Experimental and Numerical Investigation of Cutting Parameters, Coated and Uncoated Tools on Surface Roughness During Turning Operation

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Abstract. Surface roughness consistency is one of the challenges for producing high-quality goods in the industry. Surface predicting efficiency plays a vital role in correctly managing the machining parameters during turning operations. Selecting the correct cutting instrument is considered one of the most critical factors influencing the machined surface's consistency. Accordingly, this work investigates the effect of cutting tool form, coating material, and cutting parameters on surface roughness during the AISI 1045 turning process. Coated (TIN) and uncoated cutting tools were used. The operation was conducted on a computer numerically controlled (CNC) turning unit. The experiments were carried out using cutting speed, feed rate, tool type as process parameters. Taguchi method was used with three factors and two levels, which are the spindle speed (800, 1100, and 1400) rpm, feed rate (0.05, 0.1, 0.15) mm/rev, and the depth of cut (3) mm. The results revealed that the most important consideration for surface roughness is cutting speed, followed by the feed rate and tool coating, respectively.

Keywords. Cutting Parameters, Coated, Uncoated Tools, Roughness, Turning Operation.

1. Introduction
Surface roughness always was a prevailing aspect characteristic in estimating the products' surface quality [1]. Typically, the proper output of a component is linked to that. Therefore, in most machining applications, good surface quality is expected because it plays a pivotal role in affecting consumer contentment in manufacturing. However, the pressures on machined surface characteristics directly affect manufacturing costs and the price of a commodity. Several variables in the machining process influence the surface roughness. During their useful life, machined components are greatly affected by the surface's roughness, which affects many features such as fatigue, corrosion resistance, wear resistance, friction coefficient, and the capability to distribute and hold a lubricant, load-bearing capacity, coating and heat transfer [2]. Regulation of the machined surface roughness is, therefore, necessary [3]. Suitable process parameters must be chosen to achieve optimal machined sections of the surface consistency and be chosen to reach the desired surface quality machined sections, whereas the surface roughness was a paramount factor of the quality of a product and a measure that affects manufacturing cost. In the future, the production of advanced cutting tool materials will continue manufacturing the surface by coating. According to consumer statistics, about 40% of the modern
industry's cutting tools are coated using PVD and CVD techniques \[4\],[5]. Coated carbide tools assure lower heat generation, lower cutting forces, improved surface roughness, and higher wear resistance, enabling them to perform better at higher cutting conditions than their uncoated counterparts \[6\].

2. Surface roughness (SR)
Surface roughness is determined by vertical differences from the ideal horizontal shape of a real surface. If those variations are comparatively high, the surface is rough. If they are comparatively slight, it is smooth \[7\]. Suitable selection of tool and cutting conditions can give a better surface finish and tool life \[8\]. The roughness of the surface for the machined surface in turning operation resulted from the combined influence of both natural and ideal roughness. Ideal roughness was due to marks on the feed rate. It crosses the edge's cutting edge and the cutting edge with the same crossing, as seen in Figure (1). Using Equation (1), it can be modeled and projected from the cutting instrument's geometry. For tools with the sharp intersection of main and auxiliary, however, cutting edges is more common with the round corner nose because it supports a smoother surface finish. Equation 2 exemplifies ideal surface roughness when using a round corner nose cutting tool.

\[
R_t = \frac{f}{\cot K + \cot K'}
\]

Where; \(R_t\): Peak to the Valley Surface Roughness, \(K\): The main Cutting Angle, \(K'\): The auxiliary Cutting Angle, \(r\): The tool Nose Corner Radius, and \(f\): Feed Rate Length.

The theoretical ideal of surface roughness would not be reliable as the actual surface roughness when the feed rate is very low under machine conditions \[10\]. This is consequent to plastic deformation in the cutting zone expanded to the machined surface \[11\]. Also, many other reasons affect surface roughness, such as cutting angle and temperature. One of the factors that improve surface roughness is by changing the setting distance. Simultaneously, the inclination angle by eliminating the chip curl far from the machined surface \[12\].

3. Experimental work
An AISI 1045 steel sample of 32 mm in diameter and 500 mm in length was used in this experimental work and machined in a CNC turning machine and with the use of two various carbide tools (uncoated, TiN coated). It was divided into two groups, each of nine experiments, each experiment of 32 mm in diameter and 30 mm in length was used, as shown in Figure (2). The chemical composition of the work piece given in Table 1. The used linear cutting speeds were (80, 110, and 140 m/min), as shown in Equation 3, while the feed rates were (0.05, 0.1, and 0.15 mm/rev) and the depth of cut fixed at (3 mm).

\[
V_c = \frac{\pi \times D \times N}{1000}
\]
Where; \( V_c \): cutting speed, \( D \): diameter of the workpiece, and \( N \): rotational speed.

The linear cutting speeds are (80, 110, 140 m/min) respectively. The parameters used in the cutting process can be illustrated as shown in Table (2)

![Figure 2. Work piece divided according to the experiment setting.](image)

### Table 1. Chemical composition of the work piece.

| No. | Element | The ratio % | No. | Element | Percent |
|-----|---------|-------------|-----|---------|---------|
| 1   | C       | 0.42–0.50   | 6   | Cr      | < 0.25  |
| 2   | P       | 0.035 max   | 7   | Ni      | < 0.3   |
| 3   | Mn      | 0.50–0.80   | 8   | Mo      | 0.02    |
| 4   | Si      | < 0.4       | 9   | Cu      | < 0.25  |
| 5   | S       | 0.03 max    |     |         |         |

### Table 2. Cutting.

| No. | Cutting Parameters | Unit | Level 1 | Level 2 | Level 3 |
|-----|--------------------|------|---------|---------|---------|
| 1   | Cutting speed (v)  | m min\(^{-1}\) | 80      | 110     | 140     |
| 2   | Feed (f)           | mm rev\(^{-1}\) | 0.05    | 0.1     | 0.15    |
| 3   | Depth of cut (d)   | mm   | 0.3     | 0.3     | 0.3     |

### 4. Results and discussion

Experimental and predicted results with the machine parameter are shown in Table (3). The design of experiment approach is done by using full factorial to give all prospects 18 numbers of experiments using Minilab 17 software.

In this research, the cutting tools (uncoated, TiN coated) were used for machining samples in dry cutting conditions. The cutting conditions were: cutting speeds are (80, 110, and 40 m/min); feed rates are (0.05, 0.1, and 0.15 mm/rev), and at constant the depth of cut (3mm). A portable surface roughness device, which was produced by (MAHR FEDRAL INC, USA), was used to measure surface roughness (Ra), with range (0.03 µm to 6.35 µm). Figure (3) show the relationship between feed rates and surface roughness, the increase in feed rate ranges (0.05 - 0.15 mm/rev) will increase the surface roughness according to the same values of cutting speeds. Figure (4) shows the relationship between the cutting speed and the surface roughness; increasing the cutting speed in ranges (80, 110, and 140 m/min) reduces the surface roughness in case of using fixed feed values.

In terms of the coated tool, Figure (4) shows the relationship between cutting speed and surface roughness and feeding rates and surface roughness. It shows an increase in cutting speed in the ranges (80,110 and 140 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 when the cutting speed values are constant, where the percentage of that increases is approximately (25%).
Table 3. Experimental and predicted surface roughness $Ra$.

| No. | Type of Coat | Cutting speed (m/min) | Feed rate ($f$ (mm/rev)) | $Ra$ ($\mu$m) | Predicted $Ra$ ($\mu$m) |
|-----|--------------|-----------------------|--------------------------|--------------|------------------------|
| 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  | TiN coated   | 80                    | 0.05                     | 1.17         | 1.13                   |
| 11  | TiN coated   | 110                   | 0.05                     | 0.85         | 0.88                   |
| 12  | TiN coated   | 140                   | 0.05                     | 0.74         | 0.74                   |
| 13  | TiN coated   | 80                    | 0.1                      | 1.20         | 1.19                   |
| 14  | TiN coated   | 110                   | 0.1                      | 0.95         | 0.94                   |
| 15  | TiN coated   | 140                   | 0.1                      | 0.8          | 0.80                   |
| 16  | TiN coated   | 80                    | 0.15                     | 1.45         | 1.49                   |
| 17  | TiN coated   | 110                   | 0.15                     | 1.28         | 1.24                   |
| 18  | TiN coated   | 140                   | 0.15                     | 1.11         | 1.10                   |

Figure 3. Effect of cutting speed and feed rate on the surface roughness using an uncoated cutting tool.

Figure 4. Effect of feed rate and cutting speed on the surface roughness using a TiN coated tool.
5. Conclusions.
The present work investigates experimentally and numerically the effect of some cutting parameters (feed rate and cutting speed) using uncoated and coated tools on the surface roughness, based on AISI 1045 for the turning process. A full factorial model was proposed to predict the surface roughness value. The conclusions from the work results are as follows:

1- The type of coated cutting tools plays an important role and significantly affects the resulted surface roughness (Ra).
2- Best surface roughness for uncoated tool using cutting speed (140m/min), feed rate (0.05mm/rev) where the surface roughness value was (0.81) and the worst surface roughness were at cutting speed of (80m/min) and the feed rate of (0.15 mm/rev) where the roughness value was (1.54).
3- Best surface roughness (SR) for a TiN coated tool when cutting was at the feed rate of (0.05 mm/rev) and the cutting speed of (140 m/min) where the surface roughness was (0.74), and the worst surface roughness was at the cutting speed of (80 m/min) and the feed rate of (0.15 mm/rev) where the surface roughness value was (1.45).

6. References
[1] P N Rao 2000 Manufacturing Technology Metal Cutting & Machine Tools (McGrew-Hill Companies Inc., USA)
[2] C Natarajan, S Muthu and P Karuppuswamy 2011 Investigation of Cutting Parameters of Surface Roughness for A Non-Ferrous Material Using Artificial Neural Network in CNC Turning (Journal of Mechanical Engineering Research) vol 3 no 1 pp 1–14
[3] Ilhan Asiltürk, Mehmet Çunkas, Modeling and 2011 Prediction Of Surface Roughness In Turning Operations Using Artificial Neural Network And Multiple Regression Method (ELSEVIER, Expert Systems with Applications) vol 38 Issue 5 pp 5826–5832
[4] T CSELLE and A BARIMANI 1995 Today’s Applications and Future Developments of Coatings for Drills and Rotating Cutting Tools (Surf. & Coat. Technol) vol 76–77 p 712
[5] C SUBRAMANIAN and K N STRAFFORD 1993 Review of Multi-component and Multilayer Coatings for Tribological Applications (Wear) vol 165 p 85
[6] Ezugwu EO, Soh KS 1997 Wear Of Coated Carbide Tool When Machining An Ni–Cr–Mo (817) Steel (Lubr Eng)
[7] Hassan Abdel-Gawad El-Hofy 2014 Fundemental of Machining Processes (CRC Press, Taylor & Francis Group)
[8] Ali Abbar Khleif, Lujain Hussein Kashkul 2019 Investigation of Effecting Parameters in a Turning Operation (Al-Khwarizmi Engineering Journal) vol 15 no 4 pp 45–54
[9] Steven Y Liang, Albert J Shih 2016 Analysis of Machining and Machine Tools (Springer)
[10] W Grzesik A Revised Model For Predicting Surface Roughness In Turning (ELSEVIER, Wear) vol 194 pp 143–148
[11] J Kaczmarek Principles of Machining by Cutting, Abrasion und Erosion (Peter Peregrinus, Stevenage)
[12] Dr Farhad Mohammad Kushnaw, Dr Ali Abbar Khleif 2011 Theoretical and Experimental Investigation of Tool Inclination Angle in Turning Operation (Eng. & Tech. Journal) vol 29 no 1