The Effect of Tool Rake Angle Variations On Cutting Force And Cutting Temperaturein The Turning Process of Medium Carbon Steel (S45C)

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Abstract.
The turning process is one of the most widely used machining processes in the manufacturing industry to produce cylindrical components with good dimensional accuracy and surface quality. During the turning process, the interaction between the cutting tool and the workpiece generates cutting forces and cutting temperatures, which significantly affect tool life, machining quality, and process efficiency. One of the important factors influencing cutting force and cutting temperature is the tool rake angle. This study aims to analyze the effect of tool rake angle variation on cutting force and cutting temperature in the turning process of medium carbon steel (S45C). The research was conducted experimentally using a conventional lathe machine and a High Speed Steel (HSS) cutting tool. The rake angle variations used in this study were 0°, 12°, and 22°, while other machining parameters were kept constant. Cutting temperature was measured using an infrared thermometer, whereas cutting force was determined based on machining parameters. The experimental data were analyzed using descriptive statistical methods to identify trends in the effect of rake angle variation on cutting.

Keywords*: Turning, tool rake angle, cutting force, cutting temperature and medium carbon steel (S45C).*

I. INTRODUCTION

Machining is a critical stage in the manufacturing industry aimed at producing components with dimensions, shapes, and surface qualities conforming to specifications. One of the most widely utilized machining methods is turning, which involves material removal by rotating the workpiece and feeding a relative cutting tool.

In the turning process, the cutting tool plays a vital role as it directly interacts with the workpiece. High Speed Steel (HSS) tools are commonly used due to their good toughness, ease of reshaping, and relative economy. However, HSS tool performance is heavily influenced by tool geometry, particularly the rake angle.

The interaction between the tool and workpiece generates cutting forces and cutting temperatures. Cutting forces arise due to material resistance against plastic deformation, while cutting temperatures result from the conversion of mechanical energy into thermal energy caused by deformation and friction. Both parameters affect tool life, surface quality, and machining efficiency. Adjusting the rake angle affects chip formation mechanisms and the friction level at the tool-chip contact interface. In general, a positive rake angle can facilitate chip flow, lower cutting forces, and suppress cutting temperatures.

Medium carbon steel (S45C) was selected as the testing material because it is widely applied in manufacturing for machine components such as shafts and gears that require a combination of strength, toughness, and machinability. This study aims to analyze thoroughly the simultaneous effect of tool rake angle variations (0°, 12°, and 22°) on cutting force and cutting temperature during the turning of S45C steel to identify the optimal operational condition.

II. RESEARCH METHODOLOGY

2.1. Tools and Materials

The equipment utilized in this study includes:

- Krisbow Conventional Lathe Type C6240A.
- HSS (High Speed Steel) Turning Tool of size ½ × ½ × 4 inches.

- Bench Grinder (KW07-75) for sharpening tool angles.
- Infrared Thermometer for measuring cutting zone temperature.
- Vernier Caliper (0.02 mm precision).

The main material used was an AISI 1045 / S45C medium carbon steel shaft with a diameter of 25 mm and a total length of 200 mm (effective cutting length of 150 mm).

2.2. Cutting Parameters and Research Variables

The independent variable in this study was the variation of the tool rake angle at 0°, 12°, and 22°. Cutting parameters were maintained constant during testing:

- Spindle rotational speed (n) = 755 rpm
- Cutting speed (Vc) = 59.27 m/min
- Feed rate (f) = 0.2 mm/rev
- Depth of cut (a) = 0.4 mm
- Cutting length (L) = 50 mm per test cycle.

2.3. Testing Procedure and Data Collection

1. Tool Preparation: HSS tools were ground using a bench grinder to precisely form rake angles of 0°, 12°, and 22°, while other clearance angles were kept constant.
2. Turning Operation: The S45C steel specimen was clamped in the lathe chuck. Longitudinal turning was performed with 3 replications for each rake angle variation.
3. Cutting Temperature Measurement: Cutting temperatures were measured in real-time at the tool-workpiece contact area using an infrared thermometer during the cutting process.
4. Cutting Force Calculation: The main cutting force (Fc) was calculated theoretically based on material specific cutting force empirical approaches (Cutting cross-sectional area: $A = f \times a$; Specific cutting force: $kc = (kc1 / h^m) \times$ Correction Factor; Main cutting force: $Fc = A \times kc$).
5. Data Analysis: Experimental data were processed using descriptive statistical analysis including Mean, Standard Deviation (Std Dev), Coefficient of Variation (CV), and Range.

III. RESULTS AND DISCUSSION

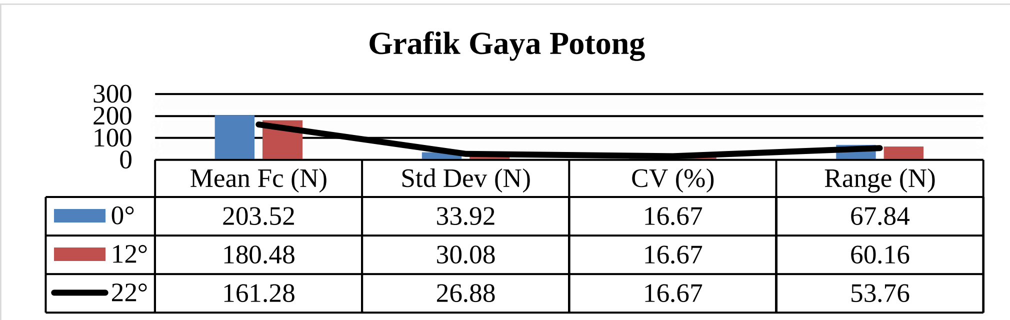
3.1. Effect of Tool Rake Angle on Cutting Force

Experimental results and descriptive statistical data processing for the main cutting force (Fc) are presented in Table 1 below.

Table 1. Descriptive Statistical Analysis Results of Main Cutting Force (Fc)

Rake Angle (°)	Sample Size (n)	Mean Fc (N)	Std Dev (N)	CV (%)	Range (N)
0°	3	203.52	33.92	16.67	67.84
12°	3	180.48	30.08	16.67	60.16
22°	3	161.28	26.88	16.67	53.76

Based on Table 1, there is a clear negative correlation between the tool rake angle and the main cutting force. At a 0° rake angle, the average cutting force reached its highest value at 203.52 N. When the angle was increased to 12°, the cutting force decreased by 11.32% to 180.48 N. The reduction continued up to 22°, where the cutting force reached its lowest value at 161.28 N (a 20.75% decrease compared to the 0° angle).



This phenomenon of cutting force reduction aligns with Merchant's chip formation mechanics theory. A more positive rake angle (22°) forms a sharper cutting wedge, thereby increasing the shear angle in the primary cutting zone. This increase in shear angle reduces the shear plane area, directly resulting in lower mechanical power and force required to deform the S45C steel material. Furthermore, the decreasing standard deviation and range values at 22° indicate a more stable cutting process.

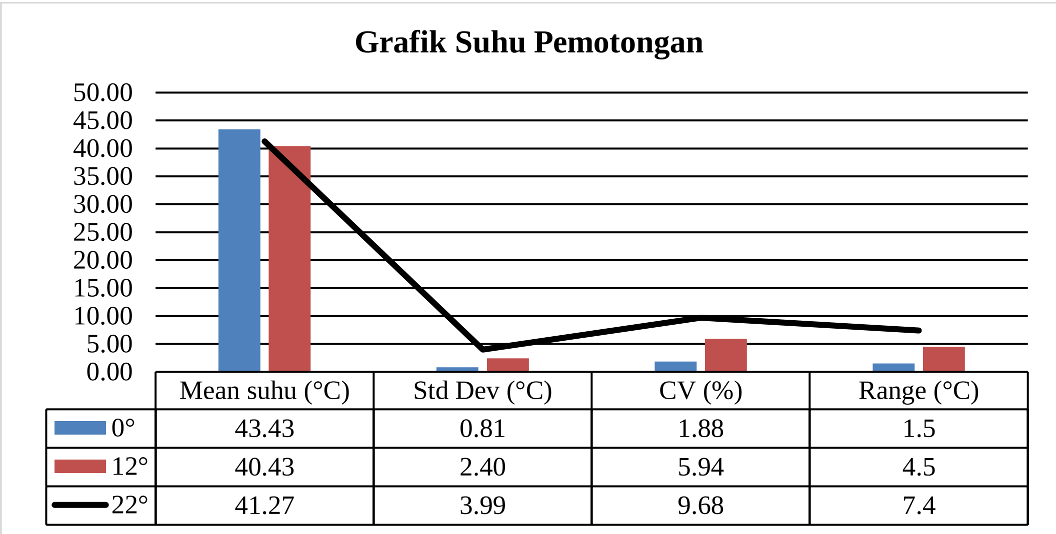
3.2. Effect of Tool Rake Angle on Cutting Temperature

The measurement results and descriptive statistical data processing for cutting temperature are presented in Table 2.

Table 2. Descriptive Statistical Analysis Results of Cutting Temperature

Rake Angle (°)	Sample Size (n)	Mean Temperature (°C)	Std Dev (°C)	CV (%)	Range (°C)
0°	3	43.43	0.81	1.88	1.50
12°	3	40.43	2.40	5.94	4.50
22°	3	41.27	3.99	9.68	7.40

Based on Table 2, the highest cutting temperature was recorded at 0° with an average of 43.43 °C. At a 12° rake angle, the cutting temperature decreased to reach its lowest value of 40.43 °C (a 6.91% reduction). However, when the rake angle was further increased to 22°, the cutting temperature experienced a slight increase to 41.27 °C.



The temperature drop from 0° to 12° occurs because a positive rake angle facilitates smoother chip flow and reduces friction between the chip and the tool rake face. Nevertheless, the temperature rise at 22° indicates the critical limit of the tool wedge cross-section. An excessively sharp grinding angle (22°) reduces the mass volume at the tip of the HSS tool, thereby diminishing the heat conduction/dissipation capacity of the tool material and lowering the structural rigidity of the tool tip, which triggers micro-vibrations during cutting.

3.3. Safe Limits and Optimal Rake Angle

Overall, comprehensive analysis of mechanical parameters (cutting force) and thermal parameters (cutting temperature) indicates that a 12° tool rake angle represents the most optimal cutting condition. The 12° angle successfully provides a significant reduction in cutting force while simultaneously producing the lowest cutting temperature (40.43 °C). The angle range of 12° to 20° is recommended as a safe operational limit for turning S45C steel with HSS tools to maintain cutting edge durability and energy efficiency.

IV. CONCLUSIONS

1. An increase in the tool rake angle is inversely proportional to the magnitude of the main cutting force (Fc). The highest average cutting force occurred at 0° (203.52 N) and decreased to its lowest value at 22° (161.28 N), representing a reduction of 20.75%.

2. Tool rake angle variations affect cutting temperature, where the highest temperature occurred at 0° (43.43 °C), decreased at 12° (40.43 °C), and slightly increased again at 22° (41.27 °C).
3. A 12° tool rake angle is the most optimal parameter in turning medium carbon steel (S45C) using an HSS tool, as it provides the best equilibrium point between cutting force reduction and thermal dissipation efficiency.

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