SJST Surman Journal for Science and Technology | ISSN: E 2790-5721 P 2790-5713
Vol3, No.1, Dec_2021 , pp. 047 ~ 058

Optimization of Cutting Parameters for Surfaces Roughness of Medium Carbon Steel C-45 in CNC Turning Machining by Using Taguchi Method

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1- الملخص.

الهدف من هذه الدراسة هو الحصول على افضل متغيرات الة الخراطة الرقمية (CNC) و التي تعطى انعم نهاية لقطع مصنوعة من الصلب المتوسط الكربوني باستخدام عدة قطع كربيديه لديها مقاومة عالية لتأكل و الاحتكاك في وجود سوائل التبريد, وذلك لان نعومة السطح النهائية هي من أهم الخصائص المطلوبة للمنتج النهائي.

اعتمادا على دراسات أجريت حديثا فى العالم وجد ان عملية الخراطة الصلدة لها اكثر فائدة مقارنة بعملية التجليخ, نذكر منها نقص التكلفة في الوقت المستهلك في خراطة الاجزاء, فى هذه الدراسة, تأثير خشونة السطح على مقاومة الاحتكاك للخراطة الصلدة النهأية للمعدن المتوسط الكربون عمليا وتحليليا وكذلك البنية المجهرية تم التحقق منها. وللحصول على أفضل نهاية سطح تم استخدام تصميم تاقوتشي (Taguchi method) لأفضل خراطة عملية معتمدا على تصميم المضروب الكلى لتحديد ثلاثة متغيرات مختلفة و مستويات باستخدام المصفوفات الثمانية, و تسع تجارب تم اجرائهاعمليا. تم اختيار ثلاث متغيرات وهى (معدل التغذية، سرعة القطع، عمق القطع) كانت مهمة, تم اختبار متغيرات القطع على النحو التالي: معدل التغذية (0.075, 0.10, 0.125 مم/لفة) سرعة القطع (166.24, 180.70, 197.32 ملم/دقيقة) عمق القطع (2.0 ,2.5 , 3.0مم) هذه المتغيرات اختيرت كما هو مطلوب من شركة ساندفك لتصنيع العدة(SANDVIC Tool Manufacturing Company).

عمليات الخراطة العملية التي انجزت تم قياس خشونة السطح للقطع التي دُرست باستخدام (MINITAB Statistical Software) و ذلك لحساب مؤشر (S/N) وكذلك تحليل التباين (ANOVA)، حيث تم الحصول على أفضل مستويات لأفضل متغيرات قطع و مدى تأثيرها على خشونة السطح , وكذلك متغيرات تجربة خشونة السطح كانت بمعدل تغذية (0.075 مم/لفة) وسرعة القطع (180.70ملم/دقيقة) وبعمق قطع (3.0 مم) و هذه تم الحصول عليها فى التجربة رقم خمسة (5). لتأكيد التجربة والحصول على المستوى الامثل لعملية التغيرات و التى اجريت لتحديد تـأثير كفاءة طريقة تاقوشى كأداة لقياس خشونة السطح.

Abstract.

The objective of this study is to optimize the Computer Numerical Control machine (CNC) turning parameters that gives the fine surface finish for the parts that made of medium carbon steel C45 using carbide cutting tool (coated insert cemented carbide) which have high resistance of deflection, wear and fraction on CNC turning operation with coolant. The surface finish quality is one of the most specified requirements in the machining process.

To obtain the optimal surface finish, 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 (166.24, 180.70, 197.32 mm/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 were performed to measure the surface roughness.

The MINITAB Statistical Software was used to calculate the signal-to-noise ratio (S/N), and analysis of the variance (ANOVA), the best optimal levels and the effect of the process parameters on surface roughness were obtained.

The parameters for experiment surface roughness were the feed (0.075mm/rev), cutting speed (180.70 mm/min), depth of cut (3.0mm) and that conducted in experiment number five (5).

A conformation of experiment to obtained optimal levels of process parameters was carried out in order to demonstrate the effectiveness and efficiency of the employed Taguchi method as a tool to measure surface roughness.

Key words: - Computer Numerical Control machine (CNC), Taguchi method, SANDVIC Tools, MINITAB Statistical Software.

Introduction:

The surface quality of the machined parts is one of the most specified customer requirements. Hard machining technique allows manufacturers to simplify their processes and still achieve the desired surface finish quality [1].

The quality of the surface plays a very important role in the performance of the turning as a good quality turned surface significantly improves fatigue strength, corrosion resistance, or creep life[2]. Surface roughness also affects several functional attributes of parts, such as contact causing surface friction, wearing, and light reflection, load bearing capacity, coating or resisting fatigue. Therefore, the desired finish surface is usually specified and the appropriate processes are selected to reach the required quality [3].

The surface roughness is a measure of the irregularities on the surface of a component resulting from machining operations. It is denoted by Ra namely, average roughness. Ra is theoretically derived as the arithmetic average value of departure of the profile from the mean line along a sampling length[4]. On the other hand, surface roughness depends on process parameters and machining irregularities, such as cutting speed, the rate of feed, the depth of cut, material properties, nose radius of tool and cutting fluid. A small change in any of the above factors can have a significant effect on the surface produced [4,5].

3.0 Experimental Procedure.

Equipment required, workpiece material, cutting tool type carbide with radius of (1.6mm), CNC lath machine, MINITAB software for analyzing the data and surface roughness device.

3.1 Instruments and equipment used for the research.

The material investigated in this study was a medium carbon, steel C45 (AISI 1045) steel, supplied in the form of Ø 10 mm rolled rods of a nominal composition listed in Table 1.

Table 1. (chemical composition AISI 1045)[5]

Element	C	Si	Mn	Ni	P	S	Cr	Mo
Composition %	0,43-0.5	Max 0.4	0.5-0.8	Max 0.6	0.045	0.045	Max 0.4	Max 0.1

Figure 1. Work pieces Medium carbon steel (AISI 104).

3.2. CNC Machine.

In this work, External turning tests were performed. All of the turning tests were performed under cooling conditions on Computer Numerical Control lathe machine (CNC). Type Samsung PLA25 CNC lath which is shown in (figure 2a) and 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 2a: Lath machine (CNC).

Figure 2 (b): Shows the carbide cutting tool (coated insert cemented carbide).

3.3 Surface Roughness Measurement.

The Surtronic 25 has a uniquely engineered stylus lift mechanism which allows a vertical adjustment of 50mm and rotation of the pick-up to different measuring positions, including right angle or inverted measurements. These adjustments to the height and position of the gauge allow areas and features of a part to be easily measured without additional complex fixtures. This feature saves the operator a huge amount of set up time and allows total flexibility.

Figure 3: Roughness test device (Surtronic 25).

3.4 Taguchi's design.

The method which presented in this study is an experimental design process called the Taguchi design method, (figure 4) illustrate the Procedure and steps of Taguchi Parameter design [4].

1-Select the Quality characteristic
2-Select noise factors and control factors
3- Select Orthogonal Array
4-Conduct the experiments
5-Analyze results: determine optimum factor-level combination
6-Predict optimum performance
7- Confirm Experimental Design

Figure 4: Procedure and steps of Taguchi Parameter design [5]

The employing design of experiments (DOE), described by Dr Taguchi, is one of the most important statistical technique of Total quality management (TQM) for designing high quality systems at reduced cost. Taguchi methods provide an efficient and systematic way to optimize designs for performance, quality, and cost. Fundamentally, traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of the process parameters increases. To solve this problem, the Taguchi method has used a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [6]. 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 [7].

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.

3.5 Analysis Software.

MINITAB statistical software is used in this study for selecting the types of design to be used for running the experiments, to display all possible combination of controllable factors and analyzing data representing main and interaction relationship between them. This software provides a wide range of basic and advanced data analysis capabilities [8]

4.Results and Discussion.

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 [9]. 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.

Table 2. Variable factor levels of medium carbon steel (1045).

Factor	Level 1	Level 2	Level 3
Feed rate (mm/rev)	**0.075**	**0.100**	**0.125**
Cutting speed (rpm	**166.24**	**180.70**	**197.32**
Depth of cut (mm	**2**	**2.5**	**3.0**

4.1. 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 research, 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 and material removal rate table (3).

Table 3. L9 (3^3) Taguchi orthogonal array.

Experiment number	Feed rate A	Cutting speed B	Depth of cut C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4.2 Conducting the Experiments.

The experiments, sorted in table (4), 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 4: Experimental design of medium carbon steel (1045)

Experiment number	Feed rate A (mm/rev)	Cutting speed B (rpm)	Depth of cut C (mm)	Ra1	Ra2	Ra3
1	0.075	166.24	2.0	1.90	1.96	2.06
2	0.075	180.70	2.5	0.96	0.92	0.95
3	0.075	197.32	3.0	3.50	3.59	3.38
4	0.100	166.24	2.5	1.68	1.66	1.66
5	0.100	180.70	3.0	0.50	0.46	0.54
6	0.100	197.32	2.0	0.60	0.72	0.68
7	0.125	166.24	3.0	0.78	0.72	0.74
8	0.125	180.70	2.0	0.94	1.20	0.96
9	0.125	197.32	2.5	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) [6,.7]. The smaller is better quality characteristic can be explained as:

$$S/N = -10 \,\text{Log}\, \text{MSD} \tag{1}$$

Where:

MSD = the mean square deviation.

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

$$MSD = \frac{y_1^{\;2} + \ldots + y_n^{\;2}}{n} \tag{2}$$

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:

$$S/N = -10 \log \left| \frac{y_1^{\;2} + \ldots + y_n^{\;2}}{n} \right| \quad (13)$$

Table 5. 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 6. 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 7. 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

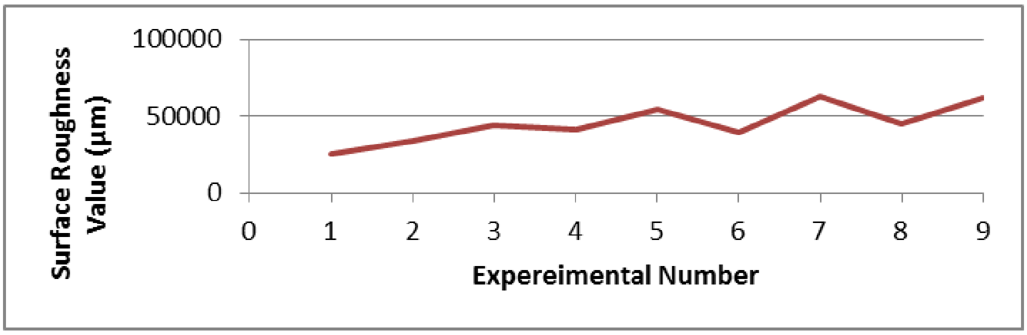

Figure 5. Experimental Result of Surface Roughness Value.

Table (7) 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 = 180.70 m/min and depth of cut = 3.0 mm). All these data can be represented graphically as in figure (6).

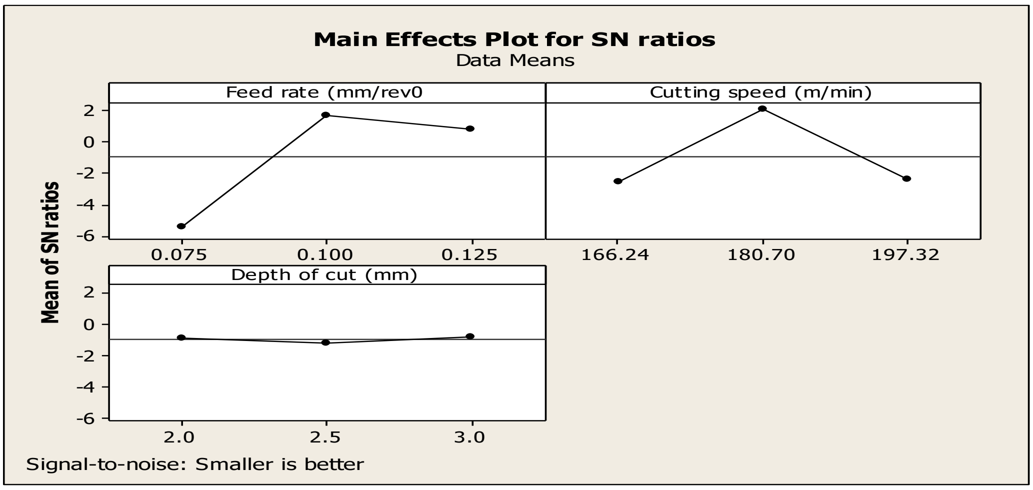

Figure 6: Mean Effects Plot for S/N Value of Surface Roughness

4.3 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 depth of cut 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 (9,10) 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 8. 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	Depth of Cut
4	-1.00832	Cutting Speed
5	-42.56580	Depth of Cut
6	+0.034946	Feed Rate
7	-275.32842	Feed Rate
8	-2.69229004	Cutting Speed
9	-4.95625	Depth of Cut

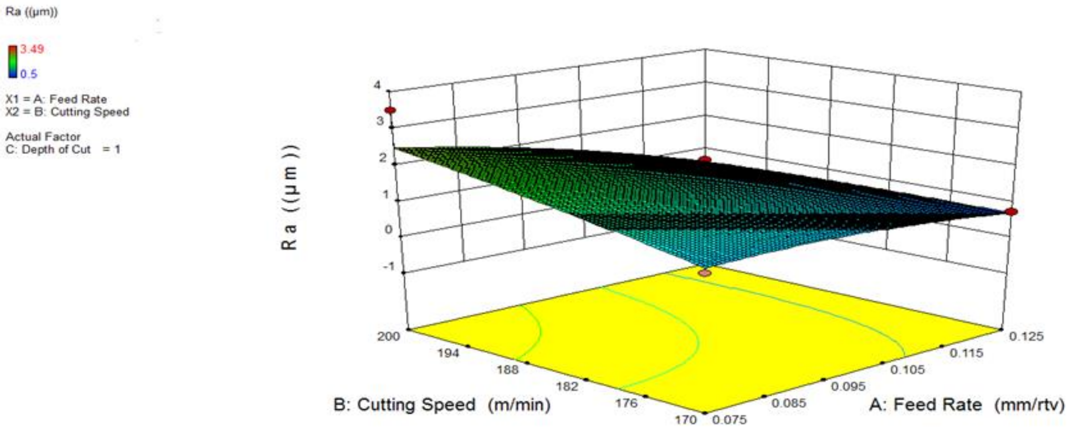

Figure 9. The relationship between surface roughness and both cutting speed and feed rate.

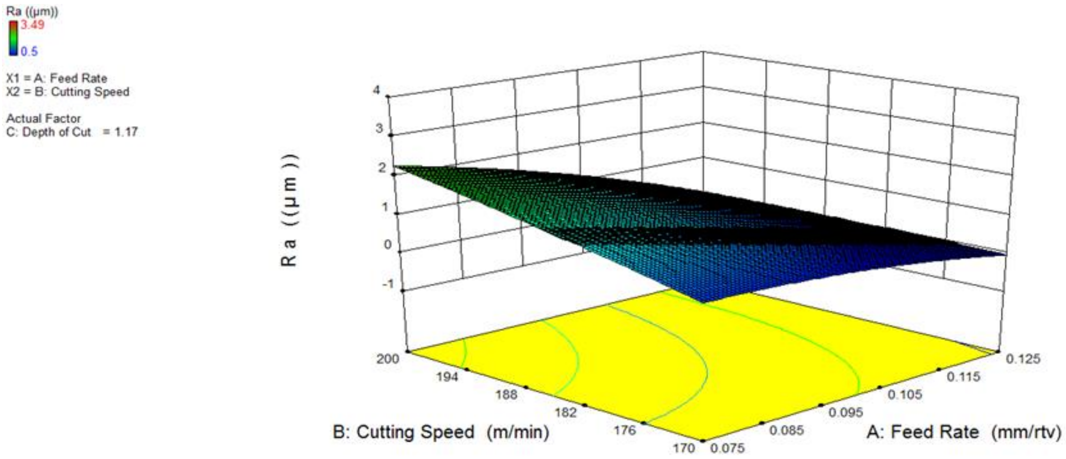

Figure 10. The relationship between surface roughness and both cutting speed and feed rate.

4.4. Surface Roughness.

The optimum cutting parameters are feed rate 0.100 mm/rev, cutting speed 180.70 m/min and depth of cut 3.0 mm. Three samples were machined under the optimal parameters that optimized in the study for the purpose of confirmation experimental.

Table (9) shows the results of the conformation experimental. Compared with the predicted value, the mean surface roughness of the two conformation experimental samples (0.503 µm), which was very close to the predicted value of surface roughness (0.5000 µm). There for, the conformation run indicated that the selection of the optimal levels for all the parameters produced the best surface roughness

Table 9. Results of Conformation Experiments for Surface Roughness.

Sample Number	Mean of Ra (µm)
1	**0.485**
2	**0.521**
Mean	**0.503**

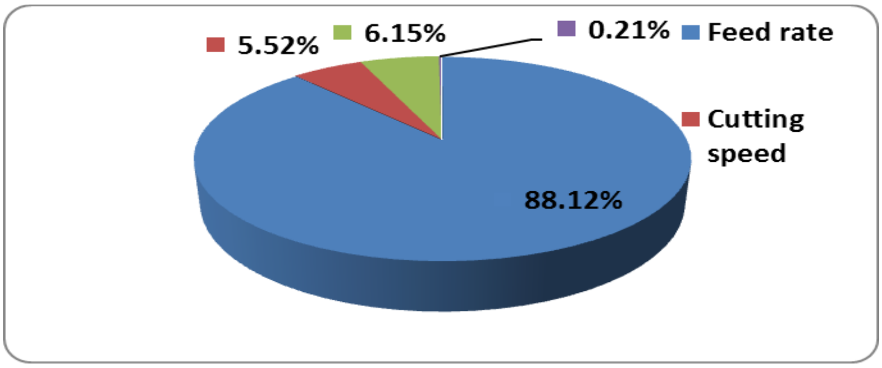

Figure 11. percent of control parameters on surface roughness of medium carbon steel (C45).

The ANOVA analysis results can be seen in figures (11), shows the influence of each factor on the performance of the turning process. According to ANOVA analysis of surface roughness of medium carbon steel (C45), 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 material removal rate of medium carbon steel (C45), the feed rate by 84.32%, the cutting speed by 9.30% and depth of cut by 5.87%.

5. Conclusion.

In the study the Taguchi orthogonal array is employed to optimize the machining parameters, with respect to surface roughness and material removal rate which produce by CNC turning machine when machining medium carbon steel. Taguchi method used to study the effect of three factors, such as feed rate, cutting speed and depth of cut under the same conditions.

1- Case one surface roughness

The optimum parameters for best surface roughness are obtained at feed rate 0.100 mm/rev, cutting speed 180.70 m/min and depth of cut 3.0 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 0.503 µm that obtained in confirmation experiments.

2-Case three the proposed methodology

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 modelling approach can also be further extended to appreciate the tool performance of other machining processes.

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