OPTIMISING CUTTING PARAMETERS OF AISI H13 TO REDUCE TOOL WEAR AND SURFACE ROUGHNESS IN THE LATHE CNC MACHINING PROCESS

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ABSTRACT: This study evaluates tool wear and surface roughness (Ra) using carbide cutting tools at various cutting speeds (Vc), feed rates (Fr), and a high constant cutting depth of 1 mm on AISI H13 using a computer numerically controlled (CNC) lathe. When the machining parameters are not matched correctly, the machining performance decreases, increasing tool wear and Ra. This study aims to obtain the most suitable machine parameters for machining AISI H13. In addition, the study reveals the wear mechanism of the cutting tool effect for various machining parameters. The experiments were conducted at 100–200 m/min Vc, a 0.05–0.10 mm/rev Fr, and a constant cut depth of 1 mm (hard turning). The results show that 170 m/min Vc at 0.05 mm/rev Fr produces the lowest flank wear than other Vc. For 0.10 mm/rev Fr, the lowest flank wear was 140 m/min Vc and increased significantly by 57% when Vc was increased to 200 m/min Vc. This cutting speed causes severe damage to the cutting tool, such as chipping, notching, built-up edge (BUE), and flaking. The result for the overall Ra shows that the combination between 0.05 mm/rev Fr and 140 m/min Vc gives the best machining parameter, 0.24 um. This study reveals the impact of machining parameters on AISI H13 and

the implications for wear characteristics and surface roughness.

KEYWORDS: *AISI H13; Cutting speed; Feed rate; Tool wear; Surface Roughness.*

1.0 INTRODUCTION

The machining process requires a cutting tool placed on a cutting tool holder in contact with the raw material or workpiece through a shear force. This machining process causes high friction between the cutting tool and the workpiece to separate the material and form the product [1,2], producing fragments and a surface finish at the end of the process. The cutting tool affects the final product, which is influenced by the machining parameters involving the Fr and Vc during the machining process. The machining parameters are important to ensure the stability and strength of lasting cutting tools [3,4]. In addition to experience, the machine operator refers to the parameter selection handbook to obtain the best machining parameters [5]. The material properties, especially the hardness and hardening characteristics of the workpiece material, also influence the machining parameters [6].

AISI H13 type raw material is a grade of tool steel widely used to make mould pins, automotive components, casting moulds, dies, and zinc. Its advantages include good toughness, abrasion resistance, and high hardness. The Rockwell hardness (HRc) of AISI H13 is 52 HRc [7]. It is suitable for a wide range of hot and cold work applications, especially hot work applications that require drastic cooling throughout their operation [8,9,10]. AISI H13 is one of the steels with good toughness and hardness and can be used optimally. This study investigates various machining parameters set on AISI H13 material using a carbide cutting tool to evaluate its capability and compare its wear performance and Ra effect.

Ra is a response to the effect of Vc and Fr, which are influenced by the finish turning. Ra is also used to evaluate the surface quality of the finished product [11,12]. Ra finish is also essential in assessing the performance capability of various machining parameters. The Ra quality is crucial to producing a product using the lathe machining process [13]. Therefore, it is essential to address all factors that affect the Ra and wear mechanisms to produce an exceptional final product. The cutting tool can cut material in ideal contact conditions. Dimensional accuracy, surface friction, resistance to stress conditions, and Ra are strongly influenced by the cutting parameters determined by the Vc, Fr, and cut depth [14]. The surface finish affects the final properties of the product, such as concentrations, fatigue resistance, thermal conductivity, light reflection, and the physical appearance of the final product [15]. Although AISI H13 is available in the industry, information on machining parameters, suitability, tool wear, wear mechanism, and Ra has not been explored well.

This study explores various machining parameters involving Vc, Fr, and a high constant cutting depth of 1 mm, which has been explored little by researchers in the machining industry. By comparing various machining parameters, this study discovers compatible parameters between Vc and Fr at low tool wear and surface roughness. In addition, this study reveals the wear mechanism and the effect of the machining parameters in detail. This study aims to assist machine operators and researchers identify the appropriate lathe CNC machining parameters for AISI H13. An important discovery is the effect of parameters that do not meet specifications on cutting tools and the final surface of AISI H13 products.

2.0 METHODOLOGY

Table 1 shows the new machining parameter that reveals the compatibility between Vc and Fr at a high constant cutting depth for AISI H13 using a CNC lathe machine brand HAAS SL 20.

Table 1: Machining parameter

Vc (m/min)	Spindle speed (rev/min)	Fr (1) (mm/rev)	Fr 2 (mm/rev)	Depth of cut (mm)
100	568.41	0.05	0.10	1
140	810.24			
170	1002.09			

200	1201.17			

The uniqueness of the new machining parameters lies in the progressive increase of Vc, combined with two distinct Fr and a constant cutting depth of 1 mm, enabling fine control over machining performance to balance surface quality and tool wear across varying operational speeds. This study used coolant or cutting fluid brand FUCH in a wet-cutting condition. The original raw material of AISI H13 is ready-made in a 50 mm cylinder bar shape, machined to 250 mm long. The Rockwell hardness (HRc) tested at the original condition is 48 HRc. Table 2 shows the chemical composition, and Table 3 shows the mechanical properties of AISI H13.

Table 2: AISI H13 chemical compositions

Chemical							
Element	C	Si	Mn	Cr	Mo	V	W
Wt%	0.51	1.26	0.413	5.5	1.52	1.0	0.02

Table 3. AISI H13 mechanical properties

Properties	
Yield tensile strength	1000-1380 MPa
Ultimate tensile strength	1200-1590 MPa
Elasticity modulus	215 GPa
Hardness	53 Hv
Thermal conductivity (k)	28.8 (w/m.k)

The cutting tool typically used for machining is a Sandvik Coromant-type carbide cutting tool TNMG 160404-MB. The cutting tool specification was Relief angle = 7°, Rake angle 8°, and Nose Radius = 0.4 mm. Figures 1(a) and (b) show the tool holder used in this study.

(a) (b)

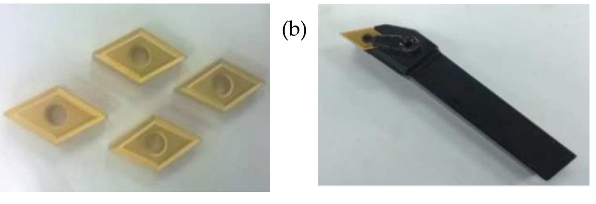


Figure 1: (a) Carbide turning tool insert and (b) tool holder

The flank wear measurement test was performed using an optical microscope, as shown in Figure 2(a), where the average flank wear (Vb) rate is 0.3mm according to the ISO 3685 standard. Measurements were made periodically according to the cutting length of the workpiece bar, and images were captured using a digital camera for each measure. Wear mechanisms were analysed using scanning electron microscopy (SEM) brand Zeiss to identify wear characters by obtaining a clearer picture to analyse, as shown in Figure 2(b).

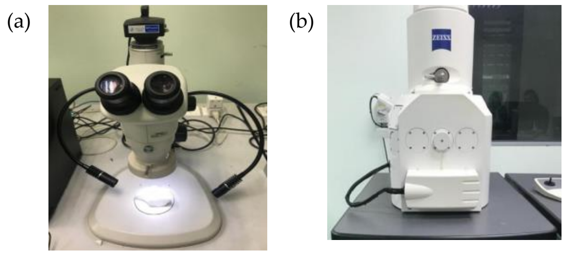


Figure 2: (a) Optical microscope and (b) SEM.

3.0 RESULTS AND DISCUSSION

3.1 Tool wear

Figure 3 compares the wear formation on carbide-cutting tools, which shows the average flank wear (Vb) vs. Vc. At 100 m/min Vc and 0.05 mm/rev, Fr recorded a tool wear of 0.17 mm, whereas 0.10 mm/rev Fr at the same Vc recorded a tool wear of 0.11 mm. When Vc increased from 140 m/min to 170 m/min with a 0.05 mm/rev Fr, tool wear decreased to 0.13 mm and 0.10 mm, respectively. However, it happens in parallel with a low Fr, producing a lower wear rate than a low Vc and Fr. Prolonged friction at high Vc increased the shear force in one place, producing wear quickly [18]. Low Fr and high Vc cause the tip of the cutting tool to rub in one place for longer than at high Fr. This condition causes rapid tool wear on the cutting tool's edges. The low Vc and Fr provided high pressure by rubbing on the tip of the cutting tool and AISI H13 in one place for a long time [19,20]. The graph shows a decreasing pattern, which is expected because a higher

Vc can cause tool wear to decrease. The tool wear increased to 27.83% at 0.10 mm/rev Fr.

The results show that the suitable machining parameter is 0.10 mm/rev Fr, 140 m/min Vc, at 1mm cutting depth. The tool wear rate increases when this specific parameter is applied to AISI H13 while increasing Vc and maintaining the same Fr [21]. This is linked to the higher thermal and mechanical loads that the tool experiences due to increased speed and consistent Fr.

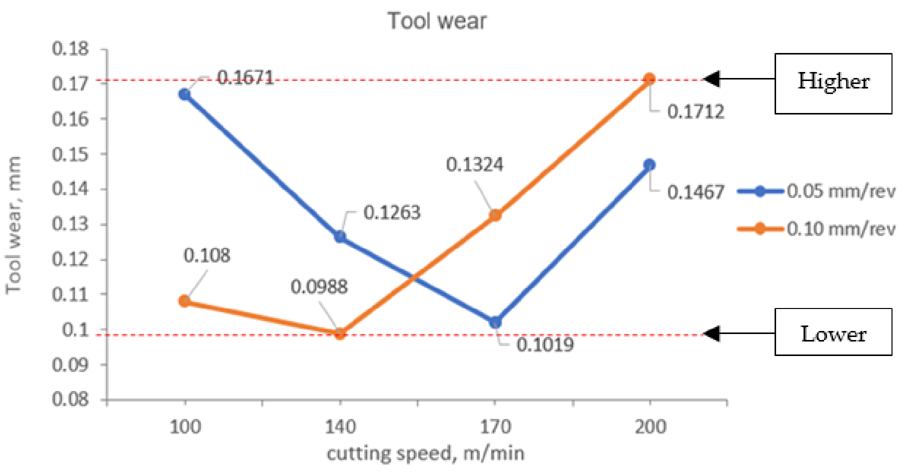
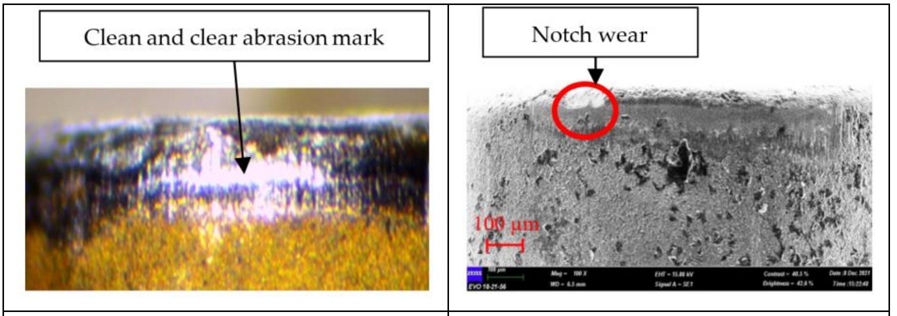


Figure 3: Cutting speed vs. flank wear

3.2 Wear mechanism

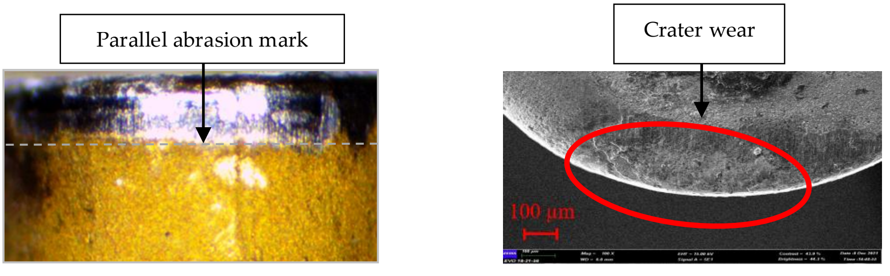
Figure 4 shows the wear mechanism when machine AISI H13 is at 100 m/min Vc and 0.05 mm/rev Fr. The abrasion marks (Figure 4 (a)) and notch wear (Figure 4 (b)) can be seen clearly at the cutting point. The notch wear is due to friction between the cutting tool and the AISI H13 that begins when a large load from a cutting tool is imposed on a rotational spindle that produces a localised V shape with severe grooves on the cutting edge [23]. This study found that low Vc and Fr resulted in cutting tool damage produced by prolonged vibration. However, the abrasion marks formed on the cutting edge also produced a clean and clear condition, reflecting the low Fr due to lower friction in the cutting zone but with little notch wear.



(a) (b)

Figure 4: Wear mechanism when a machine at 100 m/min Vc and 0.05 mm/rev Fr with (a) and (b)

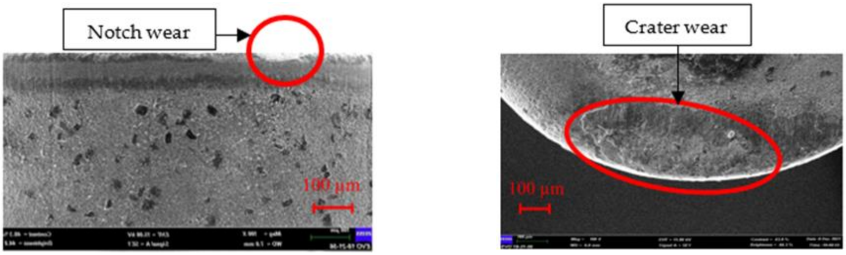
As the Fr increased to 0.10 mm/rev, the cutting tool's performance tremendously increased to 64.63%, indicating that the cutting tool could withstand higher Fr. The effect of the increased tool life can be seen in the flank wear characteristics, as shown in Figure 5. Figure 5(a) shows that the shape of flank wear is more consistent with the uniform abrasion along the cutting tool tip. Figure 5(b) shows a slight crater wear on the top view of the cutting tool, which does not affect the machining performance. Crater wear occurs due to the intense heat and pressure at the tool-chip interface during machining operations.



(a) (b)

Figure 5: Wear mechanism of (a) front view and (b) top view at 100 m/min Vc and 0.10 mm/rev Fr

Figure 6 shows a 200 m/min Vc at a 0.05 mm/rev Fr. Figure 6(a) shows a small notch at the cutting point, while Figure 6(b) shows the crater wear on the upper surface of the cutting tool. Crater wear is one of the failure modes that concerns researchers [24,25]. It also occurs because the cutting tools are too soft to withstand the temperature in intricate cutting. Increasing the hardness of the cutting tool can eliminate or reduce crater wear [26,27]. Crater wear is due to the continuous contact of the cutting tool against the AISI H13, leading to dialectic wear on the tool's rake face because of the intense heat and pressure generated during the machining process.



(a) (b)

Figure 6: Wear mechanism of (a) front view and (b) top view at 200 m/min Vc and 0.05 mm/rev Fr

Figure 7 shows the wear mechanism using a 200 m/min Vc at a 0.10 mm/rev Fr. Observations at the cutting tool's edge showed flaking and chipping. The chipping wear is due to the strong frictional force between the cutting tool and the AISI H13. Chipping wear happens when the cutting tool is heavily shocked [28]. The first contact of the cutting tool on the AISI H13 with a high Fr was also a factor in chipping wear. On hard turning, Vc and high Fr of high-strength steel can cause cracking, chipping, sticking, abrasion, oxidation, and diffusion wear on the coated cutting tool [29]. The tip of the cutting tool is prone to wear, especially chips and cracks, due to the first contact of the cutting tool and AISI H13 at high Vc and Fr, further opening the space for the molten iron to adhere to the open spaces.

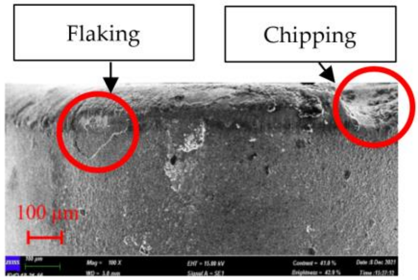


Figure 7: Wear mechanism when a machine at 200 m/min Vc and 0.10 mm/rev Fr

Figure 8 shows BUE formation at the top view of the cutting tool. BUE is a chip built into the tip of the cutting tool because the chip tends to stick to the chipping formation when the heat generated increases during the machining process [30]. The chip becomes molten during machining due to constant friction between the cutting tool and AISI H13. According to Tuan et al. [31], the coolant cannot penetrate the cutting area because the fragments of workpiece accumulate on top of the cutting tool due to high Vc and Fr. This chip interferes with the smooth flow of the coolant at the cutting zone, after which the cutting tool rubs between AISI H13. As a result, this material gradually adheres to the cutting tool as a permanent structure in the form of a bulk layer [30]. The layer formed from AISI H13 results from friction between this material and the cutting tool. The machining process produces oxide, which causes the bulky solid layer to stick [26]. Continuous friction between the rolling chips on the surface of the cutting tool and AISI H13, even with the aid of coolant, can also cause BUE formation because the coolant pressure cannot reject the chip formation completely, and the cooling jet does not penetrate right at the end of the cutting tool.

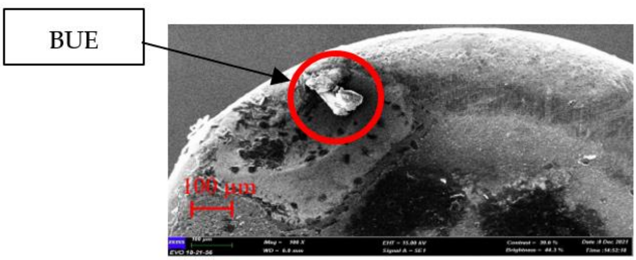


Figure 8: BUE formation on the top view of the cutting tool at the same Vc and Fr

3.3 Surface Roughness

Figure 9 shows a graph of Ra vs Vc through 0.05 and 0.10 mm/rev Fr. A Ra value of 0.524 μm was recorded at 100 m/min Vc and 0.10 mm/rev Fr. When Vc was increased to 140 m/min and 170 m/min, the Ra increased to 0.713 μm and 0.761 μm, respectively, because of the constant friction from increased Vc and high Fr that produced flank wear. Increasing Vc while maintaining the same Fr increased the roughness rate of the raw material significantly [32]. At higher Fr, transverse movement of the tool nose radius caused a more prominent feed mark on the surface. High Vc and Fr can increase the gap between peak-to-peak values and Ra [12]. However, at 200 m/min Vc, Ra slightly decreased to 0.727 μm. This phenomenon occurs because higher Vc and Ra typically result in more aggressive material removal, potentially exacerbating irregularities on the surface of the workpiece. Consequently, the amplitude of Ra peaks and valleys becomes more pronounced, accentuating the variation between the highest and lowest points on the AISI H13 surface.

The graph shows a significant reduction in the Ra value at 0.05 mm/rev Fr and various Vc compared to 0.10 mm/rev Fr. The results align with [33], where the Ra is better with a low Fr. The low Ra allows for acquiring precise dimensions and can increase the machined components' lifespan [34]. Maintaining a low Ra level in machining operations is crucial because it enables the acquisition of precise dimensions, ensuring that components meet strict tolerance and fitment requirements. Additionally, reducing surface irregularities extends the lifespan of machined components because smoother surfaces experience less wear and friction, improving durability and reliability in various applications. The findings show that a 100 m/min Vc recorded the highest Ra of 0.42 μm and decreased significantly at the lowest Ra of 0.243 μm at 140 m/min Vc.

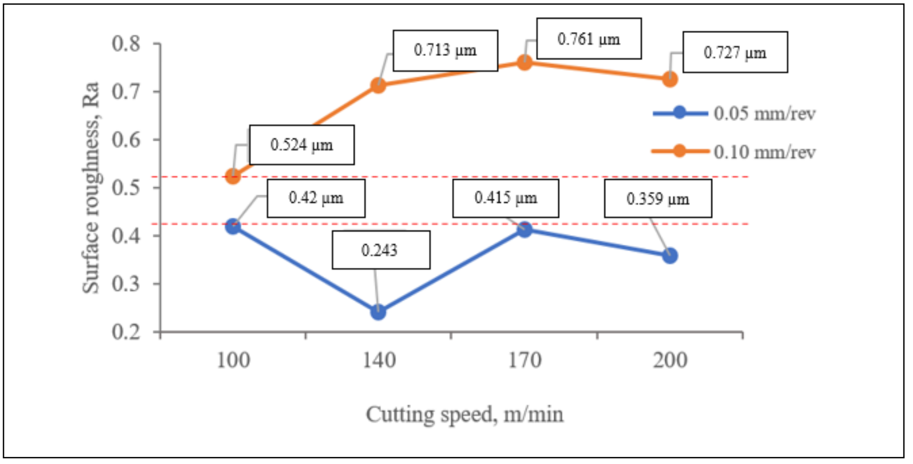


Figure 9: Ra vs Vc

4.0 CONCLUSIONS

This paper evaluates the capability of a carbide-cutting tool and the effect of various machining parameters at a constant cut depth. The wear mechanism of the cutting tool and Ra of the AISI H13 were measured and analysed to determine the suitability of the machining parameters. The conclusion is as follows:

i. The results show that 170 m/min Vc at 0.05 mm/rev Fr produced the lowest flank wear than other Vc. The lowest flank wear was recorded at 140 m/min Vc and 0.10 mm/rev Fr.
ii. Higher flank wear was recorded at a lower Vc and Fr, which was 64.63% higher than Fr of 0.10 mm/rev. The notch wear formed at the cutting point increased the flank wear. The low Vc is unsuitable for low Fr.
iii. 200 m/min Vc and 0.10 mm/rev Fr resulted in high flank wear, indicating that high Vc and Fr reduced the life span of the cutting tool.
iv. 0.05 mm/rev Fr recorded the lowest Ra at all Vc compared to 0.10 mm/rev Fr.
v. Wear formation can be seen at 200 m/min Vc because the wear mechanism was dominated by the severe chipping, adhesive, and BUE on the top view of the cutting tool.

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AUTHOR CONTRIBUTIONS

T. Norfauzi: Conceptualization, Methodology, Writing; A. Hamid: Editing, presenter; U.A.A. Azlan: Writing-Editing; M.B Ali: Writing-Editing; Darmawan: Writing-Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest on the manuscript.

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