Study the effect of turning parameters on surface characteristics of the die tool steel (D3) by using Taguchi method

Mohamed. R. Budar Mohamed. Etuohami. Swei Abdel hafid. B. Kridan Farhat Giuma Ali Giuma

College of Engineering Technology-Janzour

091-9326910

Drmohmmed51@gmail.com

Abstract:

In this paper, the parameter design of the Taguchi method applied to set the optimal parameters for the effects on surface roughness of the finish hard turning of tool steel (AISI D3) experimentally and analytically were investigated.

The optimization of the CNC turning operation of given parameters that lead to fine surface for the parts that made of D3 using carbide cutting tool (coated insert cemented carbide) which have high resistance of deflection, wear was carried out.

To obtain the optimal surface finish conjunction, the Taguchi method used for optimization of the turning experiments based on a full factorial design, to determine three different parameters and levels by using orthogonal arrays, 9 experiments were obtained. Choice of three parameters (feed rate, cutting speed and depth of cut) were important, the cutting parameters were selected as follow: Feed rate (0.075, 0.100, 0.125mm), cutting speed (170, 180, 200 m/min), depth of cut (0.5, 0.75, 1.0 mm) these parameters were chosen according to SANDVIC tool manufacturing company. The series of turning experiments was performed to measure the surface roughness.

Keywords: Taguchi method, Tool steel (AISI D3), CNC turning. Carbide cutting tool, SANDVIC.

خلاصة:

في هذا البحث، تم دراسة تصميم المتغيرات لطريقة تاجوتشي المطبقة لتحديد المتغيرات المثلى للتأثيرات على خشونة السطح النهائية لصلب العدة الفولاذية (AISI D3)عمليا وتحليلياً.

تم تحسين عملية الخراطة باستخدام الحاسب الآلي لمتغيرات معينة تؤدي إلى سطح ناعم للأجزاء المصنوعة من D3 باستخدام أداة قطع الكربيد (كربيد أسمنتي مطلي) والتي تتمتع بمقاومة عالية للانحراف والتآكل.

للحصول على السطح الأمثل ، تم استخدام طريقة تاجوشي لتحسين تجارب الخراطة بناءً على تصميم عملي كامل، لتحديد ثلاثة متغيرات ومستويات مختلفة باستخدام المصفوفات المتعامدة، تم الحصول على 9 تجارب. كان من المهم اختيار ثلاث متغيرات (معدل التغذية، سرعة القطع وعمق القطع)، وتم اختيار متغيرات القطع على النحو التالي: معدل التغذية (0.075، 0.100، 0.125 مم)، سرعة القطع (170، 180، 200 م/دقيقة)، عمق القطع (0.5، 0.75، 1.0 مم) تم اختيار هذه المتغيرات وفقًا لشركة تصنيع الأدوات SANDVIC. تم إجراء سلسلة من تجارب الخراطة لقياس خشونة السطح.

1.Introduction

The modern machining industries are mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high-production rate, minimum tool wear, economical machining and improving the performance of the product with reduced environmental impact [1]. Conventional tool materials for hard turning applications are PCBN, Ceramics and PCD because of their high hardness and toughness. But these tool materials are quite costly as compared to carbides. Coated carbides on the other hand been tried for a number of the applications in the metal-working industry and provide a suitable alternative for most turning applications [2] .

Carbides are tough and can be used for machining at higher cutting speed, feed rate, also tried for some intermittent machining operations successfully. Coated carbides tools consist of a hard carbide substrate with a surface coating (carbides, nitrides, oxides and their combinations), which increases the thermochemical stability [3]. These high-quality materials provide high rate of material removal even during intermittent machining. Tungsten carbide (TiC) thin films provided on carbide inserts act as heat barrier, protect the tools from being exposed to high cutting temperature in the cutting zone thereby enabling these to retain high hardness even at elevated temperatures of the order of 400 °C [4].

2. Experimental Procedure

Work-pieces used in the tests are cylindrical shafts made of cold work steel D3 DIN 1.2080 with a diameter of 50 mm and a length of 100 mm. The main advantage of this steel is its excellent wear resistance and can under nitration process. This steel used in manufacturing high quality cutting tools, deep drawing and extrusion template, cold rolling mill rollers, measuring tools, plastic injection melds, cold rolling mill rollers.

For the survival of the industry to achieve optimal quality fast with low cost is essential. In the machining process, it would be possible with proper and intelligent selection of machining parameters. In this study, using professional knowledge base, an algorithm has been provided on machining parameters during the process of machining which carries out the smart selection of machining parameters to achieve desired quality with respect to the presented information. In the turning process the most important parameter are feed rate, cutting speed and depth of cut. Typically, quality refers to a better surface finish and production tolerance.

In this respect, the depth of cut, material and surface finish of the work-piece are considered as the input, and the cutting speed and feed as the output. To estimate the surface roughness after machining some proper functions have been employed.

The experiment was conducted under one cutting fluid condition which was Emulsion, a mix of water and oil (5-10% oil in the water) is the most common coolant media. The coolant was supplied to the cutting area by using the Master flex pump at a flow rate of 200 ml/min. The experiment was carried out by using CNC lath machine and coated insert cemented carbide tool as shown in figure 1(a,b). The coolant type, cutting speed and feed rate were the input parameters for turning D3 steel. The output responses for the cutting fluid was then compared to find the optimum parameter.

3, CNC Machine

In this work, External turning tests were performed. All of the turning tests were performed under cooling conditions on CNC lathe machine. Type Samsung PLA25 CNC lath which is shown in (figure 1 (a) and a carbide cutting tool (coated insert cemented carbide) (b).
The CNC lathe having a maximum spindle speed of 3500 rpm and a maximum power of 20 KW.

Figure 1(a): Lath machine (CNC)

Fig. 1(b): The coated insert cemented carbide

4. Materials and Methods

4.1. Materials

The material used for this research is a round bar work die tool steel (D3) diameter 50mm × 100mm, as shown in figure 3. The Chemical composition of work piece AISI D3 shown in table 1.

Figure 2: Work pieces of tool steel (AISI D3)

Table 1: Chemical composition of work piece AISI D3

Chemical composition % of grade D3						
C	**Si**	**MN**	**V**	**W**	**Cr**	**Mo**
2 - 2.345	0.25-0.45	0.24 - 0.45	0.8	0.7	11.00-13.00	0.8

5. Taguchi's design

The method which presented in this study is an experimental design process called the Taguchi design method, figure 3 illustrate the Procedure and steps of Taguchi Parameter design.

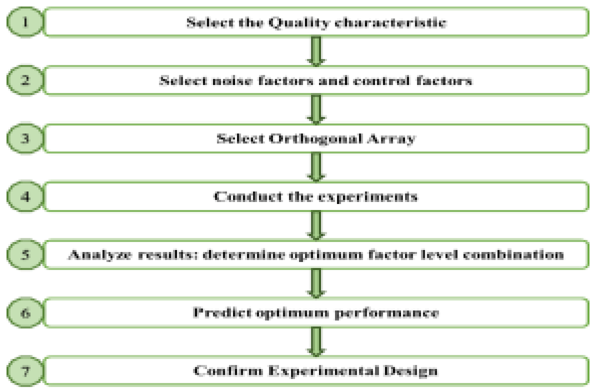


Figure 3: Procedure and steps of Taguchi Parameter design [38].

Taguchi methods has been widely utilized in engineering analysis and consists of a plan of experiments with the objective of acquiring data in a controlled way and in order to obtain information about the behavior of a given process. The greatest advantage of this method is to save the effort in conducting experiments. Therefore, it reduces the experimental time as well as the cost by finding out significant factors fast [5].

Taguchi's parameter design offers a simple, systematic approach and can reduce number experiment to optimize design for performance, quality and cost. Taguchi method offers the quality of product is measured by quality characteristics such as: nominal is the best, smaller is better and larger is better.

Optimization with Taguchi method in turning using conceptual S/N ratio approach and Analysis of variance ANOVA can be concluded that Taguchi's robust design method is suitable to analyze the metal cutting problem. Conceptual signal-to-noise S/N ratio and ANOVA approaches for data analysis draw similar conclusion.

5.1. Selection of Quality Characteristic

There are three types of quality characteristics in the Taguchi methodology, such as smaller-the-better, larger-the-better, and nominal-the-best. The goal of this research was to produce optimum surface roughness (Ra) in turning operation. Smaller Ra values represent better or improved surface roughness. Therefore, a smaller-the-better quality characteristic was implemented and introduced in this study [5].

5.2. Selection of Control Factors

The previous studies [5], indicated that feed rate, cutting speed, and depth of cut had significant effects on surface roughness in the machining operations. In this study, the controllable factors are feed rate, cutting speed and depth of cut, with two different nose radius of tool, which were selected because they can potentially affect surface roughness performance in turning operations. Since these factors are controllable in the machining process, they are considered as controllable factors in the study.

The previous study indicated that feed rate, cutting speed, and depth of cut had significant effects on surface roughness in the machining operations. As suggested in the introduction, spindle speed, feed rate and depth of cut are included as controlled parameters in this study. Considering that the literature suggested that feed rate has a much higher effect on surface roughness and material removal rate than the other two parameters. The feed rate, cutting speed and depth of cut were then given three levels as shown in the table (2). These ranges would be expected to produce a good finishing surface on the parts.

5.3. Select of Orthogonal Array

One of Taguchi method steps is selecting the proper orthogonal array (OA) according to the number of controllable factors (cutting parameters). Since three factors were selected to study in this paper, three levels for each factor were considered. Therefore L9 Taguchi method has used special design of orthogonal arrays L9 (3^3) to study the entire parameter with only a small number of experiments for surface roughness.

Table (2) Variable factor levels of tool steel (D3)

Symbol	**Parameters**	**Level**		
		1	**2**	**3**
A	Cutting speed , rev/min	170	180	200
B	Feed rate , mm/rev	0.075	0.100	0.125
C	Depth of cut mm	0.50	0.75	1.0

6. Conducting The Experiments

The experiments, sorted in table (3), is randomly run by the CNC turning machine and three measured surface roughness data values were collected, S/N signal-to-noise ratio of each experimental run were calculated in table (4).

The signal-to-noise ratio is often written as S/N or represented by the Greek letter (η). In the Taguchi method, the term (signal) represented the desirable value (mean) for the output characteristic and the term (noise) represented the undesirable value Standard deviation (S.D) for output characteristic because of some other factors which called (noise factors). Noise factors are those factors that are not controllable, and whose influences are not known.

Table (3): Experimental design of tool steel (AISI D3)

Experiment number	Feed rate A (mm/rev)	Cutting speed B (rpm)	Depth of cut C (mm)	Ra1	Ra2	Ra3
1	0.075	170	0.5	1.90	1.96	2.06
2	0.075	180	0.75	0.96	0.92	0.95
3	0.075	200	1.0	3.50	3.59	3.38
4	0.100	170	0.75	1.68	1.66	1.66
5	0.100	180	1.0	0.50	0.46	0.54
6	0.100	200	0.5	0.60	0.72	0.68
7	0.125	170	1.0	0.78	0.72	0.74
8	0.125	180	0.5	0.94	1.20	0.96
9	0.125	200	0.75	0.96	0.96	1.00

Deflection and vibration, which may be occur on cutting tool and work piece material because of cutting force during machining. The effect of uncontrollable noise factors is not the subject of this study. Therefore, the S/N ratio is the ratio of the mean to the (S.D). Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. The S/N ratios seek out the strong effects and ascertain the best levels. The most desired situation is reached when the signal is strong and the impact of the noise is weak. There are several S/N ratios available depending on type of characteristic, lower is better (LB), nominal is better (NB), or higher is better (HB).

The smaller is better quality characteristic can be explained as:

$$S/N = -10 \text{ Log MSD} \qquad (1)$$

Where:

MSD = the mean square deviation.

The mean square deviation for smaller-the –better characteristic is:

$$(5.2) \quad MSD = \frac{y_1^{\ 2} + \ldots + y_n^{\ 2}}{n}$$

Where n = number of measurements in trial/row, in this case, n=3 and yi is the measured value in a run/row. We can then rewrite the S/N equation as:

$$(5.3) \quad \text{S/N} = -10 \ \log \left| \frac{y_1^{\ 2} + \ldots + y_n^{\ 2}}{n} \right|$$

Table (4) Experimental Results for Surface Roughness

Experiment number	Response value			S/N value	Mean
	Ra1(μm)	Ra2 (μm)	Ra3(μm)		
1	1.90	1.96	2.06	-5.9089	1.97333
2	0.96	0.92	0.95	0.5053	0.94333
3	3.50	3.59	3.38	-10.8591	3.49000
4	1.68	1.66	1.66	-4.4022	1.66000
5	0.50	0.46	0.54	6.0021	0.50000
6	0.60	0.72	0.68	3.4976	0.66667
7	0.78	0.72	0.74	2.5326	0.74667
8	0.94	1.20	0.96	-0.3412	1.03333
9	0.96	0.96	1.00	0.2331	1.0100

Table (5) Experimental Results for Surface Roughness

Level	Feed rate	Cutting speed	Depth of cut
1	-5.4209	-2.5928	-0.9175
2	1.6992	2.0554	-1.2212
3	0.8082	-2.3761	-0.7748
Delta	7.1201	4.6482	0.4464
Rank	1	2	3

Table (6) Response Table for Signal to Noise Ratio value of Surface Roughness

Level	Feed rate	Cutting speed	Depth of cut
1	2.1356	1.4600	1.2244
2	0.9422	0.8256	1.1922
3	0.9178	1.7100	1.5789
Delta	1.2178	0.8844	0.3867
Rank	1	2	3

Table (6) shows that the best surface roughness value was at machining the sample NO (5) under the cutting parameters (feed rate = 0.100 mm/rev, cutting speed = 180 m/min and depth of cut = 1.0 mm). All these data can be represented graphically as in figure (4) and figure 5 respectively.

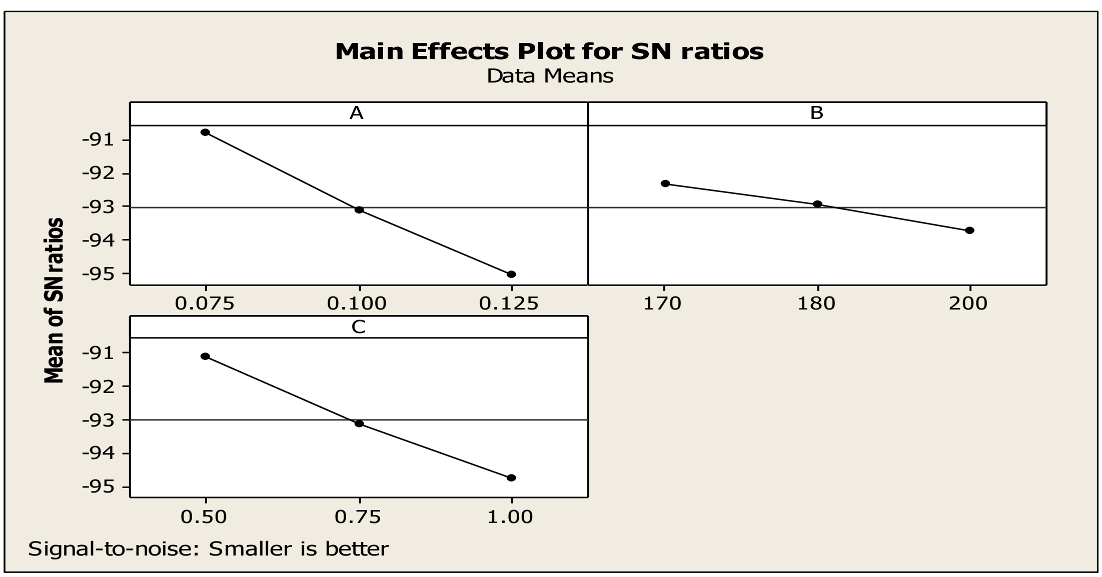


Figure (4): Mean Effects Plot for S/N Value of Surface Roughness

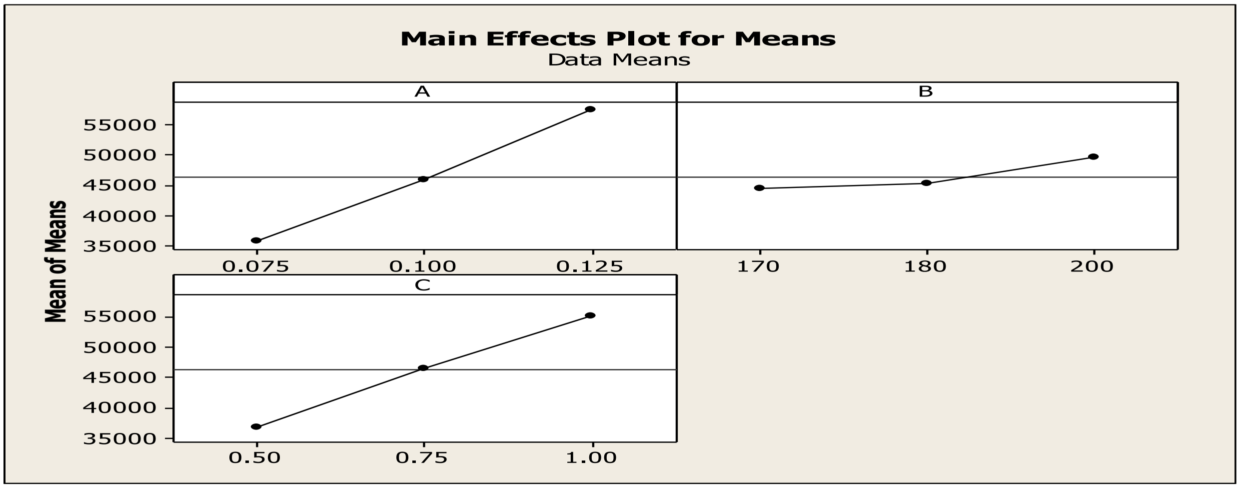


Figure (5): Mean Effects Plot for Means of Surface Roughness

6.1. The response surface for surface roughness

Response surface are usually drawn to further appreciate the effect of cutting condition in the tool performance in terms of surface roughness.

Since the type of coolant is always specified by the stock allowance, only feed rate and cutting speed are usually selectable in most finish hard turning cases.

The response surface is generated by changing cutting speed and feed rate within the interested range.

This response surface in figures (6,7 and 8) is shows that from the 3D graph the small value for the surface roughness are the better as mentioned in Taguchi methodology that the small value is the better. It can be seen that cutting speed impacts the surface roughness performance more significantly than feed rate does. Such response surface can help designers and engineers to choose optimal cutting conditions in machining hardened materials.

Table (7): Response Table for the value of Surface Roughness

Experiment number	surface roughness Ra	Cutting condition
1	+261.96891	Feed Rate

2	+0.18787	Cutting Speed
3	+5.68112	Type of Coolant
4	-1.00832	Cutting Speed
5	-42.56580	Type of Coolant
6	+0.034946	Feed Rate
7	-275.32842	Feed Rate
8	- 2.69229E004	Cutting Speed
9	-4.95625	Type of Coolant

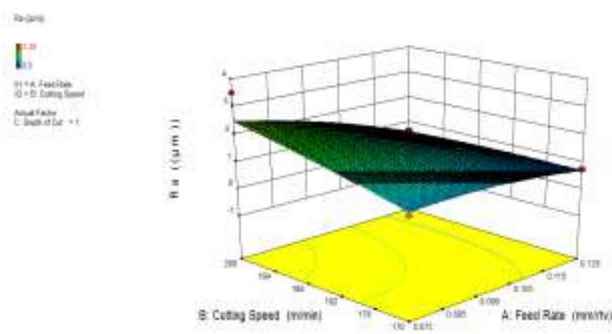
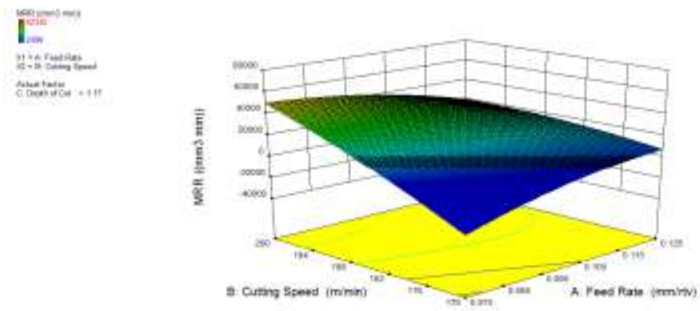


Figure (6): The relationship between surface roughness and both cutting speed and feed rate



Figure(7): The relationship between surface roughness and both cutting speed and feed rate

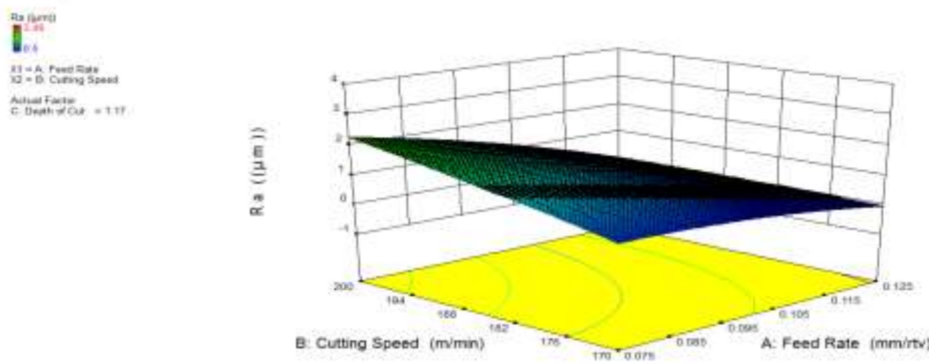


Figure (8): The relationship between surface roughness and both cutting speed and feed rate

7. Surface Roughness

The optimum cutting parameters are feed rate 0.10 mm/rev, cutting speed 180 m/min and depth of cut 1.0 mm. Three samples were machined under the optimal parameters that optimized in the study for the purpose of confirmation experimental.

Table (8) shows the results of the conformation experimental. Compared with the predicted value, the mean surface roughness of the two conformation experimental samples (0.504 µm), which was very close to the predicted value of surface roughness (0.500 µm).

There for, the conformation run indicated that the selection of the optimal levels for all the parameters produced the best surface roughness.

Table (8) Results of Conformation Experiments for Surface Roughness

Sample Number	Mean of Ra (µm)
1	0.486
2	0.522
Mean	0.504

8. Analysis of Variance (ANOVA)

The ANOVA analysis results can be seen in Table (9), figure (9) shows the influence of each factor on the performance of the turning process. According to ANOVA analysis of surface roughness on tool steel AISI D3, the feed rate influences the performance by 88.12% , the depth of cut by 6.15% and cutting speed by 5.52% . And according to ANOVA analysis of surface roughness on of S.S.T, the depth of cut by 68.16%, the feed rate by 20.43% and cutting speed by 3.51%.

Table (9) Analysis of variance for Means surface roughness on of tool steel AISI D3

Source	DF	Seq SS	Adj SS	Adj MS	F	P %
Feed rate	2	18.8992	18.8992	9.44962	429.72	88.12
Cutting speed	2	1.1839	1.1839	0.59196	26.92	5.52
Depth of cut	2	1.3192	1.3192	0.65959	29.99	6.15
Residual Error	2	0.0440	0.0440	0.02199		0.21
Total	8	21.4463				100

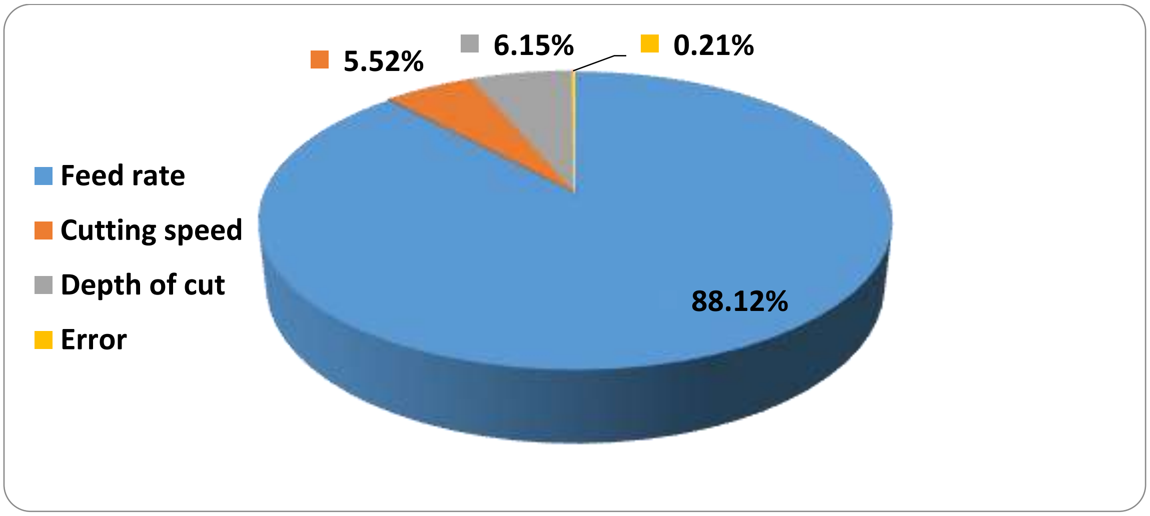


Figure (9) percent of control parameters on surface roughness of tool steel AISI D3.

9.Conclusion

*The optimum parameters for best surface roughness are obtained at feed rate 0.100 mm/rev, cutting speed 180 m/min and depth of cut 1.0 mm. It has been observed that the feed rate has the got the most significant influence on the surface roughness. A confirmation experiments were carried out to obtain the optimal conditions. The minimum surface roughness is calculated as 0.500 µm which is close to 0.504 µm that obtained in confirmation experiments.

The proposed methodology can help improve the state of the art of the cutting condition optimization in machine turning. Eventually it will help machine turning to be a viable technology. This modeling approach can also be further extended to appreciate the tool performance of other machining processes.
According to the result it is conclusive that the surface roughness reduces with the increase of feed rate and hence the feed rate has greater influence on surface roughness followed by cutting speed and depth of cut.

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