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Analysis of Cutting Parameters Impact on Forces during AISI 304 Stainless Steel Turning

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Abstract: ***In this study, the effect of cutting parameters such as cutting speed, feed rate, and depth of cut on cutting forces during the machining of AISI 304 stainless steel were investigated. Using CVD coated carbide tools on a CNC lathe, the experiments were conducted without coolant, and forces were measured with a Kistler dynamometer. The relationship between cutting parameters and forces was modeled using Response Surface Methodology, revealing significant impacts of cutting speed and feed rate on the main cutting force.***

Keywords: Cutting Force, AISI 304, Stainless Steel, Machining, Mathematical Modeling

1. Introduction

Stainless steels are widely used around the world due to their excellent material properties, such as non - magnetic characteristics, high corrosion resistance, high strength, and high ductility. This research is significant as it contributes to the optimization of machining processes for AISI 304 stainless steel, a material widely used in critical applications due to its corrosion resistance and durability. In recent years, stainless steels have been employed in parts of semiconductor manufacturing equipment and food processing machinery, where contamination must be prevented and high hygiene is required. (1) However, challenges are encountered in the machining of stainless steels. The Cr - Ni alloys in their chemical composition adversely affect their machinability. The physical and mechanical properties of stainless steels vary with the chemical composition of alloying elements. Moreover, while chromium content contributes to corrosion resistance by forming a protective oxide film, nickel content improves usage in harsher environmental conditions with a stabilized austenitic structure. (2) During machining of stainless steel alloys, severe work hardening occurs, which increases cutting resistance during the processing. Work hardening is considered a significant cause of poor surface quality and tool wear in austenitic stainless steels. (4, 5) Additionally, due to their high ductility and low thermal conductivity, stainless steels are among the materials that are difficult to cut, leading to easy damage to cutting tools (rapid tool wear and chip formation). (3)

Using cutting fluids can reduce the effect of temperature on the tool in the cutting zone. Additionally, due to their lubricating effect, cutting fluids can lower the coefficient of friction, thereby reducing cutting forces. Furthermore, the removal of chips from the cutting zone enhances tool life and processing characteristics. However, in recent years, machinability studies of AISI 304 steel have been conducted under dry, wet, and Minimum Quantity Lubrication (MQL) conditions. Additionally, fundamental cutting parameters and processing technologies play a dramatic role in production outcomes. (6, 7)

2. Materials and Methods

2.1. Material Properties Used in the Experimental Study

In the experiments, AISI 304 austenitic stainless steel was used as the workpiece material. The quality certification for the AISI 304 material used in the tests was obtained from Valbruna S. P. A. The chemical composition of the AISI 304 stainless steel is provided in Table 1. (8)

Table 1: The chemical composition of AISI 304 stainless steel

AISI	C %	Si %	Mn %	Cr %	Mo %	Cu %	Ni %	Co %	P %	S %	N %
304	0, 017	0, 54	1, 78	18, 40	0, 48	0, 46	8, 14	0, 100	0, 029	0, 029	0, 086

2.2 Cutting Tool Used in the Experiments

In the experiments, a WNMG 080408 cutting insert and an MWLNL 2525 M08 tool holder were used. The cutting insert is CVD - coated, offering high wear resistance. This tool is suitable for high - speed machining of stainless steels and provides excellent wear resistance.

2.3 Lathe Machine and Measurement Instruments Used

The machining experiments were conducted using a HYUNDAI - WIA L210LA lathe machine. No coolant was used during the experiments. For measuring cutting forces, a Kistler 9257B dynamometer was employed. Surface roughness measurements were taken using a Mitutoyo surface roughness measuring device.

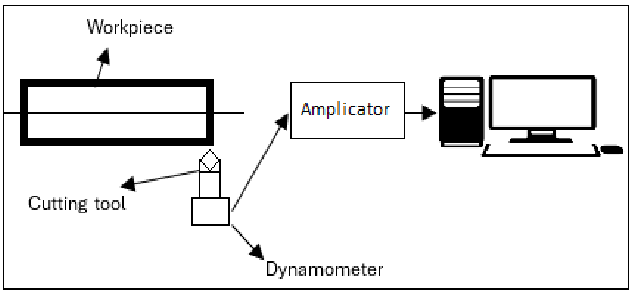

Figure 1: Schematic Diagram of the Experimental Setup

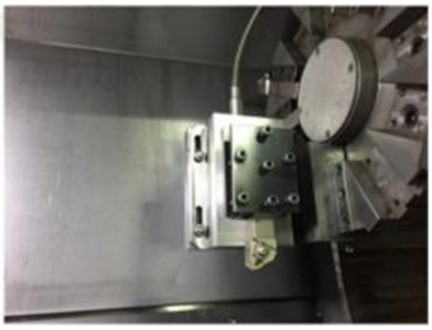

Figure 2: Connection of the Dynamometer to the CNC Lathe Machine

2.4 Experimental Plan

The experimental design is based on a full factorial design. In the full factorial design, 8 experiments were conducted for each cutting tool with different chip breaker forms, resulting in a total of 24 experiments. The cutting parameters used in the experiments were set to include two different cutting speeds, two different feed rates, and two different depths of cut (see Table 2). The three cutting forces measured during the machining process were the main cutting force (F_c), feed force (F_f), and radial force (F_r), which were recorded using a dynamometer. This dynamometer was connected to a signal amplifier (Kistler Model 9257B), and the cutting force signals were transmitted to a computer via an RS - 232C patch cable for analysis using the Dynoware software. The main cutting force (F_c), feed force (F_f), and radial force (F_r) were determined from the obtained force graphs. Surface roughness was measured after the machining experiments using a Mitutoyo surface roughness measuring device, and the values were recorded.

Table 2: Cutting Parameters Used in the Experiments

Cutting Speed v (m/dak)	Feed f (mm/dev)	Dept of cut a (mm)
100	0, 1	1
200	0, 3	2

Table 3: Experimental Plan

No	V (m/dk)	f (mm/rev)	a (mm)
1	100	0, 1	1
2	200	0, 1	1
3	100	0, 3	1
4	200	0, 3	1
5	200	0, 3	2
6	100	0, 3	2
7	200	0, 1	2
8	100	0, 1	2

3. Experimental Results

The main cutting force values obtained from the experiments, for different cutting parameters (cutting speed, feed rate, depth of cut), are provided in Table 4.

Table 4: Main Cutting Forces

No	Cutting Force (Fc, N)	Cutting Speed V (m/min)	Feed f (mm/rev)	Dept of cut a (mm)
1	535, 8	100	0, 1	1
2	457, 7	200	0, 1	1
3	782, 4	100	0, 3	1
4	664	200	0, 3	1
5	1893	200	0, 3	2
6	2337	100	0, 3	2
7	1184	200	0, 1	2
8	1431	100	0, 1	2

4. Regression and Variance Analysis and Evaluation

Regression analysis was employed to represent the cutting force and surface roughness values obtained from the experiments in terms of mathematical equations. The Minitab software was used to perform the regression analysis, and the effects of cutting speed, feed rate, and depth of cut on the experimental measurements were analyzed.
The regression model and analysis results for the main cutting force (Fc) are as follows.

Table 5: Results for the Main Cutting Force (F_c)

Regression Analysis: Fc versus v; f; a

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	6681240	2227080	69,89	0,000
v	1	278430	278430	8,74	0,008
f	1	920456	920456	28,89	0,000
a	1	5482354	5482354	172,06	0,000
Error	20	637274	31864		
Lack-of-Fit	4	422771	105693	7,88	0,001
Pure Error	16	214503	13406		
Total	23	7318514			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
178,504	91,29%	89,99%	87,46%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-372	175	-2,13	0,046	
v	-2,154	0,729	-2,96	0,008	1,00
f	1958	364	5,37	0,000	1,00
a	955,9	72,9	13,12	0,000	1,00

Regression Equation

Fc = -372 - 2,154 v + 1958 f + 955,9 a

Fits and Diagnostics for Unusual Observations

Obs	Fc	Fit	Resid	Std Resid	
6	2337,0	1911,6	425,4	2,61	R

R Large residual

Variance analysis was conducted at a 5% significance level and a 95% confidence level. The effects of cutting parameters on the main cutting force values are detailed in the ANOVA table provided in Table 13.1.

The analysis indicates that the most significant factors affecting the cutting force values are the depth of cut and the feed rate. For both factors (depth of cut and feed rate), the p - value is 0.000, which is less than 0.05, confirming their statistical significance.

When comparing other values obtained from the variance analysis, it is observed that the depth of cut is the most influential factor on the cutting forces. The feed rate is the next most significant factor after the depth of cut.

5. Conclusion

The study successfully demonstrated that cutting parameters, particularly depth of cut and feed rate, have a significant impact on the cutting forces during the machining of AISI 304 stainless steel. These findings offer valuable insights for optimizing machining processes, leading to improved tool life, enhanced surface quality, and increased overall efficiency in industrial applications where this material is prevalent. By understanding and controlling these parameters, manufacturers can reduce costs and improve the quality of their products, making this research directly applicable to the practical challenges faced in the machining of stainless steel.

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