# Application of Taguchi Method in Optimization of Tool Flank Wear Width in Turning Operation of AISI 1045 Steel

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**Abstract**

In this paper, Taguchi techniques are applied to find out the optimum tool flank wear width in turning operation of AISI 1045 Steel. A L9 orthogonal array, S/N ratios and ANOVA are used to study the performance characteristics of cutting speed, feed rate and depth of cut as turning parameters with tool flank wear width as response variable. The result of the analysis show that the selected machining parameters affect significantly the tool flank wear width of Tungsten Carbide cutting tool while machining AISI 1045 steel and also indicate that the cutting speed is the most influencing parameter out of the three parameters under study. Finally, the results are further confirmed by validation experiments or confirmation run.

**Keywords:** Taguchi Method, Optimization, Tool flank wear width, S/N ratio, ANOVA.

## 1. Introduction

Taguchi method has the objective of designing the quality in each and every product and their corresponding process. In Taguchi technique, quality is measured by the deviation of a quality characteristics from its target value. Therefore, the objective is to create a design that is insensitive to all possible combinations of uncontrollable factors and is at the same time effective and cost efficient as a result of setting the key controllable factors at optimum levels.

The major drawback in metal cutting industries is not utilizing the machine tools at their full potential. A major cause to such a situation is not to run at their optimum operating conditions (Rajendrakumar P., 2011). Robust design is an engineering methodology for obtaining product and process condition, which are sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs (Park 1996).

In this paper, objective is to obtained optimum values of turning process parameters (cutting speed, feed rate, depth of cut), for optimizing the tool flank wear width while machining AISI 1045 Steel with Tungsten carbide inserts. For this, L9 orthogonal array is used to analyze the results along with S/N ratios and ANOVA.

## 2. Literature Review

Taguchi offers a simple and systematic approach to optimize a performance, quality and cost. The quality of design can be improved by improving the quality and productivity in various company-wide activities. Those activities concerned with quality include in quality of product planning, product design and process design (Park 1996, Ranjit 2001).

Taguchi's parameter design offers a simple and systematic approach which can reduce number of experiments to optimize design for performance, quality and cost. Signal to Noise(S/N) ratio and orthogonal array(OA) are two major tools used in robust design.S/N ratio measures quality with emphasis on variation, and OA accommodates many design factors simultaneously (Park 1996, Phadke 1998).

Tong L. et al. (1997), proposed a procedure in this study to achieve the optimization of multi-response problems in the Taguchi method which includes four phases, i.e. computation of quality loss, determination of the multi-response S/N ratio, determination of optimal factor/level condition and performing the confirmation experiment.

Das et al. (1997a and 1997b), Choudhury and Apparao (1999) and Choudhury et al. (1999) have developed different models for optimization of process parameters using different responses such as surface roughness, tool wear, vibrations etc.

Antony J (2001), presents a step by step approach to the optimization of production process of retaining a metal ring in a plastic body by a hot forming method through the utilisation of Taguchi methods of experimental design.

Singh H. And Kumar P. (2006), optimized the multi machining characteristics simultaneously using Taguchi parameter approach and utility concept. They used a single performance index, utility value, as a combined response indicator of several responses.

Gusri et al. (2008), applied Taguchi optimization methodology in turning Ti-6Al-4V Ell with coated and uncoated cemented carbide tools to optimize the selected cutting parameters with tool life and surface roughness as response.

Lan T. S. ( 2009 ), uses the L9 orthogonal array of Taguchi method for optimizing the multi-objective machining in CNC with surface roughness, tool wear and material removal rate are selected as response.

Gopalsamy B.M. et al. ( 2009 ), applied Taguchi method to find out the optimum machining parameters while hard machining of hard steel and uses L18 orthogonal array, S/N ratio and ANOVA to study the performance characteristics of machining parameters which are cutting speed, feed, depth of cut and width of cut while considering surface finish and tool life as response.

Rajendrakumar P. (2011 ), focuses on a Design of experiment approach to obtain optimal setting of process parameters that may yield optimal tool flank wear width and these optimal settings accomplished with Taguchi method.

Ficici F. et al. (2011), uses the Taguchi method to study the wear behaviour of boronized AISI 1040 steel. They uses orthogonal array, S/N ratio and ANOVA to investigate the optimum setting parameters.

## 3. Problem Identification

With all the viewpoints above, the objective of the study is to optimize the tool flank wear width in turning operation of AISI 1045 steel using Tungsten Carbide inserts with the help of Taguchi's L9 orthogonal array, S/N ratios and ANOVA and also to find out the optimal levels of each cutting parameters (cutting speed, feed rate and depth of cut) with their percentage contributions. Finally, the results are further confirmed by validation experiments or confirmation run.

## 4. Experimental Details

Tool wear causes the tool to lose shape such that in time the tool ceases to cut efficiently or may be even fail completely. Tool flank wear is also considered as a criterion for judging the life of cutting tool. Cutting speed, feed rate and depth of cut are the three machining parameters that largely effect the tool flank wear width (Table 1). An AISI 1045 steel rod of 80mm diameter and 400mm length was turned on Engine lathe of HMT using Tungsten Carbide inserts in dry condition. All the three edges of Tungsten Carbide positive rake triangular inserts were used for each trial condition. Thus 27 cutting edges of carbide inserts were used according to the trial condition specified by orthogonal array. The machining time was 4 min. To measure the tool flank wear width and the tool flank wear width was measured by using Magnifying glass of 10X magnification.

## 5. Selection of proper Orthogonal Array and Signal to Noise (S/N) ratio

Taguchi method has been used to study the effect of three machining parameters (cutting speed, feed rate and depth of cut) on tool flank wear width. For proper selecting of orthogonal array, degree of freedom (DOF) is calculated. The total degree of freedom for three machining parameters each at three levels is given by

DOF = 3X(3-1) = 6

Therefore, a three level orthogonal array with at least 6 DOF was to be selected. So, L9 orthogonal array was selected for the study. In this study it was assumed that no interaction exists between the machining parameters. The experimental layout using L9 orthogonal array with responses, mean value of responses and their respective Signal to Noise (S/N) ratio is given in table 2.

Since, tool wear is a 'lower the better' type of quality characteristic (because objective is to minimize tool flank wear width), therefore, the S/N ratio for 'lower the better' type of response was used which is given by the following equation:

$$S/N = -10\log\left[\sum_{i=0}^{n} \frac{Y_i^2}{n}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Here, n represents the trial conditions and $Y_1$, $Y_2$ ,$Y_3$, ..........$Y_n$ represents the values of responses for quality characteristics.The S/N ratios were calculated using equation (1) for each of the nine trails and their values are also given in table 2.

## 6. **Experimental results and analysis**

The mean response i.e. average value of the performance characteristics for each machining parameters at different levels were calculated. These average values of tool flank wear width for each machining parameters at levels 1, 2, 3 are given in table 3 and Fig.1.

Similarly, the average values of S/N ratios of all the three parameters at different levels are calculated and are shown in table 4 and Fig. 2.

It is clear from table 3 and Fig. 1 that tool flank wear width is minimum at 1st level of parameter A (cutting speed), 1st level of parameter B (feed rate) and also at 1st level of parameter C (depth of cut). The S/N ratio analysis from table 4 and Fig. 2 also shows that the same results that tool flank wear width of Tungsten Carbide coated inserts in turning AISI 1045 steel is minimum at A1, B1 and C1. These results are also verified in Fig. 3 of surface plot of cutting speed, feed rate and depth of cut.

Now, in order to study the percentage contribution of each machining parameters ANOVA was performed. The results of ANOVA of the raw data or mean of response of tool flank wear width is given in table 5 and the results of ANOVA of S/N ratios is given table 6. It is evident from these tables that the cutting speed, feed rate and depth of cut significantly affect the value of tool flank wear width. The percentage contributions all the machining parameters are quantified under the last column of both the tables. Both the tables suggests that the influence of cutting speed (A) and feed rate (B) on tool flank wear width is significantly larger than the influence of depth of cut (C).

## 7. **Estimation of predicted mean tool flank wear width at the optimal condition**

The optimal value of tool flank wear width is predicted at the selected levels of machining parameters which are A1, B1 and C1.The estimated mean of tool flank wear width at optimal condition can be calculated as:

$U_{FWW} = A1+B1+C1-2T_{FWW}$

Where, $U_{FWW}$ = Predicted mean response of tool flank wear width

A1 = 101.11 μm

B1 = 106.11 μm

C1 = 107.78 μm

$T_{FWW}$ = Overall mean of tool flank wear width = 114.07 μm

Therefore, $U_{FWW}$ = 101.11+106.11+107.78-2x114.07

= 86.86 μm

So, the predicted mean response shows that there is 23.85% decrease in mean tool flank wear width when working at optimal condition.

## 8. **Confirmation run**

Three confirmation runs were conducted at the selected optimal settings of turning process parameters selected. In this confirmation experiments the average tool flank wear width of Tungsten Carbide tool while machining AISI 1045 steel was found to be 88.33 μm. This results are very much close to the predicted value and this confirmation run results verify the effectiveness of the study.

## 9. **Conclusions and further scope of work**

- [1] Taguchi method is suitable to optimize the tool flank wear width of Tungsten Carbide inserts while turning AISI 1045 steel.
- [2] The levels of machining parameters for minimum tool wear of Tungsten Carbide inserts while machining AISI 1045 steel are cutting speed at level 1(110m/min), feed rate at level 1 (0.15mm/rev) and depth of cut also at level 1 (0.10mm).
- [3] The percentage contributions of machining parameters to the variation of tool wear characteristics of Tungsten Carbide tool are cutting speed 47.45%, feed rate 25.75% and depth of cut 16.52%.
- [4] (4)From the experimental results it is found that tool flank wear width is reduced by 23.85% when working

at selected levels of machining parameters.

The results are valid within the given range of machining parameters and for the specific combination of work and tool material. Any further extrapolation may be confirmed by again conducting the experiment. In this study the interactions between the factors are avoided because they make the study more complicated, so in future study may be conducted while considering the interactions between the factors. Also in this study only three cutting parameters are considered but there some other parameters such as tool geometry, tool material, composition of work piece, cutting condition, type of tool etc. which may be included in the study in future.

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Table 1. Machining Parameters and their levels

| Factors | Factors Code | Levels | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Cutting Speed(m/min) | A | 110 | 150 | 200 |
| Feed Rate(mm/rev) | B | 0.15 | 0.20 | 0.25 |
| Depth of Cut(mm) | C | 0.10 | 0.15 | 0.20 |

Table 2. L9 Orthogonal Array for 3 factors each at 3 levels each with responses, their means and S/N ratios

| Run | Cutting Speed (m/min) | Feed Rate(mm/rev) | Depth of Cut (mm) | Tool Flank wear width(µm) | | | Mean | S/N Ratio(dB) |
|---|---|---|---|---|---|---|---|---|
| | | | | Trial 1 | Trial 2 | Trial 3 | | |
| 1 | 110 | 0.15 | 0.10 | 80 | 100 | 80 | 86.67 | 38.81 |
| 2 | 110 | 0.20 | 0.15 | 110 | 100 | 105 | 105.00 | 40.43 |
| 3 | 110 | 0.25 | 0.20 | 120 | 115 | 100 | 111.67 | 40.98 |
| 4 | 150 | 0.15 | 0.15 | 115 | 100 | 110 | 108.33 | 40.71 |
| 5 | 150 | 0.20 | 0.20 | 120 | 130 | 135 | 128.33 | 42.18 |
| 6 | 150 | 0.25 | 0.10 | 130 | 135 | 125 | 130.00 | 42.28 |
| 7 | 200 | 0.15 | 0.20 | 130 | 120 | 120 | 123.33 | 41.83 |
| 8 | 200 | 0.20 | 0.10 | 110 | 90 | 120 | 106.67 | 40.62 |
| 9 | 200 | 0.25 | 0.15 | 130 | 120 | 130 | 126.67 | 42.06 |

Table 3. Response table for Mean

| Level | Cutting Speed | Feed Rate | Depth of Cut |
|---|---|---|---|
| 1 | 101.1 | 106.1 | 107.8 |
| 2 | 122.2 | 113.3 | 113.3 |
| 3 | 118.9 | 122.8 | 121.1 |
| Delta | 21.1 | 16.7 | 13.3 |
| Rank | 1 | 2 | 3 |

Table 4. Response table for S/N Ratios

| Level | Cutting Speed | Feed Rate | Depth of Cut |
|---|---|---|---|
| 1 | 40.05 | 40.42 | 40.53 |
| 2 | 41.71 | 41.05 | 41.06 |
| 3 | 41.48 | 41.76 | 41.65 |
| Delta | 1.67 | 1.34 | 1.12 |
| Rank | 1 | 2 | 3 |

Table 5. Analysis of Variance for mean tool flank wear width

| Source | DOF | Sum of Squares | Mean Square | F-Ratio | % Contribution |
|---|---|---|---|---|---|
| Cutting Speed | 2 | 772.59 | 386.30 | 4.62 | 47.45 |
| Feed Rate | 2 | 419.30 | 209.65 | 2.51 | 25.75 |
| Depth of Cut | 2 | 269.00 | 134.50 | 1.61 | 16.52 |
| Error | 2 | 167.21 | 167.21 | | |
| Total | 8 | 1628.11 | | | |

Table 6. Analysis of Variance for S/N Ratios

| Source | DOF | Sum of Squares | Mean Square | F-Ratio | % Contribution |
|---|---|---|---|---|---|
| Cutting Speed | 2 | 4.8158 | 2.4079 | 5.60 | 47.67 |
| Feed Rate | 2 | 2.6293 | 1.3146 | 3.06 | 26.02 |
| Depth of Cut | 2 | 1.7981 | 0.8990 | 2.09 | 17.80 |
| Error | 2 | 0.8601 | 0.4300 | | |
| Total | 8 | 10.1032 | | | |

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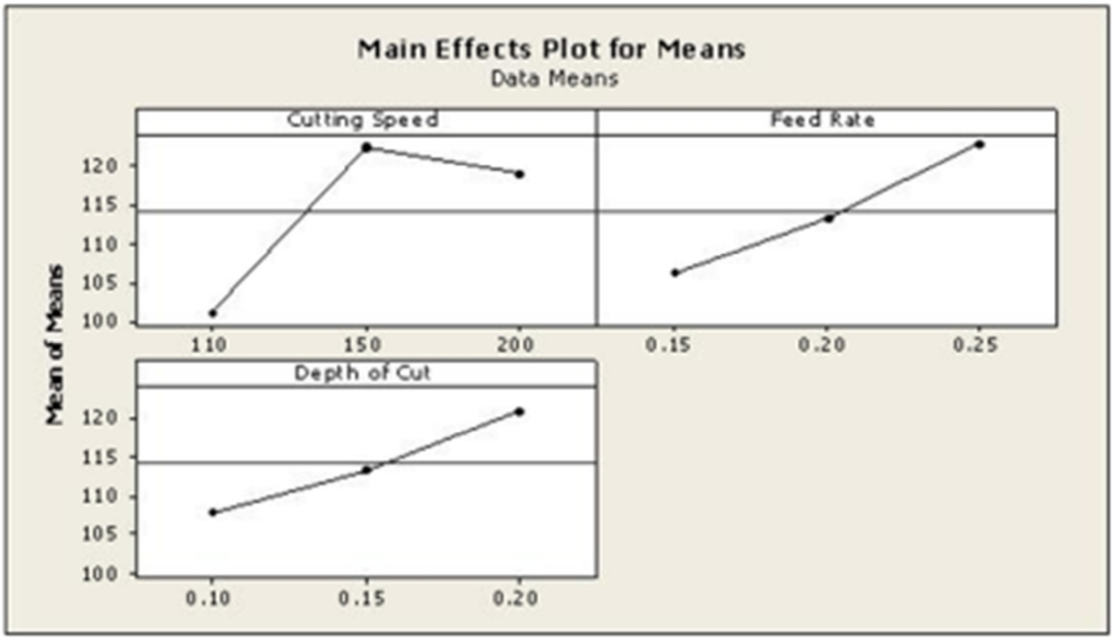


Figure 1 Main Effects Plot for Mean

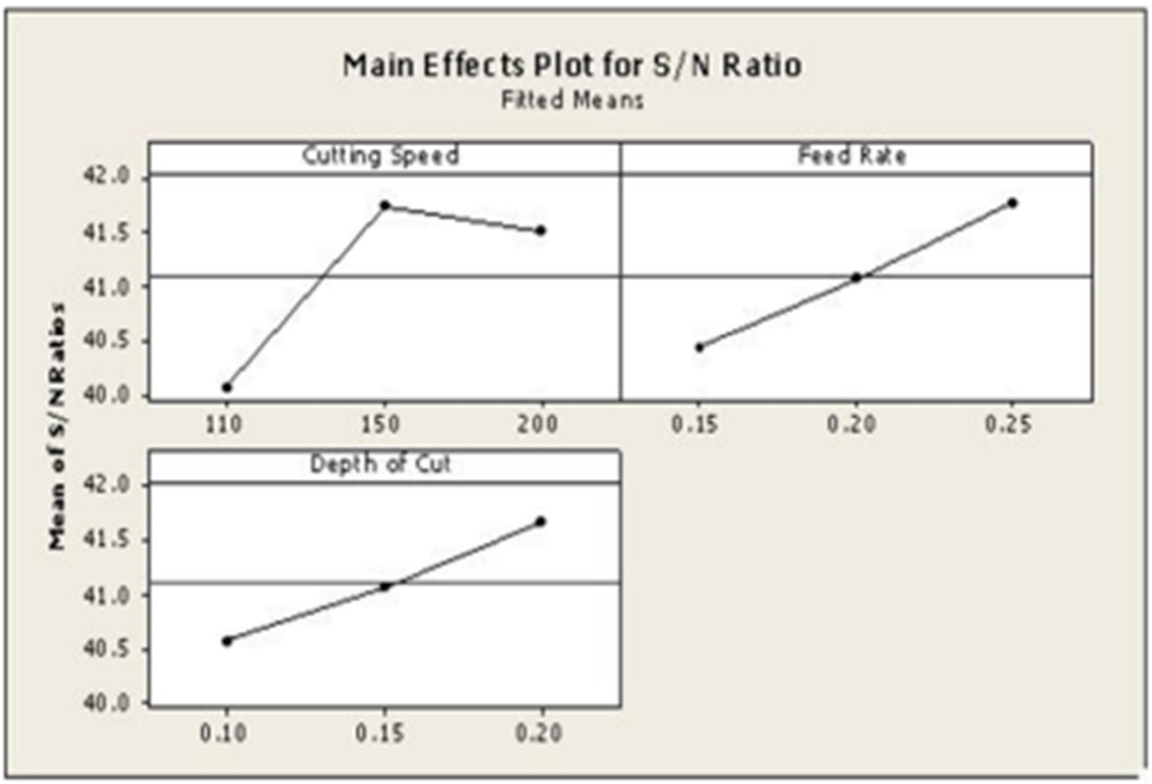


Figure 2 Main Effects Plot for S/N Ratio

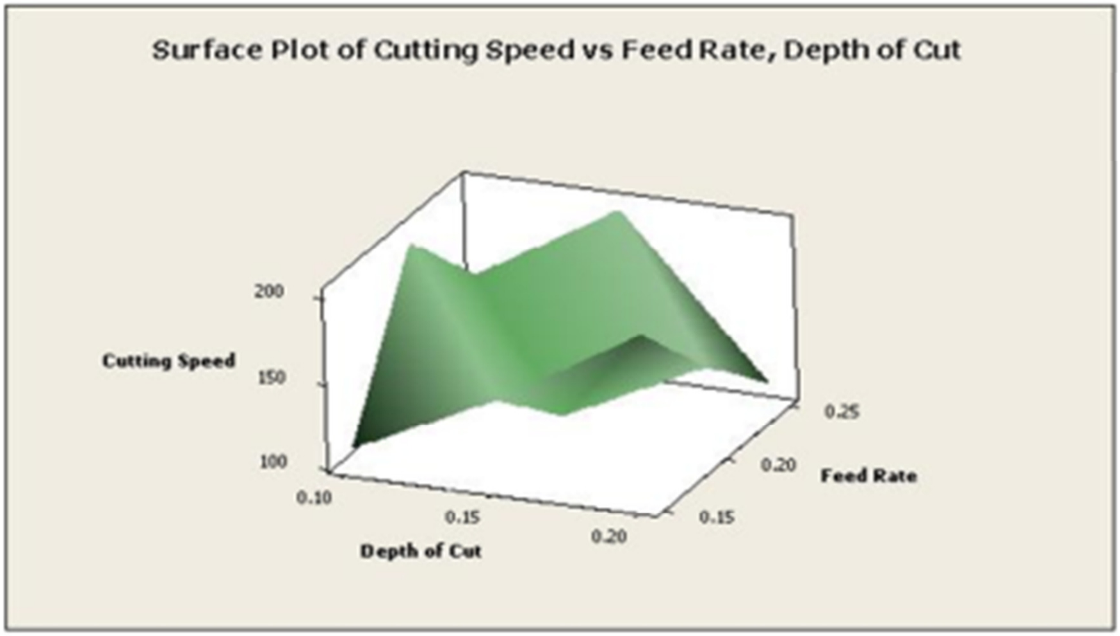


Figure 3. Surface plot of cutting speed, feed rate & depth of cut