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Review on Spot Welding of Steel sheets using different optimization methods

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Abstract

Resistance spot welding is one of the most important welding procedures.It is being modernised day by day. In earlier days we used to make spot weld by using manual spot welding machine, but now we use pneumatic spot welding machine. A lot of research is performed in thefield of optimisation of its parameters. It has very wide application in welding of 300 series stainless steel.300 Series austenitic stainless steel has austenite as its primary phase (face centered cubic crystal).These are alloys containing chromium and nickel, and sometimes molybdenum and nitrogen, structured around the Type 302 composition of iron, 18% chromium, and 8% nickel. Grade 316 is alloyed with molybdenum (~2–3%) for high-temperature strength, pitting and crevice corrosion resistance. Spot welding of stainless steel 316 grade has application in utensils making, springs, fasteners etc. In this paper work related to optimisation of spot welding parameters by various researchers (using optimisation methods like analysis of variance (ANOVA) ,Response surface methodology (RSM) , finite element method etc.) have been reviewed and categorised under three categories i.e optimisation on spot welding,optimisation on steel and optimisation by RSM. Process parameters namely electrode force weld time ,welding current and squeeze time were optimized .Researchers, applied optimisation method simultanious effect of welding parameters on adhesive strength and hardness to evaluate desired mechanical properties .It is concluded that contribution of welding current is most followed by weld time and hold time. Thus the highly effective parameter for the development of radius weld nugget and width of HAZ is the welding current.

Keywords: Resistance spot welding, Optimization, RSM, tensile strength

1. INTRODUCTION

Resistance spot welding (RSW) is widely used in sheet metal fabrication as an important joining process. It is a simple process that uses two copper electrodes to press the work sheets together and force high current to pass through it. In electric resistance spot welding, the overlapping work is positioned between the watercooled electrodes and then the heat is obtained by passing a large electrical current for a short period of time. Resistance spot welding is a widely used joining process for fabricating sheet metal assemblies such as automobiles, truck cabins, rail vehicles and home applications due to its advantages in welding efficiency and suitability for automation. For example, a modern auto-body assembly needs 7000 to 12,000 spots of welding according to the size of a car, so the spot welding is an important process in auto-body assembly.

300 Series austenitic stainless steel has austenite as its primary phase (face centered cubic crystal).These are alloys containing chromium and nickel, and sometimes molybdenum and nitrogen, structured around the Type 302 composition of iron, 18% chromium, and 8% nickel. Grade 316 is alloyed with molybdenum (~2–3%) for high-temperature strength, pitting and crevice corrosion resistance. Most commonly we use Spot welding to make welds in Stainless steel sheets. Using RSM, it is possible to evaluate simultaneous effects of many parameters on weld mechanical properties and to optimized them to achieve suitable result. Although some researchers have already applied DOE to optimize welding parameters, but no effort is yet made to perform this optimization on spot welding of stainless steel sheet grade 316 using RSM. This study is focused on the RSM optimization of some crucial welding parameters namely weld time ,welding current and squeeze time to achieve most favourable results mechanical properties.

2. Optimization Methods

Optimization is defined as the process of finding the conditions that give the minimum or maximum value of a function, where the function represents the effort required or the desired benefit. We prefer RSM method over taguchi method because RSM involves more experimentation, however it can take you closer to global optimum.

In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. This method was introduced by G. E. P. Box and K. B. Wilson in 1951. The main idea of RSM is to use a sequence of designed

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experiments to obtain an optimal response. Box and Wilson suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process.

Statistical approaches such as RSM can be employed to maximize the production of a special substance by optimization of operational factors. In contrast to conventional methods, the interaction among process variables can be determined by statistical techniques.[

An easy way to estimate a first-degree polynomial model is to use a factorial experiment or a fractional factorial design. This is sufficient to determine which explanatory variables affect the response variable(s) of interest. Once it is suspected that only significant explanatory variables are left, then a more complicated design, such as a central composite design can be implemented to estimate a second-degree polynomial model, which is still only an approximation at best. However, the second-degree model can be used to optimize (maximize, minimize, or attain a specific target for).

Response surface methodology uses statistical models, and therefore practitioners need to be aware that even the best statistical model is an approximation to reality. In practice, both the models and the parameter values are unknown, and subject to uncertainty on top of ignorance. Of course, an estimated optimum point need not be optimum in reality, because of the errors of the estimates and of the inadequacies of the model.

Nonetheless, response surface methodology has an effective track-record of helping researchers improve products and services: For example, Box's original response-surface modeling enabled chemical engineers to improve a process that had been stuck at a saddle-point for years. The engineers had not been able to afford to fit a cubic three-level design to estimate a quadratic model, and their biased linear-models estimated the gradient to be zero. Box's design reduced the costs of experimentation so that a quadratic model could be fit, which led to a (long-sought) ascent direction

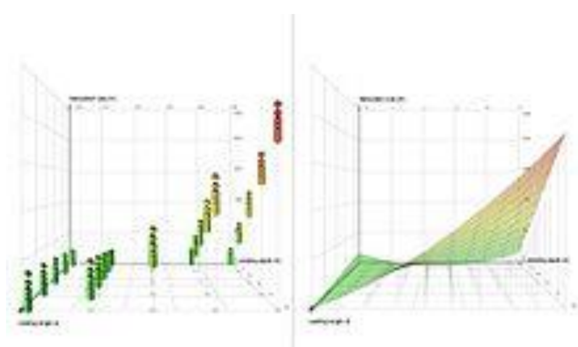

Fig Designed experiments with full factorial design (left), response surface with second-degree polynomial (right)

3. LITERATURE REVIEW

Mustafa Kemal Bilic et al. optimised welding parameters for friction stir spot welding of high density polyethylene sheets . The strength of a friction stir spot weld is usually determined by a lap-shear test. He applied Taguchi method to determine friction stir spot welding strength of HDPE sheets. An orthogonal array, the signal to noise ratio (S/N), and the analysis of variance (ANOVA) were employed to investigate friction stir welding parameter effects on the weld strength.. He concluded that the dwell time was the most dominant welding parameter for weld strength followed by the tool rotation speed. Also, the optimum welding parameters for the weld strength are the tool rotation speed of 700 rpm, the dwell time of 60 s and the tool plunge depth of 6.2 mm and the improvement in the weld strength from the initial welding parameters to the optimal welding parameters was about 40%.

Nizamettin Kahraman et al. studied the influence of welding parameters on the joint strength of resistance spot-welded titanium sheets.Commercially pure (CP) titanium sheets (ASTM Grade 2) were welded by resistance spot welding at different welding parameters and under different welding environments. The welded joints were subjected to tensile-shearing tests in order to determine the strength of the welded zones. In addition, hardness and microstructural examinations were carried out in order to examine the influence of welding parameters on the welded joints. The results showed that increasing current time and electrode force increased the tensile shearing strength and the joints obtained under the argon atmosphere gave better tensile-shearing strength. Hardness measurement results indicated that welding nugget gave the highest hardness and the heat affected zone (HAZ) and the base metal followed this.

Mustafa Kemal Bilic et al. studied effect of welding parameters on friction stir spot welding of high density polyethylene sheets The effects of the welding parameters on static strength of friction stir spot welds of high density polyethylene sheets were investigated. In lap-shear tests two fracture modes were observed; cross nugget failure and pull nugget failure. He concluded that the dwell time, tool rotational speed and the plunge depth affect the friction stir spot welding nugget formation and the strength of the joint. Optimum parameters must be used to obtain high quality welds. Melting of high density polyethylene occurred in the vicinity of the tool pin. The joint that fractures with a pull nugget failure mode has a higher strength. The plunge rate of the tool has a negligible effect on the joints strength

Zhaohua Zhang et al**.** studied the effect of welding parameters on microstructure and mechanical properties of friction stir spot welded 5052 aluminum alloy . In the study, two types of FSSW, normal FSSW and walking FSSW, were applied to join the5052-H112aluminum alloy sheets of 1 mm thickness and then the effect of the rotational speed and dwell time on microstructure and mechanical properties was discussed.The results of tensile/shear tests and cross-tension tests indicated that the joint strength decreased with increasing rotational speed, while it's not affected significantly by dwell time. At the rotational speed of 1541 rpm, the tensile/shear strength and cross-tension strength reached the maximum of 2847.7 N and 902.1 N corresponding to the dwell time of 5 s and 15 s.

R.S Flore et al. studied welding parameters influence on fatigue life and microstructure in resistance spot welding of 6061-T6 aluminum alloy.Three welding conditions, denoted as ''nominal'', ''low'' and ''high'', were studied to determine the microstructure of the weld nuggets. The process optimization included consideration of the forces, currents and times for main weld and post-heating.. This work revealed that the welding process parameters have a great influence in the microstructure and fatigue life of the2 mm-thick aluminum sheet resistance spot welded joints. Different fatigue failure modes were observed at several load ranges and ratios for a constant frequency and three welding current

Hongxin Sh et al. evaluated effects of welding parameters on the characteristics of magnesium alloy joint welded by resistance spot welding with cover plates.Magnesium alloy AZ31B sheets were welded using the technique of resistance spot welding with cover plates. The effects of welding parameters on the characteristics of the joint were investigated. The joint with larger nugget and higher tensile shear load was obtained under relatively low welding current condition. Enhancing electrode force and extending down-sloping time are effective for inhibiting pores formation and increasing the tensile shear strength of the joint under corresponding welding conditions. He also concluded tha extending down-sloping time is more effective than enhancing electrode force when down-sloping time is below 10 cycles in the respect of increasing tensile shear strength of the joint.

Hamid Eisazadeh et al. did work on new parametric study of nugget size in resistance spot welding process using finite element method . 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 the research, a mechanical–electrical–thermal coupled model in a finite element analysis environment was made using. Via simulating this process, the phenomenon of nugget formation and the effects of process parameters on this phenomenon were studied. He concluded that if the electric current flow exceeds the flow necessary for nugget growth ,it causes a rapid growth of nugget. The nugget growth rate decreases as the current flow increases but the nugget size raises until melt spattering occurs. Therefore. Increasing electric cycles remarkably raises the contact surface temperature so that the contact zone melts leading to a big nugget but no melt spattering occurs.

Zhigang Hou et al. did finite element analysis for the mechanical features of resistance spot welding process .In the paper, a 2D axisymmetric model of thermo-elastic–plastic finite element method (FEM)was developed to analyze the mechanical behavior of resistance spot welding (RSW) process using commercial software ANSYS. A transient temperature field obtained from a prior performed thermal–electrical simulation of RSW process was applied as nodal load on the model. The distributions and changes of the contact pressure at both the faying surface and the electrode– workpiece interface were obtained through the analysis. The stress and strain distributions in the weldment and their changes during the RSW process were determined. The deformation of the weldment and the electrode displacement were also calculated.

Uğur Eşme investigated effect and optimization of welding parameters on the tensile shear strength in the resistance spot welding (RSW) process. The experimental studies were conducted under varying electrode forces, welding currents, electrode diameters, and welding times. The settings of welding parameters were determined by using the Taguchi experimental design method. The level of importance of the welding parameters on the tensile shear strength is determined by using analysis of variance (ANOVA). Based on the ANOVA method, the highly effective parameters on tensile shear strength were found as welding current and electrode force, whereas electrode diameter and welding time were less effective factors. The results showed that welding current was about two times more important than the second ranking factor (electrode force) for controlling the tensile shear strength.

A.B.Verma et al In the paper ASS 304 and ASS 316 is used and its tensile strength and hardness was studied by using Taguchi approach and ANOVA while microstructure was studied by Schaeffer diagram. Tensile shear strength for different grades of Austenitic Stainless Steels (AISI304 to AISI316) was found to be comparatively more than compared with similar sheets (AISI304 to AISI304 and AISI316 to AISI316). Weld current is major governing factor affecting the tensile shear strength of the resistance spot welded specimens. As the weld current increases, size of weld nugget also increases. This results into increased values of tensile-shearing strength.

Mohsen Eshragh et al. studied effect of resistance spot welding parameters on weld pool properties in a DP600 dual-phase steel: A parametric study using thermo mechanically-coupled finite element analysis. The effects of the RSW parameters on weld properties were investigated within a design of experiments framework by altering (1) the electrical current intensity, (2) the welding time, (3) the sheet thickness, (4) the electrode face radius, and (5) the squeeze force at multiple levels. The simulation results were analyzed using the analysis of variance (ANOVA) technique .The current intensity was the most influential factor and resulted in an increased size of molten zone and the heat affected zone. The sheet thickness and welding time also showed significant contributions in changing the weld properties. The effects of the other parameters were less significant.

S. Aslanlar et al. studied the effect of welding current on mechanical properties of galvanized chromided steel sheets in electrical resistance spot welding.In the study, the effect of welding current on the quality of weld joint and obviously on tensile-shear and tensile-peel strengths of galvanized chromate steel sheets having 1.2 mm thickness in electrical resistance spot welding was investigated. A timer and current controlled electrical resistance spot welding machine having 120 kVA capacity and pneumatic application mechanism with a single lever was used to prepare the specimens. Welding periods were chosen as 5, 10, 12 and 15 cycles and also welding currents were increased from 4 kA up to 12 kA by rise of 1 kA. The electrode force was kept constant at 6 kN. The prepared welding specimens were exposed to tensile-shear and tensile-peel tests.He concluded that in the joining of galvanized chromate steel sheets, maximum tensile-shear strength is obtained at 10 kA welding current in 15 cycles.Maximum tensile-peel strength is obtained at 11 kA welding current in 10 cycles. This value is approximately half of the one obtained in tensile-shear strength, which shows the sensitivity of galvanized chromate sheets welded by electrical resistance spot welding to tensile-peel tests.

Danial Kianers et al performed resistance spot welding joints of AISI 316L austenitic stainless steel sheets and studied Phase transformations, mechanical properties and microstructure characterizations .His aim was to optimize welding parameters namely welding current and time in resistance spot welding (RSW) of the austenitic stainless steel sheets grade AISI 316L. Afterward, effect of optimum welding parameters on the resistance spot welding properties and microstructure of AISI 316L austenitic stainless steel sheets has been investigated. Phase transformations that took place during weld thermal cycle were analyzed in more details including metallographic studies of welding of the austenitic stainless steels. Metallographic images, mechanical properties, electron microscopy photographs and micro-hardness measurements showed that the region between interfacial to pullout mode transition and expulsion limit is defined as the optimum welding condition.

A.M. Oladoy et al. optimised pack chromised stainless steel for proton exchange membrane fuel cells bipolar plates using response surface methodology.Stainless steel as low cost materials, are attractive for proton exchange membrane fuel cells (PEMFC) bipolar plates. However, these metallic alloys require surface coatings or treatments to enhance its corrosion resistance and surface conductivity in PEMFC environments. In this study, response surface methodology based on Box– Behnken design was employed to investigate the influence of time, activator content and temperature on corrosion current density of pack chromised 304 stainless steel in simulated PEMFC environment of aerated 0.5 M H2SO4 + 2 ppm HF at 70 °C. These process parameters were optimised and the performance of the optimised coatings in simulated and real PEMFC environments was investigated. The results indicated that temperature had the most significant influence on the performance of chromised coatings in the selected PEMFC environment.

Óscar Martín et al .did work on quality assessment of resistance spot welding joints of AISI 304 stainless steel based on elastic nets.In the work, the quality of resistance spot welding (RSW) joints of 304 austenitic stainless steel (SS) was assessed from its tensile shear load bearing capacity (TSLBC). The results showed that the predictive and classification error of the elastic net model are statistically comparable to benchmarks of the best pattern recognition tools whereas it overcomes correlation problems and performs variable selection at the same time, resulting in a simpler and more interpretable model. These features make the elastic net model amenable to be used in the design of welding conditions and in the control of manufacturing processes.

Qiuyue Fan et al studied expulsion characterization of stainless steel resistance spot welding based on dynamic resistance signal.The effects of different expulsion conditions on the dynamic resistance and weld tensile-shear strength under shop expulsion conditions in resistance spot welding were investigated. Expulsion may occur more than once in a weld based on an analysis of the dynamic resistance. It was exposed that the expulsion dynamic resistances are similar and the tensile-shear strength values are close to each other and increasing with the welding current if the weldment surface is in good condition. When the surface is contaminated, both the dynamic resistances and the corresponding tensile-shear strength values exhibit random behavior. The relationship between expulsion parameters, specifically the first expulsion time and the number of expulsions, and welding parameters, specifically welding current and electrode force, could be used as a feedback signal for quality control.

M. Pouranvari et al. evaluated fracture toughness of martensitic stainless steel resistance spot welds.The paper is focused on the strength and fracture toughness of AISI420 martensitic stainless steel resistance spot welds under the tensile-shear loading. The failure behavior of AISI420 spot welds was featured by quasicleavage interfacial failure with low load bearing capacity and weak energy absorption capability which was a function of the weld fusion microstructure, predominately carbon and chromium rich martensite plus δ-ferrite. Fracture toughness of the fusion zone proved to be the most important factor controlling the peak load of the spot welds made on AISI420 failed in interfacial mode. A geometry-independent fracture toughness of the weld nugget (c.a. 23 MPam0.5) was determined using fracture mechanics concept..

M. Alizadeh-Sh et al. did resistance spot welding of AISI 430 ferritic stainless steel and studied phase transformations and mechanical properties ..He concluded (1) Fusion zone is featured by columnar ferrite grains and fine dispersion of carbide precipitates with some amount of martensite phase at ferrite grain boundaries. (2) The HAZ is divided to three distinct zones: high temperature HAZ (corresponding to d-ferrite region of phase diagram), medium temperature HAZ (corresponding to d + c region of phase diagram) and low temperature HAZ (corresponding to d + c + carbide region of phase diagram) based on the different metallurgical transformations that occur in each zone. The HTHAZ exhibited a martensite-free ferritic microstructure with excessive grain coarsening due to the high temperature experienced at this zone and the absence of the elevated austenite to pin the grain boundaries.. (3) All samples studied there failed in double pullout failure. It is worth mentioning that despite the fact that grain growth which occurred in FZ and HTHAZ, is a major problem accompanied with fusion welding of FSSs (that adversely affects the mechanical properties), the fracture occurred at BM instead.

Norasiah Muhammad et al. did work on optimization and modeling of spot welding parameters with simultaneous multiple response consideration using multi-objective Taguchi method and RSM.The optimization approach attempts to consider simultaneously the multiple quality characteristics, namely weld nugget and heat affected zone (HAZ), using multi-objective Taguchi method (MTM). The experimental study was conducted for plate thickness of 1.5 mm under different welding current, weld time and hold time. The optimum welding parameters were investigated using the Taguchi method with L9 orthogonal array.. He concluded (1) Multiple characteristics such as radius of weld nugget and width of HAZ can be simultaneously considered using multi-objective Taguchi method. (2) The contribution of different control factors is welding current (73.91%), weld time (16.72%) and hold time (7.14%). The highly effective parameter for the development of radius weld nugget and width of HAZ is the welding current. (3) The optimum parameters for nominal weld nugget and smaller HAZ size are: welding current at level 3 (6.0 kA), weld time at level 3 (14 cycles) and hold time at level 3 (4 cycles).

Norasiah Muhammad et al. did work on model development for quality features of resistance spot welding using multi-objective Taguchi method and response surface methodology. The experimental study was conducted under varied welding current, weld time and hold time. To validate the predicted model, experimental confirmation test was conducted for plate thickness of 1 and 1.5 mm. Based on the results, the developed model can be effectively used to predict the size of weld zone which can improve the welding quality and performance in RSW.

V.E. Beal et al. Optimised processing parameters in laser fused H13/Cu materials using response surface method (RSM) .. The analyses showed that cracks and porosity were reduced successfully. Regression analyses were performed on both methods in order to predict the defects model. The optimised process parameters reduces the cracks and porosity from 15.32 to 2.54%. Microhardness tests on both specimens produced using default and the optimised parameters shows no difference.

Dawei Zhao et al. did multi-objective optimal design of small scale resistance spot welding process with principal component analysis and response surface methodology.The paper investigated the effects of welding parameters on the welding quality and optimizes them in the small scale resistance spot welding (SSRSW) process. Experiments were carried out on the basis of response surface methodology technique with different levels of welding parameters of spot welded titanium alloy sheets. Multiple quality characteristics, namely signal-to-noise(S/N)ratios of weld nugget diameter, penetration rate, tensile shear load and the failure energy, were converted into an independent quality index using principal component analysis. The mathematical model correlating process parameters and their interactions with the welding quality was established and discussed. And then this model was used to select the optimum process parameters to obtain the desired welding quality.

Dawei Zhao et al. Process analysis and optimization for failure energy of spot welded titanium alloy.. Seventeen tests were designed according to the three-level three-facto r Box–Behnken experimental design and the mathematical model correlating the process parameters and the failure energywas established on the basis of response surface methodolog y (RSM) technique. And then this model was used to analyze the effects / interactions of the welding parameters on the failure energy. The verification test results which were conducted with completely new welding parameters verified that the model presented in this paper was effective and robust. Sensitivity analysis was also carried out to explore the impact of each process parameter on the quality of welding joint. The optimal combination of process parameters for maximum failure energy of the welded joint was obtained using the model based on artificial fish swarm algorithm (AFSA).

S.M. Darwish et al. did work on statistical models for spot welding of commercial aluminium sheets. Experiments were carried out to study the influence of spot welding parameters (welding current, welding time, electrode force and sheet thickness) on the strength of spot welded aluminum sheets with commercial purity. Experiments were planned on the basis of response surface methodology (RSM) technique. The mathematical models (failure load and nugget area) correlating process parameters and their interction with response parameters have been established. These model have been used in selecting the optimum process parameters for obtaining the desired spot welding quality at the least possible consumed power.

Yujiang Xiang et al. Optimal crashworthiness design of a spot- welded thin- walled hat section.In automotive industry, crashworthiness design is of special interest to ensure passengers safety and reduce vehicle costs. Based on comparisons to experimental data, an appropriate spot- weld model is selected and used in numerical simulations. The mass of the beam is optimized subjected to constraints of required mean crushing force and bending stiffness. A “Twostep RSM-Enumeration” algorithm is employed to efficiently solve this optimization problem of mixed- type variables.

4. Summary

This paper shows the efficient use of optimisation methods l(ike Response Surface Methodology,ANOVA,Finite Element Method etc) in order to optimise spot welding parameters like electrode force,weld time,squeeze time and weld current.Based on the discussion made above it is very clear that contribution of welding current is most, followed by weld time and hold time . Thus the highly effective parameter for the development of radius weld nugget and width of HAZ is the welding current. Increase in current intensity resulted in increased size of molten zone and the heat affected zone. Hardness of the welded zone is greater than the hardness of the unwelded zone for 300 series stainless steel. The sheet thickness and welding time also showed significant contributions in changing the weld properties. The effects of the other parameters were less significant. The joint with larger nugget and higher tensile shear load was obtained under relatively low welding current condition.

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