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OPTIMIZATION OF THE FACE MILLING PROCESS SELECTION PARAMETER USING DESIRABILITY TECHNIQUE FOR AL-SIC COMPOSITES

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ABSTRACT

Recently machining of composites was received great attention in industry. This is due to its wide spread application in aerospace, automobile, marine and also in sporting goods. In this research, the surface roughness, flank wear, build-up-edge and chip packing ratio of Al-SiC composites on face milling was investigated. Desirability technique and Design-expert software was used to establish the design matrix and to analyze the experimental data. The relationship between the face milling parameters like Percentage volume of Si-Cp, Speed, Feed, and Depth of cut with four responses such as Surface Roughness, Flank wear, Built up edge and Chip packing ratio were established.

Key words: *Face milling, Fuzzy logic, Optimization and Al-SiC Composite.*

1. Introduction

Milling is a process of removing metal by feeding the work past rotating multi point cutter. In milling operation the rate of metal removal is rapid as that of the cutter. It rotates at high speed and has a many cutting edges. Thus the jobs are machined at a faster rate than which single point tools and the surface finish is also better due to multi cutting edges. The experiment was conducted on a universal milling machine. It is similar to plain milling machine with a difference the table is placed on the swivel and the swivel is placed on the saddle. This type of machine is essentially a tool room machine, which is used for very accurate work.

Phadke (1989) used two important tools in parameter design which are orthogonal arrays and Signal-to-Noise (S/N) ratios. Orthogonal arrays have a balanced property in which every factor setting occur the same number of times for every setting of all other factors in the experiment. Harrington (1965) introduced the concept of Desirability to provide a solution to multi-response optimization problems. The most well-known desirability functions are the one of the Harrington (1965) based on the exponential function of a linear transformation of the Yi's. Govaerts and Le Bailly de Tilleghem (2005) propose smoother and differentiable desirability functions based on the logic function, normal density and normal distribution functions.

Therefore this paper firstly aims to employ the desirability function to relate the face milling input parameters on multi responses (Percentage volume of Si-Cp, Speed, Feed, and Depth of cut) to the four responses (i.e. Surface Roughness, Flank wear, Built up edge and Chip packing ratio).The second aim is to find the optimal machining combination that would minimize the Surface Roughness, Flank wear, Build up edge and chip packing ratio by comparing the design expert technique and desirability method while keeping the cost relatively low.

2. Methodology

The present work emphasizes on the optimization of various parameters that influence the surface roughness, Flank wear, Chip packing ratio and Build-up-edge through investigation using Taguchi's technique in milling. Surface roughness, which is used to determine and evaluate the quality of a product, is one of the major quality attributes of a milled product is taken as a response.

Table 1: Levels and Parameters

Sl. No	Input Parameters	Levels		
		1	2	3
1	% Volume of SiCp	10	15	20
2	Speed (rpm)	200	400	600
3	Feed (mm/min)	100	200	300
4	Depth of cut (mm)	0.5	1.5	2.5

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Table 2: L_9 Orthogonal Array

Trial No	Surface Roughness microns	Flank Wear mm	Build-up-edge mm	Chip thicken-ss ratio
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3. Parameter and their Levels

Four factors and three levels have been fixed in order to conduct the experiment. L_9 Orthogonal array has been chosen as a design matrix. The input factors are taken as %volume of Si-Cp, Speed, Feed, and Depth of cut. The output values are taken as Surface Roughness, Flank wear, Chip packing ratio, and built up edge. In this paper, the characteristics values are selected by Surface roughness, Flank wear, Chip packing ratio, and Built-up-edge. For obtaining good results Smaller the better characteristics is preferred. Smaller the better target is chosen and the formula is,

Signal noise ratio

$$(S/N) = -10 \log [\sum y_i^2/n] \quad (1)$$

Where as, y_i = average response

n = no of observations

Table 3: Response Values Measured

Trial No	Surface Roughness microns	Flank Wear mm	Build up-Edge mm	Chip Packing ratio
1	5.5	0.394	1.437	4.26
2	6.5	0.326	1.372	3.992
3	5.0	0.311	1.799	4.431
4	5.83	0.687	0.902	3.27
5	6.0	0.65	1.625	3.224
6	5.61	0.628	1.179	2.469
7	5.9	1.09	1.299	2.350
8	6.25	1.36	1.229	2.458
9	6.4	0.825	1.348	2.55

Table 4: Average Effect on Response Values

Levels	Surface Roughness (microns)	Flank Wear (mm)	Build-up-Edge (mm)	Chip packing ratio
1	5.62	0.727	1.279	3.362
2	5.91	0.773	1.207	2.936
3	6.146	0.586	1.572	3.386

Table 5: Average Effect Response for S/N Ratio

Levels	Surface Roughness microns	Flank Wear mm	Build-up-Edge mm	Chip packing ratio
1	-14.953	2.921	2.109	-10.33
2	-15.436	2.887	-1.482	-9.905
3	-15.773	4.501	-3.85	-10.342

3.1 Experimental design

The test was designed based on a four factors three levels L_9 Orthogonal design, each with three replicates. The input variables are % Volume of Si-Cp, speed, feed and depth of cut. In order to find the range of each process input parameters, trails were performed by changing one of the process parameters at a time. Table (3), represents the response measured values. Table 4 and 5 represents the average effect on response values. S/N ratio was calculated using average response values. Individual desirability (d) has been calculated using the coded response values.

3.2 Desirability approach

The desirability approach involves transforming each estimated response, Y_i, into a unitless utility bounded by $0<d_i<1$, where a higher d_i value indicates that response value Y_i is more desirable, if d_i = 0 this means a completely undesired response. In the current work, the individual desirability of each response, d_i, was calculated using equation (2) and the combined desirability function was calculated using the equation (3). In this research the Derringer's desirability function approach is transformed between the intervals 0 and 1. $A_1B_1C_1D_1$ is the factors and weights assigned to them are taken as 1.Where r is assigned value which is less than 1.

$(A_1, B_1, C_1, D_1) = (1, 1, 1, \text{and } 1)$
Say (r) = 0.5
D_1 (max) =7.5, D_1 (min) =5.0
D_2 (max) =1.5, D_2 (min) =0.325
D_3 (max) =2.00, D_3 (min) =0.800
D_4 (max) =5.0, D_4 (min) =3.25
Where D_1, D_2, D_3, D_4 = Corresponding desirability functions

$$d_1 = [(7.5-5.5)/ (7.5-5.0)]^{0.} \quad (2)$$

$$d_2 = [(1.5-0.394)/ (1.5-0.300)]^{0.5} = 0.9600$$

$$d_3 = [(2.00-1.437)/ (2.0-0.800)]^{0.5} = 0.6645$$

$$d_4 = [(5.00-4.26)/ (5.00-3.25)]^{0.5} = 0.6502$$

$$D = [d_1^{w1}\, d_2^{w2}\, d_3^{w3}\, d_4^{w4}] / \Sigma w \quad (3)$$

Assume $w_1=1$, $w_2=2$, $w_3=1$, $w_4=2$
D = Combined Desirability
w_1, w_2, w_3, w_4 = weights assigned to the individual factors.
$w = w_1+w_2+w_3+w_4$ & $w = 6$
$D = [0.8944^1\ 0.9600^2\ 0.6645^1\ 0.6502^2] / 6$
D = 0.0385.

3.3 Optimization

The optimization part in Design-Expert software V7 searches for a combination of factor levels that simultaneously satisfy the requirements placed (i.e. optimization criteria) on each one of the responses and process factors (i.e. multiple-response optimization). Numerical and graphical optimization methods were used in this work by selecting the desired goals for each factor and response. As mentioned before the numerical optimization process involves combining the goals into an overall desirability function (D). The numerical optimization feature in the design-expert package finds one point or more in the factors domain that would maximize this objective function.

4. Experimental Work

In face milling the milled surface is generally located at right angles to the axis of the cutter. The material is removed by the peripheral (main) cutting edges; the face milling edges only clean up the machine surface. During the conduct of experiment the work piece was fixed in a wire fitted to the table of the vertical milling machine. The speed was taken as 200,300 and 600 rpm. Feed used were 100,200 and 300 mm/min and Depth of cut were taken as 05, 1.5 and 2.5. % Vol of SiCp composites ranges from 10, 15 and 20.

4.1. Results and discussion

The fit summary tab in the design-expert software suggests the highest order polynomial where the additional terms are significant and the model is not aliased. Selecting the step-wise regression method eliminates the insignificant model terms automatically. The sequential F-test for significance of both the regression model and the individual models terms along with the lack of fit test were carried out using Design-Expert V7 software. Factor values at low and high have been fixed in table (7) and response prediction at 95% CI for low and high values as shown in table(8).

Table 6: Factor Values at Low and High

Response	Prediction	SE Mean	95% CI low	95% CI high	SE Pred	95% PI low	95% PI high
Surface Roughness	5.88778	0.16	5.52	6.25	0.5	4.73	7.04
Flank Wear	0.696778	0.12	0.43	0.97	0.37	-0.16	1.55
Build Up Edge	1.35444	0.086	1.16	1.55	0.27	0.73	1.98
Chip Packing Ratio	3.22267	0.28	2.59	3.86	0.87	1.21	5.24

Table 7: Desirability Function Values

Sl	L9 ARRAY				RESPONSE				DESIRABILITY (d)				D
	A	B	C	D	Y_1	Y_2	Y_3	Y_4	d_1	d_2	d_3	d_4	D
1	1	1	1	1	5.5	0.4	1.4	4.3	0.9	1	0.7	0.7	0
2	1	2	2	2	6.5	0.3	1.4	4	0.6	1	0.7	0.5	0
3	1	3	3	3	5	0.3	1.8	4.4	1	1	0.4	0.6	0
4	2	1	2	3	5.8	0.7	0.9	3.3	0.8	0.8	1	1	0.1
5	2	2	3	1	6	0.7	1.6	3.2	0.8	0.8	0.6	1	0.1
6	2	3	1	2	5.6	0.6	1.2	2.5	0.9	0.9	0.8	1.2	0.1
7	3	1	3	2	5.9	1.1	1.3	2.4	0.8	0.6	0.4	1.2	0
8	3	2	1	3	6.2	1.4	1.3	2.5	0.7	0.3	0.8	1.2	0
9	3	3	2	1	6.4	0.8	1.3	2.6	0.7	0.8	0.7	1.2	0.1

Table 8: Response Predictions at Low and High Values at 95% CI

Factor	Name	Level	Low Level	High Level
A	% Volume of SiCp	10	10	20
B	Speed	200	200	600
C	Feed	200	100	300
D	Depth of cut	0.5	0.5	2.5

In this work, a mathematical model was developed to estimate the cost for optimization purpose. According to the obtained results the developed models are statistically accurate and can be used for further analysis. The final models in terms of coded and actual factors are shown below Eqs. (4)- (11).

Final Equation in Terms of Coded Factors:
Surface Roughness = +5.89 (4)
Flank Wear = +0.70 (5)
Build Up Edge = +1.35 (6)
Chip Packing Ratio = +3.22 (7)
Final Equation in Terms of Actual Factors:
Surface Roughness = +5.88778 (8)
Flank Wear = +0.69678 (9)
Build Up Edge = +1.35444 (10)
Chip Packing Ratio = +3.22267 (11)

4.2 Validation of the developed models

Design expert tool is used to verify and validate the experimental values. It is the new proposed concept to analyze the values of desirability functions. The Taguchi OA design editor is used to implement the factors such as Surface roughness, Flank wear, built up edge, and Chip packing ratio.

5. Confirmation Experiment

The confirmation experiments are used to verify that the factors and levels chosen from an experiment cause a product or process to behave in a certain fashion. The final step of the Taguchi's parameter design after selecting the optimal parameter is to predict and verify the improvement of the performance characteristics with the selected optimum values of the SN ratio (n_{opt}) using the optimal level of process parameters which can be calculated as

$$n_{opt} = n_m + \sum (n_i - n_m) \quad (12)$$

Where, n_m=total mean
n_i=mean at the optimum level

Verification of the test results at the selected optimum conditions is shown in table (9). The predicted machining performance was compared with actual machining performance and a good agreement was obtained between these performances.

Table 9: Confirmation Experiment

	Prediction	Experiment
Levels	A1B1C1D1	A1B3C2D2
SN ratio	2.747	2.5872

6. Conclusion

In the present study a comparison made between the taguchi's S/N ratio and desirability function using design expert software were analyzed for the purpose of optimizing the parameters such as Surface roughness, Flank wear, Chip packing ratio, Built up edge. The output response measured as Surface roughness, Flank wear, Chip packing ratio, and Built up edge has been achieved. The following points have been concluded from the results.

The overall desirability was observed as 0.543. This is in acceptable level. The individual desirability function graph shows that the surface roughness value are measured as 4.9633, which shows that the parameters has been optimized effectively and falls under the smaller the better characteristics when compare to all the other methods.

The value obtained using design expert technique by taguchi's design was observed as 5.88778 at 95% CI.

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