



REVIEW ON MODELING OF RESISTANCE SPOT WELDING PROCESS

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Abstract: The paper critically studies the available methods of coupled models of resistance spot welding (RSW). Further critical analysis of the processes has been done and some recommendations also given according to the application. The quality of the weld depends upon the optimum process variables such as welding current, weld time and electrode pressure. Different developed models to simulate the three ways coupling of thermal, electrical and mechanical analysis. The coupling procedures can provide a more realistic and efficient computational approach for contact size and for electrode face. Models describing these phenomena should be interconnected with each other to simulate heat generation and growth in the nugget formation. The fuzzy logic modeling method is one of the artificial intelligence techniques which have been in use for the modeling of manufacturing processes such as machining and welding.

Keywords: Resistance spot welding (RSW); Failure mode: Numerical method; Fuzzy logic; Nuevo fuzzy

I. Introduction

The RSW process has been widely used in sheet metal manufacturing operation. RSW widely used in major industries such as automotive and aerospace. RSW have many advantages over the other one such as a no filler material is demanded, a low heat input, a small heat affected zone, low welding distortion and takes comparatively low points of skill from an operator. Resistance spot welding is that area of welding where heat is generated by the flow of current with the help of electrode in the work piece and weld nugget is produced at the faying surface of the work piece. Electrode pressure applied to ensure adequate contact between the work piece being the welded. In resistance spot welding process to produce good weld quality depend upon welding parameter such as welding current, weld time and electrode face. In the resistance welding process it is very different to find out optimal resistance spot welding process parameter. These parameters need to control to produce a good weld quality. Schematic of the process shown in fig. 1. The metal sheet to be joined is brought together under pressure by a pair of electrodes and high welding current. Weld nugget is formed on the faying surface of sheet metal due to contact resistance and joule heating. Due to the interaction between thermal, electrical, mechanical, metallurgical phenomena during the RSW process, deformation, stress and strain will develop in the weld metal. Over the last few years numerical methods are a power full tool for simulating the interaction between thermal, electrical, mechanical, metallurgical phenomena and structural fields during the resistance spot welding by one, two and three dimensional finite element models, Richard, D. et. al.[1].

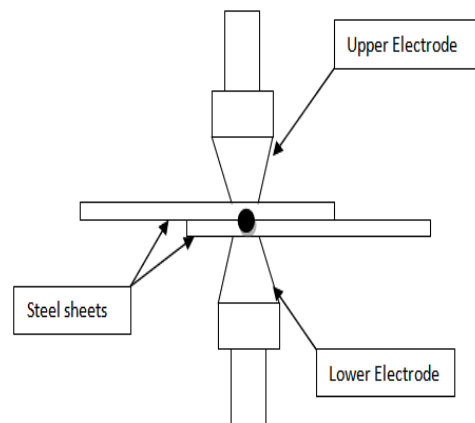


Figure 1: Schematic view of the process

Recently, a lot of research work has been carried out on the numerical simulation of the RSW. The finite element method (FEM) is capable of considering the effects of process parameters such as welding current, welding time and electrode pressure on residual stress distribution weld distortion and weld crack in the weld metal. It is a complex process in which coupled interactions exist between electrical, thermal, mechanical, metallurgical phenomena, and even surface behaviors. The coupling procedures can provide a more realistic and efficient computational approach accounts for the variation of contact size; particularly in the application of curved-face electrodes producing a spot weld. The concept of fuzzy sets as a generalization of crisp sets was first introduced by Zadeh, L. A. et. al. and Yager R. P. et. al.[3-4]. The fuzzy logic modeling method is one of the computational intelligence (CI) techniques which have been in use for the modeling of manufacturing processes such as machining and welding. Recently, CI has provided a number of successful solutions for various industrial problems with similar characteristics, Ali Y.M. [5]. The purpose of this review paper is critically studied the available methods of coupled models and future critically analysis the process and got to some recommendation according to the application.

II. Review on Experimental Work

The weld produced by RSW process is commonly known as the nugget and defines the overall integrity of the spot welded structure. The effect of electrical resistance on nugget formation was studied in detail with respect to the process variables by Kaiser et.al.[6]. The electrode deformation during RSW of coated steels was investigated by William et.al.[7]. The thermal cycle of RSW is marked by the very rapid rise of temperature beyond the melting point of the material and due to the resistance heating. The thermal cycle also defines the nugget size, residual stress and deformation of RSW joints. A theoretical study of the thermal response of the work sheet material with respect to the input variables was suggested by Na and Park.[8]. In RSW, the contact resistance between the faying surfaces of the sheets significantly affects the power drawn by the electrical circuit and subsequent resistance heating. The contact resistance is dependent on the surface nature and the applied electrode pressure. Often, too high electrode pressure and very smooth faying surface leads to less resistance heating and smaller weld nugget formation. This phenomenon was studied in detail by Davies et.al.[9]. The mechanism of electrode degradation during the RSW of coated steels was investigated by Parker et. al.[10]. A two stage experimental designing methodology was used by Li et.al.[11]. to predict the quality characteristics of resistance spot welds. The step by step formation of RSW nugget was investigated by Cho and Rhee[12] using special sensors and experimental procedure.

III. Failure Mode

Spots weld failures are characterized by complex crack paths from the notch tip in the weld nugget, that can either propagate on the faying surface (Full Interfacial Failure, FIF) or deviate through the sheet thickness (Partial Interfacial Failure, PIF). In the case of mild steel and HSLA ductile failure were observed at the weld nugget boundary under normal loads. Two type of failure mode were occurs during the tensile shear strength and peel shear strength tests: full interfacial failure and nugget pull out failure. Full interfacial failure was accompanies by little plastic deformation investigated by Pouranvari M. et. al.[13]. Fusion size (FZ) of the weld controlled the failure mode and mechanical properties of RSW process. High welding current and FZ were changed the failure mode FIF to nugget pull out. In the full interfacial failure and nugget pullout failure mode experience driving forces are shear stress and tensile stress respectively. Each driving force has a critical value, when this force reached its value failure occurred.

Zuniga S. et. al., Chao Y. et. al, Dancette, S. et. al. and Anastassiou et al.[14-16] Studied the residual stress distribution and microstructural changes in a steel sheet and also investigated the relationship between welding parameters and fatigue behavior. Long .X. et. al., Khanna S. K. et.al. and Nodeh I. R. et. al. [17-18] Developed a thermo-electric - mechanical model to analyze the effects of welding parameters such as welding current and welding time on residual stress distribution. The model also obtained the nugget size in resistance spot weld. Model result is then compared with the experimental data. Huh H. and Kang W. J.[19] Introduced the thermal, electrical analytical model for predicting the contact resistance between the electrodes and sheets. The contact resistance between electrodes and sheets is specially treated with artificial interface elements in which the material properties of electric and thermal analysis are artificially imposed for physical reasonable simulation.

IV. Fuzzy Logic

Narang H. K. et. al. [20] created a fuzzy logic model for predict the weldment macrostructure zones' shape profile characteristics of tungsten inert gas welding. This technique also employed for online prediction of the TIG weldment shape profiles. Naso D. et. al.[21] Developed a fuzzy logic model to implement an intelligent algorithm for online weld quality monitoring of GMAW processes with optical sensors. The model also predicts the weld quality and weld defect in real time. Ambelia et. At.[22] Developed rule base fuzzy logic model using Mamdani approach to identify the carnal knowledge between each input variable (percentage of green fruits, stealing time and steam pressure). Three main levels were applied to build up the theoretical account is;

fuzzification, inference engine and defuzzification. Lin *et. al.*[23]. Applied grey fuzzy logic to optimize the electric discharge machining process parameters with multiple responses such as an electrode wear ratio, material removal rate and surface roughness. An orthogonal array, gray relational generating, gray relational coefficient, gray-fuzzy reasoning grade and analysis of variance (ANOVA) are employed to study the performance characteristics in the electrical discharging machine process. Ali Y. M. *et. al.* [5] Have used three-layer fuzzy model to analyze the effect of input process parameters on surface roughness of the grinding operation. Fuzzy rule for model, generated based on experimental observation.

Often numerical deterministic modeling is time consuming and requires much simplification of the physics, A model developed by Boriwal L. *et. al.* [24]. Investigated the choice of input process parameter that create acceptable welds in the resistance spot welding of galvanized steel sheets. The process variables were also studied for the interaction effects on weld nugget, tensile-shear and peel strengths. The multiple regression equations of the model were tested for a range of test cases to predict the responses like nugget size, tensile and peel strength. The designed data were further used for response optimization. The predicted optimized input process variables were experimentally verified by comparing the measured and predicted optimized target responses. The methodology adopted in the present investigation indicated adequacy to model, predict and response, optimize the input process variables of resistance spot welding process for welding galvanized steel sheets. These concluded that Selection of the range of RSW input variables that define the acceptable weld characteristics like nugget size, tensile-shear strength and peel strength was emphasized in designing the full factorial experiment matrix. The result of the multiple regression analysis and response surface indicated the suitability of the data for predicting the output responses for a set of test cases. The design of the data was further used for response optimization and the target optimized values of the responses were compared with the experimentally observed ones.

V. Neuro Fuzzy

The neuro-fuzzy systems are hybrid intelligent systems that combine features of artificial neural networks and those of fuzzy logic systems by Kandel A.[25]. They are powerful tools which also considers the uncertainties of pattern of relations that exist between the input and output relations of process variables. The neuro-fuzzy models have been successfully applied to modeling and control of various systems Arafeh *at al.*; Duraisamy *et al.*; Alimardani and Toyserkani)[26-28]. Successfully applied nero-fuzzy system for laser solid free form fabrication. The neuro fuzzy systems can be broadly classified as cooperative nero-fuzzy systems, neural network driven fuzzy system and hybrid neural network-based systems. The hybrid neuro-fuzzy system imbibes both the quality of neural networks and fuzzy logic systems and hence seems more promising [29-30].

VI. Modeling Process For Resistance Spot Welding Process

A) Mesh Generation

The RSW process model has three surface contact areas. Contact area 1 and 2 represents the electrode work piece interference and 3 represented the faying surface between the work pieces. Fine meshes were generated between the contact surfaces for obtaining reliable results. Two dimensional axisymmetric schematic model is shown in fig.2. The developed model was meshed using three types of elements, as shown in Fig. 3. Three types of meshing element were used for model. Solid element meshing used for simulated the thermo elastic plastic behavior of the electrode and sheet metals [31-32].

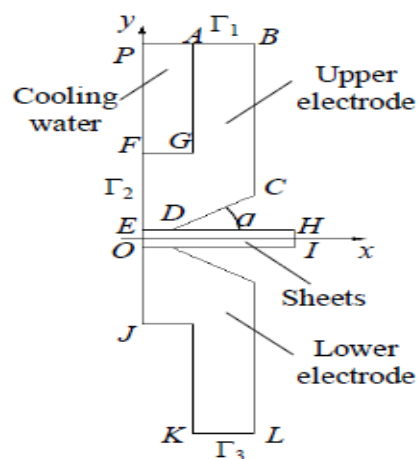


Figure 2: Schematic diagram for the model of RSW, Wang *et al.*

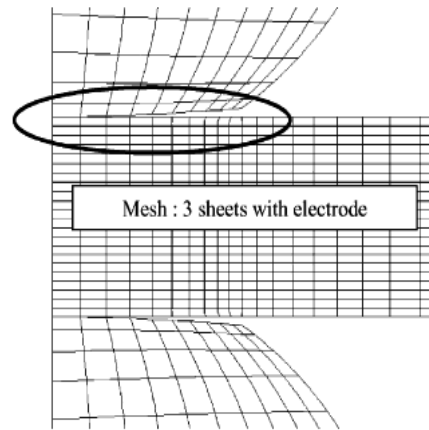


Figure 3: mesh generation of developers model.

B) Governing Equation

The governing equation for transient conduction in a two dimensional cylindrical coordinate system with internal heat generation can be stated as

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(k_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_z \frac{\partial T}{\partial z} \right) + q_v \quad (1)$$

$$[d\sigma] = [D^{ep}][d\epsilon] - [C^{th}]dT \quad (2)$$

Where

$$[D^{ep}] = [D^e] + [D^p]$$

in which, $[D^e]$ is the elastic stiffness matrix, and $[D^p]$ is the plastic stiffness matrix, $[d\epsilon]$ is the infinitesimal strain tensor, $[d\sigma]$ is the infinitesimal stress tensor, and $[C^{th}]$ denotes the thermal stiffness matrix.

The electric potential can be expressed by Quasi-Laplace equation

$$\epsilon \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial \phi}{\partial r} \right) + \epsilon \frac{\partial}{\partial z} \left(\frac{\partial \phi}{\partial z} \right) = 0$$

Where

ϵ is the electrical conductivity of material, ϕ is electrical potential [33]. The relation between electrical conductivity and electrical resistivity is given by the R

$$\epsilon = 1/R \quad (3)$$

C) Boundary Condition

A 60 Hz sine wave electrical current flow was assumed to be uniformly distributed at the top surface of the upper electrode and was permitted to flow across the contact areas at both the electrode-workpiece interfaces and faying surface between the sheets, and eventually reaching the bottom surface of the lower electrode. The simulation procedure for resistance spot welding process shown in fig. 4.

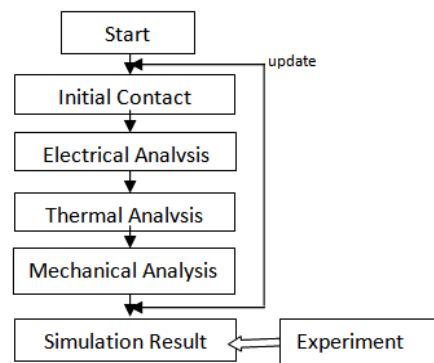


Figure 4: Simulation flow for resistance spot welding process

There are three types of thermal boundaries, temperature boundary (BC1), heat flux boundary (BC2) and heat convection boundary (BC3) defined by Eqs. (4, 5 and 6), respectively:

$$T = TBC1 \text{ at BC1} \quad (4)$$

$$q' = q'_A [J/(mm^2 s)] \text{ at BC2} \quad (5)$$

$$q' = \gamma \beta (TBC3 - T_0) \text{ at BC3} \quad (6)$$

where TBC1, q'_A , γ , TBC3, T_0 are the given temperature at BC1, heat flux at BC2, heat transfer coefficient for both convection and radiation boundary, the temperature at BC3 and the temperature of the surrounding air, respectively [33]. Temperature-dependent physical and mechanical properties of materials were used for both thermo- electrical and thermo- mechanical analysis, [34]. The electrical, thermal and mechanical boundary conditions used in the model shown in fig.5.

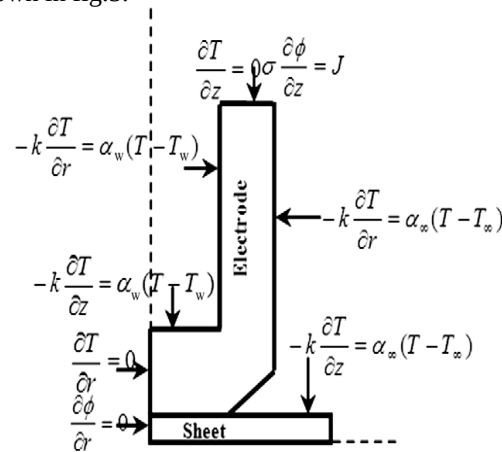


Figure 5: Schematic of the thermal and electrical boundary conditions, Esiazadeh, H.,*et. al.* [35]

VII. Conclusion

The different models used to illustrate RSW process in the last 30 years, on Finite element method and artificial intelligence technique for resistance spot welding process are presented & discussed in this paper. In most of the analysis of residual plastic strain distribution, deformation of the sheet only 2D axisymmetric electrical – thermal and thermo elastic plastic model and for nugget formation, effect of process parameters on the weld nugget size and temperature of faying surface electro-thermo-mechanical finite element (FE) models are considered. Some researchers have developed more sophisticated FEM models which considered temperature-dependent material properties, contact status, phase changing, and coupled field effects in the simulation of the RSW. Further, it was found that, the temperature distribution in the sheet metal was obtained through the electrical, thermal analysis and distribution of residual plastic strain, welding deformation after RSW was obtained through thermo-elastic-plastic analysis. There is further scope of research in three dimensional modeling and artificial intelligence technique.

References

- [1]. Richard, D., Fafard, M. R. Lacroix, M., Clery, P. and Maltais, Y. (2003) Carbon to cast iron electrical contact resistance constitutive model for finite element analysis. *Journal of Materials Processing Technology*, Vol.132, Pages 119–131.
- [2]. Zadeh, L.A. (1985), Fuzzy sets. *Inform. Control*. Vol. 8, Pages 338–353.
- [3]. Yager R. P. and Filev D.P. (1994), *Essentials of fuzzy modeling and control*. Wiley, New York, Pages 1–13.
- [4]. Ali, Y.M. and L.C. Zhang, Surface roughness prediction of ground components using a fuzzy logic approach. *Journal of Materials Processing Technology*, Vol. 89, Pages 561–568.
- [5]. Kaiser, J. G., Dunn, G. J. and Eager, T. W. The effect of electrical resistance on nugget formation during spot welding. *Welding Journal*, Vol.6, Pages 167-174.
- [6]. Holliday, R., Parker, J. D. and Williams, N. T. (1995) Electrode deformation when spot welding coated steels. *Weld. in the World*, 35(3), 160-164.
- [7]. Na, S. J. and Park, S.W. (1996) A theoretical study on electrical and thermal response in resistance spot welding, *Weld. J.* 8, 233s–41s.
- [8]. Davies, R. G., Krause, A. R. and Thornton, P. H. (1996) Contact resistances in spot welding. *Weld. J.*, 75(12), 402s–412s.
- [9]. Parker, J. D.; Williams, N. T.; Holliday, R. J. (1998) Mechanisms of electrode degradation when spot welding coated steels, *Sc. and Tech. of Welding & Joining*, 3(2), 65-74.
- [10]. Li, W., Cheng, S., Hu, S. J. and Shriver, J. (2000) Statistical investigation of resistance spot welding quality using a two-stage, sliding-level experiment. *Trans. ASME, J. Mfg Sci. Engng*, 123, 513-520.
- [11]. Cho, Y. and Rhee, S. (2003) Experimental study of nugget formation in resistance spot welding. *Weld. J.*, 82(8), 195s–200s.
- [12]. Pouranvari M. and Marashi S.P.H.(2010), Key factors influencing mechanical performance of dual phase steel resistance spot welds. *Science Technology Welding and Joining*, Vol. 15, Pages 149-155.
- [13]. Zuniga S.(1997), Resistance spot weld failure loads and modes in overload conditions.
- [14]. Fatigue and Fracture Mechanics, Vol. 27.Pages. 469–89.
- [15]. Chao Y. (2003), Ultimate strength and failure mechanism of resistance spot weld subjected to tensile, shear, or combined tensile/shear loads. *Journal of Engineering Materials and Technology*, Pages 25–32.

- [16]. Dancette. S., Febregue, D., Massardier, V., Merlin, J., Dupuy, T. and Bouzekri, M. (2011), Experimental and modeling investigation of the failure resistance of Advanced High Strength Steels spot welds. *Engineering Fracture Mechanics*, Vol. 78, Pages 2259–2272.
- [17]. Long, X. and Khanna, S. K. (2003), Numerical simulation of residual stress in a spot welded joint. *Transactions of the ASME*, Vol. 25, Pages 222-226.
- [18]. Nodeh, I. R., Serajzadeh, S. and Kokabi, A.H. (2008), Simulation of welding residual stresses in resistance spot welding, FE modeling and X-ray verification. *Journal of Materials Processing Technology*, No. 205, Pages 60–69.
- [19]. Huh, H. and Kang, W. J (1997), Electrothermal Analysis of Electric Resistance Spot Welding Processes by a 3-D. Finite Element Method. *Journal of Materials Processing Technology*, Vol.63, Pages 672-677.
- [20]. Narang, H. K., Singh, U. P., Mahapatra, M. M. and Jha P. K. (2011) Prediction of the weld pool geometry of TIG arc welding by using fuzzy logic controller. *International Journal of Engineering, Science and Technology*, Vol. 3, No. 9, Pages 77-85.
- [21]. Naso D. (2005), A Fuzzy-Logic Based Optical Sensor for Online Weld Defect-Detection. *IEEE Transactions On Industrial Informatics*, Vol. 1, No. 4, Pages 259-273.
- [22]. Amelia, L. , Wahab, D.A. and Hassan, A. Modelling of palm oil production using fuzzy expert system. *Expert Systems with Applications*, Vol. 36, Pages 8735–8749.
- [23]. Arafah L., Singh H., and S.K. Putatunda. (1999) A neuro fuzzy logic approach to material processing, *IEEE Trans. Syst., Man, Cybern.–Part C: Appl. Rev.* 29 (3), Pages 362–370.
- [24]. Boriwal, L., Mahapatra, M. M. and Biswas, P. (2012) Modelling and optimizing the effects of process parameters on galvanized steel sheet resistance spot welds. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* , Pages 226-664.
- [25]. Kandel, A.(1988) *Fuzzy Expert Systems*, 1988, Addison Wesley.
- [26]. L. Arafah, H. Singh, S.K. Putatunda (1999) A neuro fuzzy logic approach to material processing, *IEEE Trans. Syst., Man, Cybern.–Part C: Appl. Rev.* 29 (3) 362–370.
- [27]. Duraisamy, V., Devarajan, N., Somasundareswari, D., Antony Maria Vasanth, A. and Sivanandam, S. N. Neuro fuzzy schemes for fault detection in power transformer, *J. Appl. Soft Comput*, 2007, 7 (2), 534–539.
- [28]. Alimardani, M., Toyserkani, E. (2008) Prediction of laser solid free form fabrication using neuro-fuzzy method, *Applied Soft Computing*, 8, 316–323.
- [29]. Masoud Alimardani, Ehsan Toyserkani, Prediction of laser solid freeform fabrication using neuro-fuzzy method, *Applied Soft Computing*, Vol.8, Pages 316–323
- [30]. Jang J.S.R. (1993) ANFIS: Adaptive-Network-Based. Fuzzy Inference Systems, *IEEE Transactions on Systems, Man and Cybernetics*, 23(3), pp 665-685.
- [31]. Moshayedi, H. and Far, I. S., (2011), Numerical and experimental study of nugget size growth in resistance spot welding of austenitic stainless steels. *Journal of Materials Processing Technology*, 212, pages 374-354.
- [32]. Hou, Z., Kim, I. S., Wang, Y., Li, C. and Chen, C. (2007), Finite element analysis for the mechanical features of resistance spot welding process. *Journal of Materials Processing Technology*, Vol. 185, Pages- 160-165.
- [33]. Ninshu, M.A. and Hidekazu, M. (2009), Numerical and experiment study of nugget formation in resistance spot welding for high strength steel sheets for automotive bodies. *Joining and Welding Research institute*, Vol. 38, No. 2, Pages 19-24.
- [34]. ASM handbook (1990), (formerly 10th ed. and metals handbook). Properties and selection: nonferrous alloys and special-purpose materials, ASM International, Vol. 2, Pages 19–20.
- [35]. Esiazadeh, H., Hamed, M. and Ayob, H.(2010), New parametric study of nugget size of the resistance spot welding process using finite element method. *International Journal of Materials and Design*, Vol. 31, Pages 149-157.