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Multi-response Optimization of Hot Machining Process Using Grey Relational Analysis (GRA) Method

KEYWORDS: Hot Machining, Optimization, MRR, Surface Roughness, GRA, Regression Analysis

Mrs Swetha Patil	Nitin k. Kamble	S. S. Sarnobat
Research Scholar, D. Y. Patil College of Engineering, Akurdi, Pune	Professor, D. Y. Patil College of Engineering, Akurdi, Pune	Professor, D. Y. Patil College of Engineering, Akurdi, Pune

ABSTRACT *In this work, examination of surface integrity due to hot machining (specifically turning) of hard-to-machine material (EN36) is the major concern. The focus of the research work is to optimize the response (i.e. surface roughness – minimum, material removal rate – maximum and Tool Wear Rate - Minimum) of hot machining (turning) process by controlling the process parameters; e.g. [1]. Temperature –2000C, 3000C and 4000C [2].Cutting Speed -0.293 m/sec, 0.418 m/sec and 0.523 m/sec [3]. Feed – 0.05 m/sec, 0.1 m/sec and 0.16 m/sec [4].Depth of Cut – 0.5 mm, 1mm and 1.5 mm in comparison with conventional turning. The objective of the study is to optimize the responses simultaneously, so that a compromise between different process outputs can be achieved. A new technique, Grey Relational Analysis (GRA) is used here for multi-response optimization. This is one of the good methods of multi-criterion optimization, which gives the combination of factors and their respective levels, which yields to best results. Finally a mathematical model is built using multiple linear regression analysis to establish a relation between response and process parameters.*

INTRODUCTION: Machining of hard to machine materials have a major drawback in terms of surface finish, tool life, and material removal rate using conventional machining process. Hard machining is machining of such materials, although most frequently the process concerns hardness of 58 to 68 HRC. although hard machining have benefits over conventional grinding but have limiation in terms of tool cost, machining time, surface finishing.

Hot machining is the process which is used for easy machining and to eliminate the problems of low cutting speed, feeds and heavy loads on the machine bearings. These problems arise when machining process is being done on the new and tough materials. The basic principal behind this process is the surface of the work piece which is to be machined is pre heated to a temperature below the re-crystallization. By this heating, the shear force gets reduced and machining process becomes easy. During the machining process, instead of increasing the quality of the cutter materials, softening of the work piece is one of an alternate. In hot machining, a part or whole of the work piece is heated. Heating is performed before or during machining. Hot machining prevents cold working hardening by heating the piece below the recrystallisation temperature and this reduces the resistance to cutting and consequently favors the machining.

The selection of a heating method for obtaining ideal heating of metals for machining is critical. Faulty heating methods could induce unwanted structural changes in the work piece and increase the cost. In research, many heating methods are utilized.

Easy formations of chip, Lessened shocks to the tools, Good surface finish of the work piece, are some of the advantages of hot machining process. On other hand the main disadvantage of this process is the work piece micro structure may get disturbed due to heating.

LITERATURE REVIEW

Z. Y. Wang et. al. [1] presented a new approach for machining of Inconel 718. It combines traditional turning with cryogenically enhanced machining and plasma enhanced machining. Cryogenically enhanced machining is used to reduce the temperatures in the cutting tool, and thus reduces temperature-dependent tool wear to prolong tool life, whereas plasma enhanced machining is used to increase the temperatures in the workpiece to soften it. By joining these two non-traditional techniques with opposite effects on the cutting tool and the workpiece, it has been found that the surface roughness was reduced by 250%; the cutting forces was decreased by approximately 30–50%; and the tool life was extended up to 170% over conventional machining.

Production of hard-to-cut materials with uncoated carbide cutting tools in turning, not only cause tool life reduction but also, impairs the product surface roughness. M. Davami and M. Zads hakoyan [2], in their paper studied the influence of hot machining method and presented in two cases.

Case1 - Workpiece surface roughness quality with constant cutting parameter and 300^{0}C initial workpiece surface temperature.

Case 2 - Tool temperature variation when cutting with two speeds 78.5 (m/min) and 51 (m/min). The workpiece material and tool used in this study were AISI 1060 steel (45HRC) and uncoated carbide TNNM 120408-SP10 (SANDVIK Coromant) respectively. A gas flam heating source was used to preheating of the workpiece surface up to 300^{0}C, causing reduction of yield stress about 15%. Results obtained experimentally, show that the method used can considerably improved surface quality of the workpiece.

Kamdar and Patel [3] machined the EN 36 Steel specimens heated with gas flame on a lathe under different cutting conditions of Surface temperatures, Cutting speeds and Feed rates. Cutting force, feed force and surface roughness were studied under the influence of machining parameter at 200 °C, 300^{0}C, 400^{0}C, 500^{0}C and 600^{0}C at constant depth of cut 0.8 mm. The optimum result was achieved in the experimental study by employing Design of experiments with Taguchi. In present study, Analysis found that varying parameters are affected in different way for different response. The ANOVA technique was used to obtain optimum cutting parameters.

Titanium and its alloys are known as difficult-to-cut material due to some circumstances, such as high chemical reactivity, low thermal conductivity, low modulus of elasticity, and high strength at elevated temperature. Furthermore, higher cutting force and lower tool life in machining of these alloys are very common. Ginta and Nurul Amin [4] used an ap-

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proach to reduce the cutting force and increase the tool life is to employ thermally-assisted machining. The working piece surface was heated up until a certain temperature just before cutting. They establish mathematical models for cutting force and tool life in end milling of titanium alloy Ti–6Al–4V using PCD inserts under thermally-assisted machining using high frequency induction heating. Response surface methodology (RSM) was employed in developing the cutting force and tool life models in relation to primary cutting parameters such as cutting speed, feed, and preheating temperature. Design- expert software was applied to establish the first-order and the second-order model and develop the contours. The adequacy of the predictive model was verified using analysis of variance (ANOVA) at 95% confidence level.

Maity and Swain [5] carried out an experimental investigation for hot-machining operation of high manganese steel using a carbide cutting tool. The heating of the work-piece was carried out by burning a mixture of liquid petroleum gas and oxygen. An expression of tool life as a function of cutting speed, feed, depth of cut and temperature was developed using regression analysis. The model adequacy is tested using χ^2 test. The tool life is influenced by work-piece temperature, cutting speed, feed and depth of cut in that order. So the effect of temperature of work-piece is found to be the most significant on tool life. However the recrystalisation temperature of work-piece limits the maximum value of temperature. The chip-reduction coefficient decreases with increase in temperature.

EXPERIMENTAL WORK: Turning operation was carried out on lathe machine with EN 36 work material (table2) using TiAlN Coated Carbide Insert. The present work was carried out using oxyacetylene flame heating method. The machining work was carried in two cases:

Case 1(Hot machining) Work piece Temperature(A) 200°C, 300°C, 400°C Cutting speed (B) 0.293m/sec, 0.418 m/sec, 0.523m/sec Feed rate (C) 0.05m/sec, 0.1m/sec, 0.16m/sec and Depth of cut (D) 0.5mm, 1mm, 1.5mm

Case 2 (Machining at ambient temperature) Cutting speed (A') 0.293m/sec, 0.418 m/sec, 0.523m/sec Feed rate (B' 0.05m/sec, 0.1m/sec, 0.16m/sec and Depth of cut (C') 0.5mm, 1mm, 1.5mm.

Table 2: Chemical composition and hardness of EN36

Chemical composition of the work material					Hardness
C	Si	Mn	Ni	Cr	(HRC)
0.13%	0.25%	0.50%	3.25%	0.85%	44

The experimental results of EN 36 were evaluated to ascertain the machining performance, such as (1) surface roughness, (2) tool wear, and (3) metal removal rate (MRR). The surface roughness of the turned surface was measured using a Mitutoyo surftest SJ-201 P The tool wear of the TiAlN coated carbide insert was examined by Mitutoyo TM-505 microscope The metal removal rate was calculated by the following formula:

$$MRR \approx k \times V \times f_r \times t \quad [1]$$

k is a constant to "correct" speed (V) and part diameter (D) units, V given in meters per second (MPS), D in mm: k = 60000,V is desired cutting speed, D is largest part diameter (initial size),fr is machine feed rate units/revolution, t is Depth of cut (inch or mm).

Fig. 1: Experimental set-up of hot machining

Design of experiments
Hot machining
The table 3 shows the level and combination of the input factors used in hot machining process for experimentation.

Table 3: Factors and level combination for hot machining.

Sr. No.	Factor		Unit	Level 1	Level 2	Level 3
1	A	Temperature	^{0}C	200	300	400
2	B	Cutting Speed	m/sec	0.293	0.418	0.523
3	C	Feed	m/sec	0.05	0.1	0.16
4	D	Depth of Cut	mm	0.5	1.0	1.5

According to the Taguchi design concept for the 3 level and 4 parameters, a L27 orthogonal arrays table, which has 27 rows corresponding to the number of experiments, was chosen for the experiments (Table 4).

Table 4: The experimental layout using L_{27} orthogonal array (Hot machining)

Test No.	A		B		C		D	
	Level	Value	Level	Value	Level	Value	Level	Value
1	1	200	1	0.293	1	0.05	1	0.5
2	1	200	1	0.293	2	0.1	2	1.0
3	1	200	1	0.293	3	0.16	3	1.5
4	1	200	2	0.418	1	0.05	2	1.0
5	1	200	2	0.418	2	0.1	3	1.5
6	1	200	2	0.418	3	0.16	1	0.5
7	1	200	3	0.418	1	0.05	3	1.5
8	1	200	3	0.418	2	0.1	1	0.5
9	1	200	3	0.418	3	0.16	2	1.0
10	2	300	1	0.293	1	0.05	1	0.5
11	2	300	1	0.293	2	0.1	2	1.0
12	2	300	1	0.293	3	0.16	3	1.5
13	2	300	2	0.418	1	0.05	2	1.0
14	2	300	2	0.418	2	0.1	3	1.5
15	2	300	2	0.418	3	0.16	1	0.5
16	2	300	3	0.418	1	0.05	3	1.5
17	2	300	3	0.418	2	0.1	1	0.5
18	2	300	3	0.418	3	0.16	2	1.0
19	3	400	1	0.293	1	0.05	1	0.5
20	3	400	1	0.293	2	0.1	2	1.0
21	3	400	1	0.293	3	0.16	3	1.5
22	3	400	2	0.418	1	0.05	2	1.0
23	3	400	2	0.418	2	0.1	3	1.5
24	3	400	2	0.418	3	0.16	1	0.5
25	3	400	3	0.418	1	0.05	3	1.5
26	3	400	3	0.418	2	0.1	1	0.5
27	3	400	3	0.418	3	0.16	2	1.0

Machining at ambient temperature (30° C).

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Table 5: Factors and level combination of machining at ambient temperature.

Sr. No.	Factor		Unit	Level 1	Level 2	Level 3
1	A'	Cutting Speed	m/sec	0.293	0.418	0.523
2	B'	Feed	m/sec	0.05	0.1	0.16
3	C'	Depth of Cut	Mm	0.5	1.0	1.5

The above table 5 shows the level and combination of the input factors used in machining at ambient temperature process for experimentation.

Table 6: The experimental layout (Machining at ambient temperature 30°C).

Test No.	A'		B'		C'	
	Level	value	level	value	level	value
1	1	0.293	1	0.05	1	0.5
2	1	0.293	2	0.1	2	1.0
3	1	0.293	3	0.16	3	1.5
4	2	0.418	1	0.05	2	1.0
5	2	0.418	2	0.1	3	1.5
6	2	0.418	3	0.16	1	0.5
7	3	0.418	1	0.05	3	1.5
8	3	0.418	2	0.1	1	0.5
9	3	0.418	3	0.16	2	1.0

To match the test numbers as in hot machining only 9 tests are conducted with different levels of cutting speed, feed rate and depth of cut (Table6).

Table7 shows the detailed experimental results for hot machining and machining at ambient temperature and comparison of both.

Table 7: Result table

Test No.	Surface Roughness (µm)		Tool wear (mm)		Material Removal Rate (mm/min)
	Machining at ambient temperature (30°C)	Hot machining	Machining at ambient temperature (30°C).	Hot machining	Theoretically calculated
1	4.25	2.55	0.37	0.24	0.4395
2	5.32	2.78	0.42	0.29	1.758
3	5.67	3.11	0.54	0.32	4.2192
4	4.09	2.14	0.39	0.25	1.254
5	4.89	2.61	0.40	0.27	3.762
6	3.78	3.40	0.37	0.37	2.0064
7	2.87	1.59	0.41	0.24	1.881
8	3.45	2.39	0.32	0.26	1.254
9	4.11	3.32	0.39	0.34	4.0128
10	4.25	2.36	0.37	0.25	0.4395
11	5.32	2.49	0.42	0.27	1.758
12	5.67	2.70	0.54	0.28	4.2192
13	4.09	1.91	0.39	0.23	1.254
14	4.89	2.41	0.40	0.26	3.762
15	3.78	3.05	0.37	0.29	2.0064
16	2.87	1.36	0.41	0.21	1.881
17	3.45	1.61	0.32	0.18	1.254
18	4.11	2.09	0.39	0.24	4.0128
19	4.25	1.8	0.37	0.17	0.4395
20	5.32	2.11	0.42	0.15	1.758
21	5.67	2.48	0.54	0.16	4.2192
22	4.09	1.66	0.39	0.17	1.254
23	4.89	1.71	0.40	0.15	3.762
24	3.78	1.73	0.37	0.20	2.0064
25	2.87	1.30	0.41	0.19	1.881
26	3.45	1.34	0.32	0.14	1.254
27	4.11	1.42	0.39	0.18	4.0128

GREY RELATIONAL ANALYSIS (GRA) APPROACH

STEPS IN GRA

Step 1. Normalizes the experimental results of each performance characteristic.

Experimental data yij is normalized as Zij (0 ≤ Zij ≤1) for the i^{th} performance characteristics in the j^{th} experiment can be expressed as:

For S/N ratio with Larger-the-better condition

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij}, i=1,2..n)}{\max(y_{ij}, i=1,2..n) - \min(y_{ij}, i=1,2..n)} \quad \text{.... (2)[6]}$$

For S/N ratio with Smaller-the-better condition

$$Z_{ij} = \frac{\max(y_{ij}, i=1,2..n) - y_{ij}}{\max(y_{ij}, i=1,2..n) - \min(y_{ij}, i=1,2..n)} \quad \text{..... (3)[6]}$$

For S/N ratio with Nominal-the-better condition

$$Z_{ij} = \frac{(y_{ij} - Target) - \min(|y_{ij} - Target|, i=1,2..n)}{\max(|y_{ij} - Target|, i=1,2..n) - \min(|y_{ij} - Target|, i=1,2..n)} \quad \text{.. (4)[6]}$$

Using equation (3) for S/N ratio with smaller the better condition normalized response for the hot machining results of surface roughness and tool wear (table 7) are calculated and detailed in table 8. And for the material removal rate equation (2) was used.

Table 8: Normalized response of each individual quality

Test No.	Normalized Response		
	Surface Roughness	Tool Wear	Material Removal Rate
	µm	mm	m^3/min
1	0.4048	0.5652	0
2	0.2952	0.3478	0.3488
3	0.1381	0.2174	1
4	0.6000	0.5217	0.2155
5	0.3762	0.4348	0.8790
6	0	0	0.4146
7	0.8619	0.5652	0.3814
8	0.4810	0.4783	0.2155
9	0.0381	0.1304	0.9454
10	0.4952	0.5217	0
11	0.4333	0.4348	0.3488
12	0.3333	0.3913	1
13	0.7095	0.6087	0.2155
14	0.4714	0.4783	0.8790
15	0.1667	0.3478	0.4146
16	0.9714	0.6957	0.3814
17	0.8524	0.8261	0.2155
18	0.6238	0.5652	0.9454
19	0.7619	0.8696	0
20	0.6143	0.9565	0.3488
21	0.4381	0.9130	1
22	0.8286	0.8696	0.2155

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23	0.8048	0.9565	0.8790
24	0.7952	0.7391	0.4146
25	1	0.7826	0.3814
26	0.9810	1	0.2155
27	0.9429	0.8261	0.9454

Step 2. Calculate the grey relational coefficient.
The Grey relational Co-efficient γ_{ij} can be expressed as:

$$\gamma_{ij} = \frac{\Delta min + \xi \Delta max}{\Delta_{oi}(k) + \xi \Delta max}$$ .... (5)[6]

Where,

j=1,2…n; k=1,2…m, n is the number of experimental data items and m is the number of responses.

$y_o(k)$ is the reference sequence ($y_o(k)=1$, k=1,2…m); $y_j(k)$ is the specific comparison sequence.

$\Delta_{oj} = \| y_{ok} - y_{jk} \|$
=The absolute value of the difference between $y_o(k)$ and $y_j(k)$

$\Delta_{min} = \underset{\forall j \in i}{min} \underset{\forall k}{min} \| y_{ok} - y_{jk} \|$ is the smallest value of $y_j(k)$

$\Delta_{max} = \underset{\forall j \in i}{max} \underset{\forall k}{max} \| y_{ok} - y_{jk} \|$ is the largest value of $y_j(k)$

ξ is the distinguishing coefficient which is defined in the range $0 \le \xi \le 1$ (the value may adjusted based on the practical needs of the system, it will be 0.5 generally).

Step 3. Calculate the grey relational grade by the mean value of grey relational coefficient.

The Grey relational grade is expressed as:

$$\bar{\gamma}_j = \frac{1}{k}\sum_{i=1}^{m} \gamma_{ij}$$ .... (6)[6]

Table 9 gives the grey relation coefficient and grey relation grade which were calculated using equation (5) and (6).

Table 9: Grey rational coefficient and grade

Test No.	$\Delta_{0,1}(k)$	$\Delta_{0,2}(k)$	$\Delta_{0,3}(k)$	Grey Relational coefficient			Grey Relational grade
				$\gamma_1(k)$	$\gamma_2(k)$	$\gamma_3(k)$	
1	0.5952	0.4348	1.0000	0.4565	0.5349	0.3333	0.4416
2	0.7048	0.6522	0.6512	0.4150	0.4340	0.4343	0.4278
3	0.8619	0.7826	0.0000	0.3671	0.3898	1.0000	0.5857
4	0.4000	0.4783	0.7845	0.5556	0.5111	0.3893	0.4853
5	0.6238	0.5652	0.1210	0.4449	0.4694	0.8052	0.5732
6	1.0000	1.0000	0.5854	0.3333	0.3333	0.4606	0.3758
7	0.1381	0.4348	0.6186	0.7836	0.5349	0.4470	0.5885
8	0.5190	0.5217	0.7845	0.4907	0.4894	0.3893	0.4564
9	0.9619	0.8696	0.0546	0.3420	0.3651	0.9015	0.5362
10	0.5048	0.4783	1.0000	0.4976	0.5111	0.3333	0.4474
11	0.5667	0.5652	0.6512	0.4688	0.4694	0.4343	0.4575
12	0.6667	0.6087	0.0000	0.4286	0.4510	1.0000	0.6265
13	0.2905	0.3913	0.7845	0.6325	0.5610	0.3893	0.5276
14	0.5286	0.5217	0.1210	0.4861	0.4894	0.8052	0.5936
15	0.8333	0.6522	0.5854	0.3750	0.4340	0.4606	0.4232
16	0.0286	0.3043	0.6186	0.9459	0.6216	0.4470	0.6715
17	0.1476	0.1739	0.7845	0.7721	0.7419	0.3893	0.6344
18	0.3762	0.4348	0.0546	0.5707	0.5349	0.9015	0.6690
19	0.2381	0.1304	1.0000	0.6774	0.7931	0.3333	0.6013
20	0.3857	0.0435	0.6512	0.5645	0.9200	0.4343	0.6396
21	0.5619	0.0870	0.0000	0.4709	0.8519	1.0000	0.7742
22	0.1714	0.1304	0.7845	0.7447	0.7931	0.3893	0.6423
23	0.1952	0.0435	0.1210	0.7192	0.9200	0.8052	0.8148
24	0.2048	0.2609	0.5854	0.7095	0.6571	0.4606	0.6091
25	0.0000	0.2174	0.6186	1.0000	0.6970	0.4470	0.7146
26	0.0190	0.0000	0.7845	0.9633	1.0000	0.3893	0.7842
27	0.0571	0.1739	0.0546	0.8974	0.7419	0.9015	0.8470

Step 4. Perform the response table and response graph for each level of the machining parameters using eqution (6).

Table 10: Grey relational grade for input factors at different levels.

Sr. No.	Factor		Grey Relational Grade			Maximum - Minimum	Rank
		Levels					
		1	2	3			
1	A	Temperature	0.4967	0.5612	0.7141	0.2174	1
2	B	Cutting Speed	0.5557	0.5605	0.6558	0.1001	3
3	C	Feed rate	0.5689	0.5979	0.6052	0.0363	4
4	D	Depth of Cut	0.5304	0.5814	0.6603	0.1299	2

RESULT AND DISCUSSION:

Table 11: Percentage improvement of surface roughness and tool wear by hot machining.

Test No.	Surface Roughness (μm)			Tool wear (mm)		
	Machining at ambient temperature (30°C)	With hot machining	% Improvement	Machining at ambient temperature (30°C)	With hot machining	% Improvement
1	4.25	2.55	40	0.37	0.24	35
2	5.32	2.78	48	0.42	0.29	31
3	5.67	3.11	45	0.54	0.32	41
4	4.09	2.14	48	0.39	0.25	36
5	4.89	2.61	47	0.40	0.27	33
6	3.78	3.40	10	0.37	0.37	0
7	2.87	1.59	45	0.41	0.24	41
8	3.45	2.39	31	0.32	0.26	19
9	4.11	3.32	19	0.39	0.34	13
10	4.25	2.36	44	0.37	0.25	32
11	5.32	2.49	53	0.42	0.27	36
12	5.67	2.70	52	0.54	0.28	48
13	4.09	1.91	53	0.39	0.23	41
14	4.89	2.41	51	0.40	0.26	35
15	3.78	3.05	19	0.37	0.29	22
16	2.87	1.36	53	0.41	0.21	49
17	3.45	1.61	53	0.32	0.18	44
18	4.11	2.09	49	0.39	0.24	38
19	4.25	1.8	58	0.37	0.17	54
20	5.32	2.11	60	0.42	0.15	64
21	5.67	2.48	56	0.54	0.16	70
22	4.09	1.66	59	0.39	0.17	56

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23	4.89	1.71	65	0.40	0.15	63
24	3.78	1.73	54	0.37	0.20	46
25	2.87	1.30	55	0.41	0.19	54
26	3.45	1.34	61	0.32	0.14	56
27	4.11	1.42	65	0.39	0.18	54

The result (figure 2) for surface roughness shows that the heating work piece can improve the surface quality of machined surface. Also in heating condition the surface roughness is uniform when compared with the case where the workpiece were machined at ambient temperature.

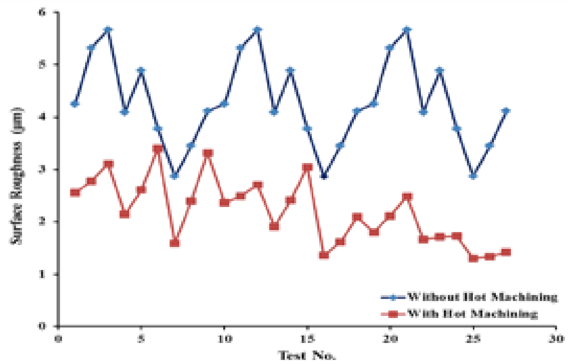

Figure 2: Comparison of surface roughness in hot machining and machining at ambient temperature.

The above figure shows the graph for the comparison of surface roughness of workpiece machined by hot machining process (red line) and by without hot machining process (blue line).

The result (figure 3) for tool wear shows that heating workpiece material reduces the tool wear with respect to that of machining at ambient temperature. Minimum tool wear is obtained at 400° C.

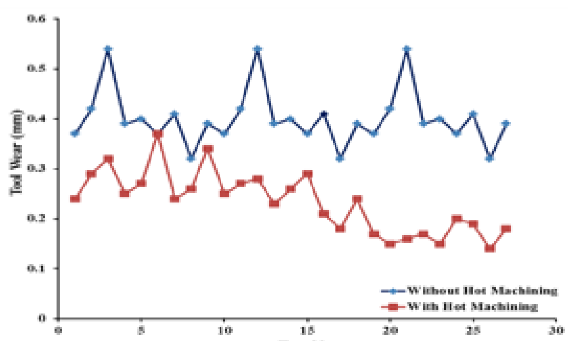

Figure 3: Comparison of tool wear in hot machining and machining at ambient temperature.

The above figure shows the graph for the comparison of tool wear of workpiece machined by hot machining process (red line) and by without hot machining process (blue line).

By using grey relational analysis for the experimental results of hot machining it is found that the optimum combination of the process parameters is $A_3B_3C_3D_3$(Work piece temperature 400⁰C, Cutting speed 0.523m/sec, Feed rate 0.16m/sec, Depth of cut 1.5mm) which is significant for the Table 5.4.

The figure(4) shows the graph which illustrates the optimum combination of the process parameters ($A_3B_3C_3D_3$).

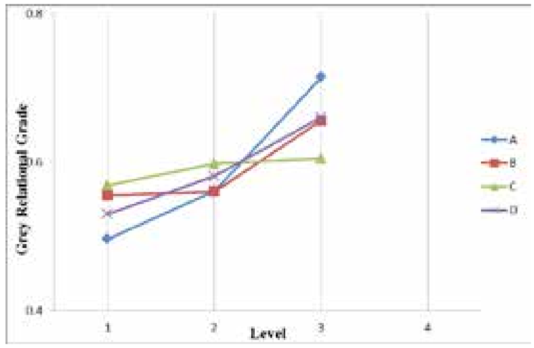

Figure 4: Effect of hot machining parameters on grey rational grade.

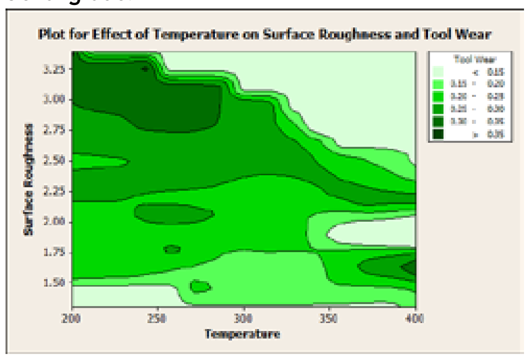

Figure 5: Effect of temperature on surface roughness and tool wear.

Figure 5 shows the effect of temperature on surface roughness and tool wear. The minimum tool wear and surface roughness are achieved when the temperature is 400ºC.

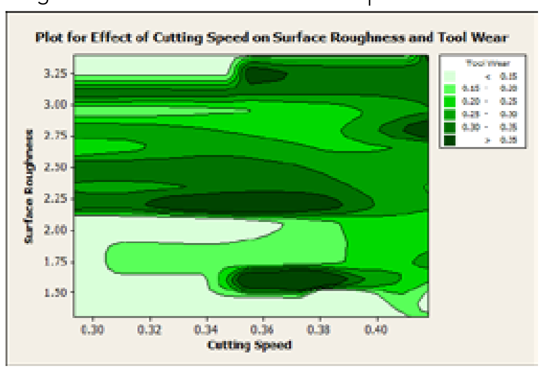

Figure 6: Effect of cutting speed on surface roughness and tool wear.

Figure 6 shows the effect of cutting speed on surface roughness and tool wear. The minimum tool wear and surface roughness are achieved when the cutting speed is0.4m/sec.

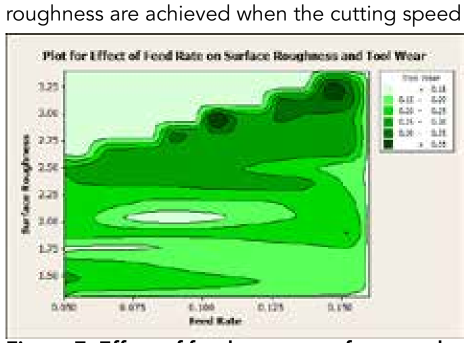

Figure 7: Effect of feed rate on surface roughness and tool wear.

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Figure 7 shows the effect of feed rate on surface roughness and tool wear. The minimum tool wear and surface roughness are achieved when the feed rate is 0.1m/sec.

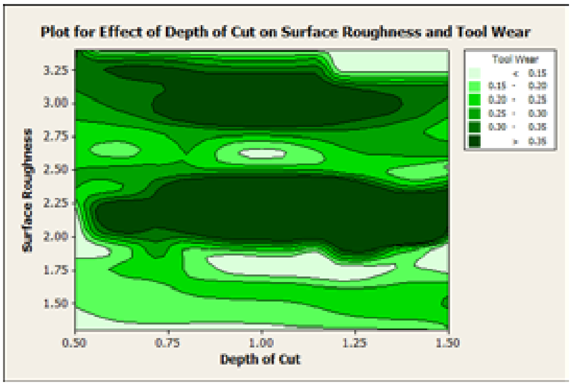

Figure 8: Effect of depth of cut on surface roughness and tool wear.

Figure 8 shows the effect of depth of cut on surface roughness and tool wear. The minimum tool wear and surface roughness are achieved when the depth of cut is 1.5m/sec.

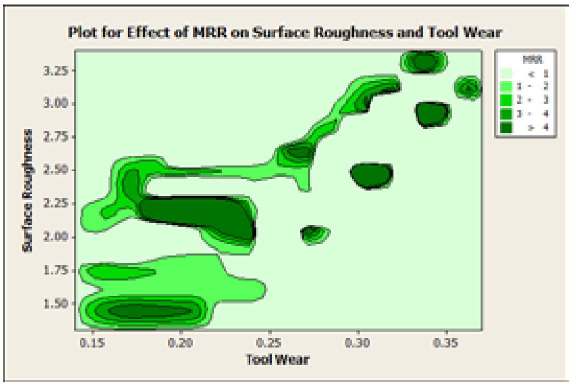

Figure 9: Effect of MRR on surface roughness and tool wear.

Figure 9 shows the effect of material removal rate on surface roughness and tool wear. It can be observed that as the MRR increases the surface roughness and the tool wear also increases.

6.1: Multiple Regression Equations

The relationship between the input parameters and response were modelled by multiple regressions. The regression equations obtained were as follows:

Y_1 = 3.5028 - 0.0031455 X_1- 1.9885 X_2 + 6.4062 X_3 - 0.20828 X_4………………………. (7)

Y_2 = 0.39244 - 0.00060194 X_1 - 0.0006014 X_2 + 0.53836 X_3 - 0.027541 X_4…………….. (8)

Where, X_1= Temperature in °C, X_2=Cutting Speed in m/sec, X_3=Feed rate in m/sec, X_4=Depth of Cut in mm, Y_1=Surface Roughness in μm, Y_2=Tool Wear in mm

CONCLUSION

By hot machining surface roughness decreased from 4.11 μm to 1.42 μm (table 11) and tool wear reduced from 0.54 to 0.16 mm (table 11)at work piece temperature 400° C

Optimum results are achieved when temperature is 400° C cutting speed is 0.523 m/sec, feed rate is 0.1 m/sec and depth of cut is1.5 mm(figure 4), for the hot turning process of 1955 EN36 using TiAlN coated carbide insert as cutting tool.

Based on Grey Relational Analysis it was found that Temperature, Depth of cut and Cutting speed are primary factors that affect the quality of hot turning of 1955 EN36, while Feed rate is found to secondary or least significant factor (table 10).

Mathematical model for surface roughness and tool wear is derived using multiple linear regression analysis technique which were

Y_1 = 3.5028 - 0.0031455 X_1- 1.9885 X_2 + 6.4062 X_3 - 0.20828 X_4.

Y_2 = 0.39244 - 0.00060194 X_1 - 0.0006014 X_2 + 0.53836 X_3 - 0.027541 X_4.

(equation (7) and (8)).

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