Optimization of Cutting Parameters for Various Work-Tool Combinations in Turning Operation: An Experimental Investigation

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Abstract: In the present research work the output responses Material Removal Rate (MRR) and Surface Roughness (SR) are studied and analyzed by varying the turning parameters like cutting speed, feed and depth of cut. The conventional turning of Stainless steel, Normalized steel and Aluminium work materials is carried out by using different cutting tool inserts. The data was compiled into MINITAB ® 17 for analysis. Design of Experiments (DOE) was conducted to analyze the impact of cutting parameters on the Material Removal Rate (MRR) and Surface Roughness (SR) by using Taguchi method. By conducting Analysis of Variance (ANOVA) the results are optimized to determine minimum surface roughness and maximum MRR. Response Surface Optimizer was used for obtaining optimum settings to carry out the machining operations effectively.

Index Terms: turning, cutting tool inserts, material removal rate, surface roughness, and optimization

I. INTRODUCTION

Turning is the basic machining operation in which the excess material from the rotated work-piece is removed in the form of chips, by moving a single point cutting tool parallel to the axis of rotation of work-piece, to get exact size and shape of the work-piece. Turning can be done on both the external surface and internal surface of the work part.

To achieve high process performance of turning, it is necessary to choose suitable parameters.

II. LITERATURE SURVEY

Singh and Kumar [1] investigated feed force optimization through turning operation of EN24 work piece material by using coated tungsten carbide inserts, varying process parameters.

Ali Riza Motorcu [2] studied the impact of surface roughness during turning of AISI 8660 steel, where the cutting tool used was P.V.D coated ceramic. The results revealed that the feed and depth of cut are more significant parameters.

Adarsh kumar et al. [3] analyzed the effect of surface roughness on EN-8 steel by altering the cutting parameters. The ultimate aim is to correlate and optimize the cutting parameters using multiple regression analysis.

Yong et al. [4] stated that there was excellent increase in life of tool after normal (28.9%), deep (38.6%) treatment of milling inserts treated cryogenically made up of tungsten carbide.

Stewart [5] implemented cryogenically cured C2 WC Co inserts to make out tool wear before and after turning operation of the work piece made of medium density fibre (MDF). The results revealed less tool wear with cryogenically treated tools in comparison to untreated one. He suggested that the cryogenic treatment might have an influence upon the cobalt binder by changing its crystallographic phase.

A lot of work has been done in improving material removal rate and surface modification with Turning Operation. From the literature survey, it is observed that many researchers used High Speed Steels, AISI Steels and composite materials with Carbide and CBN Cutting Tools and examined the various output responses like surface roughness, tool wear rate, material removal rate.

More research is required in field of turning process as there is lackage of few concepts. From the literature review, it is observed that no research work has been carried out on improvement of material removal rate and surface Roughness using Aluminium, normalised steel and Stainless
steel 316. No work has been reported on Carbide and Titanium cutting inserts. All these aspects will be addressed in the research work.

III. OBJECTIVE OF THE PROJECT

- To analyze the influence of cutting parameters on the material removal rate and surface roughness while turning of Aluminium, Normalised Steel and Stainless steel-316 by using Carbide and Titanium Cutting inserts.
- To make a comparison between the effects of cutting parameters with different materials (Aluminium, Normalised steel and Stainless steel 316) by using cutting tool inserts (Carbide and Titanium).
- To determine the optimal settings for the work-tool combinations.

IV. EXPERIMENTAL DESIGN

The aim of this research work is to study the influence of cutting parameters on the Material Removal Rate and surface roughness during turning operation of various work materials, using Carbide and Titanium Cutting tool inserts. The designed process variables can be summarized as follows:

- Two types of cutting tool inserts
- Three levels of speed.
- Three levels of feed rate.
- Three levels of depth of cut.
- Three types of work piece materials.

To carry out the Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration of the above designed process variables [6]. The influence of each cutting parameter on the concept of surface modification should be studied in order to know its behavior [7]. Thus, it was decided to conduct experiments with each combination of cutting parameters. Out of the above listed designed process variables, the orthogonal array is selected for five design variables which would represent the orthogonal array.

Based on the number of parameters and the levels, an orthogonal array is confirmed by using the array selector.

The arrays are generated using Taguchi algorithm; it allows testing of each parameter and settings, equally. MINITAB 17 which is a statistical software was used to assign factors for the present work.

| TABLE II. MACHINING PARAMETERS AND THEIR LEVELS |
|-----------------------------------------------|
| **Parameters** | 1 | 2 | 3 |
| Inserts | Carbide | Titanium |  |
| Speed | 280 | 450 | 710 |
| Feed | 0.2 | 0.4 | 0.63 |
| Depth of cut | 0.5 | 1.0 | 1.5 |
| Work piece | SS316 | Normalised steel | Aluminium |

| TABLE III. STANDARD L18 ORTHOGONAL ARRAY (TAGUCHI DESIGN) |
|-----------------------------------------------------------|
| **Exp. No.** | **Parameter 1** | **Parameter 2** | **Parameter 3** | **Parameter 4** | **Parameter 5** |
| 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 2 | 2 | 2 |
| 3 | 1 | 1 | 3 | 3 | 3 |
| 4 | 1 | 2 | 1 | 1 | 2 |
| 5 | 1 | 2 | 2 | 2 | 3 |
| 6 | 1 | 2 | 3 | 3 | 1 |
| 7 | 1 | 3 | 1 | 2 | 1 |
| 8 | 1 | 3 | 2 | 3 | 2 |
| 9 | 1 | 3 | 3 | 1 | 3 |
| 10 | 2 | 1 | 1 | 3 | 3 |
| 11 | 2 | 1 | 2 | 1 | 1 |
| 12 | 2 | 1 | 3 | 2 | 2 |
| 13 | 2 | 2 | 1 | 2 | 3 |
| 14 | 2 | 2 | 2 | 3 | 1 |
| 15 | 2 | 2 | 3 | 1 | 2 |
| 16 | 2 | 3 | 1 | 3 | 2 |
| 17 | 2 | 3 | 2 | 1 | 3 |
| 18 | 2 | 3 | 3 | 2 | 1 |
TABLE IV.
EXPERIMENTAL SETTING FOR L18 ORTHOGONAL ARRAY (TAGUCHI DESIGN)

| Exp No. | Inserts | Speed (rpm) | Feed (mm/rev) | depth of cut (mm) | Work piece   |
|---------|---------|-------------|---------------|------------------|--------------|
| 1       | Carbide | 280         | 0.2           | 0.5              | SS 316       |
| 2       | Carbide | 280         | 0.4           | 1                | Normalised steel |
| 3       | Carbide | 280         | 0.63          | 1.5              | Aluminium    |
| 4       | Carbide | 450         | 0.2           | 0.5              | Normalised steel |
| 5       | Carbide | 450         | 0.4           | 1                | Aluminium    |
| 6       | Carbide | 450         | 0.63          | 1.5              | SS 316       |
| 7       | Carbide | 710         | 0.2           | 1                | SS 316       |
| 8       | Carbide | 710         | 0.4           | 1.5              | Normalised steel |
| 9       | Carbide | 710         | 0.63          | 0.5              | Aluminium    |
| 10      | Titanium | 280        | 0.2           | 1.5              | Aluminium    |
| 11      | Titanium | 280        | 0.4           | 0.5              | SS 316       |
| 12      | Titanium | 280        | 0.63          | 1                | Normalised steel |
| 13      | Titanium | 450        | 0.2           | 1                | Aluminium    |
| 14      | Titanium | 450        | 0.4           | 1.5              | SS 316       |
| 15      | Titanium | 450        | 0.63          | 0.5              | Normalised steel |
| 16      | Titanium | 710        | 0.2           | 1.5              | Normalised steel |
| 17      | Titanium | 710        | 0.4           | 0.5              | Aluminium    |
| 18      | Titanium | 710        | 0.63          | 1                | SS 316       |

A. Tools used for experiment:

The single point cutting tool with carbide or titanium insert is used for machining operation. The material of the tool is of high speed steel. After each experiment the cutting tool properly grounded and the same tool geometry is maintained.

TABLE V.
CUTTING TOOL GEOMETRY

| S No | Angle                          | Value |
|------|--------------------------------|-------|
| 1    | Side Rack Angle                | 7°    |
| 2    | Back Rake Angle                | 9°    |
| 3    | Side Cutting Edge Angle        | 13°   |
| 4    | End Cutting Edge Angle         | 12°   |
| 5    | Side Relief Angle              | 6°    |
| 6    | End Relief Angle               | 8°    |

B. Equipments used for experiment:

Jobber XL CNC horizontal lathe machine was used to perform experiments for the present work.

Taly surf was used for measuring surface roughness of work materials.
IV. RESULTS AND ANALYSIS

A. Results of material removal rate and Surface Roughness:

The results for rate of material removed were summarized as shown in table 4. The diameter of the work piece before and after machining is determined to evaluate the MRR of each trail. The MRR is given by

\[ \text{MRR} = \frac{1000V}{\pi dn} \]

Where, \( V = \frac{\pi dn}{1000} \), is cutting speed in m/min
\( d \) is the average diameter of the work piece in mm
\( n \) is the spindle speed in rpm
\( f \) is feed in mm/rev
\( a \) is depth of cut in mm.

Fig. 9 shows that the Mean material removal rate is higher in case of Carbide insert compared to the Titanium insert. This is perhaps due to the hardness of the insert, high thermal conductivity and higher toughness. As the speed increases the mean of material removal rate decreases first up to some value and then increases. As the feed increases the mean of material removal rate decreases first up to some value and then increases. It is clear that as the depth of cut increases the mean of material removal rate increases first up to some value and then decreases. Among all the work pieces the maximum mean MRR is for Aluminium.

Fig. 10 depicts that the carbide tool insert produces minimum surface roughness as compared to titanium inserts. As the speed increases the surface roughness increases to extent and beyond it decreases. As the feed and depth of cut increases the surface roughness varies similarly. Among all work pieces stainless steel-316 is shows superior surface finish.
B. ANOVA for MRR:

The ANOVA results for MRR reveals that, as P-value for speed is less than standard value (0.05). It concludes that speed is the most significant parameter as compared to other parameters.
Fig. 12 and 13 predicts that the response doesn’t have regular structural pattern.

D. ANOVA for Surface Roughness

| Source            | DF | Adj SS  | Adj MS | F-Value | P-Value |
|-------------------|----|---------|--------|---------|---------|
| Speed (rpm)       | 2  | 18.924  | 9.462  | 0.36    | 0.710   |
| Inserts           | 1  | 5.971   | 5.971  | 0.23    | 0.647   |
| Feed (mm/rev)     | 2  | 54.996  | 27.498 | 1.04    | 0.396   |
| Depth of cut (mm) | 2  | 46.287  | 23.144 | 0.88    | 0.0453  |
| Work piece        | 2  | 153.468 | 76.734 | 2.90    | 0.113   |
| Error             | 8  | 211.581 | 26.448 | -       | -       |
| Total             | 17 | 491.227 | -      | -       | -       |

The ANOVA results for SR reveals that, as P-value for depth of cut is less than standard value (0.05). It concludes that speed is the most significant parameter as compared with other parameters.

Fig. 14 depicts that most of the points are nearer to a straight line, which reveals that the errors are normally distributed. Therefore model is satisfactory.

Fig. 15 and 16 predicts that the response doesn’t have regular structural pattern.
E. Optimum settings:

The three finest optimum settings shown below are:

| Exp No | Inserts | Speed (rpm) | Feed (mm/rev) | Depth of cut (mm) | Work piece |
|--------|---------|-------------|---------------|------------------|------------|
| 1      | Titanium| 710         | 0.63          | 1.5              | SS316      |
| 2      | Carbide | 710         | 0.63          | 1                | SS316      |
| 3      | Carbide | 280         | 0.2           | 0.5              | Aluminum   |

The optimization plot depicts that, how the required response (surface roughness and Material Removal Rate) alters with the increased speed, feed rate and depth of cut). The optimal setting is assessed by maximum desirability.

V. CONCLUSIONS

1) From the above experiments, it is concluded that the higher material removal rate and lower Surface roughness is possible with the optimum parameters.
2) By determining optimum settings for the machining operation, it is possible to reduce the machining time thereby increasing the productivity.
3) The MRR was maximum for carbide tool insert when compared to the titanium tool insert.
4) The SR was minimum for carbide tool insert when compared to the titanium tool insert.
5) The above results imply that speed has the largest influence on MRR followed by other cutting parameters.
6) The above results imply that depth of cut has the largest influence on SR followed by other cutting parameters.

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