MULTI OBJECTIVE OPTIMIZATION OF PARAMETERS INFLUENCING PERFORMANCE INDICES WHILE TURNING SUPER ALLOY HASTELLOY-C 276 USING GREY RELATION ANALYSIS OF TAGUCHI

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ABSTRACT

Conventional machining is a subtractive process in which overabundant material is removed in the form of chips.CNC turning being used as one among the primary methods of achieving different geometry and shapes for various products, its performance is of paramount importance. CNC turning of super alloys like Hastelloy- C276 posses a great challenge to machinists because of its peculiar properties, hence an aggressive cutting regime it warrants for optimum quality of final products and for improving productivity. Any deviation from optimum parameter settings may result in poor cutting performance. Turning process parameters like cutting speed, feed, depth of cut and geometrical parameters of turning tool like nose radius may impose conflicting requirements.

This investigation is an attempt to predict optimal tuning parameter settings of cutting speed, feed rate, depth of cut and nose radius for minimized surface roughness, maximized material removal rate and minimized tool wear for Hastelloy-C276 , when turned with coated carbide turning inserts on CNC lathes ,employing Grey Relation Analysis(GRA) of Taguchi.

Experiments were conducted based on L27 Orthogonal Array(OA) .The proposed cutting regime if implemented on shop floor will result in considerable savings while machining difficult to machine super alloys like Hastelloy276

Key words: CNC turning, Hastelloy276, Grey Relation Analysis (GRA), Orthogonal Array(OA).

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

1. INTRODUCTION

Turning is a machining process for generating external surfaces of revolution by the action of a single point cutting tool on a rotating work piece for producing a cylindrical surface, usually on a lathe. Like any other machining process, it is a very complex process and its performance depends on many parameters. A careful selection of process parameters and geometric parameters of the cutting tool apart from optimum parameter settings can result in better quality and productivity resulting in greater economy.

There are many controllable variables and an appropriate selection of the same can contribute to the optimum response measures like Surface Roughness (SR), Material Removal Rate (MRR) and Tool Wear (TW).

2. GREY RELATIONAL ANALYSIS:

In Grey relational analysis, measured values of the performance characteristics are normalized ranging from zero to one. Thus Grey relational generation is done. Subsequently, Grey relational coefficient is calculated based on normalized experimental data. Then overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses.

The Grey relational grade represents the overall performance characteristic of the multiple response process. This approach converts a multiple objective optimization problem into a single objective optimization situation with overall Grey relational grade as the objective function. The optimal parametric combination is determined by the highest Grey relational grade. Then Taguchi method can be utilized for obtaining optimal factor setting for maximizing overall Grey relational grade.

In Grey relational generation, smaller- the-better (SB) criterion is applied to obtain normalized values x_i (k) of R_a & $V_{b(max)}$ based on the following relation:

$$x_i(k) = \frac{\mathrm{Max}\, y_i(k) - y_i(k)}{\mathrm{Max}\, y_i(k) - \mathrm{Min}\, y_i(k)}$$

MRR follows the larger-the-better (LB) criterion, as expressed by below mentioned relation:

$$x_i(k) = \frac{y_i(k) - \mathrm{Min}\, y_i(k)}{\mathrm{Max}\, y_i(k) - \mathrm{Min}\, y_i(k)}$$

Where y_i(k) is the value of individual response, Min y_i(k) is the smallest value of

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

$y_i(k)$ for the k_{th} response, and Max yi(k) is the largest value of $y_i(k)$ for the k_{th} response.

An ideal sequence is considered as $x_0(k)=1$ for the k_{th} response. The need of Grey relational grade is to reveal the degree of relation between the 27 sequences [$x_0(k)$ and x_i (k), i=1, 2, 3…….27].

The Grey relational coefficient $\xi_i(k)$ can be calculated as:

$$\xi_i(k) = \frac{\Delta_{min} + \psi\Delta_{max}}{\Delta_{0_i}(k) + \psi\Delta_{max}}$$

Where $\Delta_{0_i}(k)$ is the absolute value of the difference of $x_0(k)$ and x_i (k); ψ is the distinguishing coefficient $0 \leq \psi \geq 1$, Δ_{min} is the smallest value of $\Delta_{0_i}(k)$, and Δ_{max} is the largest value of $\Delta_{0_i}(k)$

The Grey relational grade γ_i can be calculated by taking the mean of Grey relational coefficients

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$$

Where n is the number of process responses. The higher value of Grey relational grade corresponds to intense relational degree between the ideal sequence $x_0(k)$ and the given sequence x_i (k). Therefore, higher Grey relational grade represent parameter combination which is closer to the optimal value. The Grey relational grade with its grand mean and the main effect plot are very important for evaluating the optimal process conditions [1]

3. MATERIALS AND METHODS

3.1 Work piece material Hastelloy-C276-Superalloy

Nickel based Super alloy HASTELLOY C-276 is known for its high erosion imperviousness to an extensive range of stress full situations experienced in the industry. The nickel matrix of the alloy enables to accommodate high percentages of elements such as chromium, iron, molybdenum etc., while retaining single phase face-centered-cubic structure. The nickel-based Hastelloy C-276 was additionally one of the austenitic stainless steels, which is a high-quality erosion safe and heat resistant alloy with the high substance of Cr and Mo. It broadly utilized as a pressure vessel material at lifted temperatures. [2]

Work pieces selected were of diameter 30mm and length 100mm and is turned for a length of 50 mm as shown in figure.2

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

Figure.1.Workpiece

The turning of work piece was performed on CNC lathe. The machining variables are set according to the experimental design based on L_{27} Orthogonal Array (OA) of Taguchi. Details of input factors and their levels are shown in table 1.

The machining is done under wet condition using water soluble oil as cutting fluid. Coated carbide turning inserts were used for turning as shown in figure.2 and specifications of the same is as under.

Specifications of Coated carbide Tool inserts

1. CNMG12 04 04-SF1105
2. CNMG12 04 08- SF1105
3 CNMG12 04 12- SF1105

Figure.2.Coated carbide turning insert

Sl.No.	INPUT VARIABLES	CODES	UNITS	LEVELS			RESPONSES	UNITS
				1	2	3		
1	Cutting speed	A	m/min	25	30	35	Surface roughness(Ra)	µm
2	Feed Rate	B	mm/rev	0.08	0.11	0.14	Material Removal Rate(MRR)	mm^3/min
3	Depth of cut	C	mm	0.4	0.7	1.0	Tool Wear(TW)	µm
4	Nose Radius	D	mm	0.4	0.8	1.2		

Table1. Details of input factors and their levels

4. MEASUREMENT OF RESPONSES

In this investigation, surface roughness (Ra) is measured by MITUTOYO SJ210 SURF TEST, a stylus type profilometer. Each surface is characterized by the average surface roughness Ra value. The cut off length λc and the sampling number (N) are selected as 0.8mm and5 respectively, and travel length selected is 4mm. The Tool wear is measured after every set of experiments using Laser Scanning Microscope [3-4].

A typical Characterization of Turning inserts wear using confocal microscope for experimental run 9 is shown in figure.3. The Photographs clearly indicates wear of major flank by abrasion phenomenon.

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

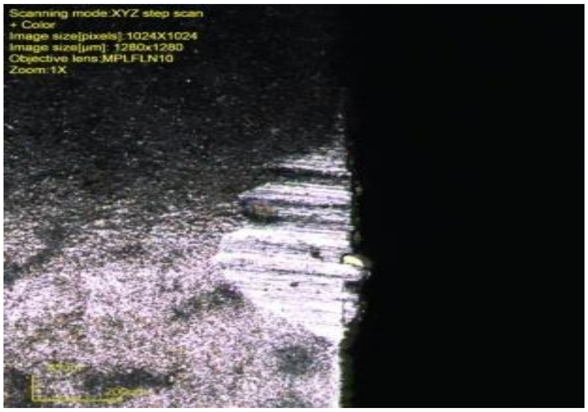

Figure.3.Turning Inserts Wear Forrun9

The Material Removal Rate (MRR) is estimated by using following mathematical equation with time consideration.

$$MRR = \frac{\pi}{4t}(D_o^2 - D_f^2) \times L \tag{5}$$

Here,

D_o stands for initial diameter of the workpiece in mm

D_f stands for final diameter of the workpiece in mm

‘ t’ is the machining time in minutes;

L= Length machined in t seconds

5. Experimental Results

In this investigation, experiments were conducted as per L27 (3) orthogonal array of Taguchi [5]. Factor assignments & experimental results are shown in table.2

RUN NO.	Cutting speed (A) (mm/rev)	Feed Rate (B) (mm/rev)	Depth of cut (C) (mm)	Nose Radius (D) (mm)	Ra (μm)	MMR (mm^3/min)	TW (μm)
1	25	0.08	0.4	0.4	1.003	452.94	51
2	25	0.08	0.7	0.8	0.804	540.63	82
3	25	0.08	1.0	1.2	0.975	962.52	50
4	25	0.11	0.7	0.4	1.286	918.95	41
5	25	0.11	1.0	0.8	1.262	1128.99	67
6	25	0.11	0.4	1.2	1.159	393.99	25
7	25	0.14	1.0	0.4	1.23	673.35	33
8	25	0.14	0.4	0.8	0.585	519.33	179
9	25	0.14	0.7	1.2	0.73	1349.56	46
10	30	0.08	0.7	0.4	0.928	845.4	56
11	30	0.08	1.0	0.8	0.527	611.98	50
12	30	0.08	0.4	1.2	0.59	284.33	58
13	30	0.11	1.0	0.4	1.269	1492.26	39
14	30	0.11	0.4	0.8	0.382	444.79	198
15	30	0.11	0.7	1.2	0.726	784.57	44
16	30	0.14	0.4	0.4	1.504	1106.4	54
17	30	0.14	0.7	0.8	0.473	940.9	44
18	30	0.14	1.0	1.2	0.452	567.9	76
19	35	0.08	1.0	0.4	0.906	1207.74	65
20	35	0.08	0.4	0.8	0.462	1060.19	66
21	35	0.08	0.7	1.2	0.65	789.19	27
22	35	0.11	0.4	0.4	0.783	693.52	49
23	35	0.11	0.7	0.8	0.581	940.23	95
24	35	0.11	1.0	1.2	1.062	781.36	87
25	35	0.14	0.7	0.4	1.944	1500.39	34
26	35	0.14	1.0	0.8	0.837	1610.56	85
27	35	0.14	0.4	1.2	0.557	622.05	52

Table 2. Factor assignments & experimental results

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

6. Multiple Objective Optimization of CNC Turning Process

The experimental data were normalized to obtained grey relational generation by using Eqns. (1) & (2). The normalized data & absolute values for each of response are shown in Table.3. For Ra & $V_{b(max)}$ smaller-the-better (SB) & for MRR larger-the-better (LB) criterion has be applied.

Table.3 Normalized data & absolute values for each of response

RUN NO.	Cutting speed (A) (mm/rev)	Feed Rate (B) (mm/rev)	Depth of cut (C) (mm)	Nose Radius (D) (mm)	Ra (µm)	MMR (mm^3/min)	TW (µm)
1	25	0.08	0.4	0.4	1.003	452.94	51
2	25	0.08	0.7	0.8	0.804	540.63	82
3	25	0.08	1.0	1.2	0.975	962.52	50
4	25	0.11	0.7	0.4	1.286	918.95	41
5	25	0.11	1.0	0.8	1.262	1128.99	67
6	25	0.11	0.4	1.2	1.159	393.99	25
7	25	0.14	1.0	0.4	1.23	673.35	33
8	25	0.14	0.4	0.8	0.585	519.33	179
9	25	0.14	0.7	1.2	0.73	1349.56	46
10	30	0.08	0.7	0.4	0.928	845.4	56
11	30	0.08	1.0	0.8	0.527	611.98	50
12	30	0.08	0.4	1.2	0.59	284.33	58
13	30	0.11	1.0	0.4	1.269	1492.26	39
14	30	0.11	0.4	0.8	0.382	444.79	198
15	30	0.11	0.7	1.2	0.726	784.57	44
16	30	0.14	0.4	0.4	1.504	1106.4	54
17	30	0.14	0.7	0.8	0.473	940.9	44
18	30	0.14	1.0	1.2	0.452	567.9	76
19	35	0.08	1.0	0.4	0.906	1207.74	65
20	35	0.08	0.4	0.8	0.462	1060.19	66
21	35	0.08	0.7	1.2	0.65	789.19	27
22	35	0.11	0.4	0.4	0.783	693.52	49
23	35	0.11	0.7	0.8	0.581	940.23	95
24	35	0.11	1.0	1.2	1.062	781.36	87
25	35	0.14	0.7	0.4	1.944	1500.39	34
26	35	0.14	1.0	0.8	0.837	1610.56	85
27	35	0.14	0.4	1.2	0.557	622.05	52

The grey relational coefficient of each response has been calculated by using Eqn.3.The analytical hierarchical method (AHM) is used for calculating distinguishing coefficients for each response (ψ_{Ra}=0.4, ψ_{MRR}=0.48 & $\psi_{Vb(Max)}$=0.12). The Table.4 shows the grey relational coefficient for each performance characteristics.

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

Table.4 Grey relational coefficient for each performance characteristics

Exp. No	Grey relational coefficient ($\zeta_i(k)$)		
	R_a	MRR	V_b(max)
Ideal Sequence	1	1	1
1	0.50153	0.3548	0.44397
2	0.59687	0.37303	0.26698
3	0.51306	0.49554	0.45367
4	0.40869	0.47929	0.56474
5	0.4152	0.56932	0.33078
6	0.44571	0.34352	1
7	0.42423	0.40449	0.72184
8	0.75477	0.36844	0.11879
9	0.64227	0.70922	0.49713
10	0.53365	0.45414	0.40108
11	0.81164	0.38931	0.45367
12	0.75024	0.32432	0.38616
13	0.41328	0.84329	0.59724
14	1	0.3532	0.10714
15	0.64492	0.43525	0.52213
16	0.35768	0.55805	0.4172
17	0.87287	0.48734	0.52213
18	0.89925	0.37909	0.2893
19	0.54387	0.61245	0.34167
20	0.88649	0.53632	0.33614
21	0.69982	0.43663	0.91213
22	0.60909	0.40974	0.46381
23	0.75844	0.48709	0.22874
24	0.47885	0.4343	0.25085
25	0.28571	0.85247	0.69758
26	0.57863	1	0.25706
27	0.7812	0.39172	0.43467

The grey relational grade shown in Table.5 is calculated using eqn.4, which represents the overall quality features of turning operation. This way multi objective optimization problem has been transformed in to an equivalent single objective optimization problem, using a combination Taguchi Approach & grey relational analysis. Higher the value of grey grade corresponds to the closest optimal factor combination.

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

Table.5 Grey relational grade with ranks

Exp. No	Grey relational grade (γ_i)	Rank
1	0.43343	24
2	0.41229	26
3	0.48742	17
4	0.48424	20
5	0.43844	23
6	0.59641	7
7	0.51685	13
8	0.414	25
9	0.61621	4
10	0.46296	21
11	0.55154	9
12	0.48691	18
13	0.61794	3
14	0.48678	19
15	0.5341	11
16	0.44431	22
17	0.62745	2
18	0.52255	12
19	0.49933	14
20	0.58632	8
21	0.68286	1
22	0.49421	15
23	0.49142	16
24	0.388	27
25	0.61192	5
26	0.61189	6
27	0.53586	10

Taguchi experimental design took the quality loss as the base and it would design to evaluate the efficiency which is called as the S/N ratio. Now all the responses have been reduced to a single quality characteristics i.e. grey relational grade for Taguchi analysis [6]. Table 6 shows the S/N ratio based on the larger the better criterion for overall grey relational grade calculated by using Eqn. (5).

$$S/N = -10 \log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right] \qquad (6)$$

Where n- number of measurement and y_i – is the measured characteristic value

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

Table.6 S/N ratio for overall Grey relational grade

Exp. No	S/N ratio for Grey relational grade
1	-7.26162
2	-7.69594
3	-6.24193
4	-6.29879
5	-7.1618
6	-4.4891
7	-5.73271
8	-7.65999
9	-4.20543
10	-6.68913
11	-5.16846
12	-6.25103
13	-4.18107
14	-6.25335
15	-5.44755
16	-7.04628
17	-4.04842
18	-5.63744
19	-6.03225
20	-4.63731
21	-3.31337
22	-6.12177
23	-6.17094
24	-8.22337
25	-4.26611
26	-4.26653
27	-5.41897

The graphical representation of main effect plots for S/ N ratio of overall grey relational grade is shown in figure 4.

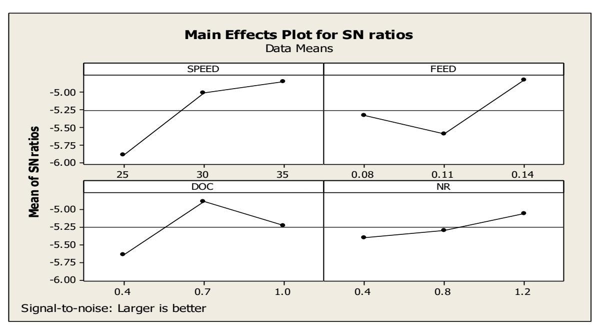

Figure 4: Main effect plots for S/ N ratio of overall grey relational grade

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

As depicted in the figure 4 optimal conditions for turning of hast alloy 276 becomes Speed at level 3(A3), Feed at level 3(B3), Depth of cut at level 2(C2) & Nose radius at level 3(D3). Table 7 shows the mean grey relational grade ratio for each level of parameters & ranks shows the significance of parameters on the responses.

Table.7 Response table for Mean Grey relational grade

Level	SPEED	FEED	DOC	NR
1	0.4888	0.5115	0.4976	0.5072
2	0.5261	0.5035	0.5471	0.5133
3	0.5446	0.5446	0.5149	0.5389
Max-Min	0.0558	0.0411	0.0495	0.0317
Rank	1	3	2	4

Total mean grey relational grade=0.52

Confirmation test:

Based on the optimal parameter settings, it is possible to predict and verify the enhancement of quality characteristics. The estimated Grey relational grade using the optimal level of the design parameters can be calculated as:

$$\check{\gamma} = \gamma_m + \sum_{i=1}^{p} (\bar{\gamma}_i - \gamma_m) \quad (7)$$

Where γ_m is the total mean Grey relational grade, $\bar{\gamma}_i$ is the mean Grey relational grade at the optimal level, and p is the number of the main design parameters that affect the quality characteristics[7-9].

Table 8 indicates the comparison of the predicted surface roughness, material removal rate & Tool wear with that of actual using the optimal conditions; The actual and predicted results was found to be in good agreement. Improvement in overall Grey relational grade was found to be as 0.37.

Table 8 Results of confirmation test

Factor levels	Initial factor settings	Optimal process condition	
		Prediction	Experiment
	A1 B1 C1 D1	A3 B3 C2 D3	A3 B3 C2 D3
Ra	1.003		0.60
MRR	452.94		1493.10
Vb(max)	51		44
S/N ratio of overall Grey relational grade	-7.26162	-2.91145	-3.0335
Overall Grey relational grade	0.43	0.7152	0.70522

For current study the objective functions have been selected in relation to parameters of surface roughness, Material removal rate & Tool wear. The results showed that using optimal parameter setting (**A3 B3 C2 D3**), the lower R_a, maximum MRR and Low tool wear have been arrived.

DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283

Conclusions:

This investigation focused on parametric optimization of CNC turning of super alloy Hastelloy C-276. By Grey relational analysis the optimal parameters settings are obtained & it is found that there is considerable enhancement in turning performance. Hence if the method is employed on shop floor, considerable saving with quality and productivity improvements can be achieved.

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DOI- 10.18486/ijcsnt.2021.10.3.07
ISSN: 2053-6283