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Experimental Investigation and Analysis of Optimum Cutting Parameters for AISI1042 Using Grey-Taghuchi Analysis

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Abstract: The paper discussed about optimization of multi-criteria problems that are used in turning operation. The theory of grey system is a new technique for performing prediction, relational analysis and decision making in multi-criteria problems. Optimization of cutting parameters which are influencing on surface roughness, and MRR of AISI 1042 (EN 41B) work material using CVD coated tool is a multi-objective criteria. In the present investigation the influence of spindle speed, feed rate, and depth of cut were studied as process parameters. The experiments have been conducted using full factorial design in the design of experiments (DOE) on a conventional lathe (PSGA141). A Model has been developed using regression technique and the optimal cutting parameters for minimum surface roughness, and maximum MRR were obtained using Taguchi technique. The use of grey relation analysis for optimizing the cutting parameters for good surface finish and more material removal rate is introduced. Optimal machining parameters were determined by the grey relation grade obtained from the Grey relation analysis. Experimental results show that the Surface roughness and MRR in turning operation is improved effectively through the new approach.

Keywords: AISI No1042 alloy steel, CVD tool, DOE, Taguchi technique, Grey Relation analysis

1. Introduction

The important goal in the modern industries is to manufacture the products with lower cost and with high quality in short span of time. There are two main practical problems that engineers face in a manufacturing process. The first is to determine the values of process parameters that will yield the desired product quality (meet technical specifications) and the second is to maximize manufacturing system performance using the available resources. Metal cutting process place major portion of all the manufacturing processes. Within these metal cutting processes the turning operation is the most fundamental metal removal operation in the manufacturing industry. Surface roughness, which is used to determine and evaluate the quality of a product, and is one of the major quality attributes of a product obtained from turning operation. Surface roughness is a widely used as an index of product quality and in most cases a technical requirement for mechanical products. Achieving the desired surface quality is of great importance for the functional behavior of a part. Surface roughness is a measure of the quality of a product and a factor that greatly influences manufacturing cost. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process takes place.

Factors such as spindle speed, feed rate, and depth of cut that control the cutting operation can be setup in advance. However, factors such as geometry of cutting tool, tool wear, and joint material properties of both tool and work piece are uncontrollable. One should develop techniques to evaluate the surface roughness of a product before machining in order to determine the required machining parameters such as feed rate, spindle speed and depth of cut for obtaining a desired surface roughness and product quality.

In addition to the quality of the product, the material removal rate (MRR) is also an important characteristics in machining operation and high MRR is always desirable. To ensure the cost of the final finished product, power consumption should be as low as possible. Hence the objective of the present work is to optimize spindle speed, feed and depth of cut so as to minimize surface roughness, and maximize MRR.

AISI 1042 is a medium carbon low alloy steel and finds its typical applications in the manufacture of automobile and machine tool parts, low specific heat, tendency to strain harden, and diffuse between tool and work material AISI 1042 alloy steel gives rise to problems like large cutting forces. High cutting tool temperatures, poor surface finish and built up edge formation. In today's manufacturing industry, special attention is given to surface finish and power consumption. Traditionally the desired cutting parameters are determined based on hands on experience.

2. Literature review

S. M. Ali, and N. R. Dhar , Tool wear and surface roughness prediction plays a significant role in machining industry for proper planning and control of machining parameters and optimization of cutting conditions. He deals with developing an artificial neural network (ANN) model as a function of cutting parameters in turning steel under minimum quantity lubrication (MQL). A feed-forward back propagation network with twenty five hidden neurons has been selected as the optimum network.

Benardos and Vosniakos discussed the surface quality is a central parameter to evaluate the productivity of machine tools as well as machined components. Hence, achieving the desired surface quality is of great importance for the functional behavior of the mechanical parts.

Black [14] defined metal cutting as the removal of metal chips from a work piece in order to obtain a finished product with desired characteristics of size, shape, and surface roughness. The challenge that the engineers face is to find out the optimal parameters for the preferred output and to maximize the output by using the available resources.

Davim[11] has presented a study of the influence of cutting parameters on the surface roughness obtained in turning of free machining steel using Taguchi design and shown that the cutting velocity has a greater influence on the roughness followed by the feed rate.

H.Ganesan, G. Mohankumar, K. Ganesan, K. Rameshkumar. Optimization of machining parameters in turning process using genetic algorithm and particle swarm optimization with experimental verification. In this paper the optimal machining parameters for continuous profile machining are determined with respect to the minimum production time, subject to a set of practical constraints, cutting force, power and dimensional accuracy and surface finish. Due to complexity of this machining optimization problem, a genetic algorithm (GA) and Particle Swarm Optimization (PSO) are applied to resolve the problem and the results obtained from GA and PSO are compared.

F.Jafarian[9]developed a new intelligent method for presenting a predictive and optimizing model of the turning process. Application of ANN and evolutionary algorithms to determine suitable input parameters for optimizing outputs of the process.
Farhad Kolahan1, A. Hamid Khajavi , A Statistical Approach for Predicting and Optimizing Depth of Cut in AWJ Machining for 6063-T6 Al Alloy, Taguchi method and regression modeling are used in order to establish the relationships between input and output parameters. The adequacy of the model is evaluated using analysis of variance (ANOVA) technique

C. Natarajan, S. Muthu and P. Karuppuswamy [2010], find a suitable optimization method which can find optimum values of cutting parameters for minimizing surface roughness. The turning process parameter optimization is highly constrained and nonlinear. To predict the surface roughness, an artificial neural network (ANN) model was designed through back propagation network using MATLAB 7 software for the data obtained.

NihatTousun[2006], Optimal machining parameters were determined by the grey relation grade obtained from the grey relation analysis for multi-performance characteristics. Conducted experiments on surface roughness and the burr height in drilling process.

L.B. Abhang, M. Hameedullah[2011], Optimization of multi-performance characteristics is more complex compared to single-performance characteristics. The theory of grey system is a new technique for performing prediction, relational analysis and decision making in many areas.

Tzeng and Chen (2007) described the application of the fuzzy logic analysis coupled with Taguchi method to optimise the precision and accuracy of the high-speed electrical discharge machining (EDM) process.

Rajyalakshmi*et al*. (2012) used fuzzy logic integrated with Taguchi method for optimization of process parameters of wire electrical discharging machine.

3. Material and methods

3.1 Specifications of Work material

The work material used for the present work is AISI No. 1042 alloy steel of 30mm diameter and 500mm length. Common application of this material in casting dies, Gears, Abrasive wheels, Spindles etc., the chemical composition of the material is given in Table 1.

Table 1: Chemical composition of EN 41B alloy steel

Element	C	Si	Mo	Al	Cr	S	Po	Mn	Ni
Composition	0.4	0.25	0.35	1.2	1.6	0.05	0.05	0.5	0.04

3.2 Taguchi Method

Taguchi method is an effective tool in designing of high quality system. It provides simple efficient and systematic qualitative optimal design to aid high performance, quality at a relatively low cost. To achieve desirable product quality by design, Taguchi recommends three stage processes: system design, parameter design and tolerance design. While system design helps to identify the working levels of the design parameters, parameter design seeks to determine the parameter levels that produce the best performance of the product/process under study. The optimum condition is selected so that the influence of uncontrollable factors (noise factors) causes minimum variation to system performance. The orthogonal arrays, variance and signal to noise analysis are the essential tools of parameter design. Tolerance design is a step to fine tune the results of parameter design by tightening the tolerance of parameters with significant influence on the product Conventional methods for experimental design are of complex in nature and difficult to use. In addition to that these methods require a large number of experiments when the process parameters increase. In order to minimize number of experiments, a powerful tool has been designed for high quality system by Taguchi. For determination of the best design it requires the use of statistically designed experiment. The control factors and levels are shown in Table 2.

Table 2: Process Parameters with Different Levels

Process Paraments	**Level s**		
	1	**2**	**3**
Cutting speed, S (rpm)	360	450	580
Feed, F (mm/rev)	0.05	0.07	0.09
Depth of cut, Doc (mm)	0.05	0.1	0.15

3.3 Analysis of variance (ANOVA)

ANOVA is used to determine the influence of any given process parameters from a series of experimental results by design of experiments and it can be used to interpret experimental data. Since there will be large number of process variables which control the process, some mathematical model are require to represent the process. However these models are to be develop using only the significant parameters which influences the process, rather than including all the parameters. In order to achieves this, statistical analysis the experimental results will be processed using analysis of variance (ANOVA).

4. **Experimentation and Mathematical modeling**

The experiment is conducted for Dry turning operation of using AISI 1042 Alloy steel as work material and CVD as tool material on a conventional lathe PSG A141. The tests were carried for a 500 mm length work material. The process parameters used as spindle speed (rpm), feed (mm/rev), depth of cut (mm). The response variables are Surface roughness, material removal rate and power consumption. Surface roughness of machined surface has been measured by a Talysurf instrument.

Fig 4.1: Experimental setup

Fig 4.2: surface roughness measuring instrument

Surface roughness need to the minimum for good quality product (Lower is the better)

The surface roughness, Ra

Min R_a (s, f, d)

Minimizing Ra = 0.905 + 0.00324 speed + 51.6 feed - 10.7 depth of c……… (4.1)

MRR need to be maximum for increasing the production rate (Higher is the better)

The material removal rate, MRR

Max MRR (s, f, d)

Maximizing MRR = - 0.286 + 0.000322 speed + 7.42 feed - 0.50 depth of c… (4.2)

4 Grey relation analyses

In the recent years, Deng proposed application of the principles of grey relational analysis. Grey relational analysis is a method of measuring the degree of approximation among sequences according to the grey relational grade. The theories of grey relational analysis have already attracted the interest of researchers. In the grey relational analysis, the measured values of the experimental results of surface finish and material removal rate were first normalized in the range between zero and one, which is also called grey relational generation. Next, the grey relational coefficients were calculated from the normalized experimental results to express the relationship between the desired and actual experimental results. Then, the grey relational grades were computed by averaging the grey relational coefficient corresponding to each performance characteristic. The overall equation of the multiple performance characteristic is based on the grey relational grade. As a result, optimization of the complicated multiple performance characteristics can be converted into optimization of a single grey relational grade. The optimal level of the process parameters is the level with highest grey relational grade. With the grey relational analysis, the optimal combination of the process parameters can be predicted.

Table 3: Experimental data and Grey Taghuchi analysis results for 3 parameters for corresponding Ra and MRR

S.No	Speed, S (rpm)	Feed, F (mm/rev)	DOC, (mm)	Ra (µm)	MRR	S/N Ratio for Ra	S/N Ratio for MRR	Grey Coeff for Ra	Grey Coeff for MRR	Grey Grade	Order
1	360	0.05	0.05	3.83	0.18	-11.66	-14.89	0.4251	0.4006	0.4128	21
2	360	0.05	0.1	3.67	0.09	-11.29	-20.92	0.4056	0.3333	0.3694	25
3	360	0.05	0.15	3	0.09	-9.54	-20.92	0.3333	0.3333	0.3333	27
4	360	0.07	0.05	6.28	0.23	-15.96	-12.77	0.9598	0.4314	0.6956	07
5	360	0.07	0.1	4.34	0.22	-12.75	-13.15	0.4947	0.4255	0.4601	18
6	360	0.07	0.15	3.3	0.12	-10.37	-18.42	0.3640	0.3583	0.3611	26
7	360	0.09	0.05	6.33	0.33	-16.03	-9.63	0.9796	0.4865	0.7330	05
8	360	0.09	0.1	5.66	0.17	-15.06	-15.39	0.7591	0.3941	0.5766	14
9	**360**	**0.09**	**0.15**	**5.54**	**1.41**	**-14.87**	**2.98**	**0.7277**	**1.0000**	**0.8639**	**01**
10	450	0.05	0.05	4.18	0.22	-12.42	-13.15	0.4715	0.4255	0.4485	20
11	450	0.05	0.1	3.26	0.22	-10.26	-13.15	0.3598	0.4255	0.3926	23
12	450	0.05	0.15	3.12	0.22	-9.88	-13.15	0.3453	0.4255	0.3854	24
13	450	0.07	0.05	5.79	0.42	-15.25	-7.54	0.7954	0.5318	0.6636	09
14	450	0.07	0.1	5.88	0.32	-15.39	-9.9	0.8222	0.4812	0.6517	10
15	450	0.07	0.15	4.01	0.3	-12.06	-10.46	0.4483	0.4706	0.4594	19
16	450	0.09	0.05	6.38	0.58	-16.1	-4.73	1.0000	0.6076	0.8038	02
17	450	0.09	0.1	5.65	0.2	-15.04	-13.98	0.7564	0.4133	0.5848	13
18	450	0.09	0.15	5.18	0.21	-14.29	-13.56	0.6442	0.4194	0.5318	15
19	580	0.05	0.05	4.64	0.29	-13.33	-10.75	0.5423	0.4652	0.5037	16
20	580	0.05	0.1	4.3	0.29	-12.67	-10.75	0.4888	0.4652	0.4770	17
21	580	0.05	0.15	3.87	0.14	-11.75	-17.08	0.4301	0.3733	0.4017	22
22	580	0.07	0.05	6.06	0.54	-15.65	-5.35	0.8800	0.5891	0.7345	04
23	580	0.07	0.1	5.97	0.34	-15.52	-9.37	0.8503	0.4917	0.6710	08
24	580	0.07	0.15	5.71	0.32	-15.13	-9.9	0.7728	0.4812	0.6270	12
25	580	0.09	0.05	5.78	0.74	-15.24	-2.62	0.7925	0.6809	0.7367	03
26	580	0.09	0.1	5.97	0.5	-15.52	-6.02	0.8503	0.5703	0.7103	06
27	580	0.09	0.15	5.94	0.27	-15.48	-11.37	0.8408	0.4542	0.6475	11

Table 4: Response Table for Signal to Noise Ratios Smaller is better for Ra for CVD

Level	Speed	Feed	D. of cut
1	**-13.6**	**-11.42**	**-14.63**
2	**-13.4**	**-14.23**	**-13.72**
3	**-14.48**	**-15.29**	**-12.60**
Delta	**1.42**	**3.87**	**2.03**
Rank	**3**	**1**	**2**

Table 5: Response table for Means for Ra for CVD

Level	Speed	Feed	Depth of cut
1	**4.661**	**3.763**	**5.474**
2	**4.828**	**5.260**	**4.967**
3	**5.360**	**5.826**	**4.408**
Delta	**0.699**	**2.062**	**1.067**
Rank	**3**	**1**	**2**

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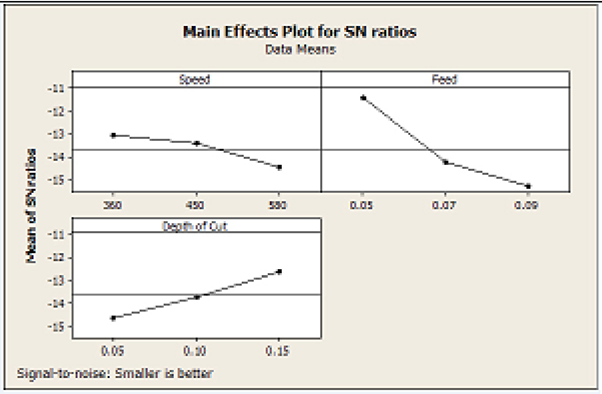

Fig 4.3: Main effects plot for S/N Ratios for Ra

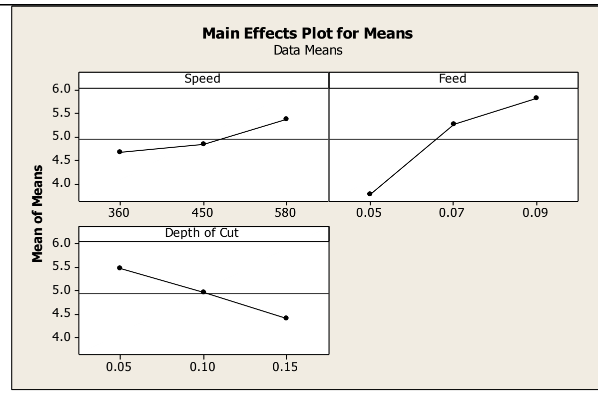

Fig 4.4: Main effects plot for Means for Ra

Table 6: Response Table for Signal to Noise Ratios Larger is better for MRR for CVD

Level	Speed	Feed	Depth of cut
1	-13.67	-14.973	-9.05
2	-11.07	-10.76	-12.52
3	-9.25	-8.26	-12.43
Delta	4.432	6.717	3.47
Rank	2	1	3

Table 7: Response table for Means for MRR for CVD

Level	Speed	Feed	Depth of
1	0.316	0.193	0.392
2	0.299	0.312	0.261
3	0.381	0.490	0.342
Delta	0.0822	0.297	0.131
Rank	3	1	2

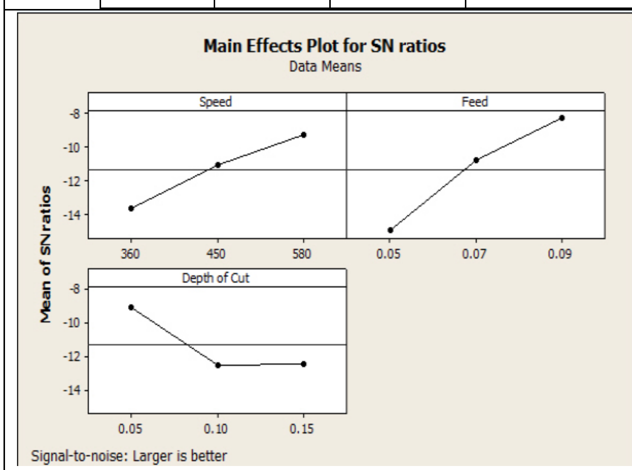

Fig 4.5: Main effects plot for S/N Ratios for MRR

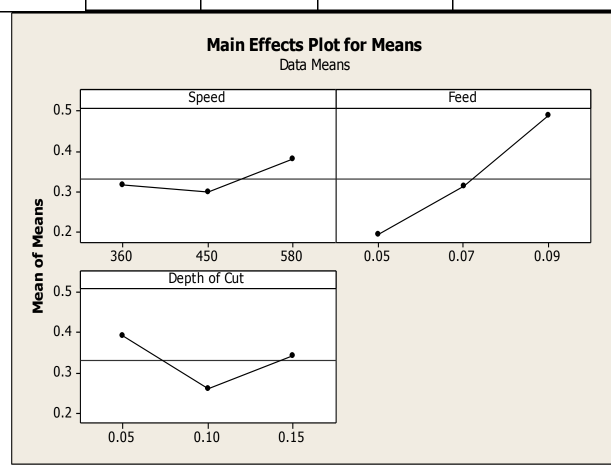

Fig 4.6:Main effects plot for Means for MRR

5. Conclusions

The results obtained in this study lead to conclusions for turning of AISI 1042 after conducting the experiments using CVD tool and analyzing the resulting data.

- From the results obtained by experiment, the influence of surface roughness (Ra) and Material Removal Rate (MRR) by the cutting parameters like speed, feed, DOC is
  - a) The feed rate has the variable effect on surface roughness, cutting speed and depth of cut an approximate decreasing trend.
  - b) Cutting speed, feed rate and depth of cut for Material Removal Rate have increasing trend.
- For the design of Experiments, Taguchi method is applied for finding optimal cutting parameters of cutting parameters
  - a) For minimum surface roughness, the optimality conditions are: Speed: 580 rpm, Feed: 0.05 mm/rev, and Depth of cut: 0.1 mm
  - b) For maximum material removal rate, the optimality conditions are: Speed: 450rpm, Feed: 0.05 mm/rev, and Depth of cut: 0.15 mm
- Using the experimental data, a multi linear regression model is developed for the responses Ra and Material Removal Rate.
- From grey relation analysis the optimum cutting parameters for combined MRR and Ra is Speed 360rpm, feed 0.09 and depth of cut as 0.15

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This research highlighted the use of Taguchi design of experiments and Grey relation analysis. In the present study, the process parameters such as spindle speed, feed and depth of cut is considered. Further the study may be extended for more parameters such as nose radius, rake angle, introduction of cutting fluids etc.

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