ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 11, Issue 3, 2019

AN ANALYSIS OF OPTIMUM PROCESS PARAMETERS USING FUZZY LOGIC AND REGRESSION ANALYSIS

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ABSTRACT:

Solving complex systems can be efficiently achieved through the application of Fuzzy models. The Taguchi design of experiments enables the identification of optimal parameters for a process with a reduced number of experiments. Regression analysis serves as a valuable tool for modelling and analysing the relationships among various influential variables and a dependent variable. In this paper, our primary emphasis lies on employing the traditional Taguchi approach, Fuzzy logic, and Regression analysis methods to determine the optimal process parameters. We undertake a comparative analysis of the results obtained through these three methods. The findings reveal that Fuzzy rule-based models yield values that closely align with experimental data compared to other conventional approaches.

Keywords: Fuzzy logic, Regression analysis, Taguchi approach, Tensile strength, ANOVA.

1. INTRODUCTION:

Taguchi's proposed experimental design methods have become a potent tool for enhancing product quality, particularly in engineering and sciences. Process control, whether manual or automatic, is a common practice, and Fuzzy logic has emerged as a modern control method for addressing complex processes. Initially conceptualized by Zadeh, Fuzzy logic's foundations were further developed by Mamdani, Assilian, and other scholars who introduced linguistic and membership functions for selected process parameters. Noteworthy studies include Aengchuan and Phruksaphanrat's (2013) exploration of fuzzy logic models in inventory system design and Sudha Hatagar's (2015) investigation into a fuzzy logic model for a washing

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 UGC CARE Listed (Group -I) Journal Volume 11, Issue 3, 2019

machine. Pratap Singh et al. (2016) conducted an interesting study on optimizing the process parameters for friction stir welding joints using the Taguchi method. They considered tool rotation speed, welding speed, and tool geometry as input parameters, generating test data for all possible combinations to observe the output response, namely, tensile strength. Buddi et al. (2018) derived optimum process parameters using soya meal adhesive, while Venkata Ratnam et al. (2017) explored a forecasting model using fuzzy logic. Ganguly and Patil (2019) developed an X-bar control chart for multi-objective economic-statistical design. Given that tensile strength significantly influences product life, manufacturers aim to provide higher grades at a lower cost. Pratap Singh et al.'s (2016) experimental work helps identify the optimum process parameters for the tensile strength of friction-stir-welded AA7075-10%wt. SiC composite joints. The study focused on three input parameters—tool rotation speed, welding speed, and tool geometry—with three specified levels for each parameter, resulting in 27 required test runs. The objective was to compare fuzzy logic control with traditional approaches such as Taguchi and Regression modeling, demonstrating that experimental results are closer to fuzzy logic than other methods, using the data from Pratap Singh et al. (2016).

2. Methodology:

Pratap Singh et al. (2016) comprehensively detailed the Friction Stir welded AA7075-SIC composite joints and their associated process. In conducting this investigation, we opted for three input parameters: Tool rotation speed (A), Welding speed (B), and Tool geometry (C), which were considered as inputs for the proposed models. The output variable was Tensile strength (MPa). MATLAB's Fuzzy Logic Toolbox was employed for the process control fuzzy inference system model to calculate Tensile strength. Aligning with Sudha and Halase's approach (2015), we determined the values of process parameters for applying the fuzzy logic controller. We established a straightforward set of rules for the fuzzification process. The subsequent analysis was carried out using MATLAB (2020a) following the defined rules.

Rule1: If (Rotational speed is low) and (Welding speed is slow) and (Tool Geometry is Square) then Tensile strength is Medium.

Rule 2: If (Rotational speed is low) and (Welding speed is slow) and (Tool Geometry is Hexagonal) then Tensile strength is Weak.

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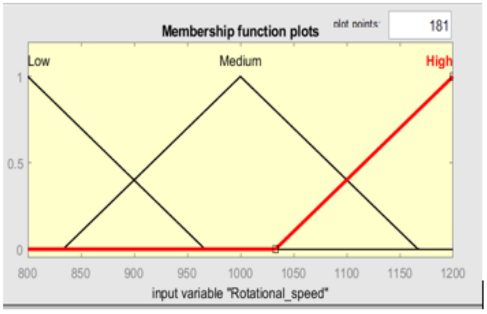
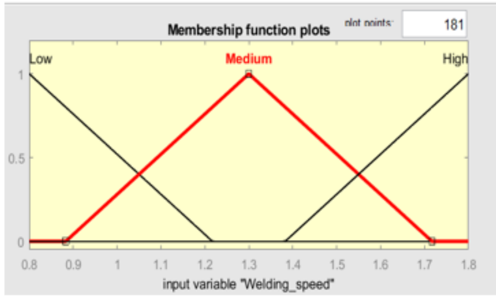
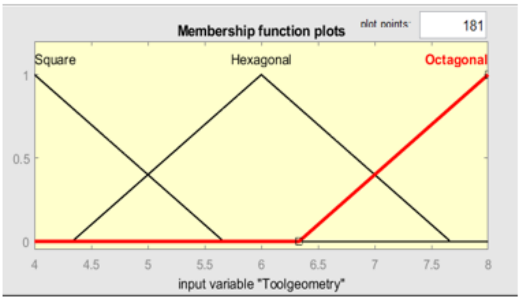
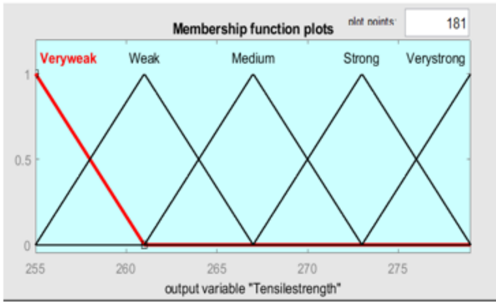
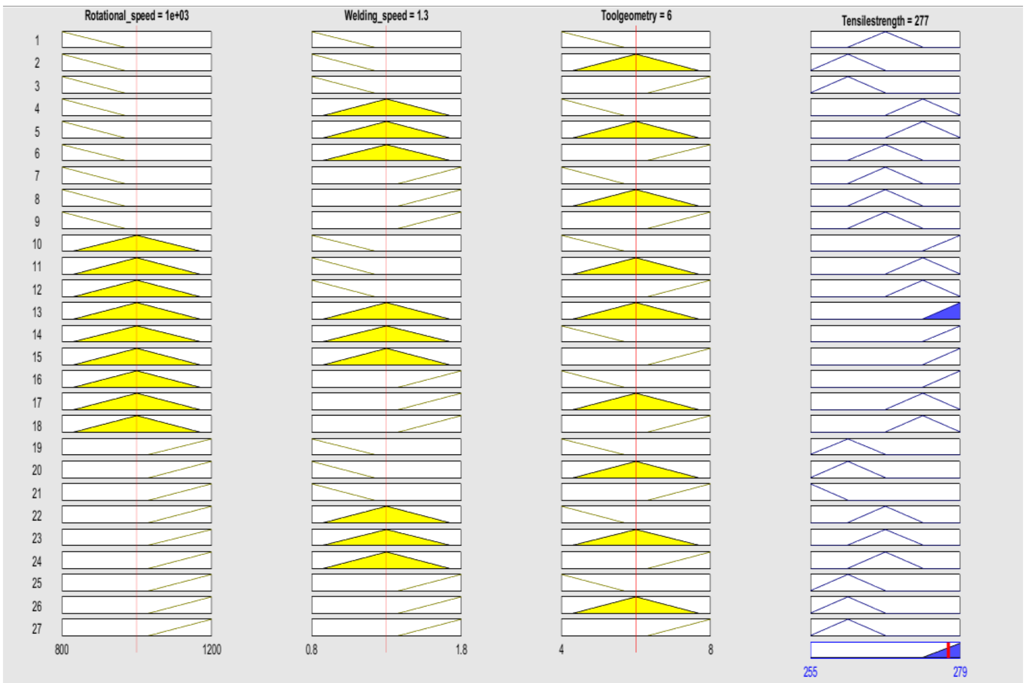
A membership for input and output variables of tensile strength have clearly shown in the following figure(s), At last the crisp value of tensile strength have been obtained as an answer.











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Defuzzification provides the maximum Tensile strength with the value of 277 Mpa for the given input parameters $A_2B_2C_1$

Taguchi approach help us to predict the output response of '3' input parameters each at three levels using L_9 Orthogonal array. Using the experimental data of Pratap Singh et al. (2016), we determine the means for each factor and obtain the estimated output response with different combination of factors at different levels are presented in Table (2). From the results of analysis of variance (ANOVA), the significant factors are determined and used to produce regression prediction model. ANOVA showing that A, B, C are the main factors affecting the tensile strength. Here we follow the assumption of Pratap Singh et al (2016) and not considering the interaction factors.

As per Taguchi design, the number of experiments (N) for the number of process parameters (v) and the number of levels (r) assigned to each process parameter can be found from

$$N = 1 + v(r - 1) \quad (1)$$

The regression model of experiment is given in (2) is used to predict the output results to compare with the Fuzzy logic and Taguchi approaches indicated in Table (4).

$$Y=278.537-00.64A+0.56B-1.25C \quad (2)$$

The Fuzzy logic control model of the Friction stir weld joints has been modelled systematically as well as with Taguchi and Regression techniques. The prediction of Tensile strength for these three models compared to actual values represented in Table IV.

3. **Result and Discussion**

The proposed models used Tool rotation speed (A), Welding speed (B), and Tool geometry (C) as input parameters to predict the output response, Tensile strength (MPa). Fuzzy logic determined the optimal solution for tensile strength at A2B2C1, with a value of 277. However, the test data in Table (1) revealed a maximum observed tensile strength of 294 at the same combination of factors and levels. A comparative analysis of the three methods and their results is presented in Table (1). Following the Taguchi approach yielded a value of 257, while the regression method indicated a value of '268'. The results distinctly show that fuzzy logic closely approximates the maximum value in the provided data. ANOVA results in Table-3 highlight that Tool rotation speed (A), Welding speed (B), and Tool geometry (C) contribute 72%, 22%, and 6%, respectively, to Tensile strength. Predicted values from the three methods are outlined

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in Table IV. The test results align much more closely with fuzzy logic than other approaches, considering the experimental data of Pratap Singh et al. (2016). Additionally, the observed error% is significantly lower when compared to alternative approaches.

4. **Conclusion**

This paper provides the comparative analysis of Optimum output response using Fuzzy logic, Taguchi approach and Regression analysis for various input parameters. The results indicated in Table (1) and Table (4) are concluding that the predicted values are much closer to Fuzzy logic when compared with other traditional approaches.

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Table-1: Input parameters and their levels (Pratap Singh et al. (2016))

Process parameters	Designation	Level-1	Level-2	Level-3
Tool Rotational speed (rpm)	A	800	1000	1200
Welding speed(mm/sec)	B	0.8	1.3	1.8
Tool geometry	C	Square	Hexagonal	Octagonal

Table-2: Output response as per L9 Orthogonal array

Test run				**Tensile Strength**			
	A	B	C	Test Data [1]	Predicted Taguchi [1]	Predicted Fuzzy [2]	Predicted Regression [3]
1	1	1	1	258	274	267	269
2	1	2	2	272	267	273	267
3	1	3	3	243	261	267	264
4	2	1	3	281	264	273	263
5	**2**	**2**	**1**	**294**	**257**	**277**	**268**
6	2	3	2	289	274	277	266
7	3	1	2	234	254	257	264
8	3	2	3	268	270	267	262
9	3	3	1	248	264	261	267

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Table-3: ANOVA

Process parameter	Output response: Tensile strength, MPa			%Contribution
	Mean-1	Mean-2	Mean-3	
A	258	288	250	72
B	258	278	260	22
C	272	267	257	6

Table-4: Predicted Response for all the combinations of various process parameters and their levels

S. No	X1	X2	X3	Tensile strength Taguchi L9	Predicted (2)	Predicted (3)	Error(%)
1	800	0.8	4	263	267	268.87	-5.87
2	800	0.8	6	261	261	266.37	-5.37
3	800	0.8	8	258	261	263.87	-5.87
4	800	1.3	4	269	273	269.15	-0.15
5	800	1.3	6	268	273	266.65	1.35
6	800	1.3	8	264	267	264.15	-0.15
7	800	1.8	4	263	267	269.43	-6.43
8	800	1.8	6	262	267	266.93	-4.93
9	800	1.8	8	258	267	264.43	-6.43
10	1000	0.8	4	273	277	267.59	5.41
11	1000	0.8	6	271	273	265.09	5.91
12	1000	0.8	8	268	273	262.59	5.41
13	**1000**	**1.3**	**4**	**279**	**277**	**267.87**	**11.13**
14	1000	1.3	6	278	277	265.37	12.63
15	**1000**	**1.3**	**8**	274	**277**	262.87	11.13
16	1000	1.8	4	273	273	268.15	4.85

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17	1000	1.8	6	272	273	265.65	6.35
18	1000	1.8	8	268	273	263.15	4.85
19	1200	0.8	4	260	261	266.31	-6.31
20	1200	0.8	6	258	261	263.81	-5.81
21	1200	0.8	8	255	257	261.31	-6.31
22	1200	1.3	4	267	267	266.59	0.41
23	1200	1.3	6	265	267	264.09	0.91
24	1200	1.3	8	262	267	261.59	0.41
25	1200	1.8	4	261	261	266.87	-5.87
26	1200	1.8	6	259	261	264.37	-5.37
27	1200	1.8	8	256	261	261.87	-5.87

Abstract: In various industries, the quest for optimal solutions involves a series of tests aimed at reducing both cost and time. This study assesses the efficacy of modified Taguchi and Central Composite Design (CCD) methods by analyzing heat pipe performance test data. The study compares optimal parameters obtained through these methods, evaluating their utility in predicting performance indicators. Additionally, the study determines the range of the output response to facilitate the identification of optimal process parameters for maximum efficiency, minimum thermal resistance, and maximum overall heat transfer coefficient, employing the modified Taguchi approach. Keywords: Modified Taguchi designs, central composite design, dummy parameters, efficiency, thermal resistance, overall heat transfer coefficient. Introduction: A heat pipe is a device designed for efficiently transferring a large amount of heat through a small cross-sectional area at low temperature differentials. It finds applications in diverse fields such as heat recovery, solar energy, electronic energy conversion, aircraft cooling, geothermal conversion, and more. Many engineering problems are inherently nonlinear, making exact solutions challenging. Experimentation becomes crucial in such cases, and statistical methods aid in handling sparse data, developing empirical relationships, and reducing the number of trials. Taguchi and Central Composite Design (CCD) are widely used Response Surface Methodology (RSM) techniques. Methodology: Taguchi's systematic approach aids in selecting control factors to nullify the impact of noise factors, determining relevant control parameters for optimal solutions. Response Surface Methodology (RSM) explores the relationship between independent and dependent variables. The study employs

ISSN PRINT 2319 1775 Online 2320 7876

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Box and Wilson CCD for analyzing the effects of output and process parameters. The methodology aims to optimize efficiency, thermal resistance, and overall heat transfer coefficient using empirical relationships derived from modified Taguchi and CCD approaches. Analysis: The study conducts a thorough analysis of heat pipe performance using both methods. The Taguchi method reveals significant contributions of input parameters to efficiency, thermal resistance, and overall heat transfer coefficient. CCD is employed to identify optimal process parameters for maximizing efficiency, minimizing thermal resistance, and maximizing overall heat transfer coefficient. The analysis involves the comparison of empirical relationships derived from the modified Taguchi approach, RSM, and test data. Conclusion: The optimal responses and associated process parameters obtained from Taguchi and CCD are closely matched, validating the efficacy of both methods. The study demonstrates that the optimal resistance achieved through the Taguchi approach closely aligns with test results, while the CCD results exhibit a slight difference. The findings underscore the utility of these methods in optimizing heat pipe performance. Acknowledgment: The authors express gratitude for the valuable feedback provided by the reviewers, contributing to the clarity and presentation improvement of this work.