International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Multi-objective optimization in Turning of EN31 steel using Taguchi based grey relational analysis

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Accepted 30 July 2016, Available online 02 Aug 2016, **Vol.6, No.4 (Aug 2016)**

Abstract

Machining can be outlined as the process of taking away material from a work piece in the grade of chips. During a machining process, isolated of the energy is turned into heat energy through the detritions yielded between the tool and the work piece and the plastic deformation of the work material in the machining zone. Turning is charmed by several constituents, for example, the cutting speed, feed rate, depth of cut and geometry of cutting instrument and so on, which are information parameters in this anticipate work. The present study investigates multi-response optimization of turning technique in machining of EN 31 tool steel for an best parametric combination to render the lowest surface roughness (Ra) and cutting force with the maximal material-removal rate (MRR) using a Grey–Based Taguchi method. Turning parameters studied are cutting speed, feed rate and depth of cut on EN31 steel with chemical vapor deposition (CVD) and physical vapor deposition (PVD) coated carbide tools. Eighteen experimental runs based on Taguchi's L18 orthogonal array will be executed accompanied by Grey relational analysis to solve the multi-response optimization problem. Based upon grey relational grade value, best levels of parameters have been identified. The significance of parameters on total quality features of the cutting process has been evaluated by the analysis of variance (ANOVA). It was seen from the results that cutting speed is the most significant parameter for surface roughness followed by feed, whereas the depth of cut is found to be insignificant by the ANOVA analysis.

Keywords: *Turning, optimization, ANOVA, EN 31 steel.*

1. Introduction

Turning is a metal cutting procedure utilized for the era of round and hollow surfaces. Regularly the work piece is pivoted on an axle and the instrument is bolstered into it radially, pivotally or both courses at the same time to give the required surface. The term turning, in the general sense, alludes to the era of any round and hollow surface with a solitary point instrument. All the more particularly, it is frequently connected just to the era of outside tube shaped surfaces situated principally parallel to the work piece hub. The era of surfaces situated principally opposite to the work piece pivot are called confronting. In turning, the course of the bolstering movement is prevalently hub concerning the machine shaft. In confronting a spiral food is prevailing. Decreased and shaped surfaces require both methods of hardware food in the meantime regularly alluded to as profiling.

After decide on the machine tool and cutting tool, the subsequent main cutting settings have to be considered. Cutting speed alludes to the relative surface pace amongst device and work, communicated in surface feet every moment. Either or the work, the apparatus, or both, can move amid cutting. Since the machine apparatus is worked to work in cycles every moment, some methods should then be accessible for changing over surface rates into cycles or revolutions per moment (RPM).

Turning operation can be performed by using coated carbide tools also. Couple of materials has deeply affected our economy and industrialized society than solidified tungsten carbide. Hard and wear-safe, this material is utilized for items as intriguing and fluctuated as ballpoint pen balls, angling pole guide rings, wear parts, dental bores, defensive layer penetrating shell centers and, most fundamentally, cutting instruments. Truth be told, covered established carbides are the most broadly utilized cutting devices available. All things considered, they convey large amounts of efficiency to the assembling procedure, which thusly, makes huge numbers of the items utilized each day more reasonable. In any case, with the variety of cutting edge covering procedures and covering materials, it's not generally simple to decide the best embed grade for a given application.

The most two popular coating process are physical vapor deposition (PVD) and chemical vapor deposition

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(CVD), used for both single layer and multi-layer coatings. CVD coatings are thick (ranges from 9-20 microns) and very wear safe, making them particularly valuable for steel and give iron machining a role as well as generally utilized as a part of turning operations. These coating compromises on edge toughness. PVD coatings are thin (ranges from 2 – 3 microns) yet harder and ordinarily smoother than CVD coatings. Thus, they are helpful for machining materials, for example, super alloys, titanium alloys and hard to-machine stainless steels, which ordinarily indent or chip front lines. Turning insert shapes are indexable turning supplements are fabricated in an assortment of shapes, sizes and thicknesses, with straight gaps, with countersunk gaps, without openings, with chip breakers on one side, with chip breakers on two sides or without chip breakers. The determination of the suitable turning tool holder geometry, joined by the right embed shape and chip breaker geometry, will eventually significantly affect the profitability and instrument life of a particular turning operation.

2. Background of the work

(G. Singh *et.al.*) analyzed the usage of cutting fluids and their demerits, they have applied low quantity lubricant as well as they have used vegetable based cutting fluid for the study. Surface roughness is analyzed by turning of EN31 tool steel with mineral based oil and vegetable based oil and indicated that vegetable oil machining the surface roughness is having a promising change. (Satish Chinchanikar *et.al.*) attempted to compare tool nose wear progression under dry and near-dry(minimum quantity lubrication) cutting conditions through experimentation and mathematical modeling in view of disagreement of the researchers about the use of coolants in hard turning. Experiments on hardened AISI 4340 steel (55 HRC) were performed using PVD-applied TiAlSiN coated carbide inserts varying the cutting speed and feed in the wide range of cutting conditions and at constant depth of cut of 0.3 mm. (Gomez *et.al.*) conducted experiments on high silicon aluminum alloys with the help of CVD coated diamond cutting tool. By using the cemented carbide the formation of interlocking effect of the diamond film was observed. CrN/Cr produces coating adhesion under dry cutting operations.

(Fernandez *et.al.*) studied the behavior of PVD coated tool in turning of austenitic steel, with four types of coatings such as TiAlCrN, AlTiN, AlCrSiN and AlTiSiN. Wear tests were conducted such as cutting forces, surface roughness. The work suggested that AlTiN coatings for better tool wear evolution, less tangential cutting force. (N. Andriya *et.al.*) investigated PVD coated in turning of Ti-6Al-4V using TiAlN coated tools. Experiment was carried out using response surface methodology. Linear model is best fitted for prediction of feed force, surface roughness in dry environment. Cutting velocity and feed are most significant on the surface roughness improvement. A feed of 46.88% and depth of cut of 47.59% are most significant factors affected the cutting force by variability model.

(Dearnley *et.al.*) studied the wear mechanisms of CVD and PVD coated tools in turning of metal cunlng applications. The measured flank 'wear land' shifted generally for titanium nitride coated and uncoated HSS drills – this might be related to variety in the high temperature shear quality of the HSS drills. Covering misfortune was sporadic in nature and there was some confirmation that crack of the PVD titanium nitride coatings occurred amid metal cutting. (Ahmad *et.al.*) studied the tool wear in dry turning of Al 6061 by using PVD and CVD coated inserts. Machining without the utilization of any cutting liquid purported dry machining is turning out to be progressively more prominent, particularly in machining Al 6061 for the car application. Experiment was conducted with five coated carbide inserts. The outcomes demonstrated that the CVD covered carbides inserts have indicated lower device wear when contrasted with PVD covered carbide inserts.

(Staszuk *et.al.*) studied the performance of multilayer PVD and CVD coating exploitative security of edges from apparatus earthenware production and sintered carbides covered with angle. Better adherence of the coatings containing the AlN stage with hexagonal cross section is associated with the same sort of inter atomic substrates (covalent) in material of both covering and artistic substrate. In the paper the exploitative properties of the explored coatings in the innovative cutting trials were additionally decided. (Umesh gupta *et.al.*) performed experiments on AISI 4340 alloy steel in the dry cutting environment by using the CVD and PVD coated inserts. The selection of AISI4340 is mainly because of difficult to cut material, high hardness, specific heat is low and the tendency to get strain hardened. The experiments were conducted by using the response surface methodology and investigated surface roughness as the major output. In turning of AISI4340 feed is the most influential factor followed by cutting speed. The developed mathematical model was proved with ANOVA analysis.

(Khorasani *et.al.*) modeled the process parameters of CVD and PVD coated tools and analyzed the thin-film coatings. He proposes the estimation of hardness of titanium dainty film layers as defensive modern instruments by utilizing multi-layer perceptron (MLP) neural system. Taking into account the test information that was acquired amid the procedure of compound vapor statement (CVD) and physical vapor affirmation (PVD), the displaying of the covering variables for foreseeing hardness of titanium slight film layers, is performed. Many researchers have not concentrated more on the coated tool in machining of steels.

Presently the work concentrates on the coated tools performance in machining of steel.

3. Methodology

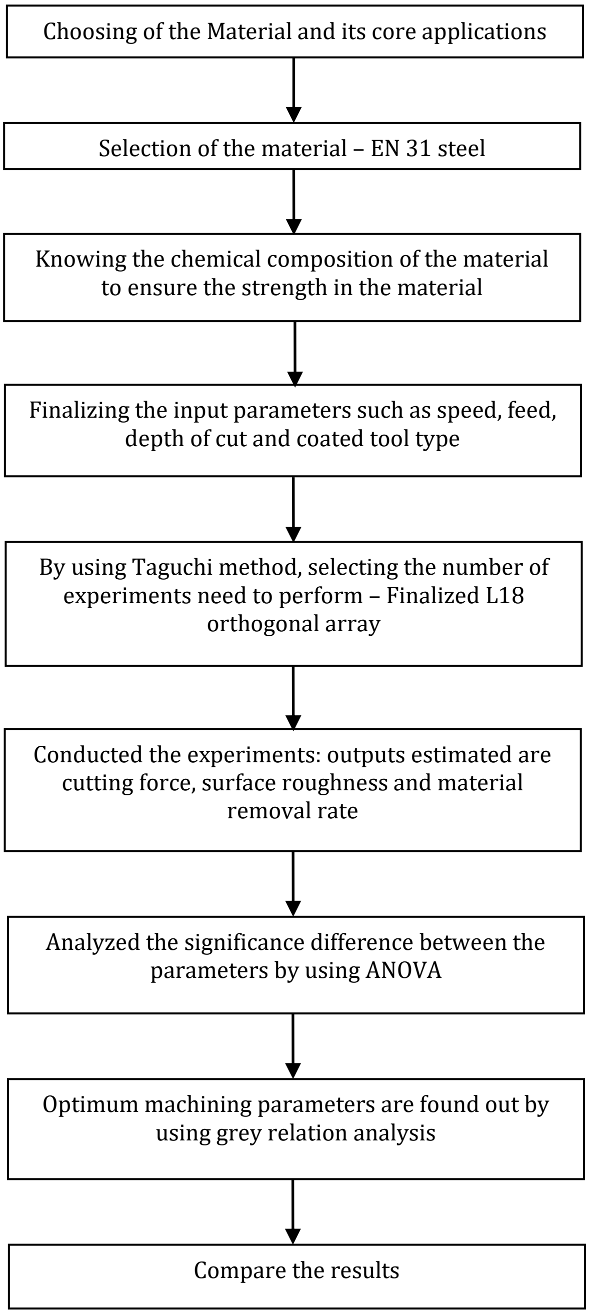

Fig.1 Methodology of the work

Fig.1 depicts the methodology of the present work and finally the results are compared.

4. Experimental procedure

EN31 steel (equivalent to 52100 grade) is medium carbon steel and it provides good and great mechanical properties and high corrosion resistance. It is used in automobile parts and aerospace industries. For turning of EN31 steel and analysis four machining parameters are considered such as type of the cutting tool, cutting speed, feed of the machine and depth of cut were selected and their levels are represented in the table 1.

Table 1 EN 31 steel machining parameters and their levels

Factors	Symbol	Levels		
		1	2	3
Coated tools	A	CVD	PVD	-
Feed (mm/rev)	B	0.08	0.16	0.24
Cutting speed (m/min)	C	110	181	242
Depth of cut (mm)	D	0.5	1.0	1.5

The L18 orthogonal array was selected because here the use of coated tools only PVD and CVD are considered for only two levels. The remaining factors are considered for three levels so the array becomes like (2^1; 3^3) so totally 18 experiments are selected and these are coded in the table 2.

Table 2 Experiment values as per L18 orthogonal array with turning parameters

Number of experiment	Type of Tool	Feed (mm/ rev)	Cutting speed (m/min)	Depth of cut (mm)
1	CVD	0.08	110	0.5
2	CVD	0.08	181	1.0
3	CVD	0.08	242	1.5
4	CVD	0.16	110	0.5
5	CVD	0.16	181	1.0
6	CVD	0.16	242	1.5
7	CVD	0.24	110	1.0
8	CVD	0.24	181	1.5
9	CVD	0.24	242	0.5
10	PVD	0.08	110	1.5
11	PVD	0.08	181	0.5
12	PVD	0.08	242	1.0
13	PVD	0.16	110	1.0
14	PVD	0.16	181	1.5
15	PVD	0.16	242	0.5
16	PVD	0.24	110	1.5
17	PVD	0.24	181	0.5
18	PVD	0.24	242	1.0

By using the L18 orthogonal array the series of experiments are conducted on the EN 31 steel and the results are tabulated in table 4.6. Surface roughness is measure by surface roughness tester; whereas the cutting force is measured with crystal dynamometer. The material removal rate is calculated by sing the formulae. The MRR is measured in mm3/sec.

Material removal rate = ((1000*V*f*d))/60 (1)

Where v is the cutting speed, f is the feed rate of the machine and d is the depth of cut.

Table 3 Experiment results

No. of experiment	Surface roughness, R_a (μ m)	Cutting force, (N)	Material removal rate, (mm^3 /sec)
1	0.9291	135	73.3333
2	2.3478	149	241.3333
3	1.6875	308	484.0000
4	2.1132	136	146.6667
5	1.1245	242	482.6667
6	0.9986	381	968.0000
7	2.5674	256	440.0000
8	1.4123	464	1086.0000
9	1.2763	161	484.0000
10	0.3491	389	220.0000
11	2.482	215	120.6667
12	2.1273	136	322.6667
13	1.2387	125	293.3333
14	2.3198	408	724.0000
15	2.3752	157	322.6667
16	1.3462	147	660.0000
17	2.8125	219	362.0000
18	2.9012	250	968.0000

5. Results & Discussions

5.1 Grey relation analysis

Due to the data differ from the parameter to parameter normally pre-processing of data is essential to get the output in precise form. It indicates getting of comparable sequence by transferring the original sequence. The data sequence depends on the different characteristics that are present in the grey relation method technique.

The target value, here if we consider in the machining of EN31 steel the surface roughness as one of the target. Now the surface quality of the machined product should be as low as possible to ensure the quality of the machined surface, then it has the characteristic of lower-the-better has to be considered. The machined output value for surface roughness can be normalized by using the formulae as shown in equation below

$$x_i^*(j) = \frac{\max x_i^o(j) - x_i^o(j)}{\max x_i^o(j) - \min x_i^o(j)}$$

Now, if the target value is the material removal rate. So for that one higher the material removal from the work piece is preferred for the getting good machined part. Here the characteristic is higher-the-best will be choosing from the original sequence of the data. The machined output value for the material removal rate can be normalized by using the formulae as shown in the equation below.

$$x_i^*(j) = \frac{x_i^o(j) - \min x_i^o(j)}{\max x_i^o(j) - \min x_i^o(j)}$$

Where i = 1, ... , m ; j = 1, ...,n. m is the number of experimental data items and n is the number of parameters. $x_i^o(j)$ denotes the original sequence , $x_i^*(j)$ denotes the sequence after the data pre-processing. $\max x_i^o(j)$ is the largest value of $x_i^o(j)$, $\min x_i^o(j)$ is the largest value of $x_i^o(j)$ and x^o is the desired value of the given set.

Grey relation analysis starts with calculating the data pre-processing step followed by grey relation coefficient and grade. To start with the output or the experimental details from the table has to be normalized. For normalizing, the maximum and minimum values of the responses need to find out.

For getting the sequence the surface roughness and cutting force the formula should be lower the better and for the material removal rate the formula should be higher the better. Let the results of 18 experiments be the comparability sequences and all are listed in the table below.

5.2 Grey relation calculation

Sample calculation performed will be

$$\Delta_{01}(1) = |x_o^*(1) - x_1^*(1)| = |1.0 - 0.7727| = 0.2273$$
$$\Delta_{01}(2) = |x_o^*(2) - x_1^*(2)| = |1.0 - 0.9705| = 0.0295$$
$$\Delta_{01}(3) = |x_o^*(3) - x_1^*(3)| = |1.0 - 1.000| = 0.0000$$

So Δ_{01}= (0.2273,0.0295,0.0000)

Table 4 Sequences after data-processing

No. of experiment	Surface roughness, R_a (μ m)	Cutting force, (N)	Material removal rate, (mm^3 /sec)
1	0.7727	0.9705	1.0000
2	0.2168	0.9292	0.8341
3	0.4756	0.4602	0.5945
4	0.3088	0.9676	0.9276
5	0.6962	0.6549	0.5958
6	0.7455	0.2448	0.1165
7	0.1308	0.6136	0.6379
8	0.5834	0.0000	0.0000
9	0.6367	0.8938	0.5945
10	1.0000	0.2212	0.8552
11	0.1643	0.7345	0.9533
12	0.3032	0.9676	0.7538
13	0.6514	1.0000	0.7828
14	0.2278	0.1652	0.3575
15	0.2061	0.9056	0.7538
16	0.6093	0.9351	0.4207
17	0.0348	0.7227	0.7149
18	0.0000	0.6313	0.1165

Table 5 Grey relation coefficient and grade

No. of experiment	Grey relation coefficient			Grey relational grade	Rank
	Surface roughness, R_a (μ m)	Cutting force, (N)	Material removal rate, (mm^3 /sec)		
1	0.6875	0.9443	1.0000	0.8773	1
2	0.3897	0.8760	0.7509	0.6722	6
3	0.4881	0.4809	0.5522	0.5070	13
4	0.4197	0.9391	0.8735	0.7441	3
5	0.6220	0.5916	0.5530	0.5889	11
6	0.6627	0.3984	0.3614	0.4742	15
7	0.3652	0.5641	0.5800	0.5031	14
8	0.5455	0.3333	0.3333	0.4041	17
9	0.5792	0.8248	0.5522	0.6520	7
10	1.0000	0.3910	0.7754	0.7221	4
11	0.3743	0.6532	0.9145	0.6473	8
12	0.4178	0.9391	0.6700	0.6756	5
13	0.5892	1.0000	0.6971	0.7621	2
14	0.3930	0.3746	0.4376	0.4017	18
15	0.3864	0.8412	0.6700	0.6326	10
16	0.5614	0.8851	0.4633	0.6366	9
17	0.3412	0.6433	0.6369	0.5405	12
18	0.3333	0.5756	0.3614	0.4234	16

In addition to the determination of optimum turning parameters for surface roughness, cutting force and material removal rate, the response table for the taguchi method was used to calculate the average grey relational grade for each level of the turning parameters.

The procedure is:

i) grouping the grey relational grades by factor level for each column in the orthogonal array,
ii) At last taking the average of the three responses.

The grey relation grade for factor A the coated tool at level 1 will be calculated by

$$Y_i = \frac{1}{9}(0.8773 + 0.6722 + 0.070 + 0.7441 + 0.5889 + 0.4742 + 0.5031 + 0.4041 + 0.6520) = 0.6025$$

For each level of turning parameters the grey relational grade values are to be calculated and they are tabulated below in table. Since the grey relational grade represents the level of correlation among the reference sequence and the comparability sequence, the greater value of the grey relational grade means that the comparability sequence has a stronger relationship to the reference sequence.

Table 6 Grey relation grade response table

	Turning Parameters			
Level	**Coated Tool (A)**	**Feed (B)**	**Speed (C)**	**Depth of cut (D)**
1	0.6025	**0.6836**	**0.7075**	**0.6823**
2	**0.6047**	0.6006	0.5424	0.6042
3	-	0.5266	0.5608	0.5243
Max - Min	0.0021	0.157	0.1651	0.158
Rank	4	3	1	2

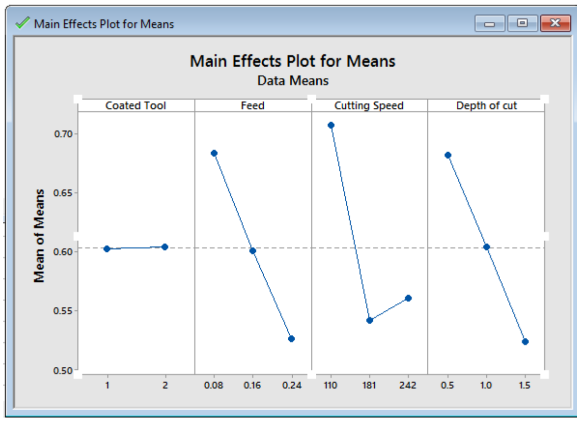

Fig. 2 Effects of turning parameters levels on the multi-performance

The order of importance of the controllable factors to the multi-performance characteristics in the turning process of EN 31 steel are in sequence can be scheduled as: factor C (Speed type), D (depth of cut), B (feed) and A (coated tool type) (i.e. 0.1651 > 0.158 > 0.157 > 0.0021). Factor C, cutting speed of the machine was the most effective factor to performance. This clearly indicates that in turning process cutting speed was the most influential in turning of EN 31 steel where the surface roughness and cutting force will be low and material removal rate should be high.

Conclusions

By conducting the experiments on EN 31 steel, the main output parameters analyzed here was surface roughness, cutting forces acting on the work piece and material removal rate. The following conclusions are stated.

- Taguchi's robust design with L18 orthogonal array the optimization of experiments has done by using the statically software.
- The experimental values, multi-objective optimization problem were solved by using grey relational analysis.
- GRA showed the main influencing parameters in turning of steel as Speed type, depth of cut, feed and coated tool type.

- The optimal combination has also showed that coated tool with CVD coating is preferred, analyzed with the help of grey grade.
- The study shows that GRA can be applied successfully to other operations in which the performance is decided by multiple quality parameters.

As a future scope, this work can be extended to coated tools with the lubricant machining as well as the multi-objective optimization approach can be solved by using meta-heuristic approaches also.

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