Modelling the resistance spot welding of galvanized steel sheets using Fuzzy logic controller

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Abstract- The paper present the fuzzy logic based simulation for the resistance spot welding process, which is capable to predict the nugget size, tensile shear strength, and peel strength. Welding current, weld cycle and electrode pressure are taken as the process variables for RSW process. The experimental data were used for construction a fuzzy logic model to predict the effect of the input variables on the responses. The fuzzy model was also tested for a number of test cases to establish its adequacy. The error in predicting the outputs for the input data was within acceptable limits indicating the adequacy of the model to be used for complex processes like RSW.

Keywords: RSW welding, Fuzzy Logic Controller, Nugget size, tensile shear strength, tensile peel strength.

I. INTRODUCTION

Resistance spot welding (RSW) is one of the widely used joining processes in sheet metal fabrication and auto mobile industries. There are thousands of spot welds on an automobile body, so RWS is an important process in auto mobile industries [1]. The metal sheets intended to be welded using RSW are held together by the electrode pressure and current of very high magnitude (often in kA) is applied. The weld produced by an RSW process is commonly known as the nugget. The effect of electrical resistance on nugget formation with respect to the process variables has been studied [2]. The coating of steels can pose a problem during RSW especially if the coating material has a lower melting temperature and thus melts and vaporizes before the welding of the steel sheets can occur. Hence, coated steels such as galvanized steels need to be welded with care using appropriate process variables in order to prevent excessive degradation of the electrodes and defective welds. The characteristics of electrode radial wear and axial wear were compared with between DP600 and uncoated steels [3-4]. The quality of spot welds generally is checked by either destructive or non-destructive methods. The strength of the spot welded joints is usually determined by the tension shear and tension tests, that used here being the shear tension test. Fuzzy logic modelling method is one of the artificial intelligence (Al) techniques which have been in use for the modelling of manufacturing process such as machining and welding [5-6].The fuzzy logic model had developed for select drilling speeds for different material. [7]. Decision-making fuzzy control and Stability analysis of fuzzy systems are proposed in [8]. General treatments of fuzzy set theory, fuzzy logic, and fuzzy systems can be found in several [9]. Rule base fuzzy inference system had developed to study the hardness of sintered high speed steel [10]. No studies have been carried out on the fuzzy rule base inference system for predict the RSW response. Theory of fuzzy sets was proposed by L. A. Zadeh in 1965 [11]. Fuzzy logic is one of the artificial intelligence techniques. It is applicable in different area of science and engineering.

The aim of this study is construct rule base fuzzy logic model for predict the RSW response (Nugget size, Tensile shear strength and Tensile peel strength) with respect to process parameters such as welding current, weld cycle and electrode pressure.

II. FUZZY MODEL

Fuzzy system structure has four modules as show in fig.6. A fuzzifier that convert crisp input in to fuzzy value. Linguistic variables are defined as the variables whose values are sentences in natural language (such as low, medium and high) and can be represented by fuzzy sets [14]. The structure of three inputs, three outputs fuzzy logic controller developed for present research.

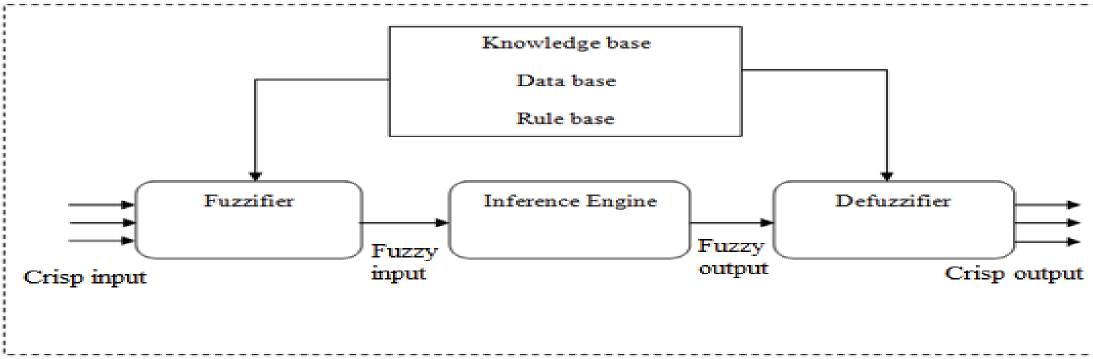


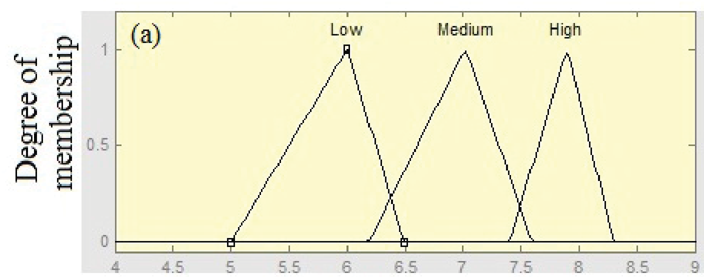
Fig. 6 General structure of fuzzy logic control system

Fuzzy logic controller use mamdani approach and contained a rule base model. This rule base comprised of groups of rules and each output was defined by 27 rules. Hence total numbers of rules for the three outputs such as nugget size, tensile shear strength and peel strength were 81. Table no. show the rule based on knowledge to predict the three output variables. The fuzzy rule base consists of a group of if–then control rules with the three input variables and three output variables that is:

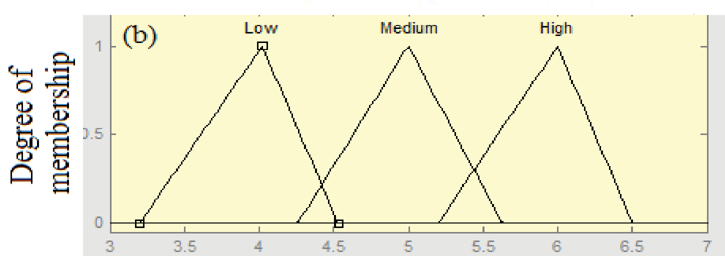
Rule 1: if x_1 is A_1 and x_2 is B_1 and x_3 is C_1 then y is O_1 else
Rule 2: if x_1 is A_1 and x_2 is B_1 and x_3 is C_1 then y is O_2 else
Rule 2: if x_1 is A_1 and x_2 is B_1 and x_3 is C_1 then y is O_3 else

Rule n: if x_1 is A_n and x_2 is B_n and x_3 is c_3 then y is C_n.

Where x_1, x_2 and x_3 are fuzzy input variables and O_1, O_2 and O_3 are fuzzy labels of fuzzy set (Low, Medium and High). The triangular membership function is linear, was used for three input variables such as welding current, weld cycle, electrode pressure to predict the RSW output variable nugget size, tensile shear strength and peel strength. The membership function for all inputs variables were divided in the three levels (Low, Medium, and High) which is shown in Fig.8 .



(a) Welding Current (kA)



(b) Weld Cycle

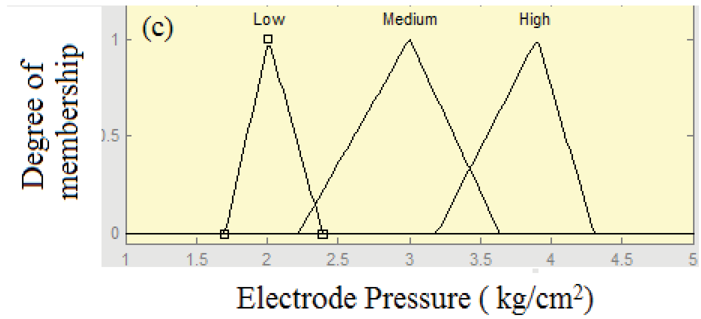


Fig.8 Membership function for input process parameters: (a) Welding current; (b) Weld cycle; & (c) Electrode pressure

In this paper, the fuzzy logic model was simulated for test cases which have been made between the fuzzy set ranges. The experiments were conducted for 3 levels of process variables such as welding current (6, 7.11 & 7.9 ampere), Weld cycle (4, 5 & 6) and electrode pressure (2, 3 & 4 kg/cm^2). The fuzzy logic model has been developed based on 27 experiments of RSW process variables. A MATLAB, Simulink model was prepared to call the output variables of RSW. The model developed was verified with a set of 12 input data for observing the predicted turnout. The predicted output of the model to test case data was further compared with the experimental output. The maximum percentage of error for prediction for peel strength was observed to be 17.44. The developed fuzzy logic model has been validated by the experiments and test case of resistance spot welding of steel sheet. Detail of the experiments is given below.

III. Experiment and Result

The test set for this evaluation experiment watermark image randomly selected from the internet. Matlab 7.0 The resistance spot welding was carried out using a constant-alternating current resistance welding machine. In the literature it is observed that electrode wearing occurred during the resistance welding of galvanized steel sheets. Because of zinc having a low melting temperature which results in it evaporating thereby affecting the surface quality of the electrode. Also, zinc fumes spoil the boundaries of the electrode tip. Each spot welding gives rise to the possibility of electrode wear. Hence the electrode diameter was checked each time before start welding operation. The electrode was ground, cleaned of scales and made to the desired diameter before each welding. A set of electrodes were kept ready with similar diameter to be used for welding. A schematic of the process and machine used and used for the experiment is shown in Figure 1. The electrode was cooled by circulating water during the entire period of the welding process. The thickness of the galvanized steel sheet used in the experiments was 0.8mm. The specimens were prepared with 100 X 30X 0.8 mm in size as shown in Figure 2. Sheet surfaces were cleaned with a dry air jet before RSW. Trial runs were initially conducted for spot weld to set the levels of three welding input process parameters such as welding current, weld cycle and electrode pressure. These parameters were set in the microcomputer for welding. Overlapped sheets (by 30 mm, Figure 2) were placed between the two electrodes centre which was marked on the specimens to set the electrode face for producing spot welds at the centre.

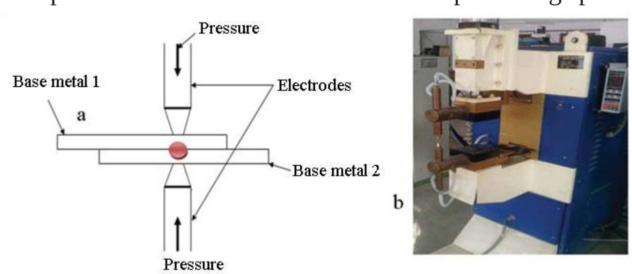


Fig. 1 Schematic view of (a) the process, (b) the machine

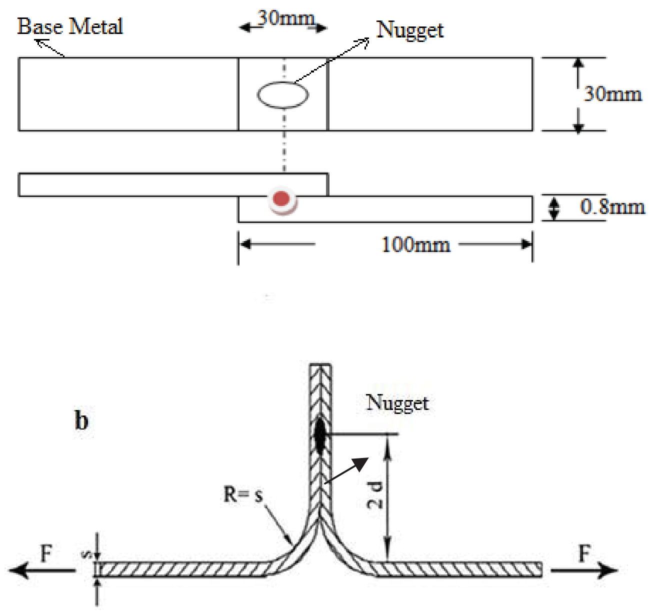


Fig. 2 Schematic illustration of a weld specimen

The chemical composition of the galvanized steel sheet material is given in Table 1. The schematics of the specimens used for testing strength are shown in Figure 2. Copper alloy was as the electrode material in the experiments. Chemical composition of the electrode material is shown in Table 2. Experiments were conducted for 27 test samples to obtain data for building the fuzzy logic model. Test case study of galvanized steel sheet was done with same experimental procedure expect the values of process parameters used in the design matrix. Process parameters for the test cases are shown in Table 4.

Table 1 Chemical composition (%) of steel sheet used in experiment

C	Mn	S	P	Si	Cr	Ni	Mo	Cu	Nb	Fe
0.115	0.39	0.017	0.018	0.065	0.017	0.032	0.004	0.051	0.001	Base

Table 2 Chemical composition of electrode used in experiment

Al	Mg	Cu%	Si	P
0.6353	0.0768	99.065	0.1954	0.0272

Table 4 Process parameter for test case

Sl. No	Welding current (kA)	Welding cycle	Electrode pressure (kg/cm^2)
1	6.66	4	2.6
2	6.66	5	3.2
3	6.66	5	3.4
4	6.66	5	3.6
5	6.66	6	3.6
6	7.02	4	2.6
7	7.02	4	2.8

8	7.02	5	2.8
9	7.02	5	3.2
10	7.02	6	3.6
11	7.8	4	3.6
12	7.8	5	3.6
13	7.8	6	3.6

Table 5 Predicted and measured values of the outputs in the test cases

	Nugget size (mm)			Tensile shear strength (kN)			Tensile peel strength (kN)		
Sl. No	Measured (mm)	Predicted (mm)	Error (%)	Measured (kN)	Predicted (kN)	Error %	Measured (kN)	Predicted (kN)	Error %
1	1.95	1.815	6.923	2.6	2.262	13	1.37	1.311	17.44
2	3.09	3.436	11.197	3.8	3.532	7.052	1.88	1.664	11.489
3	3.1	3.452	11.354	3.6	3.494	2.944	1.75	1.655	5.428
4	2.92	3.416	16.986	3.3	3.412	3.393	1.65	1.612	2.303
5	3.89	3.436	2.234	4.52	4.583	1.39	2.128	2.278	7.048
6	1.88	1.834	2.446	2.2	2.267	3.045	1.09	1.121	2.844
7	1.76	1.83	3.977	2.15	2.2	2.325	1.075	1.122	4.372
8	3.01	3.324	10.43	3.25	3.55	9.23	1.6	1.659	3.687
9	2.89	3.2	10.72	4	3.54	11.5	1.9	1.668	12.21
10	3.68	3.435	6.657	4.1	4.582	11.756	2.09	2.275	8.851
11	3.58	3.431	4.162	3.3	3.433	4.03	1.52	1.664	9.473
12	3.89	3.542	8.946	3.9	3.533	9.41	1.95	1.754	10.051
13	4.5	4.77	6	4.42	4.582	3.665	2.19	2.278	4.018

IV.CONCLUSION

An Fuzzy logic model was developed for the RSW process and the developed model was used to predict the nugget Size, tensile strength and peel strength in terms of the three inputs welding current, weld cycle and electrode pressure of RSW process. In this research RSW outputs (Nugget size, tensile shear strength and Peel strength) have been successfully predicted for full factorial design experimental data and for test case. The developed fuzzy model was also tested for a number of test cases, the input data of which was not used in the building the fuzzy logic model. The error in predicting the outputs for the input data was within acceptable limits indicating the adequacy of the model to be used for complex processes like RSW.

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