

Some aspects of modelling and simulation of spot welding

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Abstract. Mathematical modelling and finite element analysis of thermal processes, much more complex in welding different metals in terms of chemical composition and structure, have allowed investigation and deepening of heat transfer phenomena and the establishment of a new technological spot welding variant for these joints. The distribution of temperatures in welded joints is influenced by the linear energy of the thermal source, the thermal properties of the base material (heat specific heat conductivity, material density and thermal diffusivity) and heat losses to the environment. Thermal field viewing, longitudinal and transverse variations of temperature in heterogeneous welded joints, as well as temperature values recorded at different nodes (points) located in the welding area and adjacent areas, lead to conclusions that will result in specific spot welding technologies.

1 Introduction

Spot welding is an important process of welding, widely used in industry, especially in the automotive industry. The main quality control tests are destructive tests carried out on welds obtained from the production product. These were complemented by non-destructive methods.

The scraps are detected, examined and evaluated. If there is a substantial increase in failure rates, the entire batch of products is rejected. The labour costs incurred during this type of testing and the loss of products make this approach unattractive. Industry needs to increase productivity and reduce production costs.

When welding through points on stainless steel, the required welding force and stress is higher than normal steels. This has implications for energy consumption during the creation of each spot (Figure 1) [2].

In practice, creating an acceptable welding quality depends on the definition of optimal welding parameters and the use of appropriate controls to

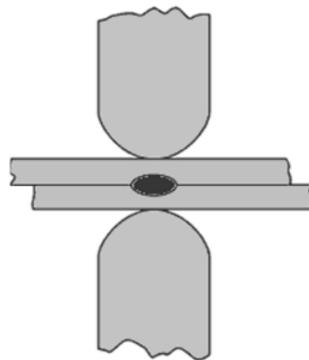


Fig. 1. Spot welding [2].

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provide constant welding points during a production cycle. The industry has accepted various methods to optimize spot welding.

Energy consumption at industrial welding points generally affects both financially and environmentally. Research can improve productivity, as abnormalities can be identified and changed during the manufacturing process. The quality of sources can be monitored in real time through its electrical properties, i.e. current, voltage, etc.

Spot welding using electrical resistance is a solid state welding process applied to join the parts and components of welded structures made from sheets but also applies to wire elements or rods. The connection is accomplished by overlapping a certain thickness of the thickness of the plate, the tightening being effected by copper or copper alloy contact electrodes, the mechanically actuated discharge force, and the electric current preheat switch between the contact electrodes for welding the two plates.

In simulation of spot welding, electrical, thermal and mechanical fields are included in most studies separately, focusing on the thermoelectric aspect. One of the most important research that focuses on the thermoelectric side is 3D modelling to simulate the thermal and electric fields. Take into account the durability of electrodes using an electric-thermal torque model, while no mechanical analysis was included. The thermoelectric model may be useful for determining some aspects of the RSW process.

Some general mathematical equations used for the electrical, thermal and mechanical aspects of the RSA process of RSW are presented below.

-Electric equipment

The voltage distribution for spot welding is considered together with adjacent welding to investigate the effect generated. This voltage distribution is used to calculate the shunt current alternations caused by heat generation during welding. By using these hypotheses, the quasi-Laplace equation of the electrical potential can be written in 3D coordinates as (according to [1]):

$$\frac{\partial}{\partial x} \left[\frac{1}{\rho} \cdot \frac{\partial \phi}{\partial x} \right] + \frac{\partial}{\partial y} \left[\frac{1}{\rho} \cdot \frac{\partial \phi}{\partial y} \right] + \frac{\partial}{\partial z} \left[\frac{1}{\rho} \cdot \frac{\partial \phi}{\partial z} \right] = 0 \quad (1)$$

Where p is the electrical resistivity.

- Thermal equipment

A continuous thermal equation for the temperature distribution within the point welds is shown as (according to [1]):

$$D \cdot c \cdot \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left[k \cdot \frac{\partial T}{\partial x} \right] + \frac{\partial}{\partial y} \left[k \cdot \frac{\partial T}{\partial y} \right] + \frac{\partial}{\partial z} \left[k \cdot \frac{\partial T}{\partial z} \right] + \frac{1}{\rho} \nabla \phi \cdot \nabla \phi \quad (2)$$

Where D is the volumetric density, c is the specific heat capacity, k is the thermal conductivity coefficient, T is the temperature and Φ is the electrical potential.

-Mechanical equations

The main equation used for mechanical analysis to establish the relationship between voltage, voltage and thermal expansion is the elastic-plastic incremental equation (according to [1]):

$$d\{\sigma\} = [C]d\{\epsilon\} - \{C_T\}dT \quad (3)$$

Where $d\{\sigma\}$ is the stress vector differences, $[C]$ is the elastic-plastic matrix, $d\{\epsilon\}$ is the spreading vector differences, $\{C_T\}$ is the coefficient of heat and dT : temperature differences.

For equilibrium stress, the following equations are used (according to [1]):

$$\nabla\{\sigma\}_{xyz} + D.\{b\} = D.\{a\} \tag{4}$$

Where $\{b\}$ is the body force vector that is not considered in this analysis, $\{a\}$ is the acceleration vector, which is a very small parameter and is usually considered zero.

All the introduced equations are generally used for RSA from RSW and may change somewhat depending on the chosen coordinate system and the number of dimensions, but the main concept and base form are the same.

The common method of detecting contact between two welds or welds and an electrode uses an arc-like layer at the contact area. The main purpose of this layer is to detect mechanical contact. The presence of mechanical contact means that electrical and thermal contact must also be established between the two entities. There are electrical and thermal conductive parameters that are set according to the contact state. This approach can be seen in Figure 2 as an algorithm.

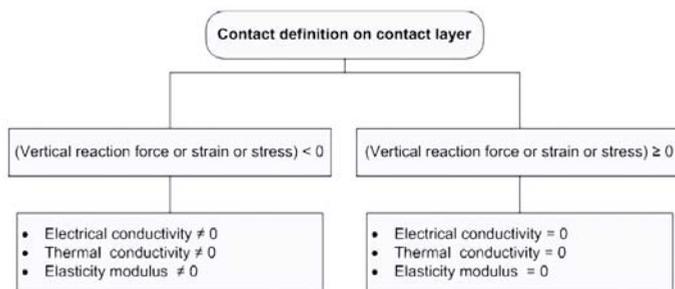


Fig. 2. The simple algorithm of the method of defining the contact in the FEA [1].

A well-formed algorithm is the FEA basis, because the sequence and relation between the different aspects of the simulation process are specified in algorithms.

A general algorithm for the RSW process contains the initial definition of contact, thermal analysis and, finally, mechanical analysis. Each of these steps has several entries as the different properties required for each analysis. A typical RSW FEA algorithm is shown in Figure 3.

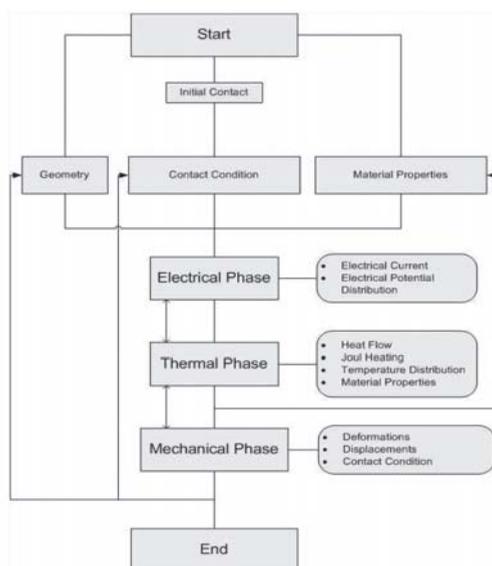


Fig. 3. A typical RSW FEA algorithm [1].

2 Experimental research

Spot welding is a type of resistance welding used to weld different boards. Typically, the panels are in the thickness range of 0.5-3.0 mm (concrete case 1mm). The process uses two copper alloy electrodes by which the welding current is concentrated to a point where the plates are simultaneously fastened. Passing a large current between the electrodes will melt the metal and form the weld. The electric voltage required for welding depends on the strength of the material to be welded, the thickness of the layer and the desired size of the welding point. When welding a common combination such as 1.0 + 1.0 mm, the voltage between the electrodes is only about 1.5 V at the beginning of the welding, but may drop to 1 V at the end of the welding. This drop in electric voltage comes from the resistance caused by the melting of the steel. The open circuit voltage in the transformer is much higher than in this case, usually in the range 5-10 V, but there is a very high voltage drop in the electrodes and the secondary side of the transformer when the circuit is closed.

To determine the current effectiveness of existing technology, there have been several experiments to monitor the welding quality by step-by-step. Experiments using industrial 1mm variable steel were performed: current pressure, voltage, power, water pressure and cooling agent.

In the industry (including automotive, welded, welding, electronics and metalworking), in order to determine and evaluate combinations of materials to be welded, weldability must be determined and design and selected spot welding electrodes after optimization general parameters of the welding process.

Material for spot welding is 304 stainless steel (chemical analysis: C - Carbon .08 max; Mn - Manganese 2.00 max; P - Phosphorus 0.045 max; S - Sulphur 0.030 max; Si - Silicon 0.75 max; Cr - Chromium 18.00 – 20.00; Mo - Molybdenum 8.00 – 12.00). Type 304 is an austenitic stainless steel. It has good corrosion resistance in many environments and may be formed and welded with ease. It has excellent ambient and low temperature toughness properties. This grade of stainless steel is the general purpose austenitic stainless steel used in chemical processing, pulp and paper mills, and many other industries such as food and dairy, where its corrosion resistance is suitable and adequate.

The SPOT-3D module in the SmartWeld program is an application for calculating optimal spot welding parameters where the heat flow is predominant. Specify the size required for welding, and SPOT-3D calculates combinations of pulse energy and pulse duration (i.e. welding mode) that produce welding of desired size in the metal or alloy chosen.

The model is based on the continuous point source solution using the conduction heat flow equation. SPOT-3D can be used for resistance welding, pulse arc welding, laser spot welding and other short duration processes where melting takes place very quickly.

SPOT-3D allows (Figure 4, Figure 5):

1. Selection of welding material from the program database.
2. Obtain an optimal welding regime for the specified weld width on the board surface.
3. It is possible to display the welding pattern as determined by the technologist and allows the welding pattern to be obtained on two-dimensional contour areas.
4. It is possible to determine the effect of welding parameters on the welding point dimensions.

The resulting curves are functions of the procedure variables pulse energy (Q) and pulse duration (tp). The program is based on a heat transfer model that calculates the following process variables (PVs) according to the welding procedure parameters (WP) for a thick plate. Process variables (PV) are calculated as a parameter function (WP) that is pulse energy (Q) and pulse duration (tp):

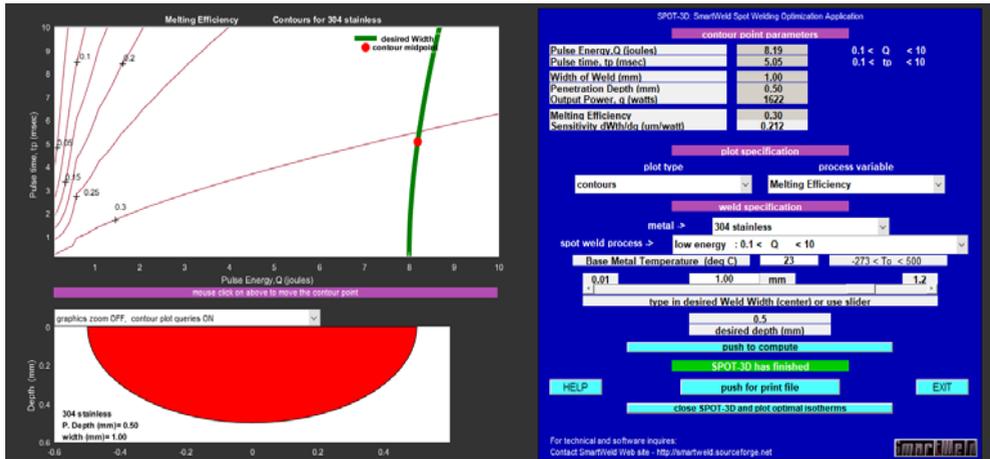


Fig. 4. Spot welding regime (plot type contours).

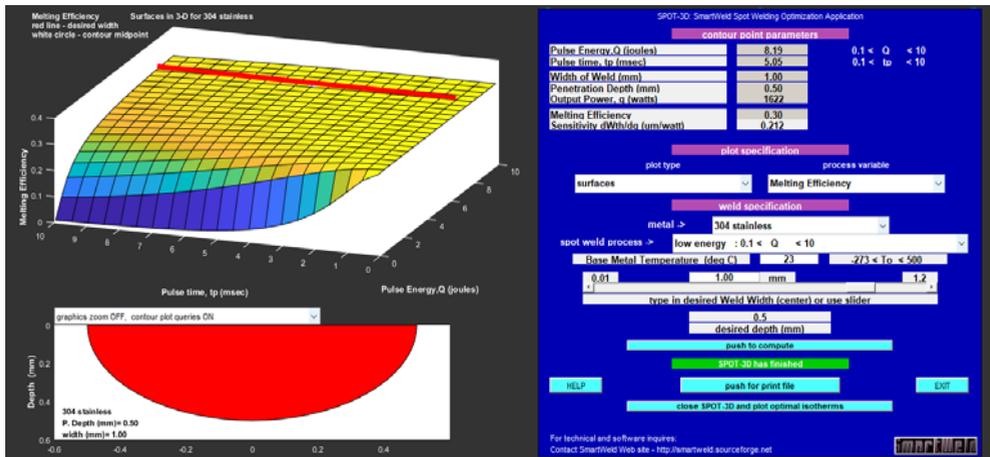


Fig. 5. Spot welding regime (plot type surfaces).

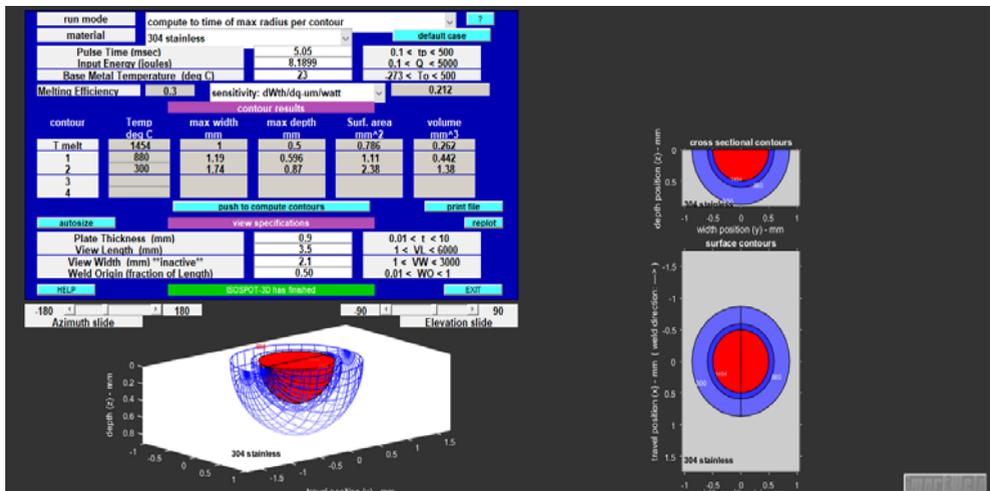


Fig. 6. ISOSPOT-3D the optimal isotherms.

- 1) Melting efficiency - the amount of heat required to melt the contact area relative to the amount of heat deposited (MeltE)
- 2) Width (millimetres, mm) - based on the circular weld surface (W)
- 3) Penetration depth (mm) - the depth of the semisferric weld (P)
- 4) Power (Watts) - Q / t_p , (qo)
- 5-6) Surface Derivatives Relative to Temperature and Base Metal Temperature (To) (dW / dq (microns / watts / watt), dW / dT_o (um / degK)

Minimizing the melt efficiency leads to a welding regime that minimizes the amount of heat. The welding mode can determine the maximum or optimum MeltE Melt Efficiency or the use of a minimum amount of heat. The technologist can constrain the width of the surface, W.

The resulting solution can be visualized through the resulting temperature contours that can be displayed directly in ISOSPOT-3D for later analysis.

After selecting the material, two specifications, power limits and basic temperature are available. Since spot welding can be done with both laser and arc sources, one of the three energy stages can be chosen:

- 1) low energy, $0.1 < Q < 10$ joules
- 2) Medium energy, $10 < Q < 30$ joules
- 3) high energy, $30 < Q < 250$ joules

After selecting the welding power range, the final specifications are:

- 1) the temperature of the base metal
- 2) the welding width (W) by means of the type of editing or by using the colour bar. W /

The second is used as the radius (or depth) of the semi-circular welding area.

3 Conclusion

Process variables for a Q, t_p value network determine the characteristics of the desired material and interpolate within that network to obtain the Q, t_p values for the specified weld size. Numeric results are displayed in a 2-D contour chart type; the intermediate point is specified under the contour point parameters.

After a procedure is computed, the optimal isotherms are compared and the corresponding contours of temperature to steady state in ISOSPOT-3D are plotted (Figure 6).

References

1. M. Jafari Vardanjani, J. Senkara, A. Arayee, *Welding Technology Review* **88**, 2 (2016)
2. V. Cohal, *Applied Mechanics and Materials* **657**, 226-230 (2014)