Model development for quality features of resistance spot welding using multi-objective Taguchi method and response surface methodology

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Introduction

The use of Design of Experiment (DoE) in different applications has grown recently (Ghoreishi and Atkinson 2002; Ghoreishi et al. 2002; Benyounis et al. 2008; Ghoreishi 2006). DoE is a scientific method for identifying the parameters associated with a process and thereby determining the optimal settings for the process parameters for enhanced performance and capability. To predict the welding parameters accurately without consuming time, materials and labour effort, there are various methods of obtaining the desired output variables through models development. Using appropriate statistical technique such as Taguchi Method (TM), the number of necessary experiments can be reduced and the statistical significance of parameters can be safely identified.

In general, optimization is the process of estimating the potential minimum value of machining performance at the optimal point of process parameters. Some researchers carried out investigations dealing with machining parameters modeling and optimization to determine the optimal values of the process. An intelligent approach for process modeling and optimization of Electric Discharge Machining (EDM) was reported by Joshi and Pande (2011). Process modeling using Finite Element Method has been integrated with soft computing technique and Genetic Algorithm (GA) to improve prediction of the model. The proposed integrated approach was found efficient and robust as the suggested optimum process parameters can give the expected optimum performance of the EDM process. Another work using combined modeling function of fuzzy inference with the learning ability of Artificial Neural Network (ANN) for modeling the flank wear of cryogenically treated AISI M2 high speed steel tool was presented by Gill et al. (2012). It was determined that the prediction showed a good agreement with the experimental data. Another approach is using Simulated Annealing
and GA techniques to estimate optimal process parameters of machining performance which was investigated by Mohd Zain et al. (2011). The authors found out that the proposed integration systems were managed to estimate the optimal process parameters, leading to the minimum value machining performance when compared to the experimental data.

In welding process, literature reports that work has been done on various aspects of modeling and optimization in order to determine the welding input parameters that lead to the desired weld quality. TM approach has been applied by Anawa and Olabi (2008) to optimize the laser welding process of dissimilar material with the same thickness. The experimental results indicated that the process could be optimized using TM in order to obtain superior welded joints. Response Surface Methodology (RSM) was applied by Kolcova (2005) to establish the relationship between performance characteristics and their influencing factors. A new statistical approach was proposed to choose the focus position at a condition of maximum thermal efficiency and welding depth. Application of RSM for predicting weld bead quality in submerged arc welding of pipes was investigated by Gunaraj and Murugan (1999). The authors found out that the proposed method are useful for predicting the weld bead quality and selecting optimum process parameters for achieving the desired quality and process optimization. A mathematical model has been developed to predict the tensile strength of friction stir welded AA6061 aluminum alloy joint by incorporating welding parameters and tool profiles using RSM and this was presented by Elangovan et al. (2009). The developed mathematical model can be effectively used to predict the tensile strength of Friction Stir Welding (FSW) joints at 95% confidence level. The used of TM and regression analysis in order to optimize Nd-YAG laser welding parameter to seal an iodine-125 radioisotope seed into a titanium capsule was studied by Thakur et al. (2010). The confirmation experiments were conducted at the optimal welding conditions, the results showed that the titanium tube ends were sealed perfectly. A modified TM to analyze the effect of welding process parameter on the weld pool geometry and then to determine the TIG welding process parameters combination associated with the optimal weld pool geometry was adopted by Juang and Tarng (2002). The authors reported that the quality characteristics were greatly improved by using this approach.

The following are reviews of some works that have been carried out for modeling and optimization in the Resistance Spot Welding (RSW) process. The investigation on the optimization and the effect of welding parameters on the tensile shear strength of spot welded galvanized steel sheet was presented by Thakur and Nandedkar (2010). The authors found that it is possible to increase tensile shear strength significantly using the proposed statistical technique. Investigation on the optimization and effect of welding parameters on the tensile shear strength of spot welded SAE 1010 steel sheet using Taguchi method was reported by Esme (2009). The author concluded that TM can be effectively used for optimization of spot welding parameters. A mathematical model for predicting the nugget diameter and tensile shear strength of galvanized steel was developed by Luo et al. (2011) using nonlinear multiple regression analysis and ANN approach. According to the prediction models, the prediction systems of welding process parameters were formulated in order to obtain the desired welding quality. A systematic approach to determine the effect of process parameters on tensile shear strength of resistance weld joint of austenitic stainless steel AISI 3040 using Taguchi Method was studied by Thakur and Nandedkar (2010). The confirmation test was conducted and the result shows it was within 95% confidence interval of predicted optimal value of selected parameters. The use of Taguchi’s loss function analysis to a spot welding process in order to discover the key process parameters which influence the tensile strength of welded joints was investigated by Rowlands and Antony (2003). The purpose of this research was to illustrate an application of DoE to a spot welding process.

Various techniques have been developed for solving multiple objective optimization problems. One of the techniques is the weighted additive utility function (Malakooti 2000, 2010, 2011). In this approach, the objective values of different objectives are combined to form a single objective function that represents the utility of each alternative. Multiple objective optimization deals with identifying a compromising solution that simultaneously satisfies multiple objectives (Li et al. 2012; Berrichi et al. 2009). Another technique for multi-objective optimization is using Taguchi Quality Loss function which was presented by Aslan (2008). The results show considerable improvement in both the quality characteristics, as compared to the initial value. The MTM approach is also reported by Dubey and Yadava (2008a) for the optimization of laser beam cutting process. The authors found that the quality characteristics were improved considerably.

The design of experiment based studies on RSW process so far have been mainly aimed at the optimization of the single quality characteristic at a time. As the main objective of manufacturing process is always to improve the overall quality of a product, it is necessary to optimize multiple quality characteristics simultaneously. RSW is one of the most important manufacturing processes in automotive industry for assembling bodies. Quality and strength of the welds are defined by the quality of the weld nuggets (Eisazadeh et al. 2010). The quality is best judged by the nugget size, Heat Affected Zone (HAZ) and joint strength (Thakur et al. 2010). Therefore, it is of important to select the welding process parameters for obtaining optimal size of the weld nugget. Simultaneous consideration of multiple responses approach has yet not been explored in the study of RSW process using