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Experimental Investigation of Surface Roughness Using Uncoated and Coated Tungsten Carbide Cutting Tool in Turning Operation

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Analyses of variance (ANOVA)cutting tools; Cutting parameters; coating ; surface roughness

ABSTRACT

The cutting process is an important process of industrialization. It is requisite to using advantage quality cutting tools in order to preserve the type of product. Coating on the cutting tool has a substantial effect in terms of mechanical properties and the end results of the product. The cutting tool can be manufactured in various material types, but today's cemented tungsten carbide is the most commonly used material in the tool industry because its properties comply with manufacturers' requirements. This study investigates the impact of an Al2O3 coated cutting tool relative to an uncoated cutting tool on the dry cutting process. Different parameters are used in the cutting process when cutting the metal. The cutting parameters used are feed rate and cutting speed, An analysis of the effects of these parameters on the surface roughness. In this analysis, the surface roughness are measured for components turned from steel1040, The L9 Taguchi orthogonal arrays and analyses of variance (ANOVA) was employed to analyze the influence of these parameters. In the case of (uncoated, Al2O3 coated tool), the better surface roughness (SR) with used feed rate (0.05 mm / rev) and cutting speed (140 m/min) where the roughness value was (0.81μm) and (0.78μm) Respectively. The results of this study indicate that the ideal parameters combination for the better surface finish was high cutting speed and low feed rate.

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1. INTRODUCTION

The surface roughness has a prime influence on the dimensional accuracy, performance of mechanical parts, and the product price [1]. For these causes, the manufacturers are carried out to optimized the cutting condition to attain the specific surface roughness [2,3]. Regulation of the machined surface roughness is, therefore, necessary [4], frequently, as a consequence of early tool wear, the cutting tool shift leads to a rise in run-down time for machine tools, which influences manufacturing and efficiency costs [5]. What is important about the tool or the material in the cutting process is that the type of tool material should always be harder than the material that is to be processed. It is very important this basic fact because it will determine the quality of the final product. The requirements for the selection of a cutting material are very important and have been summarized in (High strength at high temperatures, High compressive and bending and fracture strength, high chemical stability, Heat resistance, High deformation, and fatigue resistance and High stiffness)[6]. Thus, the development of convenient coatings to get better the wear resistance of cutting tool material was a large challenge that is faced by the cutting tool manufacturers. Different monolayer coatings like Al2O3 were used as a coating on the cemented carbide tools, which improve the hardness on the cutting tool surface and lower the friction between the workpiece and the tool. As a result, the wear of the tool has reduced, improved the workpiece surface finish [7]. Still, a combination of appropriate machining parameters and tool materials are important. Inexpensive tool inserts made by the tungsten carbides are easily available and affordable.

The combination of excellent toughness, thermal, and hardness stability makes tungsten-carbide a result suitable candidate for the machining process of the engineering materials [8]. Various cutting tools were developed continually since the material of the first tool appropriate for use in metal cutting, carbon steel, was progressing a century ago [9]. The metal cutting process can be defined as a mechanical industrial process where a piece is formed by separating or take off out materials that are known as chips until the required shape is obtained [10].

The main objective of the research is to address the challenges of improving the surface roughness by using coating materials for cutting tools that help to improve surface roughness.

2. SURFACE ROUGHNESS

In many mechanical goods, the surface roughness was among the important indicators of consistency. The customers now have extremely high-quality expectations as the competition gets closer, making surface roughness one of the most strategic factors of today's manufacturing industry. [11].

Each machining operation produces its own feature confirmation on the machined surface. This confirmation is in the form of fine position of micro unevenness produced by the cutting tool on the workpiece. Every type of cutting tool makes its own pattern that can be identified. This irregularity is known as surface finish or surface roughness [12].

There are several metrics describing the roughness of a machined surface. The arithmetic average (AA) value, usually known as Ra, is one of the most critical ones [13]. By calculating the depth and height of the valleys on the surface with the respect to the average centerline, the AA value was obtained. The higher AA number, the rougher the surface of the machine is. A magnified cross section of the normal machined surface is seen in Figure 1.

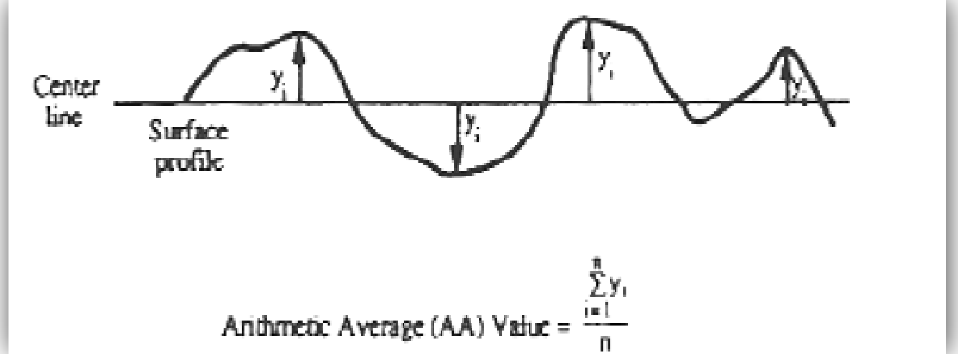


Figure 1: Illustration of surface roughness

Many variables in the turning operation affect the development of the surface roughness. Such variables include the chip deformation, the tool nose radius, the side flow and the geometrical contribution of the feed. The geometrical contribution is determined by classical surface roughness-based equations as in Eq. (1) Eq. (2)[13] :

$h \approx f2 / 8R$………. **(1)**

$hCLA \approx f2 / 18\sqrt{3}R$……. **(2)**

Where;

h: is the peak to the height of the slope,

hCLA: is the typical roughness of the middle line,

f: the feed

R the nose radius.

This indicates that surface roughness depends mainly on the feed rate and radius of the nose. Under adequate cutting conditions, howbeit, the equations above have ideal surface roughness values. The wear of the tool influences the surface roughness of the work piece and one of the main metrics used to determine the moment of change in final turning is surface roughness value [14]. The mechanical detachment of comparatively large fragments of cutting tool material (attrition wear) can create carbide tool wear. This contributes to a major rise in surface roughness and promotes ridge formation. [15, 16].

3. EXPERIMENTAL WORK

AISI 1045 steel of (32 mm) diameter and (500 mm) length, used in this experimental work and machined in a CNC turning machine and with the use of two carbide tools (uncoated, Al_2O_3 coated). Where it divided into two groups, each of nine experiments, each experiment of 32 mm in diameter and 30 mm in length used, As shown in figure 2 . The depth of cut was (3mm), The cutting speeds used were (80, 110 and140 m/min), feed rates were (0.05, 0.1 and 0.15 mm/rev).

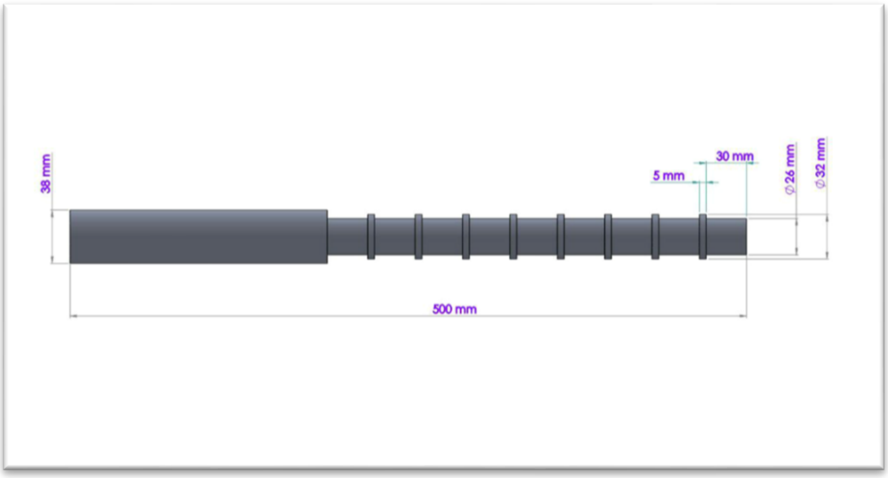


Figure 2: Work piece divided according to the experimental work

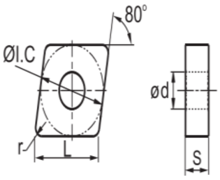
TABLE I: Chemical composition for the work piece

N	Element	Percent	N	Element	Percent
1	C	0.45	5	Mo	0.20
2	Si	0.35	6	Ni	0.45
3	Mn	0.65	7	Cr	0.50
4	P	0.045	8	s	0.03

4. TUNGSTEN CARBIDE CUTTING TOOL

The material of the cutting tool is one of the most significant factors that is specifically determined to improve surface roughness. (uncoated and coated) cutting tool for tungsten carbide (WC), was used as shown in figures (3,4). The promotional tungsten carbide inserts used are (CNMA12 0.4 0.8 K15).

Figure 3: Uncoated CT



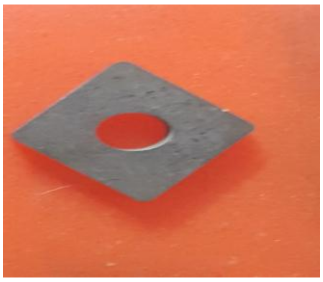


Figure 4: Al_2O_3coated CT

The adopted parameters used in the cutting process can be illustrated as shown in Table 2, It was found that a lot of Previous research has used cutting parameters with values close to the values used In this research, and also these values were used for the purpose of the experiment and obtaining new results.

TABIEII: Cutting Parameters

Sr. No.	Cutting Parameter	Units	Level 1	Level 2	Level 3
1	Feed rate	mm/rev	0.05	0.1	0.15
2	Cutting speed	m/min	80	110	140

5. DESIGN OF EXPERIMENT

Taguchi method was used in this analysis. It is one of the most effective defensive approaches for evaluating the experimental results to determine and incorporate process or product changes. These changes are aimed at enhancing the quality characteristics of the calculated performance needed. The Taguchi approach involves decreasing the number of defects by observing the key factors that influence the mechanism and decreasing the variation by a rigorous nature of experiment [17].

All the data were analyzed by (Minitab 17) software by utilizing two designs of the experiments (DOE). The designs of the experiments were utilized based on the Taguchi design L9 (3^3) orthogonal arrays for each tool. And the total experiments were carried out (18).

6. RESULTS AND DISCUSSION

The experimental and predicted results are shown in table (3), with machine parameter are Design of experimental is done by using full factorial to give all prospects 18 numbers of experiment on program minilab17 software.

TABIE III: Experimental and Predicted Surfaces Roughness Ra.

No.	Type of tool	Cutting speed *(m/min)*	Feed rate *f (mm/rev)*	experimental SR (µm)	Predicted (SR (µm)
1	uncoated	80	0.05	1.24	1.23
2	uncoated	110	0.05	1.1	1.08
3	uncoated	140	0.05	0.81	0.83
4	uncoated	80	0.1	1.36	1.29
5	uncoated	110	0.1	1.14	1.14
6	uncoated	140	0.1	0.83	0.89
7	uncoated	80	0.15	1.54	1.60
8	uncoated	110	0.15	1.44	1.45
9	uncoated	140	0.15	1.29	1.20
10	Al2O3 coated	80	0.05	1.14	1.20333
11	Al2O3 coated	110	0.05	1.02	0.98667

12	Al2O3 coated	140	0.05	0.78	0.75000
13	Al2O3 coated	80	0.1	1.31	1.25000
14	Al2O3 coated	110	0.1	0.96	1.03333
15	Al2O3 coated	140	0.1	0.81	0.79667
16	Al2O3 coated	80	0.15	1.43	1.42667
17	Al2O3 coated	110	0.15	1.25	1.21000
18	Al2O3 coated	140	0.15	0.93	0.97333

The used cutting tools (uncoated, Al2O3 coated) In this work, in dry cutting conditions were used for machining Samples. The cutting conditions were: feed rates (0.05,0.1 and 0.15 mm/rev), cutting speeds (80,110 and140 m/min), at fixed depth of cut (3mm) . The surface roughness device, which produced by (MAHR FEDRAL INC, USA), used to measure surface roughness (Ra), with a range (0.03 µm - 6.35 µm).

Figures 5 and 6 shows both the relationship between surface roughness and feed rates also between surface roughness and cutting speed shows any increasing the cutting speed in ranges (80, 110 and 140 m/min) when the feed values are fixed the surface roughness will be reduced. While increase in the feed rate ranges (0.05 - 0.15 mm/rev) according to the same values of cutting speeds will an increase the surface roughness. The above figures also shown that the residuals generally fall on a straight line or near a straight line, indicating that the errors are normally distributed.

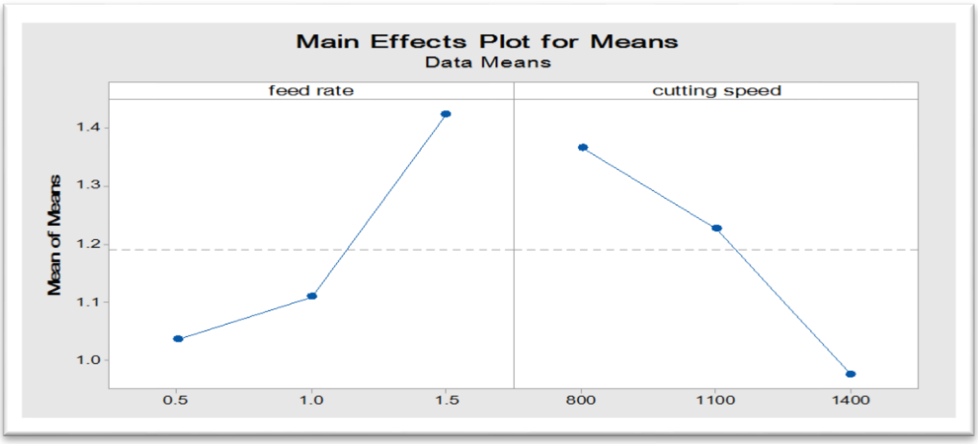


Figure 5: Effect of the cutting speed and the feed rate on SR using an uncoated cutting tool

With regard to the coated tool as shown in Figure (4), it shows the relationship between cutting speed and surface roughness and feeding rates and surface roughness. This shows an increase in cutting speed in the ranges (80,110 and140 m/min) will reduce the surface roughness to approximately (31%), while the feed values are constant. Whereas, increasing the feed rate in ranges (0.05, 1 and 0.15 mm /rev) will increase the surface roughness according to the same values of the cutting speeds, where the percentage of that increases approximately (25%).

Figure 6: Effect of the cutting speed & the feed rate on SR using Al2O3 coated cutting tool.

Surface roughness is increased by increasing the feed in all of the cases. It Proves the theoretical relation between the ideal surface roughness and feed [17]. Another famous application to improve surface roughness is decreasing the feed rate values و according to the Ref. [18,19].

Figures from (7) to (8) show that the measured and predicted values based on the design model of the surface roughness were together close values.

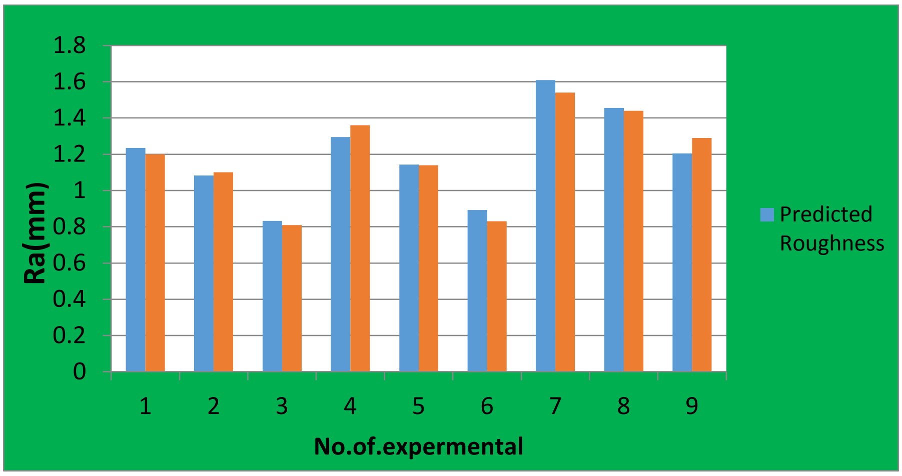


Figure 7: Measured and predicted value for SR to (uncoated)

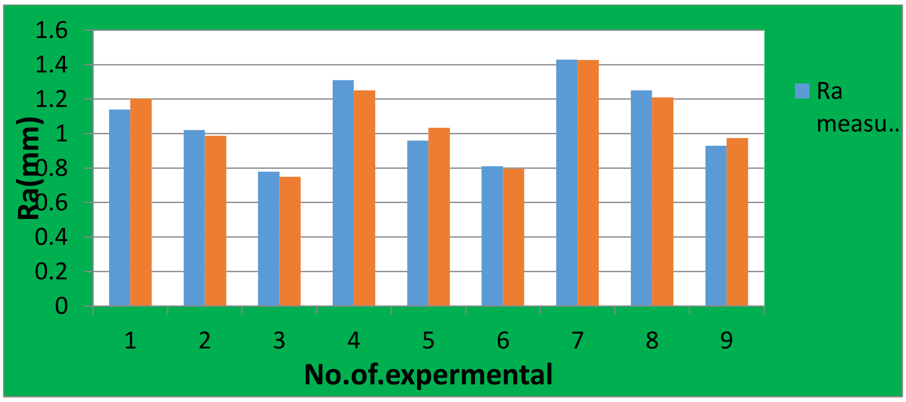


Figure 8: Measured and predicted value for SR to (Al2O3)

7. DETERMINING THE REGRESSION MODEL DEGREE FOR SR

To develop the mathematical model, these coefficients were used. The mathematical relationship between input parameters and SR, for correlating SR has been obtained in regression equations for the uncoated carbide cutting tool and (Al203) coated tool (as shown in [(3), (4)] equations), respectively.

$$SR1 = 1.695 - 9.70 f + 0.0021 cs + 50.7 f*f - 0.000054 cs * cs + 0.0300 f*cs \quad \textbf{(3)}$$

$$SR2 = 1.510 - 0.040f - 0.00028 cs + 0.260 f*f - 0.000000 cs * cs - 0.000233 f*cs \quad \textbf{(4)}$$

8. ANALYSIS OF VARIANCE USING BY MEANS (ANOVA) OF THE SURFACE ROUGHNESS

The analysis of the variance (ANOVA) for surface roughness, is given in Tables from (4) to (5), of specimen-based on Taguchi design. This table illustrates that the feed rates, cutting speeds, and also different cutting tools affected the surface roughness of the workpiece. The cutting speed was more influential than the other parameters. The F -Value of cutting speeds (Which represents the effecting value) was (23.71), and (33.05) for uncoated carbide cutting tool, and Al2O3 coated tool, respectively, the F -Value of feed rates was (22.99), and (9.19) for the above tools respectively.

TABLE IV: Analysis of the variance for the surface roughness to uncoated cutting tools

Source	DF	Seq SS	Adj SS	Adj MS	F -Value	P -Value
feed rate	2	0.24116	0.24116	0.120578	22.99	0.006
cutting speed	2	0.24869	0.24869	0.124344	23.71	0.006
Residual Error	4	0.02098	0.02098	0.005244	/	/
Total	8	0.51082	/	/	/	/

TABLE V: Analysis of variance for surface roughness to cutting tools Al2O3 coated.

Source	DF	Seq SS	Adj SS	Adj MS	F - Value	P - Value
feed rate	2	0.08327	0.08327	0.041633	8.92	0.034
cutting speed	2	0.30847	0.30847	0.154233	33.05	0.003
Residual Error	4	0.01867	0.01867	0.004667	/	/
Total	8	0.41040	/	/	/	/

Table (6) based on a Taguchi design for the workpiece represents a summary of the model of the surface roughness. This table displays the R-square value, which is the capacity of the independent values to predict the values of the dependent (93.9%), and (93.7) for the uncoated carbide cutting tool and Al2O3 coated tools, respectively. This implies that the coefficient of correlation between the dependent variable value observed and the expected value based on the regressions model is good.

TABIE VI: Model summary R-Sq for different cutting tools

Type of cutting tool	S	R-Sq	R-Sq (adj)
`	0.07242	93.9%	91.8%
Al203	0.06831	95.5%	90.9%

.

Tables from (7) (8) represent the response for means of (smaller is better). This table illustrates the rank of every parameter with respect to the effect of surface roughness. The ranks indicate the relative significance of each parameter to the response. The cutting speed (rank1) is a parameter that has a large effect and is followed by the feed rate (rank2).

TABIE VII: Responses for means of smaller is better to the uncoated cutting tool

Type of cutting tool	Level	Feed rate	Cutting speed
Uncoated,	1	1.0500	1.3800
	2	1.1100	1.2267
	3	1.4233	0.9767
	Delta	0.3733	0.4033
	Rank	2	1

TABIE VIII: Responses for means of smaller is better to Al203 cutting tool.

Type of cutting tool	Level	Feed rate	Cutting speed
Al203 (HDP)	1	0.9800	1.2933
	2	1.0267	1.0767
	3	1.2033	0.8400
	Delta	0.2233	0.4533
	Rank	2	1

9. CONCLUSION

The present work investigates experimentally and numerically the effecting of some cutting parameters like (feed rate, cutting speed) using the uncoated and coated tool on surface roughness, when AISI 1045 used for turning. From the results one can conclude the following:

1 -The type of coated plays an important role in cutting tools and have a great influence on the resulted surface roughness (Ra).

2 -Better surface roughness SR in the case uncoated tool used feed rate (0.05 mm /rev) and cutting speed (140 m/min) where the roughness value was (0.81µm).

3- Worse surface roughness in the case uncoated tool was at feed rate (0.15 mm /rev) and the cutting speed (80m/min) where the roughness value was (1.54µm).

4- Better surface roughness SR for Al2O3 coated tool when cutting was at cutting speed (140 m/min) and feed rate (0.05 mm /rev) where the roughness value was (0.78µm).

5 - Worst surface roughness for Al2O3 coated tool was at a feed rate (0.15 mm /rev) and the cutting speed (80 m/min) where the roughness value was (1.43µm).

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