MODELING OF A DEFORMATION RESISTANCE WELD OF A TUBE TO SOLID

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ABSTRACT

The modeling of a resistance spot welding process used in large volume by the automotive industry is extensively documented and published. Commercially available models effectively predict the correlation between input parameters, such as sheet thickness welded, electrode geometry, Weld current, welding process etc. to output parameters such as nugget shape and size and microstructure.

This paper presents a model of a Deformation Resistance Weld (DRW) made between a folded tube and a solid. The current paths from one electrode to other, distribution of currents along these paths, various resistances to the flow of current along these paths, all become complicated due to the geometry of parts welded and the electrode used. Correlation of the model measurement results from the Deformation Resistance Weld of a welded steel tube to and cast iron solid block presented. The ability of this process to create solid-state resistance welds in material combinations that are conventionally difficult is highlighted. Resulting weld microstructures are also described.

KEY WORDS: Welding of tubes, Resistance welding, Deformation welding, interface sliding, welding of dissimilar and difficult-to-weld materials

INTRODUCTION:

Introduction to Resistance spot welding

Resistance welding invented over a century ago, has evolved into an elegant and robust manufacturing process that is fast, easily automated, and maintained compared to other welding processes. These characteristics make resistance welding a preferred process in mass production. Resistance Spot Welding (RSW) is one of the welding processes extensively used in assembling automobile body parts. Joule heating (I^2R) is used to produce a heat at the contact surface of the work pieces. This resistance involves electrode and tube bulk resistances as well as the faying resistances at contact. Figure.1 shows a schematic of Resistance Spot Welding (RSW) process.

In Resistance Spot Welding (RSW) the heat to form a weld is generated by the resistance to the flow of electric current through the metal being joined. The dynamic interactions (coupling) between the electrical, thermal and mechanical aspects of the process pose significant difficulties in modeling the Spot Resistance Welding process.

The electrical-thermal coupling effect stems from the fact that the electrical properties (bulk resistivity and contact resistances) are a function of temperature. This coupling effect has been the subject of extensive studies. Numerical modeling procedures call for dealing with the electrical-thermal coupling of resistance spot welding and an appropriate accounting of temperature dependent properties.

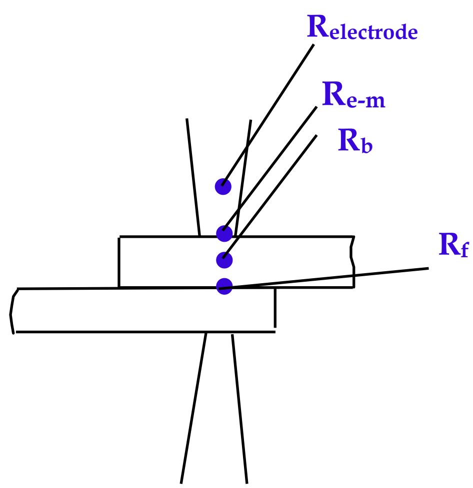

Figure.1: Schematic of Spot Resistance Welding.

Most of the conventional resistance welding process used in the automotive industry use the welding electrodes and tooling to hold the parts welded from sliding during welding. [1]. The electrode functionalities include: (a) passing a high density current through the parts welded, (b) providing appropriate cooling at the electrode-metal interfaces and (c) holding the parts rigid without relative sliding along the weld interface.

Forces applied by electrodes in resistance welding are counteracted by opposing electrodes or a tool-part combination that provides an equal and opposite reaction to the electrode force applied. In conventional spot resistance welding, welding of dissimilar metals and thin walled tubular component is complicated and practically impossible. Fig 2 shows tubular component to be welded by DRW. The process involves the following operations such as: Making a fold in the tube to be welded, controlled heating and interference sliding.

Introduction to Deformation Resistance spot welding

Thermally driven metallurgical processes occur during welding. These include nucleation and grain growth, recrystallisation, phase transformation and precipitation. These processes influence the formation of internal stresses and distortion during welding.

Thermal and thermo-elastic stresses are caused during welding due to thermal expansions and shrinkages. The residual stresses formed due to variety of reasons cause distortion of welded structures, during and after termination of the welding process [1, 2].

A new welding method called Deformation Resistance Welding (DRW), developed and patented by Delphi Automotive makes widespread use of tubular structure viable. Conventional resistance weld equipment is used, but generally with higher weld current requirements. Welding currents up to 300KA may be used to weld 6 inch diameter thin walled tubing. Consequently the use of mid-frequency DC resistance weld technology in which the transformer packs operate at frequencies of 1000-1200 Hz are proposed in order to enable the use of existing welding buses while carrying out of these welds. The mid-frequency DC technology draws power from all three phases of the bus and also uses transformer combination packs that help improve the secondary weld current/primary bus current ratio. To prepare the tubes for DRW, the tubes are formed to introduce folds and flanges at their ends. The Figure.2 shows a tube with flange and Figure.3 shows a tube with fold.

The first method involves making a fold in the tube to be welded and uses the law of thermal similarity to generate thermal profiles in the mating parts that are favorable for deformation welding. The second welds mating parts with controlled interference and again uses the law of thermal similarity to provide controlled heating and interface sliding. The deformation occurs when the materials across the weld interface are close to their melting temperatures. Strong solid state welds are created. Such method can be used to weld dissimilar materials and can enable the resistance welding of difficult-to-weld materials such as cast iron, titanium, aluminum etc.

Figure.2 Tube with a flange (left) and a tube with a fold right for welding shown with a Welded tube.

DRW of tubes to solids:

A hole is drilled on a solid with a hole diameter nearly equal to the diameter of the tube. Then the tube is folded to make a DRW as shown in Figure.3. A force 2N is applied on the tube, and then passed through the fold into the solid, creating a leak-tight DRW weld. The electrode on the solid just surrounds and grips it.

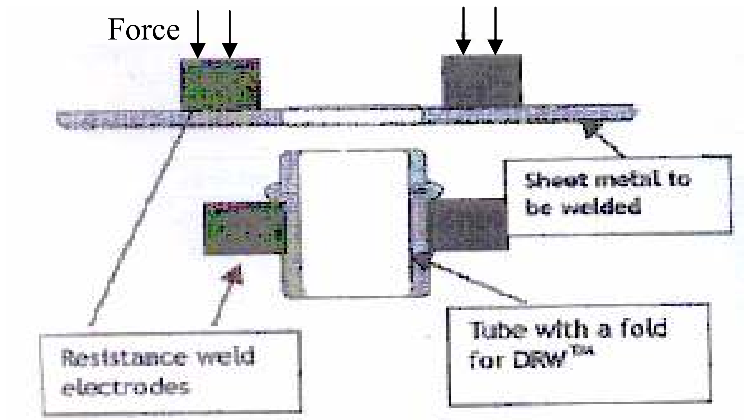

Figure.3 Resistance weld set-up of DRW of a tube to a solids

Modeling of spot resistance welding

Finite element method to Spot resistance welding

FEM simulation of welding process is useful for improving the quality and reducing the cost by developing a clear understanding of the welding process. By FEM Simulation of a Spot Resistance Welding process, the current distribution, temperature, voltage plot, heat flux can be estimated. By process modeling using non-linear, transient, coupled FEM analysis, one can obtain the field variables in the entire domain of interest for the entire process cycle time. Once a FEM process model is developed and fine tuned, the same can be used as a **virtual weld shop** to conduct numerical experiments varying any of the process, material, and designed parameters such numerical experiments can yield quick results for new process development.

The prediction accuracy of any model is very dependent on the input data. It is essential therefore to include any simulation [4]. Continuous change in the apparent interface resistances during the welding cycle due to the deformation of the welding electrodes. These effects change the average current density across the contact interfaces, thereby influencing the rate of heat generation.

The spot welding process is a complicated phenomenon, which involves the mechanical, thermal and electrical and metallurgical factors. Two types of analysis would be carried out through this model; a structural model and thermal-electric analysis. An axisymmetric 2-dimensional model was developed using commonly available FEM software. The structural analysis was used to analyze the compressive stresses developed during the welding process and the thermo-electric analysis was used to analyze the nugget growth during the weld time through the temperature distribution during the period and the current density distribution and below flow chart shows the schematic illustration of analysis in Figure.4.

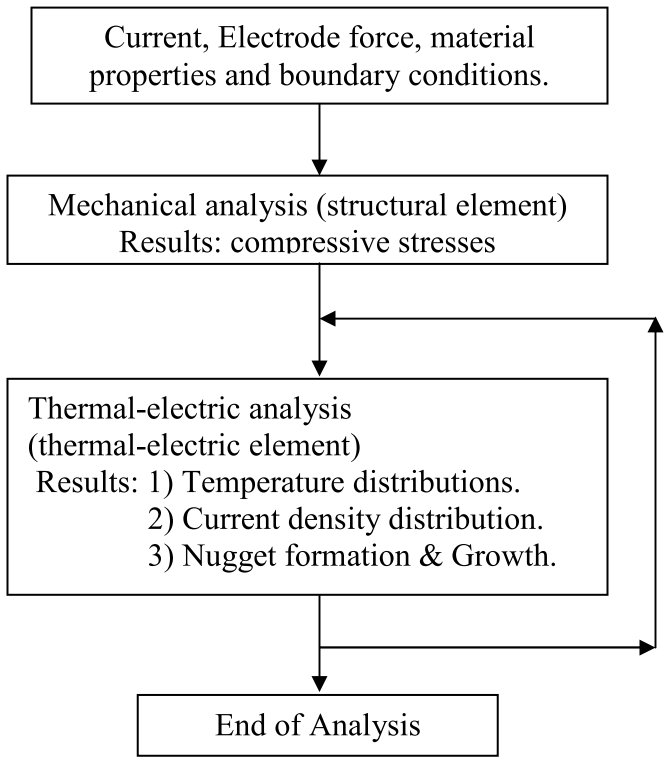

Figure.4 Schematic Illustration of Analysis.

Electro-thermal modeling

In this paper a Finite Element Formulation is derived for both electro-thermal and thermal analysis. The fully-coupled thermal-electrical model predicts the electrical current density distribution, potential drops, heat generation and temperature history.

The heat for electric spot resistance welding is obtained by a large electric current through the workpieces which have electrical resistance in the domain and contact surfaces. The amount of heat generation per unit volume can be calculated by the electric potential in the domain and then it can be applied to the heat transfer equations to calculate the temperature distribution in the electrode and workpiece. The workpiece temperature approaches the phase change temperature and the effect of latent heat is considered by increasing the specific heat in temperature range of eq. (1) [9]

$$\mathbf{C}' = \frac{\mathbf{H_L}}{\mathbf{T_L} - \mathbf{T_S}} + \mathbf{C} \qquad \text{Eq (1).}$$

Where H_L is the latent heat, T_L is a melting temperature and T_S is the solidifying temperature.

The electrical potential can be expressed by Quasi-Laplace equation (2). The governing equation and its boundary condition are as follows.

$$\frac{\partial}{\partial x_i}\left(\sigma_{ij}\frac{\partial V}{\partial x_j}\right)=0 \qquad \text{Eq (2).}$$

$$\sigma_{ij}\frac{\partial V}{\partial x_j}n_i=-\sigma_O\left(V-g_1\right) \qquad \text{Eq (3).}$$

Where $\boldsymbol{\sigma_{ij}}$ is a temperature dependant electrical conductivity.
The electrical current density and electric current can be expressed by equations (4) and (5), respectively.

$$J_i=-\sigma_{ij}\frac{\partial V}{\partial x_j} \qquad \text{Eq (4).}$$

$$I=\int_A J_i n_i dA \qquad \text{Eq (5).}$$

Where A is the area passed by electric current and N_i is the normal vector of the surface.
The amount of heat generation by joule's effect per unit volume can be expressed by the following eqn. (6).

$$f=\sigma_{ij}\frac{\partial V}{\partial x_i}\frac{\partial V}{\partial x_j} \qquad \text{Eq (6)}$$

For a given electric current Eq (5). matches the value by calculating electric potential V

Formulation for heat transfer

The governing equation of heat transfer and boundary conditions are as follows

$$\rho c_p\frac{\partial T}{\partial t}=\frac{\partial}{\partial x_i}\left(k_{ij}\frac{\partial T}{\partial x_j}\right)+f \qquad \text{Eq (7)}$$

$$k_{ij}\frac{\partial T}{\partial x_j}n_j=-k_O\left(T-g_2\right)+h \qquad \text{Eq (8)}$$

$$T = T_o \quad \text{at} \quad t = 0 \qquad \text{Eq (9)}$$

Where $\boldsymbol{\rho}$ is the density, $\mathbf{C_p}$ is the specific heat per unit volume, K_{ij} is the heat conductivity and f is the heat generation calculated from eq (6).

Numerical modeling of the Spot Resistance Welding process has also shown a current constriction at the electrode face edge. Green wood [27] noted that the current in resistance welding does not flow directly across the material being welded, but diverges into the worksheet. Furthermore, he stated that most of the current that spreads into the sheet enters near the electrode edge, causing a current constriction at that location.

To simulate the electric current flow through the RSW setup, the magnitude of voltage was set to positive at the upper electrode, while the potential at the lower electrode was set to zero. To model current and heat flow across the interfaces, surface contact elements were applied to all the matching surfaces. The incorporation of temperature dependent properties into the model is essential, because the analysis involves large temperature variations.

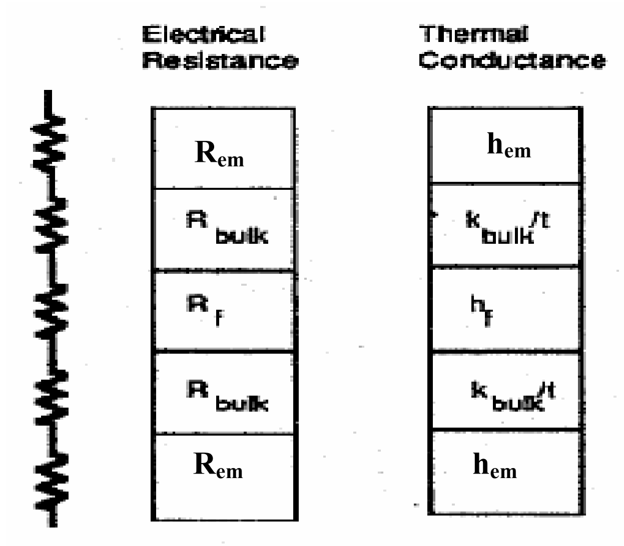

Figure.5 Axial Electric and heat flow in resistance spot welding [3]

The variation of resistances with welding time is shown in the following figure.

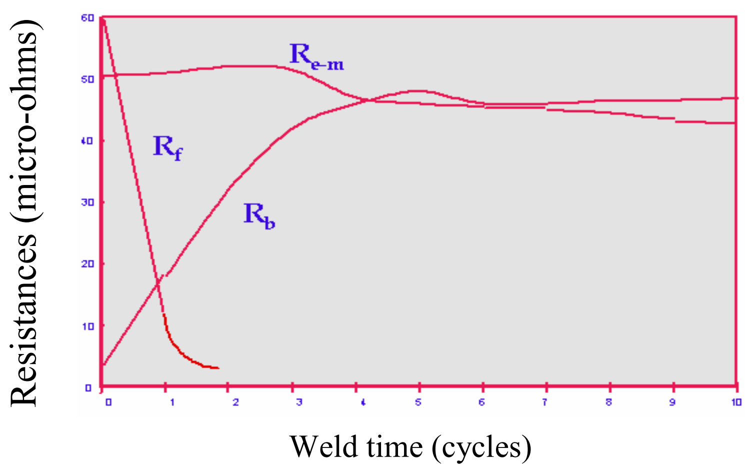

Figure.6 Variation of resistance with Weld time

The numerical results provide the electric potential field, the electric current distribution and the temperature distribution.

Thermal modeling

In thermal modeling of spot welding, the main thermal conditions are as shown in Figure.5 at the interfaces i.e., between workpieces interfaces and workpiece-electrode interface and the variation of resistance at the interfaces with weld time is as shown in Figure.6. The faying surface temperature affects the size and quality of the welds. Numerical methods have been employed to predict cap temperature distributions. The object of this investigation was to determine the temperature distribution (in particular, the maximum tip surface temperature) without relying upon heat loss test data. In heat transfer analysis, the energy equation must be coupled with the equations of continuity and motion to describe the process of heat conduction and convection. In classical heat transfer analysis, convection has been considered only as one type of thermal boundary condition to be applied at the surface of a conducting solid. In this approach, since convection is given at the boundary, only the energy equation is required.

In the electric resistance spot welding process shown in Figure.7, electrode press against workpieces and a current is then passed through these components. Because of the electrical contact resistance, heat will be generated at electrode/workpiece interfaces and faying surface. The heat at the faying surface of electrode tube melts the tube. To prevent melting at the electrode/tube interface, water is circulated in the cooling chamber of the electrodes Figure.1. For a reduction of the problem size in this investigation, only two dimensional geometry was considered. Both the ambient air and initial water temperatures were assumed to be 20°C (68°F) [7]. If the water does not boil, the physical properties can be assumed to be temperature independent.

Input data received:

Material properties like electrical resistivity, thermal conductivity, heat capacity, welding current, electrode force, type of welding machine i.e., AC or DC, electrical contact resistances and thermal conductance at the interface together with friction conditions at the surface. During the spot welding the heat generated depends on the applied current density, which is not uniform due to the differences in the contact resistance across the surfaces being welded and at the electrode/sheet interfaces

Boundary Conditions:

The following Figure.7 shows the boundary conditions applied to the model.

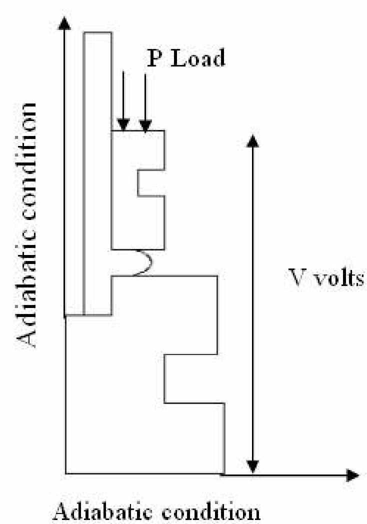

Fig.7 Boundary conditions

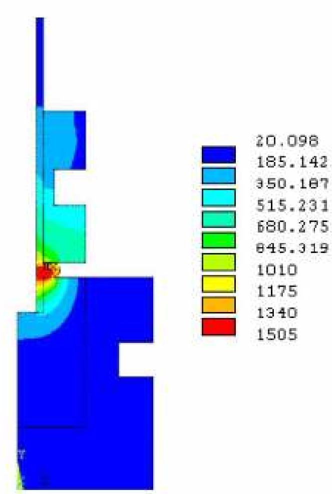

Fig.8 Temperature plot distribution

The above Figure.8 shows the predicted temperature distributions plot, while the current density distributions plot as shown in the following Figure.9 at the contact surfaces.

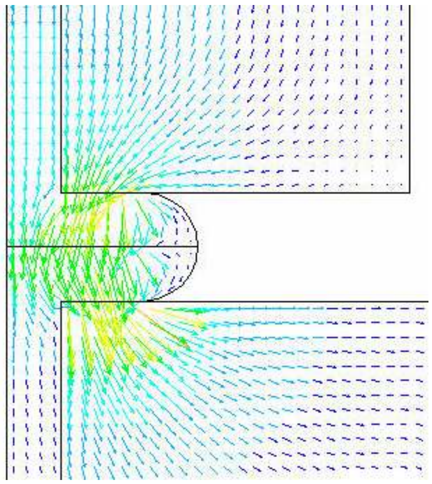

Figure. 9 Current density distribution. cast iron-steel tube combination.

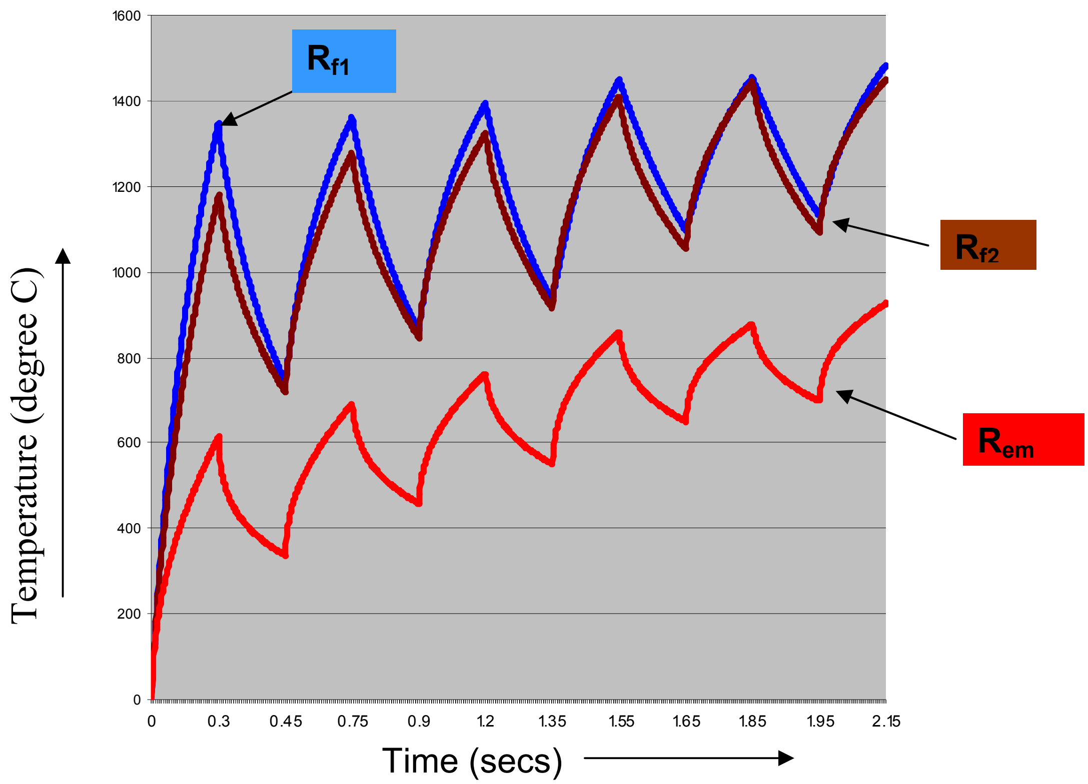

Figure.10 Graph Temperature Vs Time for Rf_1, Rf_2 and R_{em}

Conclusion

In this paper FEM modeling of DRW is considered to predict the temperature distribution and current density distribution .The new technique of deformation resistance welding has been shown to be effective in welding thin-walled tubing to a number of other mating components. Dissimilar and difficult-to-weld combinations have been shown to be weldable using these techniques.

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