Parametric Optimization of Hard turning of AISI 4340 Steel by solid lubricant with coated carbide insert.

Jitendra. M. Varma*, Chirag. P. Patel**
*Student,M.Tech, (Department of MechanicalEngineering, Ganpat University, Kherva-384012,)
** Associate Prof., (Department of Mechanical Engineering, Ganpat University, Kherva-384012,)

Abstract
This study investigated the optimization of Hard turning of AISI 4340 steel by solid lubricant assisted environment using the Grey relational analysis method. Hexagonal boron nitride (H-bn) has been selected as solid lubricant. All the experiment are carried out at different cutting parameter (Cutting speed, Feed rate, Depth of cut and nose radius) in Dry, Wet and solid lubricant assisted environment.Twenty Seven experiments runs based on an orthogonal array of Taguchi method were performed. Each nine experiments were carried out in Dry, Wet and Solid lubricant assisted environment. Surface roughness and cutting force selected as aresponsevariable.An optimal parameter combination of the turning operation was obtained via Grey relational analysis. By analyzing the Grey relational grade matrix, the degree of influence for each controllable process factor onto individual quality targets can be found. The optimal parameter combination is then tested for accuracy of conclusion with a test run using the same parameters.

Keywords: *Optimization, Grey relational analysis, surface roughness, cutting force, feed force.*

1. Introduction

During the past few years, unprecedented progress has been made in the hard turning. The greatest advantage of using hard turning is the reduced machining time and complexity required to manufacture metal parts.Before few years problem associated with the hard turning was the generation of high temperature in cutting zone. This adversely affects the quality of the products produced. Cutting fluids have been the conventional choice to deal with this problem. But, the application of conventional cutting fluids creates some techno-environmental problems like environmental pollution, biological problems to operators, water pollution, Further; the cutting fluids also incur a major portion of the total manufacturing cost.

Reduction of environmental pollution has been the main concern in the present day metal cutting industry. The government has put pressure on industries to minimize the use of cutting fluids. Although the cutting fluid can be recycled. Recycling services in the United-state charge twice price for disposal and the cost is four times as much in Europe. In addition to environmental and health concerns, the metal cutting industry continues to investigate ways to achieve longer tool life, higher cutting speed, better work surface quality, less built up edge, easier chip breaking, lower production cost, overall quality and productivity. Although dry machining eliminates the use of cutting fluid, it negatively affects too life.

Application of solid lubricant in dry machining has proved to be a feasible alternative to cutting fluid, if it can be applied properly. Advancement in modern tribology has identified many solid lubricants like graphite, boric acid, hexagonal boron nitride (White graphite), molybdenum disulfide and tungsten disulfide, which can sustain and provide lubricity over a wide range of temperatures. If suitable solid lubricant can be applied in a more refined and defined way.

In machining operation, the quality of surface finish is an important requirement of work pieces and parameter in manufacturing engineering. During the turning operation, the cutting tool and the metal bar are subjected to a prescribed deformation as a result of the relative motion between the tool and work-piece both in the cutting speed direction and feed direction. As a response to the prescribed deformation, the tool is subjected to thermal loads on those faces that have interfacial contact with the work-piece or chip. Usually the material removal occurs in a highly hostile environment with high temperature and pressure, in the cutting zone.

The ultimate objective of the science of metal cutting is to solve practical problems associated with efficient material removal in the metal cutting process. Turning is by far the most commonly used operation in a lathe. In this the work held in the spindle is rotate while the tool is fed past the work piece in a direction parallel to the axis of rotation. The surface generated is the cylindrical surface.

Lathe turning parameter like cutting speed, feed rate, depth of cut and nose radius are optimize with multi response optimization method. By using this method, complicated multiple responses can be converted into normalized response known as Grey Relational Coefficient (GRC). Grey relational analysis was performed to combine the multiple responses into one numerical score, rank these scores, and determine the optimal cutting parameter settings. Confirmation tests were performed by using experiments.

2. Experimental details

2.1 Work piece material

AISI 4340 has been selected as work piece Material .It widely used for aircraft landing gear, power transmission gear, shaft and other parts. The diameter and Length of work piece was 47 mm and 200 mm respectively. Chemical composition of this material is Carbon 0.38 to 0.48%, Chromium 0.7 to 0.9%, Manganese 0.6 to0.8, Molybdenum 0.2 to 0.3, Nickel 1.65 to 2%, Phosphorus 0.035 max, Silicon 0.15 to0.30%, Sulphur 0.04max.

2.2 Cutting inserts

All the experiments were performed by using coated carbide insert of PR series (TNMG-PR1125) of different geometry. It is hard TiAlN base PVD coated super micro-grain carbide insert having superior toughness and heat resistance. It is used for Finishing and light interrupted cutting of stainless steel. Right hand side cutting tool holder of GRADE-MTJNR 2020 K16 has been used.

2.3 Cutting fluid

In order to perform the experiment in wet cutting environment, soluble oil (KOOLKUT-40, a product of Hindustan Petroleum, Mollifiable oil, Emulsion strength 5–10%) has been used as a cutting fluid. HP KOOLKUT-40 is general-purpose emulsifiable oil and forms milky white emulsion. Suitable for all metals for machining operations where emulsifiable oil is normally used. The recommended concentration is between 5 to 10 percent depending on the severity of machining. Sometimes used successfully for even grinding operations.

2.4 Solid lubricant

In order to perform the experiment in solid lubricant cutting environment, Hexagonal boron nitride powder has been selected.Boron Nitride is a ceramic powder lubricant. The most interesting lubricant feature is its high temperature resistance of 1200°C service temperature in an oxidizing atmosphere. Furthermore, boron has a high thermal conductivity. Boron is available in two chemical structures, i.e. cubic and hexagonal where the last is the lubricating version. The cubic structure is very hard and used as an abrasive and cutting tool component. Another advantage of h-BN over graphite is that its lubricity does not require water or gas molecules trapped between the layers. Therefore, h-BN lubricants can be used even in vacuum, e.g. in space applications. It doesn't affect the environment and human health. Hence, the lubricating properties of fine-grained h-BN are used in cosmetics, paints, dental cements.

2.5Experimental apparatus

The hard turning of work piece is conducted on Latheturning center having followingSpecifications:

Height of center: 175 mm, Swing over bed: 350mm, Swing over slide: 190mm,Swing in gap: 550mm,Width of bed: 240mm, Spindle speed NO. 8: 60 To 1025 RPM, Cross slide travel: 200mm, Top slide travel: 125mm, Net weight: 700 kg, Lead screw: 4 TPI, Power required: 1.5W/2H.P, Bed length: 4'.5"/600mm

2.6 Measurement of surface roughness and cutting forces

The surface roughness of the turned samples was measured with Mitutoyo make Surface roughness tester (SJ-110) and the cutting forces measured with the help of 2-D dynamometer.

2.7Design of experiment

In this study, four controllable variables, namely, cutting speed, feed rate, depth of cut and nose radius has been selected. In the machining parameter design, three levels of the cutting parameters were selected, shown in Table 1.

Table1.Factors with levels value

Factors	Level 1	Level 2	Level 3
Cutting speed (m/min)	67.1	100.8	151.3
Feed rate (mm/rev)	0.4	0.8	1.0
Depth of cut (mm)	0.3	0.4	0.5
Nose radius (mm)	0.4	0.8	1.2

As per table 1, L9 orthogonal array of "Taguchi method" has been selected for the experiments in MINITAB 15. Each 9 experiments will carry out in dry, wet and solid lubricant assisted environment. Surface roughness, cutting force and feed force has been selected as response variable.All these data are used for the analysis and evaluation of the optimal parameters combination.Experiment result as shown in Table2.

Table2. Experimental results.

Sr. no	V. (m/min)	FR. (mm)	DOC (mm)	NR (mm)	SR (µm)	F_c (Kg)	F_f (Kg)
	DRY						
1	67.1	0.8	0.4	0.8	2.033	49.0	68.6

2	67.1	1.0	0.5	1.2	3.308	107.9	176.5
3	100.8	0.8	0.5	0.4	2.489	78.4	117.7
4	151.3	0.4	0.5	0.8	0.901	49.0	78.4
5	151.3	0.8	0.3	1.2	1.987	29.4	39.2
6	151.3	1.0	0.4	0.4	2.469	68.6	107.9
7	67.1	0.4	0.3	0.4	1.358	39.2	49.0
8	100.8	0.4	0.4	1.2	1.423	58.8	68.6
9	100.8	1.0	0.3	0.8	2.121	29.4	49.0
	WET						
10	67.1	0.8	0.4	0.8	1.967	39.2	58.8
11	67.1	1.0	0.5	1.2	3.316	88.2	166.7
12	100.8	0.8	0.5	0.4	2.444	68.6	98.1
13	151.3	0.4	0.5	0.8	0.842	39.2	58.8
14	151.3	0.8	0.3	1.2	1.919	39.2	39.2
15	151.3	1.0	0.4	0.4	2.429	49.0	78.4
16	67.1	0.4	0.3	0.4	1.348	29.4	39.2
17	100.8	0.4	0.4	1.2	1.402	49.0	58.8
18	100.8	1.0	0.3	0.8	2.097	19.6	49.0
	SOLID LUBRICANT						
19	67.1	0.8	0.4	0.8	2.123	29.4	68.6
20	67.1	1.0	0.5	1.2	3.256	68.6	166.7
21	100.8	0.8	0.5	0.4	2.376	58.8	107.9
22	151.3	0.4	0.5	0.8	0.866	29.4	58.8
23	151.3	0.8	0.3	1.2	1.826	19.6	49.0
24	151.3	1.0	0.4	0.4	2.531	39.2	88.2
25	67.1	0.4	0.3	0.4	1.369	39.2	49.0
26	100.8	0.4	0.4	1.2	1.389	19.6	78.4
27	100.8	1.0	0.3	0.8	1.842	19.6	58.8

3. Methodology

3.1 Grey relational analysis method

In the grey relational analysis, experimental results were first normalized and then the grey relational coefficient was calculated from the normalized experimental data to express the relationship between the desired and actual experimental data. Then, the grey relational grade was computed by averaging the grey relational coefficient corresponding to each process response (3 responses). The overall evaluation of the multiple process responses is based on the grey relational grade. [4]

3.2 Data preprocessing

In grey relational generation, the normalized data corresponding to Lower-the-Better (LB) criterion can be expressed as:

$$Xi(k) = \frac{\max\ yi(k) - yi(k)}{\max\ yi(k) - \min\ yi(k)} \qquad (1)$$

For Higher-the-Better (HB) criterion, the normalized data can be expressed as:

$$Xi(k) = \frac{yi(k) - \min\ yi\ (k)}{\max\ yi(k) - \min\ yi(k)}$$

(2)

Where xi (k) is the value after the grey relational generation, min yi (k) is the smallest value ofyi (k) for the kth response, and max yi (k) is the largest value of yi (k) for the k^{th} response.

An ideal sequence is x0(k) (k=1, 2) for two responses. The definition of the grey relational grade in the grey relational
analysis is to show the relational degree between the twenty-seven sequences (x0(k) and *xi*(k), i=1, 2, . . . , 27; k=1, 2). The grey relational coefficient *ξi*(k) can be calculated as:

$$\xi i(k) = \frac{\min \Delta + \theta \max \Delta}{\Delta i(k) + \theta \max \Delta} \qquad (3)$$

Where Δi = | X0 (k) – Xi (k) | = difference of the absolute value x0 (k) and xi (k); θ is the distinguishing coefficient 0 ≤ θ ≤ 1; minΔ = ∀j min ϵ i∀kmin= | X0 (k) – Xi (k) | = the smallest value of Δ0i; and maxΔ = ∀jmax ϵ i∀kmax = largest value of Δ0i. After averaging the grey relational coefficients, the grey relational grade γi can be computed as

$$yi = \frac{1}{n} \sum_{k=1}^{n} \xi i\ (k) \qquad (4)$$

Where n = number of process responses. The higher value of grey relational grade corresponds to intense relational degree between the reference sequence x0 (k) and the given sequence xi (k). The reference sequence x0 (k) represents the best process sequence. Therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal. [5]

4. Results and discussions

A level average analysis was adopted to interpret the results. This analysis is based on combining the data associated with each level for each factor. The difference in the average results for the highest and lowest average response is the measure of the effect of that factor. The greatest value of this difference is related to the largest effects of that particular factor. Data preprocessing of each performancecharacteristic and the experimental results for the grey relational according to formulas (1),(2),(3) and (4) are given in Table 3 and 4.

Table 3 Normalize value of SR, Fc and Ff for dry, wet and solid lubricant environment.

Ex NO.	Normalize value of SR	Normalize value of Fc	Normalize value of F_f
	DRY		
1	0.5297	0.7500	0.7857
2	0	0	0
3	0.3403	0.3750	0.4286
4	1	0.7500	0.7143
5	0.5488	1	1
6	0.3486	0.5000	0.5000
7	0.8101	0.8750	0.9286
8	0.7831	0.6250	0.7857
9	0.4931	1	0.9286
	WET		
10	0.5453	0.7143	0.8462
11	0	0	0

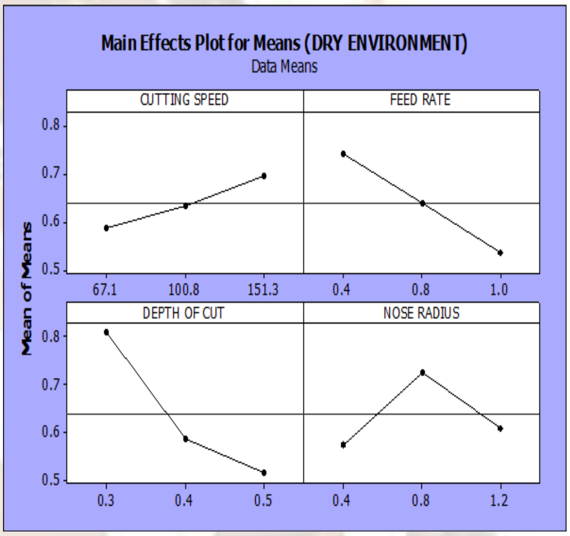
12	0.3525	0.2857	0.5385
13	1	0.7143	0.8462
14	0.5647	0.7143	1
15	0.3585	0.5714	0.6923
16	0.7955	0.8571	1
17	0.7736	0.5714	0.8462
18	0.4927	1	0.9231
	SOLID LUBRICANT		
19	0.4741	0.8000	0.8333
20	0	0	0
21	0.3682	0.2000	0.5000
22	1	0.8000	0.9167
23	0.5983	1	1
24	0.3033	0.6000	0.6667
25	0.7895	0.6000	1
26	0.7812	1	0.7500
27	0.5916	1	0.9167

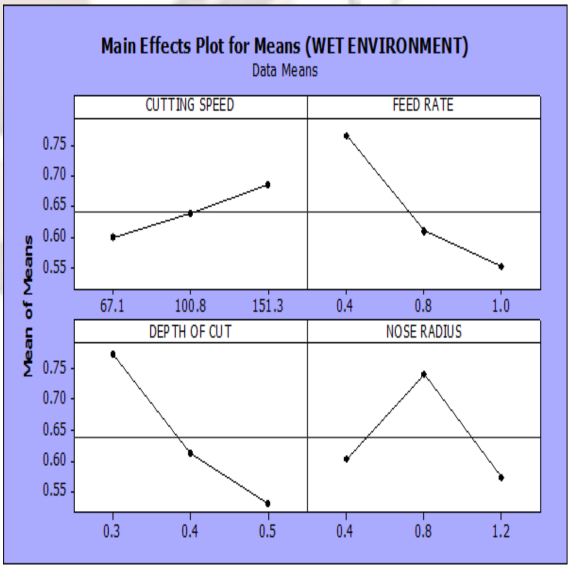
Table 4 Calculation of GRC and GRD

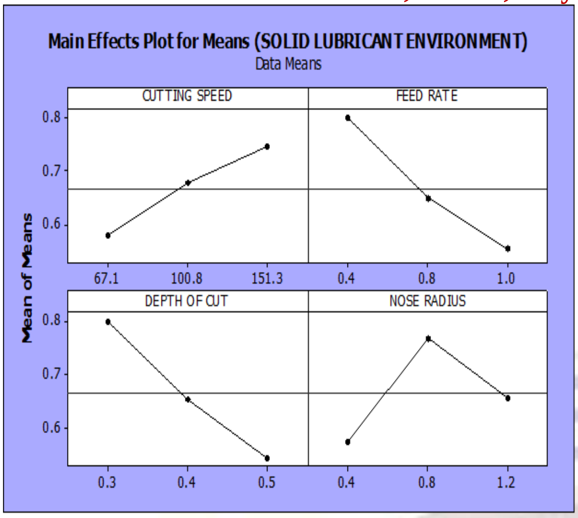
Ex. No	GRC of SR	GRC of CF	GRC of FF	GRG	Grade No.
	DRY				
1	0.5153	0.6667	0.7000	0.6273	6
2	0.3333	0.3333	0.3333	0.3333	9
3	0.4311	0.4444	0.4667	0.4474	8
4	1	0.6667	0.6364	0.7677	4
5	0.5257	1	1	0.8419	1
6	0.4343	0.5000	0.5000	0.4781	7
7	0.7247	0.8000	0.8750	0.7999	2
8	0.6974	0.5714	0.7000	0.6562	5
9	0.4966	1	0.8750	0.7905	3
	WET				
10	0.5237	0.6364	0.7648	0.6416	6
11	0.3333	0.3333	0.3333	0.3333	9
12	0.4357	0.4118	0.5200	0.4558	8
13	1	0.6364	0.7648	0.8004	2
14	0.5346	0.6364	1	0.7236	4
15	0.4380	0.5384	0.6190	0.5318	7
16	0.7097	0.7777	1	0.8219	1
17	0.6883	0.5384	0.7648	0.6638	5
18	0.4964	1	0.8667	0.7877	3
	SOLID LUBRICANT				
19	0.4874	0.7143	0.7500	0.6505	6
20	0.3333	0.3333	0.3333	0.3333	9
21	0.4418	0.3846	0.5000	0.4421	8
22	1	0.7143	0.8572	0.8571	1
23	0.5545	1	1	0.8515	2
24	0.4178	0.5556	0.6000	0.5244	7
25	0.7037	0.5556	1	0.7531	5
26	0.6956	1	0.6667	0.7874	4
27	0.5504	1	0.8572	0.8025	3

In grey relational analysis higher the grey relational grade of experiment says that the corresponding experimental combination is optimum condition for multi objective optimization and gives better product quality. Also form the basis of the grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined. From Table 4. It is found that experiment 22 has the best multiple performance characteristic among 27 experiments, because it has the highest grey relational grade of 0.8571.

The main effects plot of grey relational grade vs. process parameter can generated by Minitab 15 statistical software to find out optimum parameter combination, is shown in graph 1.







Graph 1. Mean effect plot of grey relational grad Vs. cutting speed, feed rate, depth of cut and nose radius.

From the graph 1. It is conclude that the optimum condition for better surface finish is meeting at cutting speed (A3), feed rate (B1), depth of cut (C1) and nose radius (D2).

The final step in the experiment is to do confirmation test. The purpose of the confirmation runs is to validate the conclusion drawn during the analysis phases. In addition, the confirmation tests need to be carried out in order to ensure that the theoretical predicted parameter combination for optimum results using the software was acceptable or not. The parameters used in the confirmation test are suggested by grey relational analysis. The confirmation test with optimal process parameters is performed in solid lubricant environment at levels A3 (151.3 m/min Cutting speed), B1 (0.4 mm/rev Feed), C1 (0.3 mm Depth of cut) and D2 (0.8 mm nose radius) of process parameter takes for 10 mm length of cut and gives 0.721 Ra value.

5. Conclusion

It is concluded that the application of solid lubricant in dry machining has proved to be a feasible alternative to cutting fluid, if it can be applied properly. There is a considerable improvement in surface roughness and quality of product produced.

6. Acknowledgment

It is a privilege for me to have been associated with Mr. C. P. Patel, Asso. Prof. of Mechanical Engg.Dept. at U.V Patel College of engineering, Kherva.During this paper work. I have been greatly benefited by his valuable suggestions and ideas. It is with great pleasure that I express my deep sense of gratitude to him for his valuable guidance and constant encouragement throughout this work.

References

[1]. APS Gaur, Sanjay Agarwal“Investigation to Study the Applicability of Solid Lubricant in Turning AISI 4340 Steel”,Procedia CIRP 1 (2012) 243 – 248.

[2]. PatilDeepak Kumar h, Dr. M. Sadaiah, “investigations on finish turning of AISI 4340 steel in different cutting environments by CBN insert”ISSN : 0975-5462, Vol. 3 No.10 October 2011.

[3]. Dilbag Singh, P. VenkateswaraRao, “Improvement in Surface Quality with Solid Lubrication in Hard Turning”International Journal of Materials Science and Engineering, Vol. 2, No. 1-2, January-December 2011.

[4]. L B Abhang, M. Hameedullah, “Experimental investigation of minimum quantity lubricants in alloy steel turning”,International Journal of Engineering Science and Technology, Vol. 2(7), 2010, 3045-3053.

[5]. P. Vamsi Krishna, D. NageswaraRao, “The influence of solid lubricant particle size on machining parameters in turning”,International Journal of Machine Tools & Manufacture 48 (2008) 107–111.

[6]. N.R. Dhar, M. Kamruzzaman, Mahiuddin Ahmed, “Effect of minimum quantity lubrication (MQL) on tool wear and surface roughness in turning AISI-4340 steel”.Journal of Materials Processing Technology 172 (2006) 299–304

[7]. PatrikDahlman, Fredrik Gunnberg, Michael Jacobson, “The influence of rake angle, cutting feed and cutting depth on residual stresses in hard turning”, Journal of Materials Processing Technology 147 (2004) 181–184

[8]. R.F. Avila,A.M. Abrao, “The effect of cutting fluids on the machining of hardened AISI 4340 steel”Journal of Materials Processing Technology 119 (2001) 21–26

[9]. Mohd H.I. Ibrahim, NorhamidiMuhamad , Khairur R. Jamaludin , Nor H.M. Nor and Sufizar Ahmad, Optimization of Micro Metal Injection Molding with Multiple Performance Characteristics using Grey Relational Grade, Chiang Mai J. Sci. 38(2) : 231-241, (2011)

[10]. Ramanujam R., Raju R., Muthukrishnan N. , Optimization Of Machining Parameters For Turning Al-Sic (10p) Mmc Using Taguchi Grey Relational Analysis, International Journal Of Industrial Engineering, 18(11), 582-590, (2011)

[11]. J.L. Deng, “Introduction to Grey system,” J. Grey Syst., vol. 1, pp. 1–24, 1989.