Optimization of Process Parameter for Turning of Nimonic 263 using Dry and Flood Cooling.

Pranit Mehata[1], Dr. Vasim A. Shaikh[2]

[1] Research Scholar, Department of Mechanical Engineering, Fr. Conceicao Rodrigues College of Engineering, Bandra, Mumbai, Maharashtra, India.
[2] Associate Professor & Head, Department of Mechanical Engineering, Fr. Conceicao Rodrigues College of Engineering, Bandra, Mumbai, Maharashtra, India.
Corresponding Author:
Pranit Mehata

Abstract
This study presents an experimental investigation on the machining performance of Nimonic 263 under dry and flood cooling conditions using the Taguchi method and Grey Relational Analysis (GRA). The experiments were designed using an L9 orthogonal array considering cutting speed, feed rate, and depth of cut as input parameters, while surface roughness (Ra) and cutting zone temperature (CZT) were taken as performance characteristics. Multi-response optimization was carried out using GRA by converting multiple responses into a single Grey Relational Grade (GRG). The results indicate that depth of cut is the most significant factor affecting machining performance, followed by feed rate and cutting speed. The optimum parameter combination for dry machining was 50 m/min cutting speed, 0.35 mm/rev feed rate and 0.5 mm depth of cut, whereas flood cooling achieved optimum performance at 80 m/min cutting speed, 0.35 mm/rev feed rate and 0.5 mm depth of cut. Confirmation experiments validated the optimization results, showing good agreement between predicted and experimental GRG values with prediction error of 6.89 % under dry and 3.67% under flood cooling. The study concludes that while optimized dry machining can yield acceptable results, flood cooling provides superior performance in machining Nimonic 263....
Keywords: Nimonic 263, Grey Relational Analysis (GRA), Optimization, Taguchi Method, Grey Relational Grade (GRG), Multi-response optimization..

Introduction

Today's rapidly changing manufacturing environment demands the use of optimisation techniques in metal cutting processes in order to effectively respond to severe market competition and meet the market's increasing demand for specialised quality products (low cost, high quality, easily deliverable). The key concerns of the metal-based sector are increasing productivity and the quality of machined parts; there is a growing interest in monitoring all aspects of the machining process. The surface finish is an important characteristic for manufacturing engineering. It is a property that has the potential to affect the performance of mechanical parts as well as production costs. The cutting temperature is a significant factor that directly impacts cutting tool wear, work piece surface integrity, and machining precision based on the relative motion between the tool and work piece. The amount of heat created varies with the type of material being machined and cutting parameters, particularly cutting speed, which has the greatest influence on temperature. Designing and developing a control system to manage temperature results in a superior surface finish. Taguchi and Multi-response method can be used to easily optimise cutting parameters throughout a series of well-designed experiments. Taguchi parameter design can optimise performance characteristics by adjusting design parameters and reducing the system's sensitivity to sources of variation. In contrast, Grey Relational Analysis is used to determine the most important variables and interaction effects.

Material and Methodology:

In this experimental study, machining process was conducted using a centre lathe machine. The work piece material used was Nimonic 263 bar with 60 mm diameter and 120 mm length. Coated carbide inserts was used as a cutting tool with ISO designation SNMG 120408 MM. The experiment conducted under Dry and Flood Cooling. Blascout is a high-performance cutting fluid with good characteristics and performance that is based on water-miscible mineral oil was applied using conventional (flood) method. Since it is widely employed in medium-sized and small-scale industries

Table 1.1. Properties of Blascout Oil

Flash Point	Density	Viscosity	Acid value
144	0.845	48	0.98

In this experiment study, cutting speed, feed rate and depth of cut have been consideed as process variable.

Table 1.2 Process Parameter with their levels

Parameters	Symbol	Level 1	Level 2	Level 3
Cutting Speed (m/min)	v	35	50	80
Feed Rate (mm/rev)	f	0.35	0.40	0.45
Depth of Cut	d	0.5	1.0	1.5

Surface roughness and Cutting Zone Temperature (CZT) was chosen as output parameters for evalutaion using two machining methods. The surface roughness of the work piece was measured at three different points along the length of the cut bar using stylus type surface roughness tester Mitutoyo. During the turning operations, all cutting experiments were stopped after every 35 mm machining length, in order to measure surface roughness (Ra). The temperature of cutting zone is to be measured during the machining time of every set of parameter at differenet machining environment (Dry and Flood).

Design of Experiment and Grey Relational Analysis:

Taguchi has developed a methodology for the application of designed experiments. This methodology has taken the design of experiments from the exclusive world of the statistician and brought it fully into the world of manufacturing. Taguchi methods of experimental design provide a simple, efficient and systematic approach for the optimization of experimental designs for performance quality and cost. The experiments were carried out on the basis of L9 array which was selected using an array selector depending upon the number of levels. L9 array suggests that a total of 9 experiments are required per cutting environment.

Table 2.1 Observations under Dry and Flood Machining

Run	v	f	d	Dry Machining		Flood Machining	
	m/min	mm/min	mm	Surface Roughness	Cutting Zone Temperature	Surface Roughness	Cutting Zone Temperature
1	35	0.35	0.5	3.71	82.96	3.57	67.26
2	35	0.4	1	4.30	108.96	3.78	92.41
3	35	0.45	1.5	4.71	133.25	4.13	113.5

4	50	0.35	1	3.76	93.6	2.21	77.3
5	50	0.4	1.5	4.33	119.01	2.60	101.85
6	50	0.45	0.5	3.12	102.47	2.74	84.45
7	80	0.35	1.5	3.57	112.97	1.84	96.98
8	80	0.4	0.5	3.69	85.05	2.25	68.25
9	80	0.45	1	4.96	110.51	2.80	95.63

In order to determine optimal machining conditions for each cooling environment, multi objective optimization performed and for the same Grey Relational Analysis was utilized. For surface roughness and cutting zone temperature, "the smaller the better" objective function was selected. The following procedures are involved in the GRA optimisation of multiple performance characteristics.

Normalization of the experimental results

Determination of deviation sequences

Determination of grey relational coefficient (GRC)

Determination of grey relational grade (GRG)

Determination of optimal parameters

The optimal variables and their respective level are identified centred on the higher value of GRG. All the five steps were applied for dry and flood cooling environments and presented in the table 3.1 and table 3.2.

Result and Discussion:

3.1 Grey Relational Analysis for Dry Machining:

The Grey Relational Grade (GRG) values for dry machining conditions are presented in Table 3.1. The GRG serves as a comprehensive performance index, combining multiple response characteristics into a single value, where a higher GRG indicates superior performance. Among all the experimental runs, Run 1 exhibits the highest GRG value indicating the optimal combination of machining parameters under dry conditions. Runs 6 and 8 also show relatively high GRG values, suggesting near-optimal performance. In contrast, Run 3 records the lowest GRG, reflecting poor machining performance. The variation in GRG values highlights the significant influence of cutting parameters on machining performance in dry conditions. Based on the analysis, Run 1 is identified as the optimal setting for dry machining, providing the best overall performance in terms of the selected response characteristics.

Table 3.1 GRA values for Dry Machining

Run	**Dry Machining**		**Normalized Value**		**Deviation Sequence**		**GRC**		**GRG**	**Rank**
	Ra	**CZT**	**Ra**	**CZT**	**Ra**	**CZT**	**Ra**	**CZT**		
1	3.71	82.96	0.679	1.000	0.321	0.000	0.609	1.000	0.805	**1**

2	4.30	108.96	0.359	0.483	0.641	0.517	0.438	0.492	0.465	6
3	4.71	133.25	0.136	0.000	0.864	1.000	0.367	0.333	0.350	9
4	3.76	93.6	0.652	0.788	0.348	0.212	0.590	0.703	0.646	4
5	4.33	119.01	0.342	0.283	0.658	0.717	0.432	0.411	0.421	7
6	3.12	102.47	1.000	0.612	0.000	0.388	1.000	0.563	0.782	**2**
7	3.57	112.97	0.755	0.403	0.245	0.597	0.672	0.456	0.564	5
8	3.69	85.05	0.690	0.958	0.310	0.042	0.617	0.923	0.770	**3**
9	4.96	110.51	0.000	0.452	1.000	0.548	0.333	0.477	0.405	8

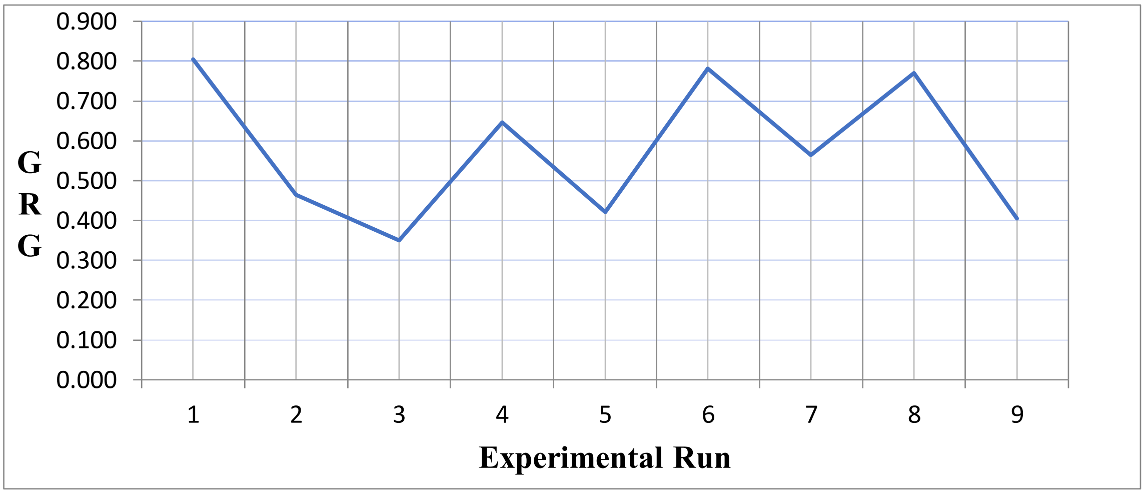

Fig. 3.1 Graph of Experimental Run v/s Grade Relation Grade for Dry Machining

The response table for Grey Relational Grade (GRG) under dry machining conditions is presented in Table 3.2. The average GRG values at different levels of machining parameters indicate the influence of cutting speed, feed rate, and depth of cut on overall performance. On the basis of highest GRG values the optimal levels of parameters are cutting speed at level 2, feed rate at level 1 and depth of cut level 1. This analysis indicates that, in dry machining of Nimonic 263, depth of cut is the most dominant factor affecting performance, whereas cutting speed has comparatively lesser influence.

Table 3.2 Response Table for Dry Machining

Parameters	**Level 1**	**Level 2**	**Level 3**	**Max-Min**	**Rank**
Cutting Speed (v) m/min	0.54	**0.616**	0.579	0.076	3
Feed (f) mm/min	**0.671**	0.552	0.512	0.159	2
Depth of cut (d) mm	**0.785**	0.505	0.445	0.34	1

3.2 Grey Relational Analysis for Flood Machining

The Grey Relational Grade (GRG) values for Flood machining conditions are presented in Table 3.3. Among all trials, Run 8 achieved the highest Grey Relational Grade and was ranked first, signifying the most optimal combination of machining parameters for minimizing surface roughness (Ra) and cutting zone temperature (CZT). This is followed by Run 4 and Run 7 which also demonstrate favourable machining performance. In contrast, Run 3 exhibited the lowest GRG value (0.333), indicating poor performance under those parameter settings

Table 3.3 GRA values for Flood Machining

Run	Flood Machining		Normalized Value		Deviation Sequence		GRC		GRG	Rank
	Ra	CZT	Ra	CZT	Ra	CZT	Ra	CZT		
1	3.57	67.26	0.245	1.000	0.755	0.000	0.398	1.000	0.699	4
2	3.78	92.41	0.153	0.456	0.847	0.544	0.371	0.479	0.425	8
3	4.13	113.5	0.000	0.000	1.000	1.000	0.333	0.333	0.333	9
4	2.21	77.3	0.838	0.783	0.162	0.217	0.756	0.697	0.727	**2**
5	2.60	101.85	0.668	0.252	0.332	0.748	0.601	0.401	0.501	6
6	2.74	84.45	0.607	0.628	0.393	0.372	0.560	0.574	0.567	5
7	1.84	96.98	1.000	0.357	0.000	0.643	1.000	0.438	0.719	**3**
8	2.25	68.25	0.821	0.979	0.179	0.021	0.736	0.959	0.848	**1**
9	2.80	95.63	0.581	0.386	0.419	0.614	0.544	0.449	0.496	7

. **Table 3.4 Response Table for Flood Machining**

Parameters	**Level 1**	**Level 2**	**Level 3**	**Max-Min**	**Rank**
Cutting Speed (v) m/min	0.485	0.598	**0.687**	0.202	3
Feed (f) mm/min	**0.715**	0.591	0.465	0.25	2
Depth of cut (d) mm	**0.704**	0.549	0.445	0.259	1

The response table for Grey Relational Grade (GRG) under flood machining conditions is presented in Table 3.4. The average GRG values at different levels of machining parameters indicate the influence of cutting speed, feed rate, and depth of cut on overall performance. On the basis of highest GRG values the optimal levels of parameters are cutting speed at level 3, feed rate at level 1 and depth of cut level 1. This analysis indicates that, in flood machining of Nimonic 263, depth of cut plays a dominant role in controlling surface roughness and cutting zone temperature, while cutting speed has comparatively lower influence under flood cooling conditions.

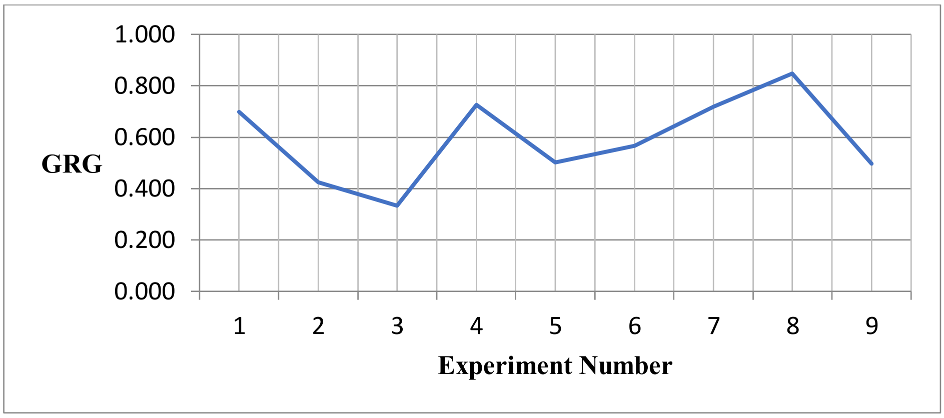

Fig. 3.2 Graph of Experimental Run v/s Grade Relation Grade for Flood Cooling

3.3 Confirmation Test (Validation)

To validate the reliability of the optimal machining parameters obtained from Grey Relational Analysis (GRA) confirmation experiments were conducted under both dry and flood cooling conditions. The optimum machining parameters identified from the response table were 50 m/min cutting speed, 0.35 mm/rev feed rate and 0.5 mm depth of cut for dry machining while 80 m/min cutting speed, 0.35 mm/rev feed rate and 0.5 mm depth of cut for flood machining were selected.

3.3.1 Dry Machining

The predicted Grey Relational Grade (GRG) was calculated using the Taugchi confirmation equation:

$\mu = \mu_m + \sum_{i=1}^{n}(\mu_i - \mu_m)$

$\mu = predicted\ value\ of GRG\ at\ optimum\ level$

$\mu_m = overall\ mean\ of\ GRG$

$\mu_i = mean\ GRG\ at\ the\ optimum\ level\ of\ each\ parameter$

$n = various\ input\ parameters.$

$\mu = 0.579 + (0.616 - 0.579) + (0.671 - 0.579) + (0.785 - 0.579)$

$$\mu = 0.914$$

A confirmation experiments was then performed using the optimum machining parameters. The measured surface roughness and cutting zone temperature were 3.20μm and 90°C respectively. Table 3.5 shows the confirmation test results for dry machining.

Table 3.5 Predicted v/s Experimental Comparison of GRG for Dry Machining

Optimum Parameter			Experimental Responses		GRG	
v (m/min)	f (mm/rev)	d (mm)	SR	CZT	Predicted	Experimental

50	0.35	0.5	3.20	90	0.914	0.851
Percentage Error=6.89 %						

The confirmation test validates the proposed Grey Relational Analysis- based optimization model. The predicted GRG (0.914) and experimental GRG (0.851) exhibit good agreement with percentage error of only 6.89 %, confirming the adequacy and reliability of the developed optimization methodology. Hence the identified optimum machining parameters can be recommended for achieving enhanced overall machining performance under dry conditions.

3.3.2 Flood Machining:

The predicted Grey Relational Grade (GRG) was calculated using the Taugchi confirmation equation:

$\mu = \mu_m + \sum_{i=1}^{n}(\mu_i - \mu_m)$

$\mu = predicted\ value\ of GRG\ at\ optimum\ level$

$\mu_m = overall\ mean\ of\ GRG$

$\mu_i = mean\ GRG\ at\ the\ optimum\ level\ of\ each\ parameter$

$n = various\ input\ parameters.$

$\mu = 0.591 + (0. -0.591) + (0.671 - 0.591) + (0.785 - 0.579)$

$$\mu = 0.924$$

A confirmation experiments was then performed using the optimum machining parameters. The measured surface roughness and cutting zone temperature were 1.84 and 75°C respectively. Table 3.6 shows the confirmation test results for Flood machining.

Table 3.5 Predicted v/s Experimental Comparison of GRG for Flood Machining

Optimum Parameter			**Experimental Responses**		**GRG**	
v (m/min)	**f (mm/rev)**	**d (mm)**	**SR**	**CZT**	**Predicted**	**Experimental**
80	0.35	0.5	1.84	75	0.924	0.890
Percentage Error=3.67 %						

A conformation experiment was conducted at the optimum parameters combination of 80 m/min cutting speed, 0.35 mm/rev feed rate and 0.5mm depth of cut. The predicted Grey Relational Grade (GRG) obtained from the Taugchi additive model was 0.924 while the experimentally obtained GRG was 0.890 resulting in prediction error confirms the adequacy and reliability of the proposed Taguchi- Grey Relational Analysis model for multi response optimization under flood machining conditions.

Conclusion

The results of Grey Relational Analysis indicate that depth of cut is the most influential parameter affecting the combined performance of surface roughness and cutting zone temperature. The Grey Relational Grade (GRG) values under flood machining are observed to be consistently higher than those obtained in dry machining, indicating better simultaneous optimization of surface roughness and cutting zone temperature an improvement of approximately 9–16% in GRG is achieved with the application of coolant. The results of the present investigation show the benefits of using Flood cooling in comparison with dry machining. Surface roughness is reduced nearly 5-12 % and cutting zone temperature shows a significant decrease of about 15-20 % in comparison with the dry machining. The optimal machining condition under dry environment was found at cutting speed of 50 m/min, feed of 0.35 mm/min, and depth of cut of 0.5 mm and for flood cooling was found at cutting speed of 80 m/min, feed of 0.35 mm/min and depth of cut 0.5 mm. A comparative study between dry and flood machining reveals that flood cooling significantly improves machining performance by reducing both surface roughness and cutting zone temperature. The presence of coolant enhances lubrication and heat dissipation, resulting in better surface integrity and tool performance....

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