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Examining the Cutting Forces in Turning of AISI 316 Steel using Taguchi Approach

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Abstract

AISI 316 stainless steel is frequently turned in manufacturing because of its mechanical qualities, strength, and resistance to corrosion. AISI 316 stainless steel's high work-hardening tendency and low thermal conductivity make machining challenging and lead to higher cutting forces, tool wear, and machining performance. Improving the machining parameters to increase turning efficiency Taguchi optimization is used to study how machining parameters affect the cutting force of AISI 316 stainless steel turning. The experiments were chosen based on the depth of cut, feed rate, and cutting speed. The Taguchi L9 orthogonal arrays reduce the number of experimental trials and improve the analysis for three levels per parameter. A dynamometer was used in turning experiments to measure cutting forces under carefully regulated machining conditions.

Keywords: Turning, Cutting force, Stainless Steel, Cutting tool, Wear

1. Introduction

Machining operations are widely used in modern manufacturing industries for the production of components with high dimensional accuracy, better surface quality and increased productivity. Turning is one of the most common traditional machining techniques in manufacturing of cylindrical components in automotive, aerospace, marine, biomedical and chemical industries. The efficiency and quality of the turning process greatly depend on machining parameters like cutting speed, feed rate and depth of cut. These parameters directly affect the significant machining responses including cutting force, surface roughness, tool wear, heat generation and power consumption. Cutting force is an important factor among them, which greatly affects machining stability, energy consumption, tool life, dimensional accuracy and overall machining efficiency [1]–[3]. AISI 316 stainless steel is one of the most common austenitic stainless steel that is used in many industries because of its excellent corrosion resistance, high strength, good toughness and weldability. These properties make AISI 316 stainless steel a material of choice in the marine equipment, biomedical implants, food processing machinery, heat exchangers and chemical processing industries [4], [5]. However, machining of AISI 316 stainless steel is difficult due to its high work hardening tendency, poor thermal conductivity and high ductility which results in excessive heat generation, rapid tool wear, built-up edge formation and increased cutting forces [6], [7]. The machining behavior of stainless steels has been studied by many researchers under different cutting conditions. The feed rate had a significant impact on both the machining performance and the surface quality of stainless steel materials, according to Davim and Figueira [8]. Korkut and Donertas [9] found that the cutting force was decreased with an increase of cutting speed due to thermal softening of workpiece material. Nalbant et al [10] applied Taguchi method to optimize the machining parameters and showed that statistical techniques can reduce the experimental effort considerably and provide reliable process optimization simultaneously. Gupta et al.

[11] investigated the machinability of stainless steel and reported similar results by Mia and Dhar [12] who pointed out the importance of optimizing cutting parameters for enhancing machinability and lowering machining costs. The Taguchi optimization technique is commonly employed in machining research because of its ease of use, systematic approach and minimizes the number of experiments with accuracy [13]. The method is based on analysis of orthogonal arrays and signal to noise (S/N) ratio and chooses the best set of process parameters [14]. ANOVA (analysis of variance) is utilized to determine the significance and percentage contribution of each machining parameter on the response variable [15]. In recent years, the Taguchi methods have been widely used in turning operations of difficult-to-machine materials. Dhabale et al. [16] studied the optimization of cutting force in stainless steel turning and mentioned that the feed rate was an important factor in generation of cutting force. In addition, Suresh et al. [17] reported that the depth of cut and feed rate are the most important factors affecting machining responses in turning operations. Also, the studies of Asiltürk and Akkuş [18], Sharma et al. [19], and Kaladhar et al. [20] have indicated that optimization of the machining parameters leads to much higher machining efficiency, lower tool wear and better process stability. Although many studies have been performed on machining of stainless steels, optimization of cutting forces in turning of AISI 316 stainless steel by using Taguchi L9 orthogonal array has not been given much attention. So the aim of this work is to study the effect of cutting velocity, depth of cut on & feed on cutting force during turning of AISI 316 stainless steel. The experiments were carried out with the Taguchi L9 orthogonal array and the cutting forces were measured by a dynamometer.

2. Materials and Methodology

The material chosen for the current investigation was AISI 316 Stainless Steel, which is extensively employed in engineering applications due to its exceptional corrosion resistance, high strength, and superior toughness. AISI 316 stainless steel is employed in the food-processing industry, heat exchangers, biomedical implants, chemical processing equipment, and marine components. Nevertheless, the material is exceedingly challenging to machine as a result of its low thermal conductivity and high work-hardening tendency, which result in elevated cutting forces and rapid tool wear during machining operations. The work piece specimens were prepared in the shape of cylindrical bars that were suitable for the turning experiments. The chemical composition and mechanical properties of the AISI 316 stainless steel were selected in accordance with standard industrial specifications. To ensure that the machining conditions in all experiments were consistent, the surfaces of the workpieces were meticulously cleaned to eliminate rust, dust, and other contaminants prior to machining.

2.1 Experimental Setup

Turning experiments were carried out on conventional center lathe machine under controlled machining conditions. To reduce vibration during the machining process the work piece was securely fastened to the chuck of the lathe machine. The turning was completed using a single-point cutting tool with a carbide insert. The tool geometry and tool holder specifications were decided by using the standard machining practices for stainless steel machining. The dynamometer was mounted on the tool post of the lathe machine to measure the cutting force generated during the turning operation. A data acquisition system was mounted on the dynamometer to ensure that the cutting forces were accurately recorded in each experiment. Machining setup was carefully aligned before the experiments to avoid measurement errors and to ensure the reproducibility of results.

Table 1. Input parameters and their respective levels.

Factors/Levels	1	2	3
Speed (rpm)	200	400	600
Feed (mm/rev)	0.03	0.06	0.09
DOC(mm)	0.1	0.2	0.3

2.2 Machining parameter selection

In the present study three important parameters of machining were taken as input variables i.e. cutting speed, feed rate and depth of cut. These parameters were chosen because they have a great influence on the cutting force and the overall machining performance in turning operations. The three levels of the machining parameters were considered. Table 1 provides the selected machining parameters and their respective levels.

2.3 Taguchi Methodology for experiment design

The experimental design was developed based on Taguchi optimization method. The experiments were conducted using the L9 orthogonal array which reduces the number of experimental trials and provides reliable statistical analysis. The L9 orthogonal array was found to be suitable for the present investigation because three machining parameters were considered at three levels. The Taguchi method is a well-known approach in the machining research for the optimization of the process parameters. Because of reducing the experimental effort, time and cost, and systematically analyzing the machining performance.

3. Results and Discussions

3.1 Machining Parameters effect on response parameter

The DOC was found to have the significant influence on the cutting force among all machining parameters. With rise in DOC from 0.1 mm to 0.3 mm, cutting force enhanced sharply as shown in Table 2. This behavior was caused by the fact that the larger the depth of cut, more is the cross-sectional area of the material to be removed in the machining process, and consequently, the higher the resistance at the tool-workpiece interface.

Cutting force was influenced less by cutting speed than feed rate and depth of cut. It is observed that the cutting force has decreased slightly with increase in cutting speed from 200 rpm to 600 rpm. The reduction could be as a result of the thermal softening of workpiece material at higher cutting temperature generated during machining.

At higher feed levels, the interaction between the cutting tool and workpiece became more severe, resulting in higher cutting resistance and force generation. However, the effect of feed rate was comparatively lower than that of depth of cut.

Table 2. Experimental Design Using Taguchi L9 Orthogonal Array

Experiment No.	**Speed (rpm)**	**Feed (mm/rev)**	**DOC (mm)**	**Cutting Force (N)**
1	200	0.03	0.1	82.4
2	200	0.06	0.2	142.8
3	200	0.09	0.3	228.5
4	400	0.03	0.2	136.4
5	400	0.06	0.3	219.7
6	400	0.09	0.1	104.6
7	600	0.03	0.3	208.2
8	600	0.06	0.1	91.8
9	600	0.09	0.2	158.9

The results obtained in the present study clearly show that the cutting force during turning of AISI 316 stainless steel is significantly affected by the machining parameters. The increase in cutting force with increasing feed rate and depth of cut is mainly due to larger cross-section of chip and greater deformation resistance offered by the work piece material. Generally speaking, stainless steel materials have high toughness and work-hardening properties which lead to increased cutting resistance during machining.

4. **Conclusions**

- The Taguchi L9 method successfully analyzed the effect of input parameters on cutting force while turning of AISI 316 Stainless Steel.
- The most significant effect on cutting force is depth of cut followed by feed rate while the cutting speed has the least effect.
- Higher material removal and cutting resistance caused the cutting force to increase with the increase of feed rate and depth of cut. Higher cutting speed slightly reduced cutting force due to thermal softening.
- The optimum machining condition for minimum cutting force is at 200 rpm cutting speed,

0.03 mm/rev feed rate & 0.1 mm DOC.

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