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Optimization and Analysis of Surface Roughness and Flank Wear of AISI 304 Stainless Steel using CNC Turning

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ABSTRACT

Turning of different materials for different purposes has become a field of interest in very recent years. The present work deals with optimization of the cutting parameters in turning of AISI 304 stainless steel. Here turning is carried out using CNC machine in dry condition. The cutting conditions which generally be considered are cutting speed, feed rate and depth of cut. In this experiment, depth of cut is kept constant. The objectives considered are flank wear and surface roughness. The experiments are conducted using two types of uncoated carbide tools. The behavior of the objectives is analyzed against the cutting parameters. As a part of the study, an attempt has been done to minimize the flank wear and surface roughness (multi objective) using an RSM optimization.

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Introduction

Turning is one of the most basic machining processes. The part is rotated on the chuck and a single point cutting tool is moved parallel to the axis of rotation. The starting material is generally a work piece generated by other processes such as forging, casting, drawing or extrusion. Turning can be done manually, on a traditional form of lathe or by using a Computer-controlled and automated lathe. AISI 304 belongs to the family of stainless steels. In the past two decades, stainless steel materials have found their application enormously in various fields. The combination of excellent corrosion resistance, a wide range of strength levels including strength retention at cryogenic and elevated temperatures, good formability, and an aesthetically pleasing appearance have made stainless steel materials of choice for a diverse range of applications, from critical piping components in boiling water nuclear reactors to the ubiquitous kitchen sink [1]. Poor surface finish and a high tool wear rate are commonly appearing problems during machining of these kinds of materials. A good surface finish is highly important to measure the quality of the products. Also it is essential to improve the corrosion resistance, fatigue strength, and aesthetic outlook of manufactured products. It is expressed as surface roughness value. The surface roughness is influenced by various factors such as the cutting parameters, cutting tool geometry, microstructure of work piece, chip interface, built-up edge formation, tool and work piece vibration, etc. So the perfect surface finish is difficult to obtain due to the above stated reasons [2]. Flank wear is one of the severe problems in machining of materials and this will directly affect the surface quality of the work piece. Therefore, tool monitoring is a very important task in the context of advancing tool life as well as to maintain the surface quality. One of the most critical functions in the field of tool monitoring is to determine the tool's wear caused by erosion, abrasion or other influences. The result of abrasive wear of the cutting edge against the machined surface is called as flank wear [2]. Many scientists and researchers have suggested several techniques to improve the surface quality of the difficult to cut materials, such as providing coating to the edges of cutting tools, etc. The soft tool optimization techniques are popular now a day, as they are cost effective and many such soft techniques have shown their prominence in correctness of their output.

Ch. Maheswara Rao et al. [3] optimized the surface roughness in CNC turning using Taguchi method and ANOVA. The material AA7075 was turned using tungsten carbide insert. Experiments were designed using Taguchi technique. ANOVA was performed to study the significance of cutting parameters on surface roughness. The results showed that cutting speed and feed influenced the surface roughness the most.

Ilhan Asilturk et al. [4] made an attempt to determine the effect of cutting parameters on surface roughness in hard turning using the Taguchi method. Here AISI 4140 workpiece was turned in dry condition. Surface roughness parameters considered were Ra and Rz. SNR and ANOVA were applied to determine the effect of cutting parameters on surface roughness. Taguchi L9 orthogonal array method was used to minimize the surface roughness. Results showed that the feed rate was the most influential factor on the surface roughness.

Ashvin J. Makadia et al. [5] optimized the machining parameters for turning operations based on response surface methodology. Here AISI 410 steel was turned using the turning parameters cutting speed, feed rate, depth of cut and tool nose radius. Design of experiment was used to study the effect of these parameters on surface roughness. The effect of these parameters was investigated by using Response Surface Methodology (RSM). The study revealed that the feed rate followed by the tool nose radius were the main influencing factors on surface roughness.

Daniel Lawrence et al. [6] tried to optimize the machining parameters in turning of AISI 304 steel using Gray Relational Analysis (GRA) and RSM. The experiment was designed using Taguchi L9 orthogonal array, with the combination of three speeds (450,550 and 650 rpm), three feed rates (0.2, 0.25 and 0.3mm/rev) and three depths of cut (0.2, 0.3, and 0.4 mm). The values were analyzed using

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GRA and conditions were optimized using Response Surface Methodology to achieve minimum surface roughness. The study concluded the feed rate is the essential factor to decide the surface roughness, followed by the cutting seed.

Shreemoy Kumar Nayak et al. [7] made an attempt to do multi-objective optimization of machining parameters during dry turning of AISI 304 Austenitic stainless steel using Grey Relational Analysis (GRA). The different objectives such as material removal rate, cutting force and surface roughness were considered as the objectives against the cutting parameters. Uncoated cemented carbide inserts were used in the dry turning operation. L27 orthogonal array design of experiments was used for the machining parameters. 88.78% improvement was observed, in grey rational analysis upon the confirmatory test.

In this study, an attempt has been made to analyze the behavior of surface roughness and flank wear in turning of AISI 304 stainless steel in dry turning using two types of uncoated carbide inserts. The cutting conditions used are three speeds, three feed rates and a constant depth of cut. Also, as a part of the study, the cutting conditions are optimized to minimize both surface roughness and flank wear using Response Surface Methodology (RSM).

Experimental

Materials and Methods

The experiments were carried out on ACE Designers Cub LM CNC machine, which has the maximum spindle speed of 4000 rpm. The workpiece material made of AISI 304 stainless steel had the initial diameter 50 mm and length of 150 mm. The chemical composition of AISI 304 is given in Table 1.

Table 1: Composition of AISI 304

Element	Weight (%)
C	0.08
Mn	2
Si	1
P	0.05
S	0.03
Cr	19
Ni	9
Fe	68.84

Two types of tool inserts are used: TTS and TTR. Both are uncoated carbide tools only, but they differ in their composition and their application towards certain workpiece materials. Flank wear after each experiments was measured using Tool maker's microscope whose model number is MET2-1395A with magnification of 150X and having least count 0.01mm. Surface roughness was measured using Tally Surf model SJ-201. The surface roughness Ra (in micro inch) was considered for the experiment.

Experiments were carried out in dry condition using CNC machine. Three speeds and three feed rates were used as the cutting conditions keeping the depth of cut constant. Total 90 mm of experimental length on the workpiece was divided into three passes of 30 mm each. The surface roughness was measured in three points on each passes and the average of three measurement was considered as the surface roughness of that pass. The flank wear was measured after the each pass. The experiment was carried out till the tool shows the flank wear of 0.3 mm [8]. The experimentation condition is shown in the Table 2.

Table 2: Machining conditions for CNC turning

Condition	Cutting parameters		
	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
Low	125	0.1	0.8
Medium	175	0.2	0.8
High	225	0.3	0.8

Optimization Technique

Optimizing the cutting conditions has become a field of interest in recent years, with the arrival of several soft tool techniques, which reduced the trial and error methods, wastage of materials and more importantly they are time saving techniques. In this study, we tried to optimize the cutting conditions using Response Surface Methodology (RSM) using Minitab 17.0.

Response Surface Methodology (RSM) is a combination of mathematical theory and statistical techniques and useful for modeling and analyzing problems in which a response of the output is influenced by several parameters and the objective is to optimize this response. RSM was introduced by Box and Wilson in 1951 and later it was popularized by Montgomery. As per the introducer of the idea, response surface methodology can be defined as an empirical statistical technique employed for multiple regression analysis by using quantitative data obtained from properly designed experiments to solve multivariate equations simultaneously [9].

The graphical representations of these equations are called response surfaces, which can be used to describe the individual and cumulative effect of the test variables on the response and to determine the mutual interactions between the test variables and their subsequent effect on the response. Design Of Experiments (DOE) techniques are employed before, during, and after the regression analysis to evaluate the accuracy of the model.

In this work, the response output for the given input data has been obtained in the form of regression equations (by RSM) using MINITAB 17.0.

It is possible to obtain the output response in the form of equations for the given input data in these forms: Full quadratic, linear, linear+interactions and square+linear. In this work, among these forms, Full quadratic form has produced a good response against input data. The correctness of the equation can be determined by R^2 value. Higher the R^2 value, greater is the prediction of the response.

Results and Discussion

The experiments were conducted in dry condition with three speeds, three feeds and a constant depth of cut.

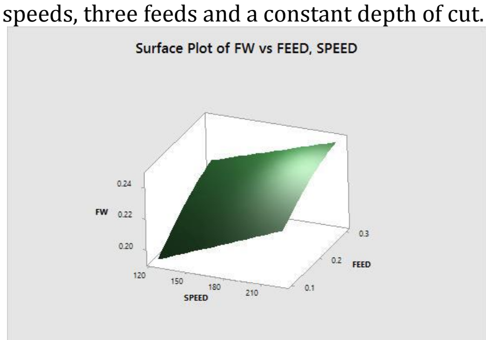

Figure 1: Flank Wear variation for TTR

The behavior of flank wear and surface roughness against the cutting conditions for both TTS and TTR tool inserts are shown below in the form of surface plots.

Figure 1 shows the Flank wear variation for TTR tool insert. It can be seen that flank wear was increasing with increase in feed rate. As per the graph, flank wear is minimum at minimum speed and feed rate.

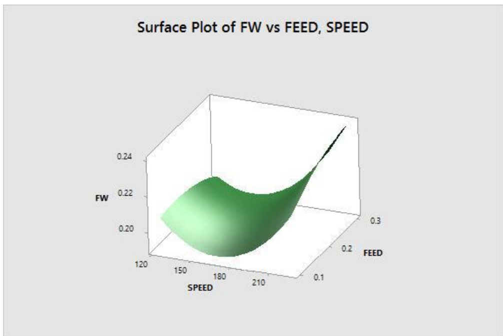

Figure 2: Flank Wear variation for TTS

Figure 2 shows the Flank wear variation for TTR tool insert. It can be seen that flank wear was increasing with increase in feed rate. Also, flank wear is minimum at medium speed and minimum feed rate.

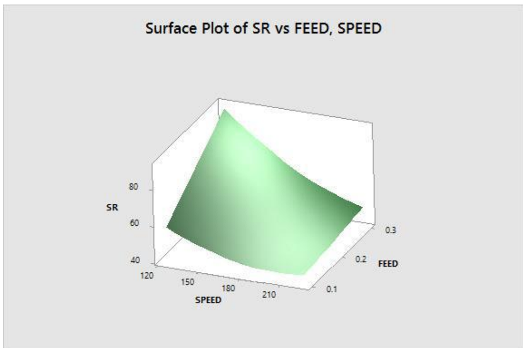

Figure 3: Surface Roughness variation for TTR

It can be seen from Figure 3, the surface roughness showed a decreasing tendency with an increase in cutting speed and decrease in feed rate of TTR tool insert. Surface roughness is minimum when the speed is at maximum and when the feed rate is minimum.

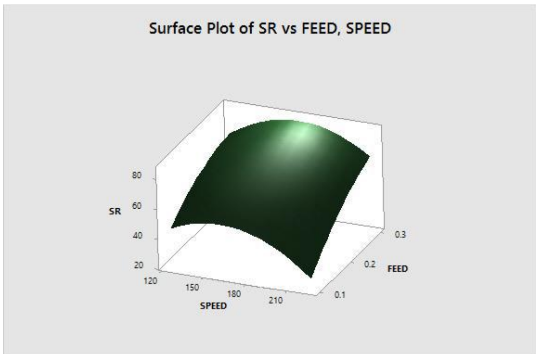

Figure 4: Surface Roughness variation for TTS

From the Figure 4, it can be seen that the surface roughness showed a decreasing tendency with an increase in cutting speed and decrease in feed rate of TTS tool insert. Surface roughness is minimum for the maximum speed and for minimum feed rate.

Optimization

In modern day technology, it is very essential to optimize the process parameters to reach the higher efficiency or a greater success rate. In this study, an attempt has been done to minimize both surface roughness and flank wear by performing multi-objective optimization of cutting parameters using RSM.

The RSM optimization has been carried out using MINITAB 17.0. The regression model with high R^2 value has been considered for carrying out the RSM optimization. It has been observed that the full quadratic model gives the higher R^2 value for the given input and the output variables.

The RSM optimization has been carried out for both the tool inserts data. The plot obtained for RSM optimization for TTR and TTS are shown in Figure 5(a) and 5(b).

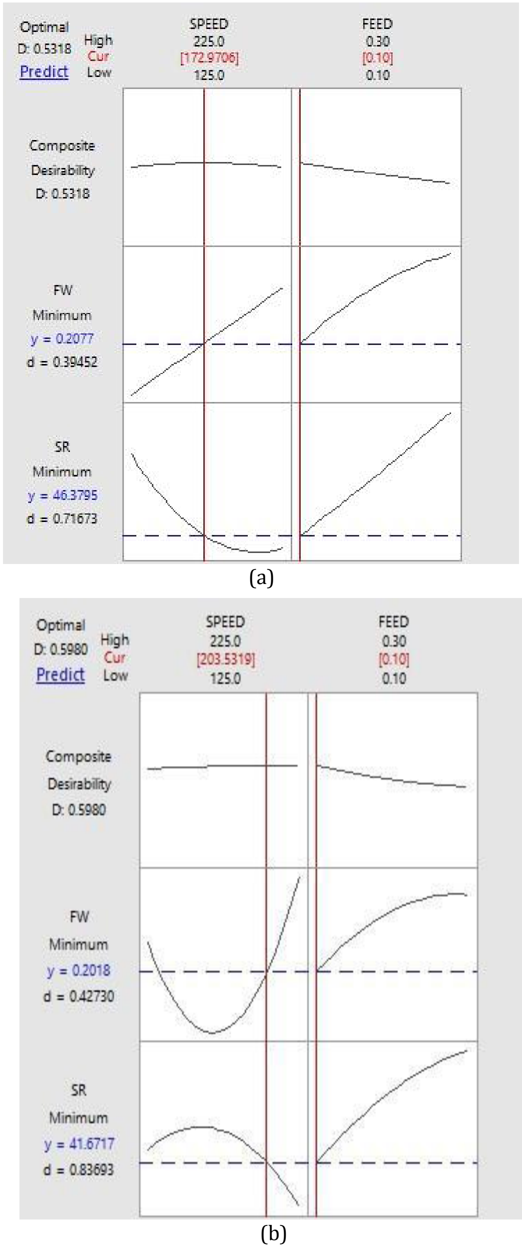

Figure 5: RSM optimization for a) TTR, b) TTS

The RSM optimization was carried out with an intension of minimizing the flank wear and surface roughness together. The optimized cutting conditions (speed and feed) for minimum flank wear and surface roughness has been listed in the Table 3.

Table 3: Result of RSM optimization

Tool inserts	Minimum values		Optimized condition	
	Flank wear (mm)	Surface roughness (μinch)	Cutting speed (m/min)	Feed rate (mm/rev)
TTR	0.2077	46.3795	172.9706	0.1
TTS	0.2018	41.6717	203.5319	0.1

The optimization was carried through RSM optimization, in MINITAB 17.0. But to check its credentials, it is necessary to perform a validation experiment. Since the turning has been done using a CNC machine, the exact values of cutting conditions with decimal points can be set. The Table 4 shows the values of validation experiment for the optimized cutting conditions.

Table 4: Result of validation experiment

Tool inserts	Cutting conditions		Measured values	
	Cutting speed (m/min)	Feed rate (mm/rev)	Flank wear (mm)	Surface roughness (μinch)
TTR	172.9	0.1	0.18	69.88
TTS	203.5	0.1	0.21	54.92

The percentage error is calculated between the values through RSM optimization and the values from validation experiment and is shown in Table 5.

Table 5: Comparison of optimized and validated values

Parameters	Tool inserts	RSM optimized values	Measured values	% error
Flank wear (mm)	TTR	0.2077	0.18	13.33
	TTS	0.2018	0.21	4.1
Surface roughness (μinch)	TTR	46.3795	69.88	50.67
	TTS	41.6717	54.92	31.8

It can be seen that the percentage error between RSM optimized value and the values from validation experiments, is little high. The reason behind this may be, both flank wear and surface roughness are uncontrollable factors. Also, the surface roughness depends on whether machining is done near the chuck end or at the free end. It is seen that, for the same cutting condition, values differ based on the region of machining.

Conclusions

In this study, the turning of AISI 304 stainless steel was done in dry condition in CNC machine. Here two types of uncoated carbide inserts were used namely TTS and TTR. The experiments were done using three speeds, three feed rates and a constant depth of cut. Further, an objective was set to minimize both surface roughness and flank wear using RSM optimization. The following conclusions were noted from the study.

1. The behavior of flank wear and surface roughness were plotted against different cutting conditions.
2. For both the tool inserts, flank wear was increasing with increase in feed rate. Hence flank wear is influenced by feed rate followed by cutting speed.
3. It is also observed that, the surface finish becomes good for higher speeds and lower feed rate.
4. Through experimentation data, it is observed that wear rate of TTS is little less than TTR. Hence, TTS can withstand more number of passes.
5. The percentage error between RSM optimization technique and validation experiment was little higher than expected, since both surface roughness and flank wear are uncontrollable factors.
6. RSM optimization showed constant optimized values for repeated number of trials.

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