EVALUATION OF NUGGET FORMATION IN RESISTANCE SPOT WELDING PROCESS OF GALVANIZED SHEET

Joseph Richard Pinheiro de Carvalho, eng_mec_joseph@yahoo.com.br
Joanes Silva Dias, joanesbr@yahoo.com.br
Hector Reynaldo Meneses Costa, hectorey@gmail.com
CEFET/RJ - Department of Mechanical Engineering - Av. Maracanã, 229, 20271-110 - Rio de Janeiro - RJ - Brazil

Flavio Moore, **flaviomoore@petrobras.com.br**
UFF - Department of Mechanical Engineering – Volta Redonda and PETROBRAS

Abstract. *Resistance spot welding is a main joining of sheet metal process in most industries, including: the automotive, aerospace and implementing. The biggest challenge is to control the time and quality of the nugget, which is the molten region. This work has as purpose to evaluate the nugget behavior and the distribution of temperature in a joint welded for Resistance spot welding. The methodology used for the evaluation had as characteristic the study through microscopy optics and numerical simulation for Finite Elements. For distribution of temperature of the welding in two distinct sets of metal sheets was adopted the increase method with Ansys Parametric Design Language (APDL) using commercial finite element code ANSYS. Galvanized sheet, with 0.6 and 1.2mm thicknesses, with 8 µm of coating, were used. The specimens were cut in the size of 38x125 mm according to the French standard NF A-87-001. An assessment was made by optical microscopy to validate this model to verify the geometry and dimensions of the nugget. The results obtained in predicting of size nugget were similar when comparing the assessment of numerical simulation and the measurements obtained by optical microscopy. The differences are due to the simplified model, where was not considered the indentation. The proposed methodology seems to be of great importance because in addition to predicting the behavior of the nugget, it was possible to obtain the thermal cycle and distribution of temperature.*

Keywords*: Spot Welding, galvanized steel, Numerical Simulation, Finite Element Method.*

1. INTRODUCTION

Resistance spot welding (RSW) is considered as the dominant process for joining sheet metals in automotive industry. Typically, there are about 2000–5000 spot welds in a modern vehicle. Simplicity, low cost, high speed (low process time) and automation possibility are among the advantages of this process, Zun *at al.* (2007), Hamedi and Pashazadeh (2008). Quality and mechanical behavior of spot welds significantly affect the durability and crashworthiness of the vehicle. Resistance spot welding is a process of joining two or more metal parts by fusion at discrete spots at the interface of work pieces. Resistance to current flow through the metal workpieces and their interface generates heat; therefore, temperature rises at the interface of the workpieces, Zhang et al (2008). When the melting point of the metal is reached, the metal will begin to fuse and a nugget begins to form. The current is then switched off and the nugget is cooled down to solidify under pressure.

All of the equations in this study are based on the column (cylindrical-polar coordinate) coordinate system, Khanna and Long et al. (2008). The governing Eq. (1) for calculation of the electrical potential φ in the whole model is :

$$\frac{\partial}{\partial r}(\sigma\frac{\partial\varphi}{\partial r})+\frac{\sigma}{r}\frac{\partial\varphi}{\partial r}+\frac{\partial}{\partial z}(\sigma\frac{\partial\varphi}{\partial z})=0 \qquad (1)$$

where r is the radial distance in this column coordinate system, z is the distance in the axis direction of the coordinate system, and σ is the electrical conductivity. By solving Eq. (1), the electrical potential φ is obtained. According to the electric current heat generation (q) rule:

$$q = I^2Rt \qquad (2)$$

where I is the current, R is the material electrical resistance, and t is the time for which current is passed. Since I = φ/R, Eq. (2) can be rewritten as:

$$q = \varphi^2 t/R \tag{3}$$

The governing equation for transient temperature field distribution, which involves electrical resistance heat, can be written as:

$$\rho c\frac{\partial T}{\partial t} = \frac{\partial}{\partial r}(\frac{\partial T}{\partial r}) + \frac{k}{r}\frac{\partial T}{\partial r} + \frac{\partial}{\partial z}(k\frac{\partial T}{\partial z}) + q \tag{4}$$

where ρ is the material's density, c is the heat capacity, T is the temperature, t is the time, *and* k is the thermal conductivity, respectively. The material properties c, k and σ are temperature dependent (which is further explained in a later section). Substituting Eq. (3) in (4), then the equation which describe the temperature distribution with heat source of current induced Joule heat is obtained.

According to the literature, Ranjbar *et al. (2008) and* Yong *et al.* (2009), there are several models and approaches for modeling welding processes. Although there are various published works on the modeling of spot resistance welding process, more studies are still useful to reach to a better understanding of thermo-mechanical behavior of materials during and after the process.

In this paper a bi-dimensional model of finite element method was developed to simulate RSW process, using commercial code ANSYS, ANSYS (2006). Temperature distributions at different weld stages were obtained. Through temperature distributions weld nugget formation and its size were predicted using numerical simulation e optical microscopy. A parametric model is used to study welded steel sheets that can be applied to more complex geometries

2. EXPERIMENTAL PROCEDURE

Galvanized sheet , with thicknesses of 1.2 and 0.6 mm and 8µm of coating, were used as the base metal in this research.. These sheets were named "A" and "B", respectively. The chemical composition of galvanized low carbon steel is given in Tab. 1. This type of galvanized sheet is used by many industries, including automotive.

Table 1. Chemical Composition of galvanized sheet.

Chemical Composition (%wt)						
Sheet	**C**	**Mn**	**Si**	**P**	**S**	**Al**
A	0,0026	0,23	0,063	0,009	0,012	0,039
B	0,04	0,31	0,008	0,014	0,009	0,045

Two different cases consisting of two sheets mentioned above were mounted. The nomenclatures related to sheets were used. The sets were fitted with the following classification: AA and AB. So this way, case AA is formed by two sheets of 1.2 mm thickness, and case AB is formed by a sheet of each thickness.

The specimen tested had the dimension of 38x125 mm, according to the French standard NF A-87-001 (1994). Figure 1 shows dimensions of the spot weld specimens**.** Spot welding was performed using a PLC controlled, 120 kVA AC pedestal type resistance spot welding machine. Welding was conducted using a Class 2 electrode with 6-mm face diameter, NF A87-001 (1994) and Miller (2005).

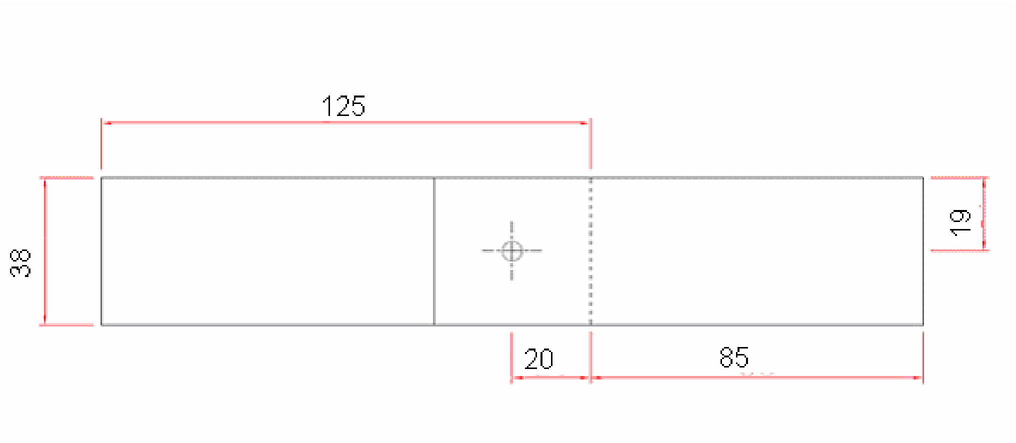

Figure 1. Schematic of the resistance spot welding specimen (unit mm).

For metallographic observation, samples were cut along the center of the spot weld nugget in the direction of the width of the sample. Subsequently, standard metallographic procedure was applied for microstructural as well as macro structural investigations. Optical microscopy was used to examine the microstructures and to measure the area of nugget.

3. MODEL DESCRIPTION

The RSW process involves a complex coupling among thermal, electrical, physical and chemical processes. The whole welding process includes four stages: squeezing, welding, holding and cooling. In the present study a commercial finite element code ANSYS (2006) and the APDL (ANSYS Parametric Design Language) were used to model Transient Thermal Analysis in the welding and cooling stages, employing element PLANE 55 for spatial discretization.

3.1. Geometrical Model and Boundary Conditions

Finite element method analysis is applied for the temperatures prediction in case of the spot fusion welding. Temperature variation over thickness is neglected and heat flow is considered two-dimensional in case of the thin sheets. Convection influence and thermo-physical properties, depending on the temperature, are considered in the mathematical model developed by authors.

The element used for space discretization was PLANE55 (Fig. 2), which has the ability to analyze the thermal conduction, heat generation, heat flux and radiation, ANSYS (2006). The element has four nodes with 1 degree of freedom, temperature, and is applied in two-dimensional problems in stead state or transient thermal analysis. A bi-dimensional model is chosen in order to minimize the computational cost.

3.2. Boundary conditions

The temperature at the water cooling cavity was restrained to 298.15 Kelvin, and the convection heat transfer to ambient air was specified on all the lateral surfaces of the electrode and workpieces that are not in contact, Fig. 3. The coefficient of thermal transfer was of 5 W/ m². K. Moreover, in fixed welding current of 11.5 kA, welding time was 12 cycles, PSA GE34.007G (2000). Table 2 shows the parameters used.

The Young's modulus 'E' was set to 200 GPa and Poisson's ratio was set to 0.3, a commonly used value for steels, Kong *et al.* (2008). Due to small thickness of galvanized coating and amount of contact resistance between electrode/work-piece comparing with that of work-piece/work-piece contact resistance, these factors were ignored and the contact resistance between the work-pieces supposed to be as 0.26μΩ, Nodeh *et al.* (2008).

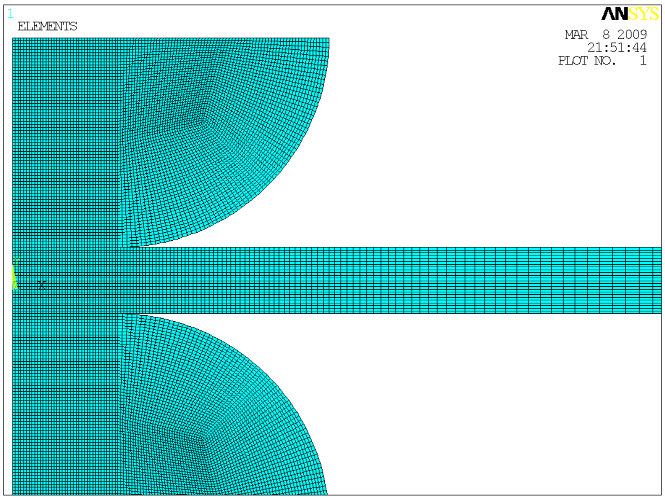

Figure 2. Mesh generation of model of condition AA.

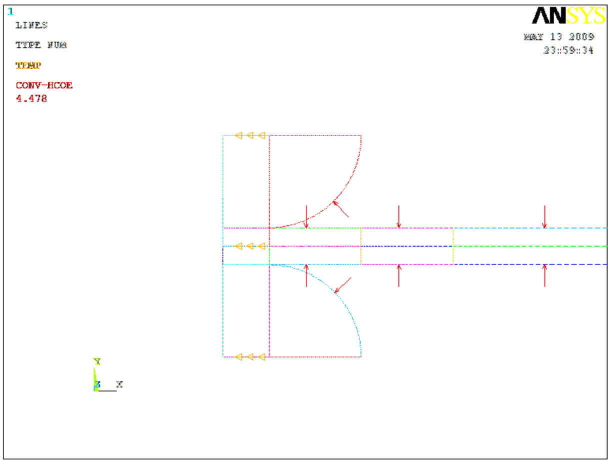

Figure 3.Geometry and Boundary conditions of case AA.

Table 2. Model Parameters.

Model parameters	
200 GPa	Young’s modulus
5 W/m^2 K	Convection heat transfer coefficient
0.3	Poisson´s ratio
0.26μΩ	Contact resistance
53 W/m.K	Thermal conductivity
569 kJ/kg	Enthalpy
486J/Kg.K	Specific heat

4. RESULTS AND DISCUSSION

At first results for case AA are presented. Figure 4 shows temperature evolution along the spot welding. A peak temperature of approximately 1800°C is observed on centre of nugget at time instant t = 0.2 s. Figure 4 shows the temperature distribution for the time instant where the peak temperature occurs and Fig 5 shows the positions of electrodes, sheets and details of nugget. Figure 6 shows comparative result between numerical and experimental of case AA.

In order to validate the numerical model, for the two cases, galvanized sheet of different thicknesses were chosen for experimental verification.

The spot welding specimen was cut along the centre cross-section, polished and etched to verify the spot nugget shape. Figure 6a shows the experimentally obtained spot nugget shape for case AA. The contour of the nugget was shown by a black line, which represented a change over from larger grain size (typical weld microstructure) to a finer grain size [typical heat affected zone (HAZ) microstructure]. Considering 1500°C as the melting point of steel, Zhang *et al.* (2008), the galvanized spot nugget shape appeared as colorful area in Fig. 6a.

In Fig. 7 is presented temperature evolution along the spot welding for case AB and Fig. 8 shows comparative results between numerical and experimental . A peak temperature of approximately 1733°C is observed on centre of nugget at time instant t = 0.2 s and there were no significant changes for temperature evolution.

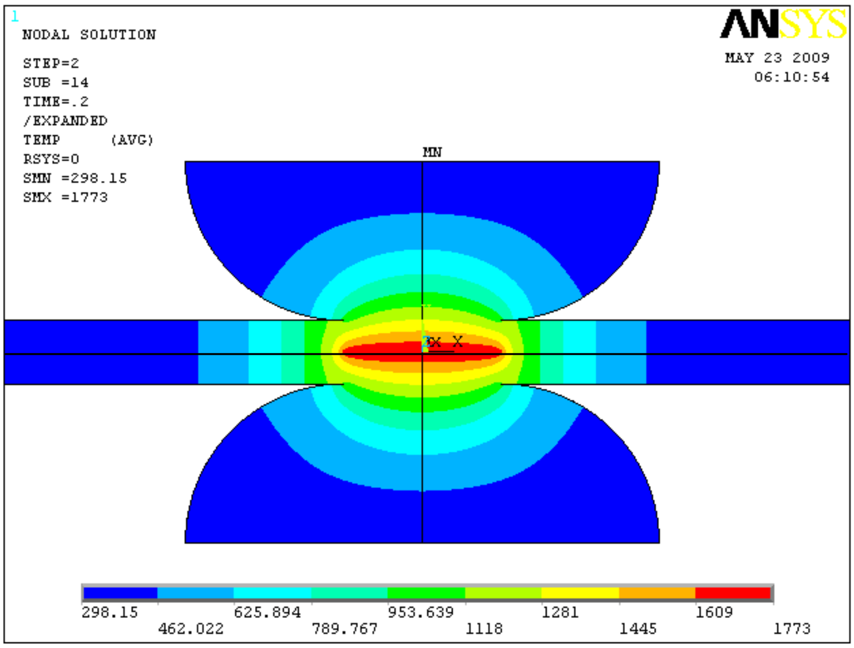

Figure 4. Temperature distribution at the peak temperature for t = 0.2 s . Case AA.

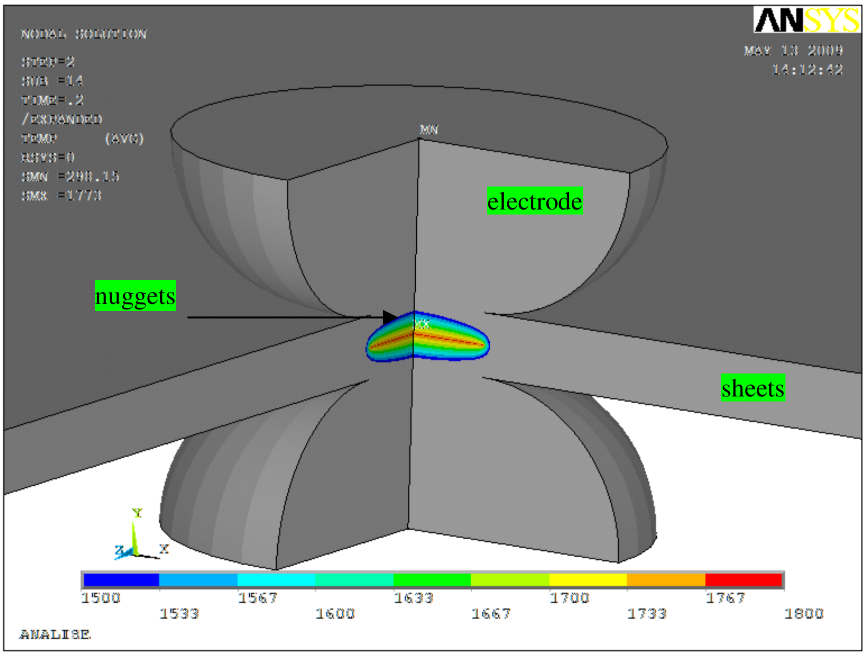

Figure 5. Figure shows the nugget in case AA.

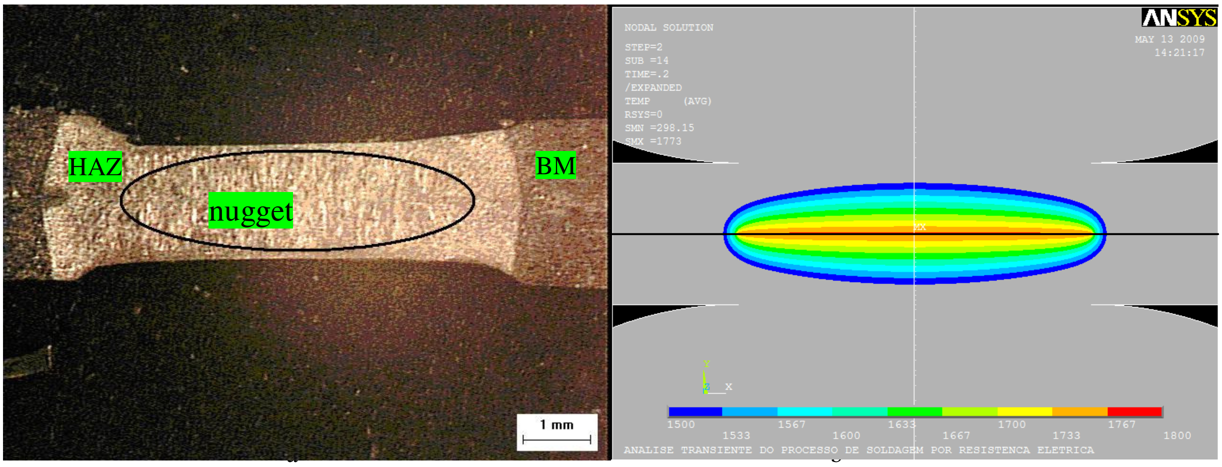

Figure 6. Figure shows comparative result between experimental (a) and numerical (b) of case AA. Fusion zone or weld nugget (FZ). Heat Affected Zone (HAZ). Base Metal (BM).

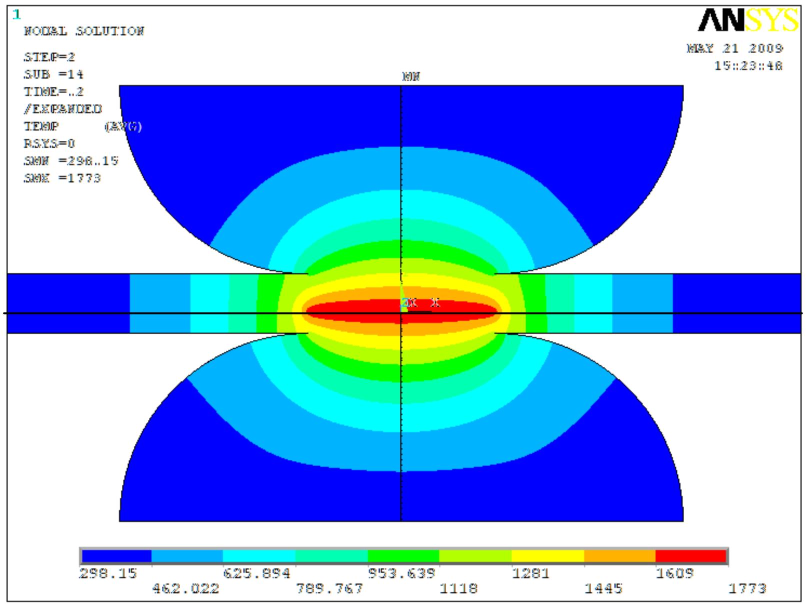

Figure 7. Temperature distribution at the peak temperature for *t* = 0.2 s . Case AB.

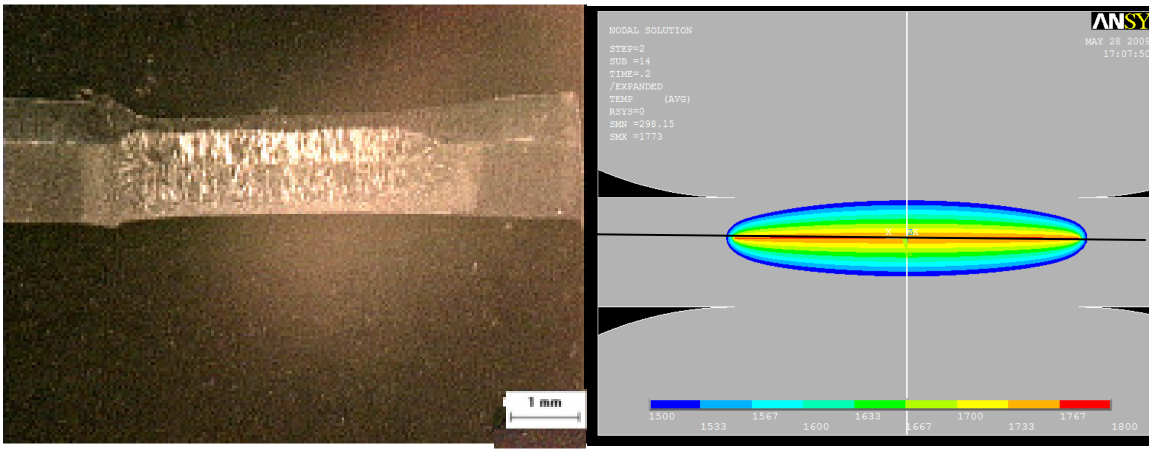

Figure 8 shows comparative result between experimental (a) and numerical (b) of case AB.

The case AA, with thickness of 1,2 mm, had a nugget more uniform and better quality than the other condition studied.

The simulation of spot welding galvanized sheet under the same welding conditions was also carried out. The results of experiments (average of 5 measurements) and numerical simulation were listed in Tab. 3. From the table it can be found that the predicted nugget size and experimental results agreed very well. The deviations between them were, between 5% and 20%, which verified the effectiveness of the numerical model. This model can be applied to different geometries and welding conditions.

Table 3. Nugget size comparison between experimental results and simulative results.

Nuggets dimensions				
	Optical Microscopy		Simulation	
Sets	height (mm)	Width (mm)	height (mm)	Width (mm)
AA	1,58	5,96	1,28	6,23
AB	1,05	7,98	1,26	6,42

There were two main causes for these deviations. One is that the shunting mechanism of depressed zinc coat around the electrode was not considered in the present study.

The other reason is that the measured value of simulated nugget size was the result at peak temperature. When the temperature cools down, shrinkage will happen with the nugget zone, Zhang *et al.* (2008).

It is important to note that the proposed model presents some approximations that can influence the response. When analyzing the results, the following must be taken into account.

-Adjustment of sheets and electrodes properties.

- Simplicity of the model where indentation was not considered due the approximate geometry.
- It is necessary to study the thermo-electric coupling and the geometry settings.

According to Nodeh *et al.* (2008), generally, in welding processes in final stage, nugget and its neighboring zones tend to expand and contract and these phenomena induce an undesirable effect on remaining parts of the work-piece, that affect the prediction of dimension of nugget.

The study of temperature distribution is very important for perfomance of welded joint. When is temperature changes, it directly affects the stress and strain status in the welding area as a result of material's mechanical properties (such as yield strength) change, Kong *et al.*(2008), Zhang *et al.*(2008) and Gould *et al.(*2006). If plastic strain occurs during the process, residual stress will be developed after welding. Temperature change can also affect the stress and strain status through metallurgical evolution.

Kanna and Long (2006) shown that most of the earlier numerical simulations of the spot welding process have focused on electrical and thermal models, which include determining the temperature distribution, spot nugget formation, electrode design and welding parameters optimization, with relatively less focus on residual stress that can have a major effect on fatigue performance of the welded joint, Sun *at. al* (2007).

The results obtained with the proposed model show that the behavior is very complex as it involves several coupled phenomena. Moreover, the proposed methodology can be used as a powerful tool to study the influence of welding parameters, like the time or current in the development of residual stresses in welded mechanical components. The finite element approach permits the direct application of the model to more complex geometries.

One of the major difficulties in this type of simulation is the lack of information about the values of material properties as functions of temperature. The numerical results, presented in terms of the temperature distributions and geometry of the nugget, showed good agreement with experimental results reported in the literature.

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5. CONCLUSION

This work has as purpose to evaluate the nugget behavior and the distribution of temperature in a joint welded for resistance spot welding. The methodology used for the evaluation had as characteristic the study through microscopy optics and numerical simulation for Finite Elements.

A bi-dimensional model was developed and an analysis was applied to predict the heat development and nugget growth during spot welding of galvanized sheet. Experimental and numerical results shown a good agreement and this proposed methodology was capable of predicting the nugget dimensions as well as temperature distribution in the weld region which strongly affects the welded joint performance. The differences are due to the simplified model, where was not considered the indentation. The proposed methodology seems to be of great importance because in addition to predicting the behavior of the nugget, it was possible to obtain the thermal cycle and distribution of temperature.

The proposed methodology can be used as a powerful tool to study the effects of welding parameters, like time, current in the welding nugget and this model can be applied to different geometries and welding conditions.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Brazilian Research Agency CNPq and PEUGEOT Brazil.

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