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The process parameters were optimized using Taguchi designs and a modified second-order response surface in an empirical study

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Abstract In this paper, the methods of modified second order response surface design and Taguchi design of experiments were employed to determine the optimum level of process parameters, following the works of Rajendar et al. (2004) and Prabhakar et al. (2014). The focus of this study was primarily on the statistical analysis of these two methods, with an emphasis on obtaining the optimum response using a smaller number of design points through the use of modified second order response surface design.

The study's results demonstrate that the utilization of modified second order response surface designs led to the requirement of fewer design points for obtaining the optimum value. The determination of optimal process parameters for surface roughness was accomplished using a combination of modified response surface designs and the Taguchi approach, supported by response graphs.

Keywords: Taguchi approach; modified second order response surface designs; surface roughness.

1. INTRODUCTION

A powerful tool has been proposed by Taguchi for conducting experimental designs aimed at enhancing product quality. Recently, the significance of these methods has grown substantially in the fields of engineering and sciences. Typically, the process is controlled either manually or automatically[1]. Quantitative variables were examined by Box and Benhen (1960) through the development of three-level designs for various factors. The optimization of CNC machining parameters was carried out by Prabhakar et al. (2014) using ANOVA and ANN Techniques[2]. Optimum process parameters were determined using soya meal adhesive by Buddi et al. (2018). Rajyalakshmi and Nageswara Rao (2019a) employed the Modified Taguchi approach to trace optimal weld dilution parameters for ST-37 plates[3]. Expected ranges were determined using the Modified Taguchi approach by Rajyalakshmi and Nageswara Rao (2019b). Multi-objective economic-statistical design was addressed through the development of an X bar control chart by Ganguly and Patel (2019)[4]. Chevron criteria's performance in heat exchange applications was observed by Dutta and Nageswara Rao (2018)[5]. Chakravarthi et al. (2018) utilized processing maps to identify workability and control conditions of microstructure[6]. The analysis of high-strength steel rocket motor casing testing using experimental stress was the focus of Tanuja et al. (2018)[7]. Optimum process parameters for laser beam welding were identified through Taguchi CFD simulations

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by Satyanarayana et al. (2018). Dharmendra et al. (2019) proposed a straightforward and dependable Taguchi approach for process parameter identification[8].

Experimental work carried out by Prabhakar et al. (2014) aided in the identification of optimum process parameters for surface roughness. They presented surface roughness and material removal rates as output responses[9]. Three input parameters, namely Cutting speed, Feed rate, and depth of cut, were considered, each with three specified levels. The total number of required test runs was 27, encompassing all possible combinations of the three input parameters and their respective levels, as presented in Table 3. For the purpose of this paper's analysis, we have focused exclusively on one output response from their test data, namely surface roughness[10]. Several authors have proposed various methods for determining optimum parameters and have applied the concepts of Taguchi and response surface designs to diverse applications .

The objective of this study is to compare the predicted responses of the Taguchi approach, modified second order response surface designs, and response surface designs. It is observed from tables (1) and (2) that the low surface roughness values are exhibited by the few parameter runs at different levels obtained through modified second order response surface designs with 16 runs when compared with the values obtained from Taguchi L27 orthogonal array and response surface designs.

2. MATERIALS AND METHODS

Prabhakar et al. (2014) employed a comprehensive analysis and methodology involving ANOVA and Artificial Neural Networks to optimize CNC machining parameters. For this investigation, we considered the experimental data from Prabhakar et al. (2014), where three input parameters, namely cutting speed (x1), feed rate (x2), and depth of cut (x3), were designated as the input variables. The resulting output variable was surface roughness (Ra). A suggestion was made by them to utilize the Taguchi L27 Orthogonal array (OA) approach to predict the output response for the '3' input parameters, each at three different levels. The percentage contribution of each parameter is detailed in Table (2). By utilizing the L27 OA, the means of each factor were calculated. Subsequently, based on these means, predictions for the Taguchi design were established for the provided test data.

Following the principles of the Taguchi design, the number of experiments (N) can be determined based on the number of process parameters (v) and the number of levels (r) assigned to each process parameter. This relationship can be expressed as:

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

Response surface methodology encompasses a collection of statistical techniques and analyses that address problems influenced by several variables. The design for fitting a response surface entails considering various appropriate combinations at different levels of factors. The formulation for second-order response surface designs is expressed as:

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$$Y_u = b_0 + \sum_{i=1}^{v} b_i x_{ui} + \sum_{i=1}^{v} b_{ii} x_{ui}^2 + \sum_{i\leq j}^{v} b_{ij} x_{uj} + e_u \quad (2)$$

If the properties of simple symmetry, nonsingularity, and equation (3) are satisfied by the second-order response surface design, the design is referred to as a modified second-order response surface design.

$$\left(\sum_{u=1}^{N} x_{iu}^2\right)^2 = N \sum_{u=1}^{N} x_{iu}^2 x_{ju}^2 \quad (3)$$

Here, the experiment pertaining to the determination of optimum parameters involves the consideration of the modified response surface design (Box and Behnken). This design incorporates three factors, each spanning three levels, resulting in a total of 16 points. The specifics of these factors and their corresponding levels can be found in Table (3) and Table (4). The coded levels, denoted as -1, 0, and 1, are used to represent the design points. Initially, the experimental data for the modified design points are derived from the data provided by Prabhakar (2014).

3. RESULTS AND DISCUSSION

An experimental study of L27 data for three factors, each at various levels, was presented by Prabhakar et al. (2014). The corresponding experimental values are provided in table (1). The % contribution of each individual factor is detailed in table (2), where X1 exhibits a significant contribution of 66%, X3 has a lower contribution at 9%, and X2 accounts for 25% of the total contribution. The experimental data for '16' runs, in accordance with the modified second-order response surface designs, are presented in table (3). The equation derived from the experimental data is as follows:

ŷ = 0.9330 + 0.6001x1 + 0.3203x2 + 0.1749x3 + 0.4355x12 + 0.1337x22 − 0.1095x32

0.0773 x1x2 + 0.0195x1x3 + 0.0043x2x3 (4)

The Taguchi points were obtained utilizing table (2), and the predicted values have been included in the last column of table (3). It is observed that the optimum parameters with coded levels are 0, -1, and -1. When decoded into their original values, the parameters yielding low surface roughness are X12, X21, and X31, respectively. According to ANOVA, the optimal parameters are achieved at the levels of cutting speed (1000), feed rate (10), and depth of cut (0.2).

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Table-1: Input parameters and their levels (Prabhakar et al (2014))

Process parameters	Designation	Level-1	Level-2	Level-3
Cutting speed (rpm)	X1	500	1000	1500
Feed rate (mm/Min)	X_2	10	40	70
Depth of cut (mm) Z	X_3	0.2	0.5	0.8

Table 2: ANOVA Table

	Mean1	Mean2	Mean3	Grand mean	% contribution
X1	1.006111	**0.916556**	1.821	1.247888889	66
x2	**0.990778**	1.163667	1.589222	1.247888889	25
x3	**1.073667**	1.232556	1.437444	1.247888889	9

Table: 3: Optimum process parameters as per Modified second order response surface design

Sno	X1	X2	X3	Experimental data Surface Roughness	Predicted [1] Modified SORD	Taguchi Predicted [2]
1	1	1	0	2.764	2.4999	2.146778
2	1	-1	0	1.392	1.7047	1.548333
3	-1	1	0	1.458	1.1451	1.331889
4	-1	-1	0	0.395	0.6591	0.733444
5	1	0	1	2.021	2.0535	1.926111
6	1	0	-1	1.746	1.6647	1.562333
7	-1	0	1	0.733	0.8143	1.111222
8	-1	0	-1	0.536	0.5035	0.747444
9	0	1	1	1.225	1.4567	1.447222
10	0	1	-1	0.753	1.0983	1.083444
11	0	-1	1	1.153	0.8075	0.848778
12	0	-1	-1	0.698	**0.4663**	**0.485**
13	0	0	0	0.933	0.933	0.816778
14	0	0	0	0.867	0.933	0.816778
15	0	0	0	0.962	0.933	0.816778
16	0	0	0	0.97	0.933	0.816778

4. CONCLUSION

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The optimum parameters with a reduced number of design points can be obtained through the utilization of modified second-order response surface designs, as indicated by the preceding analysis. The outcomes of the test data, ANOVA table, and predicted values achieved via the Taguchi approach and modified second-order response surface design have been obtained and are presented in Table 1, Table 2, and Table 3, respectively. The graphical representation vividly illustrates a comparison between the experimental and predicted data for all proposed designs involving '16' runs (Figure 1) and '27' runs (Figure 2).

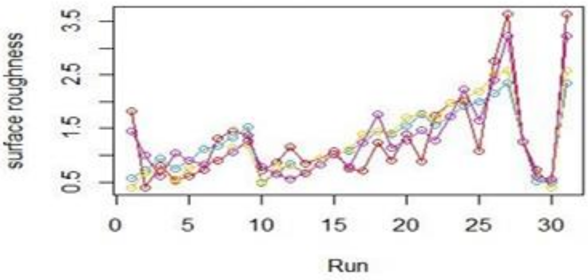

Figure 2: Experimental and predicted values of '27' runs under different approaches

Conflict of Interests

The authors declare that there is no conflict of interests.

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