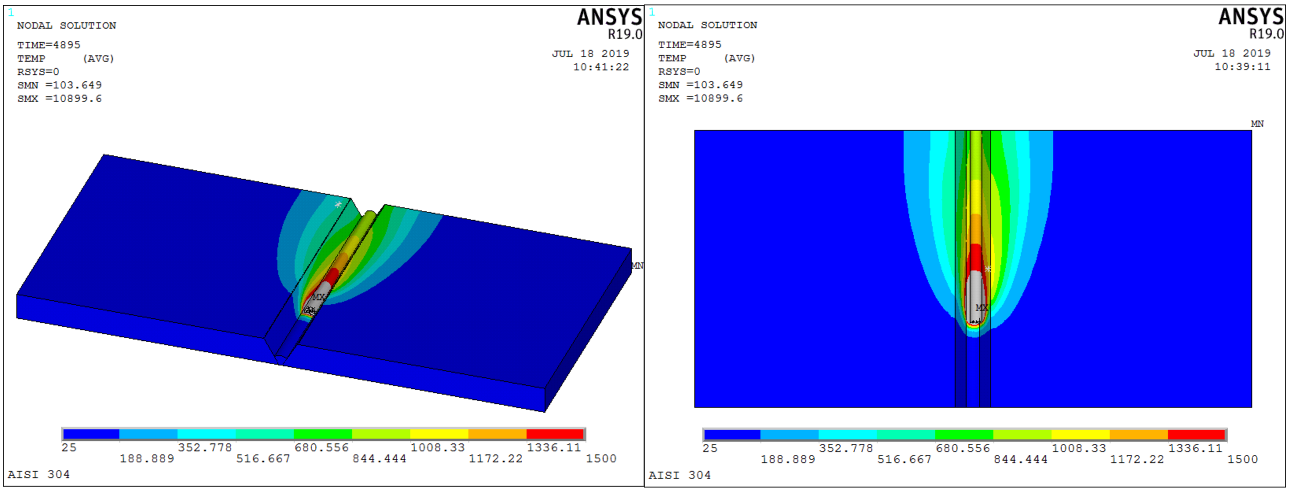

Figure 5. Third welding pass

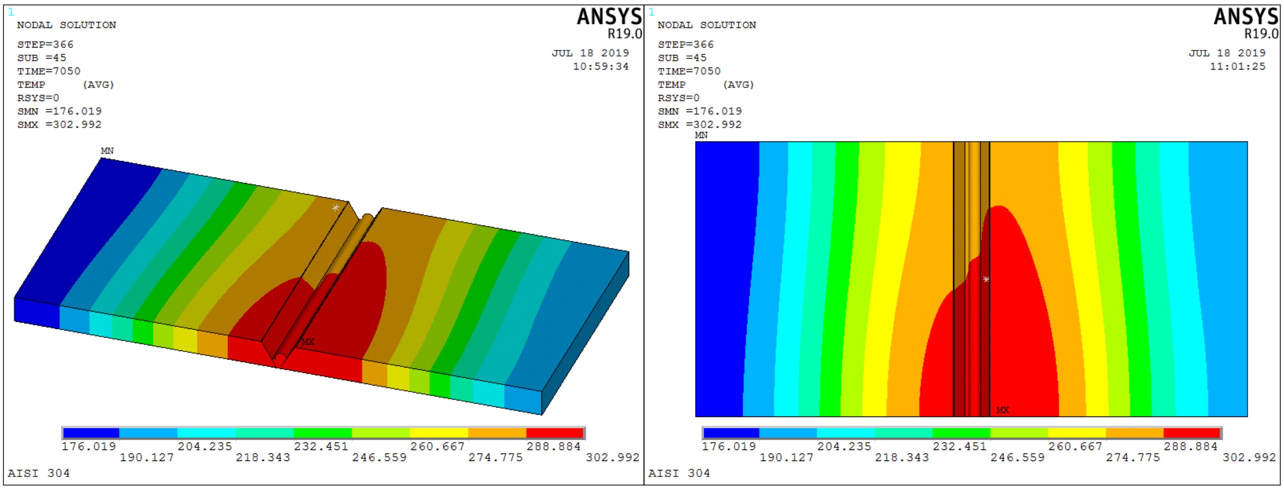

Figure 6. End of the cooling time after the third welding pass

4. REFERENCES

Eagar, T. W., and Tsai, N.S.,1983. "Temperature fields produced by traveling distributed heat sources." *Welding journal* 62.12, pp. 346-355.

Elmesalamy, A. S., et al., 2016. "Measurement and modelling of the residual stresses in autogenous and narrow gap laser welded AISI grade 316L stainless steel plates." *International Journal of Pressure Vessels and Piping* 147, pp. 64-78.

Marques, P. V. and Modenesi, P.J., 2014. "Algumas equações úteis em soldagem." *Soldagem e Inspeção,* Brasil 19.1, pp. 91-102.

Venkatkumar, D., and Ravindran, D., 2016. "3D finite element simulation of temperature distribution, residual stress and distortion on 304 stainless steel plates using GTA welding." *Journal of Mechanical Science and Technology* 30.1, pp. 67-76.

5. RESPONSIBILITY NOTICE

The author is the only responsible for the printed material included in this paper.