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EVALUATING THE CONVECTION EFFECT IN STUDY OF TEMPERATURE FIELDS

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Abstract. *Among the studies in the field of welding, the evaluation of stress and temperature field are the focus in area. In a welded joint, the temperature field helps in determining the zone heat affects which phase transformations occurring and is a basic tool in the study of stress field. Therefore, it will be report as convection affects the mathematical model of the temperature distribution. With this knowledge is possible analyze how the model approaches the experimental reality, and whether it is possible to disregard the surface heat loss in modeling a welding process. To this end, heat lines were performed, produced by a Bunsen beak using LPG as fuel, in a SAE 1020 sheet, two hundred millimeters in length, where was positioned five type K thermocouples located to 20, 60, 100, 140 and 180 millimeters, along the length for temperature monitoring by a digital data collector. The Bunsen beak moves below the sheet with a constant speed. The mathematical model proposed by Green, as solution for Fourier heat conduction equation, proves the importance of boundary conditions. The Green's model approach is very close to the experimental results.*

Keywords: *Convection, Modelling, Welding.*

1. INTRODUCTION

In welding research, stress and temperature field evaluation is the focus, because the temperature field helps to determine the heat-affected zone and phase transformations, being an important tool in stress field analyses.

The present research done by the Thermometry and Thermo-mechanical Simulations Laboratory on Federal University of Pernambuco aim determine if and why the convection effects in the temperature field on welded joints, and how use forced convection to improve welded joints characteristics.

2. CALCULATING THE TEMPERATURE FIELD

In arc welding processes, the arc heats the joint to temperatures in range of two thousand degrees Kelvin, concentrated at an area of a few square millimeters. The displacement of this small area forms the weld bead, melting the metal in this area (Modenesi, 2014).

In most of the welding process, is applied a heat source at a point and moved along the joint, so the heat flow is mainly dissipate by conduction through the metal. Except for small parts it is possible disregard the losses by convection and radiation.

The three-dimensional heat conduction equation, to determinate the sheet internal temperature can be obtained for each point (x, y, z) in a particular domain by Eq. (1), where "Q" is the heat rate per unit volume in the material. “K” the thermal conductivity, "T" the temperature, "ρ" the density, "C_P" the thermal capacity, and "t" the time. (Goldak, et al., 1978)

$$\frac{\delta K_x}{\delta x}\frac{\delta T}{\delta x}+\frac{\delta K_y}{\delta y}\frac{\delta T}{\delta y}+\frac{\delta K_z}{\delta z}\frac{\delta T}{\delta z}+Q=\rho C_P\frac{\delta T}{\delta t} \tag{1}$$

The losses in the sheet surface represent the boundary conditions of Eq. (1). The conduction Eq. (2), in direction "Z" parallel to the sheet thickness "ϵ", where "ΔT" is the variation between the upper and lower face temperature. The convection Eq. (3), consider the convection coefficient "h_{conv}" by multiplying the difference between the surface temperature "T_S" and the initial temperature "T_0". The radiation, Eq. (4), where "σ" is the constant of Stefan Boltzmann (5.6704 x 10-8 W / m^2K^4) and "ε" emissivity material (0.21 to SAE 1020).

$$Q_{cond}=K\Delta T/\epsilon \tag{2}$$

$$Q_{conv}=h_{conv}(T_S-T_0) \tag{3}$$

$$Q_{rad}=\sigma\varepsilon\left({T_S}^4-{T_0}^4\right) \tag{4}$$

To solve the Eq. (1), must be made some considerations as the temperature distribution occurs in a quasi-stationary state, independent of time; the heat source is considered a point or a line transversal to surface; the piece has infinite dimensions and in some cases only a finite thickness is considered. Therefore, it is not necessary to specify the boundary conditions at the edges.

Considering the metal properties constants, the temperature distribution assumes a specific format for each configuration, and the Rosenthal solution has presented in three groups: thick, thin and intermediate shapes.

By using the Eq. (5). Where "ε" is the plate thickness, the plate is thin if the relative thickness (τ) is less than 0.6, thick if greater than 0.9 and intermediate for values included within the range. "T_C" represent the material critical temperature and "H_L" the liquid energy of welding (Guimarães, 2010).

$$\tau=\epsilon\sqrt{\frac{\rho C_P(T_C-T_0)}{H_L}} \tag{5}$$

For the sample on analysis, the relative thickness is 0.15 classifying the sheet as thin. The temperature distribution obey the Eq. (6), where "$\dot{q}$" is the input heat rate, "V_S" the welding speed, "w = x - vt" is the static coordinate, "α" the thermal diffusivity of material, "r" the polar coordinate, and "K_0" the modify Bessel function of second type and zero order.

$$T(r)=T_0+\frac{\dot{q}}{2\pi k\epsilon}\exp\left[\frac{-V_s w}{2\alpha}\right]K_0\left[\frac{V_s r}{2\alpha}\right] \tag{6}$$

2.1 The Green Approach

The Green approach for heat conduction is an alternate solution to Fourier heat conduction. However the solution presented by Rosenthal, considers the heat source to be moving along the sheet. The Green solution considers a transient heat conduction and the temperature distribution generate by a local and instantaneous heat pulse (Flint, Francis and Yates, 2013).

For the point (x, y, z) at time "t" when a heat pulse is applied at point (x ', y', z ') in time "t '= 0 " the Green approach can be defined using the Eq. (7) (Atabaki, 2014).

$$G(x,y,z,t)=\frac{1}{\sqrt[3]{4\pi\alpha t}}\times\exp\left(-\frac{\left(\sqrt{(x-x')^2+(y-y')^2+(z-z')^2}\right)^2}{4\alpha t}\right) \tag{7}$$

(Modenesi, Marques and Santos, 2014) Affirms that can be neglected the losses by convection and radiation without damaging the results of the temperature field. However, the experiments show that this is not fully true.

The use of boundary conditions proposed by (Goldak, et al., 1978), in Green approach, changes the peak temperature far away from experimental value, and this is not desirable. Facing this problem (Pathak, 2012) proposed a correction factor Eq. (8) to be applied on Green approach.

$$F_C = \frac{Q_A}{\sqrt{4\pi\alpha t}} \times \exp\left(\frac{(x-x')^2}{4\alpha t}\right) \tag{8}$$

This correction factor consider the radiation and convection losses on surface by the "Q_A", defined by Eq. (9).

$$Q_A = h_e A(T_S - T_\infty) \tag{9}$$

The Eq. (10) defines the effective convection coefficient. In addition, the Eq. (11) defines the radiation coefficient. The correction factor, does not consider the loss by conduction along the sheet, so using a thin plate with two-dimensional heat distribution, the solution becomes acceptable.

$$h_e = h_{conv} + h_{rad} \tag{10}$$

$$h_{rad} = \varepsilon\sigma({T_S}^2 - {T_0}^2)(T_S - T_0) \tag{21}$$

3. EXPERIMENTAL PROCEDURE

To analyze the convection effect on the temperature field in a thin SAE 1020 sheet (τ = 0.15), a sheet with dimensions of 570 x 200 x 3.4 mm, was used; schematically show on Fig. 1, and it's properties are listed in Tab. 1.

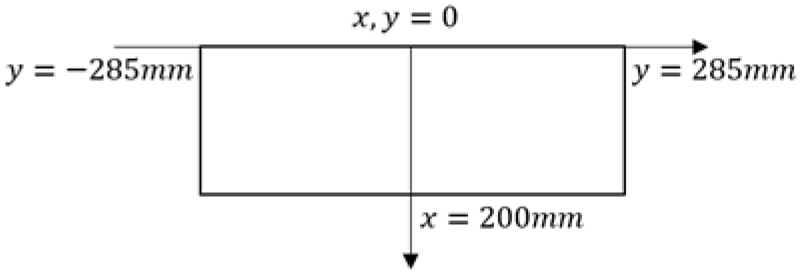

Figure 1. Coordinate system on the sheet.

Table 1. Properties of SAE 1020 (ASM, 1990)

Density	7870 Kg m^{-3}
Thermal Conductivity (373 K)	51.9 W / m K
Specific Heat (373 K)	486 J / Kg K
Thermal Diffusivity	0.0000014 m^2 / s

Using a LPG burner (data presented on the Tab. 2), were performed heat lines, moving along the sheet centerline with two hundred millimeters in length at speed of 0.5 mm/s. within this line, five type K thermocouples were placed, twenty millimeters of the borders, and forty millimeters apart. Fig. 2.

Table 2. Data of used Gas (Branco, 2014)

Type	LPG (Liquefied Petroleum Gas)
Density	2,2Kg/m^3
Volumetric Flow Rate	0,00001m^3/s
Mass Flow Rate	0,000022Kg/s
Lower Heating Value	48 148 200 J/Kg
Thermal Capacity	2 500 J/Kg K
Temperature	300 K

Figure 2. Thermocouples position along the center of the sheet.

For temperature monitoring, a digital data collector was use. With a constant speed was moved the Bunsen burner under the sheet, Fig. 3.

Figure 3. Experimental array for temperature measurement.

The Bunsen burner has an efficiency of 25%, and liquid energy of 265 W. Considering the superficial losses, the convection is responsible for 3.5 W using the Eq. (3), and the radiation for 1 W of energy loss, Eq. (4). Because the sheet is thin, there is no loss by conduction along the thickness; however, the "ΔT" in Eq. (2) is zero.

4. RESULTS

The first significant research result is that the Rosenthal solution does not describe, coherently, the thermal cycle, show on Fig. 4. Where the curve shows not response for temperature lower to 500 K.

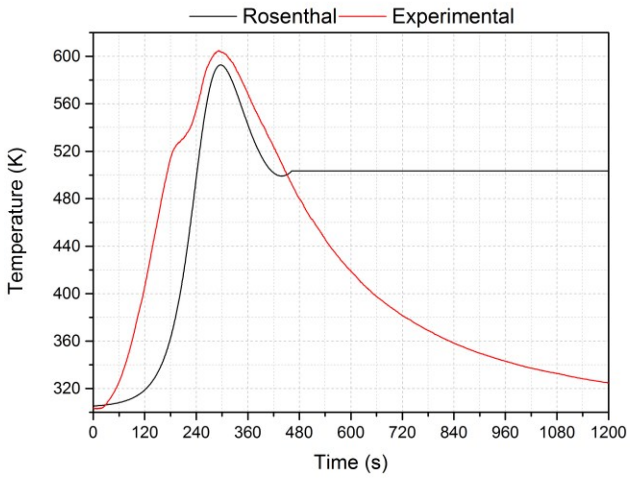

Figure 4. Comparative between the experimental results and Rosenthal approach. Point x = 100.

In the other hand the Green approach, showed the best result, as shown on Fig. 5.

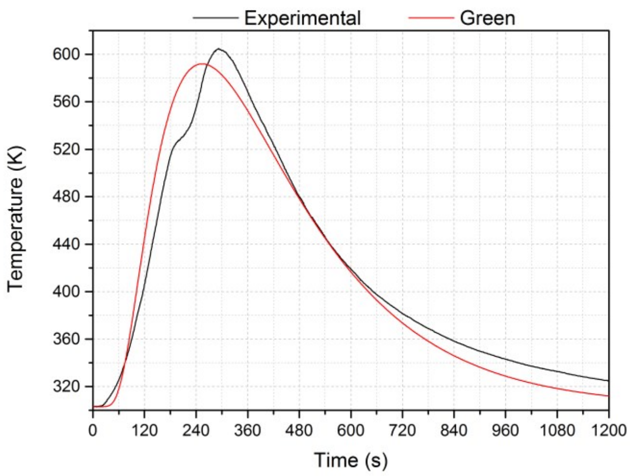

Figure 5. Comparative between the experimental results and Green approach. Point x = 100.

Table 3 shown the peak temperatures results for Rosenthal approach in the.

Table 3. Peak temperature for Rosenthal Approach

Position	Experimental (K)	With Loss (K)	Without loss (K)
X = 020 mm	562,15	587,75	592,75
X = 060 mm	598,45	587,75	592,75
X = 100 mm	604,95	587,75	592,75
X = 140 mm	608,85	587,75	592,75
X = 180 mm	631,65	587,75	592,75
Average	601,25	587,75	592,75

Table 4 shown the peak temperatures results for Green approach.

Table 4. Peak temperature for Green Approach

Position	Experimental (K)	With Correction (K)	Without Correction (K)
X = 020 mm	562,15	542,65	508,25
X = 060 mm	598,45	573,25	521,65
X = 100 mm	604,95	591,95	527,55
X = 140 mm	608,85	605,85	530,85
X = 180 mm	631,65	617,25	532,95
Average	601,25	586,15	524,25

5. CONCLUSIONS

The convection and radiation has influence in temperature fields for both methodologies. However, the Rosenthal approach give a medium value of the peak temperatures along the heat line, and show no sensibility to surface loss effect.

On the other hand, the Green approach give more realistic peak temperatures, with a discrepancy of 20 K.

The no use of correction factor gives a peak temperature out of range.

So, if the surface losses are unknown, must be used the Rosenthal approach to obtain the medium temperature. However, if are known the surface losses, it is recommend to applicate the Green approach to obtain the peak temperature point to point with a good precision.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE