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New parametric study of nugget size in resistance spot welding process using finite element method

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ABSTRACT

Resistance spot welding process (RSW) is one of important manufacturing processes in automotive industry for assembling bodies. Quality and strength of the welds and therefore body mainly are defined by quality of the weld nuggets. The most effective parameters in this process are: current intensity, welding time, sheet thickness and material, geometry of electrodes, electrode force, and current shunting. In present research, a mechanical–electrical–thermal coupled model in a finite element analysis environment is made using. Via simulating this process, the phenomenon of nugget formation and the effects of process parameters on this phenomenon are studied. Moreover, the effects of welding parameters on temperature of faying surface are studied. Using this analysis, shape and size of weld nuggets are computed and validated by comparing them with experimental results from published articles. The methodology developed in this paper provides prediction of quality and shape of the weld nuggets with variation of each process parameter. Utilizing this methodology assists in adjusting welding parameters so that costly experimental works can be avoided. In addition, the process can be economically optimized to manufacture quality automotive bodies.

1. Introduction

Resistance spot welding is commonly used in the automotive industry for joining thin sheet metals. Compared with other welding processes such as arc welding processes, resistance spot welding is fast, easily automated and easily maintained. This welding is a complicated process which involves interaction of electrical, thermal, mechanical and metallurgical phenomena. In this process, the materials to be joined are brought together under pressure by a pair of electrodes and then a high electric current is passed through the workpieces between the electrodes. Due to contact resistance and Joule heating, a molten weld nugget is formed in the workpieces. The workpieces are joined as solidification of the weld pool occurs. Moreover, force is applied before, during and after the application of electric current, to maintain the electric current continuity and to provide the pressure necessary to form the weld nugget. The total heat generation between two sheets per unit time is defined as the product of the current intensity squared, multiplied by the total resistance and the welding efficiency.

Quality and strength of the welds are defined by shape and size of weld nuggets. The nugget size has referenced to the welding quality as specified in the handbook provided by the Resistance Welder Manufacturers' Association. Fig. 1 shows a cause-and-effect diagram that nugget size is a dominant factor. In general, there is a direct correlation between heat generation and nugget size in RSW process. The contact resistances at the faying surface between workpieces, current density, welding time and sheet thickness mainly determine the heat generation during welding and the subsequent nugget size. In present research, the phenomenon of nugget formation and the effect of process parameters on shape and size of weld nuggets are studied. In order to gain greater nugget diameter, the effects of RSW parameters are studied by simulation of this process in a finite element analysis. To simulation of this process, a mechanical–electrical–thermal coupled model has been made in a FEM environment using commercially available software. The effects of welding time and current, electrode force, contact resistivity and sheet thickness on the temperature of faying surface is investigated. Using this analysis, shape and size of weld nuggets are computed and validated by comparing them with experimental results from published articles. These results can be used to optimize the RSW parameters.

1.1. Literature review

In order to increase the strength of products, many researchers have studied RSW process by experimental and numerical tech-

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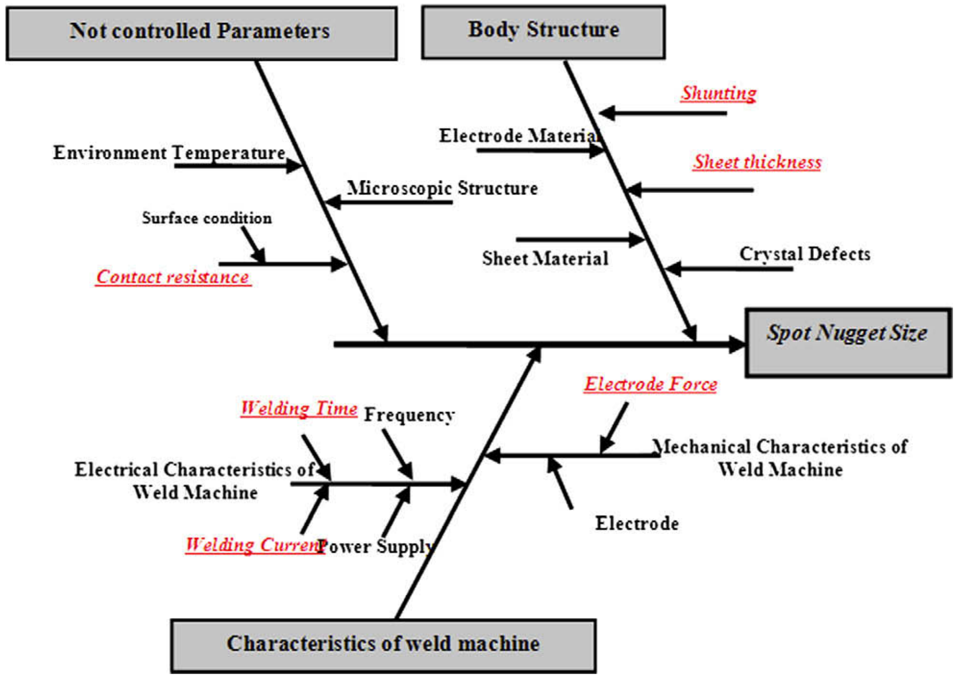

Fig. 1. Cause-and-effect diagram for nugget size in resistance spot welding.

niques [5–18]. Nugget formation experimental studies [5–8] are able to provide valuable temperature data, however, the test techniques have their limitations and require expensive equipment. Furthermore industries are trying to reduce the expenses used for the testing process. These shortcomings make numerical simulation an attractive tool for complimenting experimental temperature. For this reason, researchers have studied RSW process by developing one-dimensional, two-dimensional and rarely three-dimensional models. Gould [5] measured the nugget growth by using metallographic techniques and proposed a finite difference based one-dimensional heat transfer model. This model demonstrated the importance of radial heat transfer, which inhibits the calculation of nugget expansion. This model did not account for non-uniform current density distribution. Tsai and Jammal [6,7] have created a two-dimensional symmetric model using ANSYS to perform some parametric studies on the spot welding process. Khan et al. [8] have developed a model to predict the nugget development during RSW of Al alloys. The model calculates time varying interface pressure and is used to determine the effect of the electrode shape and applied pressure on the nugget growth only. Khan were employed the iterative method to simulate the interaction between coupled electrical, thermal and structural fields. Feulvarch and co-workers [10,11] have presented a finite element formulation to measure the interface contact properties. It has been shown that the calculated nugget appears earlier. It has also been noticed that the nugget was growing faster across the thickness. Hou and Kim [13] developed and analyzed a two-dimensional axisymmetric thermo-elastic–plastic FEM model; it was developed and analyzed in the commercial FEM program, ANSYS. The objective of this research was to investigate the behavior of the mechanical features during the RSW process. Through the analysis, the following results were obtained: the distribution and change of the contact pressure at the electrode–workpiece interface and faying surface, the stress and strain distribution and deformation of the weldment, and the displacement of the electrode. Recently, Loulou and Bardon [14,15] used a method for estimation of thermal contact conductance coefficient at the electrode tip–metal sheet interface. His articles describe an experimental and numerical methodology for estimation of interface transient heat transfer coefficient during resistance welding. Aslanlar et al. [17] have investigated the effects of welding time on the tensile-peel strength and tensile-shear strength of welding joints in electrical resistance spot welding. More recently, Rogeon et al. [18] has measured electrical contact resistances on a specific device, allowing to rise high pressure and elevated temperature. Performed measurements concern electrode–sheet and sheet–sheet interfaces.

2. Theoretical analyses

2.1. Governing equation

All the equations in this study are based on the two-dimensional cylindrical coordinate system. The governing equation for calculation of the heat generation per unit volume may be shown as [1]:

$$q = \frac{1}{R}[\nabla \Phi]^2 \tag{1}$$

where q is the heat generation per unit, R is the electrical resistivity and Φ is the electrical potential. The governing equation for transient temperature field distribution, which involves electrical resistance heat, may be written as [2]:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\alpha\frac{\partial T}{\partial r}) + \frac{1}{r}\frac{\partial}{\partial z}\left(r\alpha\frac{\partial T}{\partial z}\right) + q = \rho c\frac{\partial T}{\partial t} \tag{2}$$

where r and z are radial and axial coordinates and, ρ, c and K are density, specific heat, and thermal conductivity, respectively. The term $\dot{Q}$ refers to the rate of the internal heat generation per unit volume within the boundary of the region of analysis. This particular term accounts for the Joule heating due to bulk resistivity in the sheet-electrode system.

For stress and strain analysis, since the thermal–elastic–plastic behavior is a highly nonlinear phenomenon, the stress–strain relation is described in incremental form [3]:

$$\{\Delta\sigma\} = [D]\{\Delta\varepsilon\} + \{C\}\Delta T \tag{3}$$