# Optimization of Surface Roughness and Tool Life for Turning S45C Steel Using Response Surface Methodology

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***Abstract*- Response surface methodology is successfully applied in optimizing the tool life and surface roughness for the chosen tool work combination and for the selected domain of the input machining parameters. The work develops a predictive and optimization model by coupling the two approaches, artificial neural network and response surface methodology. Surface roughness, an indicator of surface quality is one of the most specified customer requirements in a machining process. For efficient application of machine tools, optimum cutting parameters (speed, feed and depth of cut) are required. Therefore, it is necessary to determine a suitable optimization method which can find optimum values of cutting parameters for minimizing surface roughness and improve the tool life. The turning process parameter optimization is highly constrained and nonlinear. In present work, machining process was carried out on S45C steel material in dry cutting condition in a lathe machine. To predict the surface roughness and tool life, an artificial neural network model was designed through back propagation network for the data obtained. The predicted data was designed by using central composite design and analysed in Minitab 17.0 and compared the optimized result in good literature. The results obtained, conclude that RSM is reliable and accurate for solving the cutting parameter optimization.**

***Keywords- Response surface methodology, surface roughness, tool life, cutting speed, feed, depth of cut etc.***

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## 1. Introduction

The turning operation is a basic metal machining operation that is used widely in industries dealing with metal cutting [1]. The selection of machining parameters for a turning operation is a very important task to accomplish high performance [2]. By high performance, we mean good machinability, better surface finish, lesser rate of tool wear, higher material removal rate, faster rate of production etc.

The surface finish of a product is usually measured in terms of a parameter known as surface roughness. It is considered as an index of product quality [3]. Better surface finish can bring about improved strength properties such as resistance to corrosion, resistance to temperature, and higher fatigue life of the machined surface [4,5]. In addition to strength properties, surface finish can affect the functional behaviour of machined parts too, as in friction, light reflective properties, heat transmission, ability of distributing and holding a lubricant etc. [6,7]. Surface finish also affects production costs [3]. For the aforesaid reasons, the minimization of the surface roughness is essential which in turn can be achieved by optimizing some of the cutting parameters.

### 1.1 Surface roughness and Tool life

Surface roughness and tool life plays a vital role in deciding about the productivity in global manufacturing. Surface roughness and tool life is one of the important quality control parameter for evaluating of production process. Efficient turned component improves many functional attributes like excellent tolerance, less tool wear, fatigue strength or creep life, load bearing capacity, corrosion strength and frictional
resistance etc. [1,2] Surface roughness determines how a real object interacts with its environment.

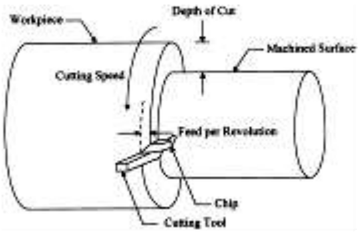


**Fig 1. Basic turning operation [10]**

### 1.2 Response Surface Methodology (RSM)

Response surface methodology is a specialized DOE technique that may be used to detail and optimize transfer functions of a DFSS project. The method can be used in the optimization phase of the DFSS algorithm. Response surface methodology (RSM) is a combination of statistical and optimization methods that can be used to model and optimize designs. It has many applications in design and improvement of products and processes. And it is a fundamental method to derive the relationship between the different parameters affecting the process.

RSM works by applying different designed experiments to obtain a polynomial model of the process keeping the independent variable as the system output which is minimized. A comprehensive algorithm of the calculations involved. These approaches comprise a systematic method of scheduling experiments as well as gathering and analysing records with a near optimum use of resources. The most widely employed methodologies for surface roughness prediction terms of machining parameters are the Response Surface Methodology (RSM). The various forms of regression analysis concentrate on using existing data to predict future results. It is used to examine the relationship among several factors and the results. Regression is applied to create models to predict the results when combinations of factors interact under various conditions. It is one of the most widely used statistical tools because it provides a simple method of establishing a functional relationship among variables. The relationship is expressed in the form of an equation connecting the response or dependent variable (y), and one or more independent variables, $x_1, x_2, x_3, \ldots\ldots x_n$.

## 2. METHODOLOGY

From literature [8] was experimentally done his work. The experimental data has been collected from the literature [8], which used work material as test specimen was Inconel 718. A cylindrical bar of test specimen 50mm diameter and 1000mm length were used for the turning tests. The Inconel 718 material was pre-processed in the fully-heat treated condition. The fully heat-treated condition is meant that the specimen is solution treated at 980°C for two hours followed by oil quenching and then ageing at 720°C for eight hours, furnace cooling to 620°C, holding for eight hours, followed by air cooling. The chemical compositions of Inconel 718 are given in Table 1.

Table 1. Chemical compositions of Inconel 718 [10]

| Grade | C | Si | Mn | P | S | Cr | Ni | Cu |
|---|---|---|---|---|---|---|---|---|
| S45C | 0.42-0.50 | 0.17-0.37 | 0.50-0.80 | 0.035 | 0.035 | 0.25 | 0.25 | 0.25 |

### 2.1 Response Surface Methodology (RSM)

To improve the process quality attention was given & methodology was developed for using experimental design, specifically for the following: -

- To design the product and processes so that they are robust to component variation.
- To minimize variability in output response of a product or process around a target value.
- To design product & processes so that they are robust to environment condition.

$$R_a = \beta_0 + \beta_1(F) + \beta_2(D) + \beta_4(R) + \beta_5(FD) + \beta_6(FV) + \beta_7(FR) + \beta_8(DV) + \beta_9(DR) + \beta_{10}(VR) + \beta_{11}(F^2) + \beta_{12}(D^2) + \beta_{13}(V^2) + \beta_{14}(R^2)$$

-------------------------------------------(1)

Table 2. Factors (parameters) and levels for Design of Experiments

| Factors | Levels | | |
|---|---|---|---|
| | Low | Intermediate | High |
| Speed ‘v’ (m/min) | 135 | 210 | 285 |
| Feed ‘f’ (mm/rev) | 0.08 | 0.20 | 0.32 |
| Depth of Cut ‘a’ (mm) | 0.6 | 1.1 | 1.6 |

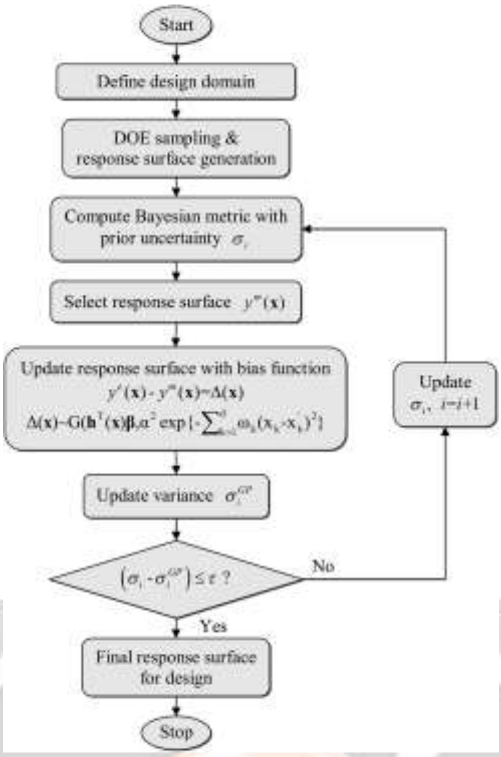


**Fig 2. Flowchart of the Response Surface Methodology**

## 3. RESULTS AND DISCUSSIONS

The results of ANN coupled with RSM used to predict and optimize the surface roughness based on input machining parameters in turning process are shown and discussed below.

**Validation**

In this section, the validation has been done for optimization work. The work has been done in Minitab 17.0 Response Surface Analysis. The Figure 5.1 and 5.2 has been shows the residual plot of tool life and surface roughness.

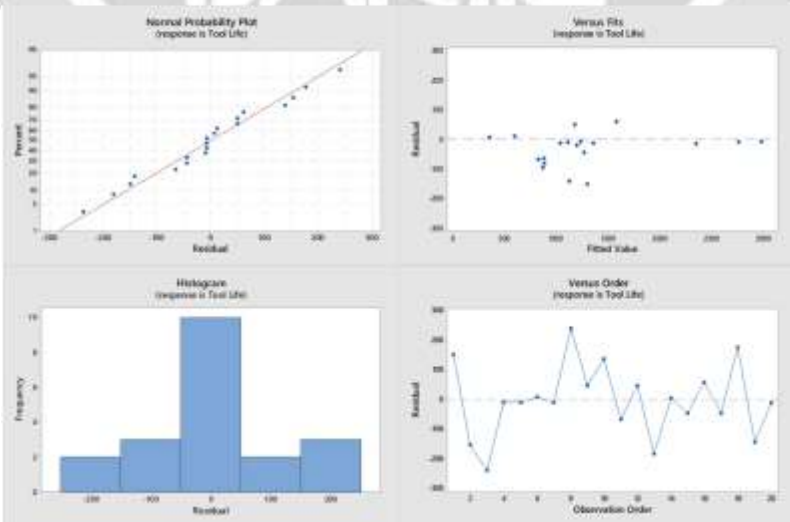


**Fig. 3 Residual plot for tool life**

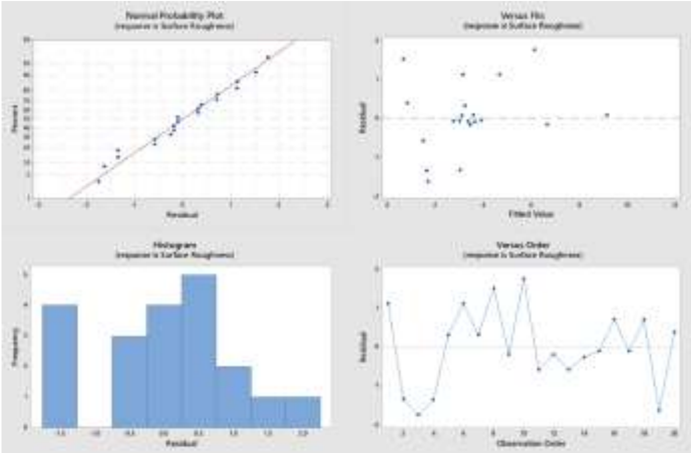

**Fig 4. Residual plot for surface roughness**

In Figure 3 and 4, shows the normal probability model is adequate as represented by the points falling on a straight-line plot. It mentioned that the errors are normally distributed. Also, the plot of the residuals vs predicted response is structure less i.e. containing no obvious pattern.

The main effects and interaction effects plots for the tool life and surface roughness are shown in Figure 5-6.

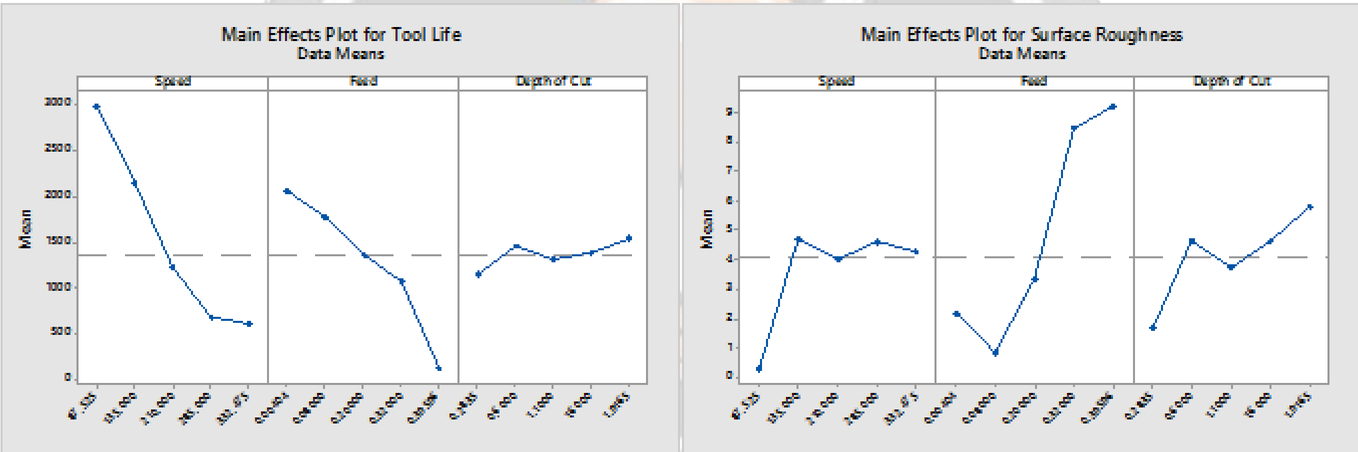


Figure 0.1 Mean effect plot of tool life and surface roughness

## 4. CONCLUSION

- Response surface methodology is successfully applied in optimizing the tool life and surface roughness for the chosen tool work combination and for the selected domain of the input machining parameters.
- In this investigation, the good agreement with an artificial neural network coupled with Response surface methodology for the prediction and optimization of machining parameter leading to maximize the tool life and minimize the surface roughness.
- The result obtained from the data analysis that the cutting speed, feed and depth of cut have significant effect on tool life and surface roughness.
- From the main effect plot, the surface roughness first decreases sharply with the increase in cutting speed. The surface roughness reduces with increase in depth of cut to that particular level after which it is found to have a steep increase with further increase in the depth of cut.
- From main effect plot, the tool life for a decrease in any one of the three parameters up to a certain level with other parameters kept constant. Tool life increases thereafter for fall in any one of cutting speed, feed, or depth of cut with other factors kept constant.
- The response surface model fits the predicted data of tool life well with coefficient of correlation nearing 93.43%, R-sq (adjusted) 93.89% and R-sq (predicted) 86.82% with insignificant lack of fit, and predicted data of surface roughness well with coefficient of correlation nearing 91.85%, R-sq (adjusted) 93.52% and R-sq (predicted) 89.01% with insignificant lack of fit.

## REFERENCES

[1] Surendra Kumar Saini, Sharad Kumar Pradhan, "Optimization of Multi-Objective Response during CNC Turning using Taguchi-Fuzzy Application", Procedia Engineering, Vol. 97, pp. 141 – 149 2014.

[2] Dr. C. J. Rao, Dr. D. Nageswara Rao, P. Srihari, "Influence of cutting parameters on cutting force and surface finish in turning operation", Procedia Engineering, Vol. 64, pp. 1405 – 1415, 2013.

[3] M. Durairaj, S. Gowri Parametric Optimization for Improved Tool Life and Surface Finish in Micro Turning using Genetic Algorithm Procedia Engineering, Vol. 64, pp. 878 – 887, 2013.

[4] Ashvin J. Makadia, J.I. Nanavati, "Optimisation of machining parameters for turning operations based on response surface methodology", Journal of the International Measurement Confederation, Vol. 46, pp. 1521–1529, 2013.

[5] Shreemoy Kumar Nayak, Jatin Kumar Patro, Shailesh Dewangan, Soumya Gangopadhyay "Multi-Objective Optimization of Machining Parameters During Dry Turning of AISI 304 Austenitic Stainless Steel Using Grey Relational Analysis", Vol 6, pp 707-708, 2013.

[6] Libor Beraneka, Kamil Kolarikb "Surface integrity analysis of duplex steel by design of experiment Approach" International Symposium on Intelligent Manufacturing and Automation, Vol 69, pp 630-637, 2013.

[7] G. Mahesh, S. Muthu, S.R. Devadasan, "Experimentation and Prediction of Surface Roughness of the Machining Parameter with Reference to the Rake Angle in End Mill", International Review of Mechanical Engineering, Vol. 6 Issue 7, pp.1418-1426, 2012.

[8] K. Saravanakumar, M.R. Pratheesh Kumar, Dr. A. K. Shaik Dawood, "Optimization of CNC Turning Process Parameters on INCONEL 718 Using Genetic Algorithm", IRACST – Engineering Science and Technology: An International Journal (ESTIJ)Vol.2, No.4, pp.532-537, 2012.

[9] Esmail Soltani, Hesam Shahali, "An investigation of surface roughness and main cutting force during the hard turning of AISI D3 tool steel using Ceramic tools", Vol 12, pp 1727-1289, 2012.

[10] W. H. Yang, Y.S. Tarng, Design optimization of cutting parameters for turning operations based on the Taguchi method Journal of Materials Processing Technology, Vol. 84, pp. 122–129, 1998.