Optimization of Cutting Speed in Steel Turning

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Abstract

Tool and workpiece are two main machining elements which have strongly influence to each other so that, many machining parameters such as; stock removal rate and tool wear ratio directly depend on this interaction. In this research, regarding to the role of machining process in cutting speed and its affection on tool wear, cutting speed is optimized in order to achieve the best long lasting of the tool. The machining process is carried out in both dry and with coolant conditions. So that, in each condition, cutting speed as a major parameter is varied whereas, the other set up machining parameters are remained constant. In this case, the long lasting of tool is analyzed regarding to the results of machining process and theoretical equations. The results show that long lasting of tool in dry machining increases rapidly with the cutting speed less than 20 mm/min but, the material removal rate decreases in the same case. The long lasting of tool is also decreased in 20-40 mm/min domain of cutting speed but, it rapidly decreases in upper speeds. Therefore, long lasting of tool is optimized in 20-30 mm/min of cutting speed. The results also show that, 30-40 mm/min domain of cutting speed is the optimized value for the best long lasting of tool in coolant machining condition.

Keywords
Turning, Flak wear, Crater wear, Invertor, Coolant.

1. Introduction
Tool's long lasting prediction and the determination of its situation in machining process is a very important tool design issue. So that, the closed information the affection of machining parameters on tool wear can improve its long lasting and afterwards decreasing in machining cost. The force signals which have process information are the best choice to show the tool wear. S.K. Choudhury and K.K. Kishore (2000) used a mathematical model to show the tool wear so that, by the determination of the flank wear and forces ratio in various positions and then mathematically modeled, the tool wear was predicted. Barry et.al (2001) analyzed CBN/TiC tool cutting wear in AISI 4340 turning. On the machined surface of the crate in three various conditions, they showed that CBN phase is under TiC phase so that, the sticked built up edge layer of tool with Al-Si-Mn-S-Fe combinations can be observed. Sőderberg (2002) found a relationship between wear zone and cutting forces in CNC turning process. He analyzed the profile of the wear zone Taly surf TM series software. A mathematical model was also used to show the relation between wear zone and machining forces. This model which was created in MATLAB software showed that the wear zone is created with the extension of the tool and workpiece contact surfaces. Choulhurg et.al (2004) measured the flank wear in high speed steel cutting tool by using a mathematical model and its comparison with the experimental results. Arsecularatne et.al (2006) analyzed the wear mechanism of Tungsten Carbide,PBN and PCD cutting tools in steel turning. They showed that in WC/Steel machining the wear mechanism is based on friction phenomenon whereas, in PCBN/hardening steel, this wear is based on chemical reaction. In these two machining processes, the wear is related to the thermal reaction but the steel machining with PCD cutting tool is still under evaluation. Maity (2008) investigated the long lasting equation of Manganes-hardening steel cutting tool. This equation was obtained using regression analysis.

2. Machining Conditions
Temperature, cutting speed, feeding rate and depth of cut are the main and most effective factors in cutting tool wear which are considered in this research. The machining operations are carried out with and without coolant and in each case four cutting speeds are considered. Invertor is used to set up each value of cutting speed on turning machine so that, the spindle speed can be set with the variations of input frequency. In this manner, a special cutting speed can be regulated so that, the other set up machining parameters are to be constant. The machining parameters is shown in

Table1. It is noteworthy that the spindle speed is directly related to the diameter of the work piece and when this diameter decreases during machining process, the spindle speed should be increased to have a constant cutting speed. In this case, as long as the tool's long lasting is ended, the time is determined via chronometer and its variations diagram can be plotted. At lower cutting speed in which the tool's tip may be damaged, the machining operation will be stopped if the crater wear and flank wear are created. In this manner, the depth of crater on the surface of the chip and wear width on free surface of the work piece are measured.

3. Experimental Tests

The equipments which are used in experimental tests are as follows:

- Machine Tool: TN50 B12 turning from Tabriz Co., Iran.
- Variable Frequency Drive: IG5 model from LG Co., Korea.
- Tachometer, IG model from LG Co., Korea.
- Microscope: N5253 model from Japan with 0.005mm power resolution and 50 magnification.
- Tool electrode: High speed steel with combination of W (18%) and Cr (4%).
- Workpiece: Steel 37 rode with 500mm length and 60 mm dia.
- Coolant: 5% oil 95% water.

4. Wear Model

The equation between wear and applied load is dependent to the rigidity deformation of weared particles. The volumetric wear rate equation is as follows:

$$\frac{dv}{dt} = \left(\frac{Z}{H}\right) N^m V_c \tag{1}$$

Where H ، Z ، N ، Vc and m are; tool-work piece relative hardness, wear coefficient, applied load, wear speed and constant coefficient dependent to the nature of removed layers respectively. The value of wear coefficient can be calculated from the following equation:

$$Z = Z_0\, e^{-U/R\theta_f} \tag{2}$$

Where Z_0 ، R ، θ_f and U are; Coefficient dependent to the materials of tool and work piece, gas constant, absolute temperature and active energy respectively.

For the area which is non-sensitive against temperature, the average wear coefficient can be determined as follows:

$$Z = Z_0(\theta_f)^p_{avg} \tag{3}$$

Where $(\theta_f)_{avg}$ is the average wear temperature and is calculated as:

$$(\theta_f)_{avg} = \sqrt{V_c}\, f^{\beta} d^{\gamma} \tag{4}$$

Where V_c ، f and d are; cutting speed, feeding speed and depth of cut respectively. β and γ are the coefficients which are determined from experimental results.

5. Testing Methods

The tests are carried out as machining with and without coolant conditions.

5.1 Dry Machining

In this case machining is done without coolant. Machining parameters is shown in Table1.

Table 1: Machining parameters

Parameter	Value
Rake Angle (γ)	ȯ 14
Clearance Angle (α)	ȯ 8
Oblique Angle (X)	ȯ 0
Main Setting Angle (X´)	ȯ 90
Secondary Setting Angle (X´)	ȯ 6
Feed Rate (mm)	1
Feeding Speed (mm/rev)	0.11
Cutting Speed (m/min)	20,30,45,120

The geometric configuration of cutting tool is shown in Figure 1.

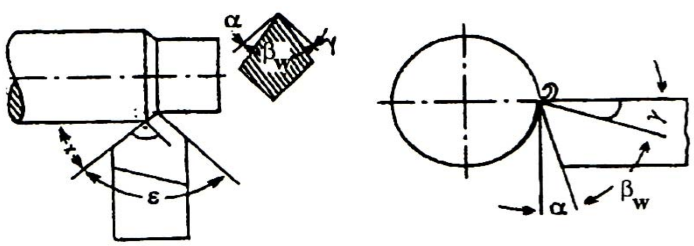

Figure 1: Schematic view of cutting tool

It is noteworthy that the main timing angle is the angle between longitudinal axis of workpiece and basic cutting edge of tool. Also, bypass timing angle is the angle between longitudinal axis of workpiece and bypass cutting edge of tool. In order to setup cutting speed, the spindle speed will be calculated according to this cutting speed first and then the related machine input frequency to this speed will be determined. After that, the spindle speed will be checked via chronometer and the input frequency will be corrected if there are any differences. In each step of machining setup, the cutting tool is changed according to the Table 1. After every machining operation, the tool long lasting is calculated. Table 2 shows the long lasting of cutting tools [7].

Table 2: Long lasting of tool

Cutting Speed (m/min)	Tool Long Lasting (min)
120	0.0167
45	1. 167
30	27
20	255

The variations of tool's long lasting with time in dry machining condition is shown in Figure 2.

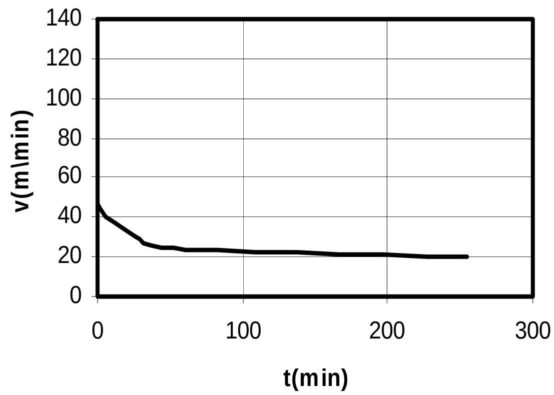

Figure 2: variations of tool's long lasting with time in dry machining

The variation equation of tool's long lasting is as follows:

$$V_c.t^{(0.15)}=cte \tag{5}$$

In this equation V_c is cutting speed (mm/min) and t is long lasting time.
According to the experimental results of tool's long lasting time determination and regarding to the cutting speed which is a setup parameter, constant value in eq. (5) can be determined. This value is approximately 45 therefore, the following equation can be used to determine the tool's long lasting time in our experimental test:

$$V_c.t^{(0.15)}=45 \tag{6}$$

5.2 Machining With Coolant

In this case, machining is carried out with coolant. The specifications of coolant materials are shown in section 2. The machining sequences and setup are the same as dry machining case. The tool's long lasting time can be analyzed in mechanical wear and thermal effect points of view. Mechanical wear of tool is the same as mentioned in the previous case. The thermal damage of tool occurs when the tip of the tool is burned and blacked. The standard failure criteria of high speed steel cutting tool as its long lasting time is when the flank wear width reaches to 0.3 mm. The long lasting time of tool in machining with coolant condition is shown in Table 3.

Table 3: Long lasting of tool for various cutting speeds with coolant condition

Cutting Speed (m/min)	Tool Long Lasting (min)
120	0.05
60	0.47
45	34
30	341

Variations of tool's long lasting with time in coolant turning condition is shown in Figure 3.

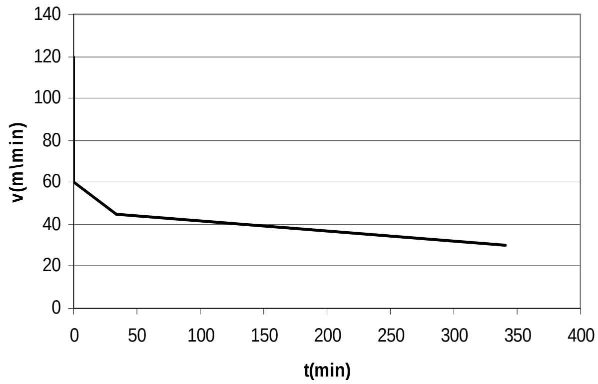

Figure 3: Tool long lasting variations with time in coolant condition

Equation (5) which is general for calculation of tool's long lasting time is also valid in this machining condition. After using the experimental results in this case, the constant term of this equation is determined and the following equation can be used in this condition:

$$V_c.t^{(0.15)} = 70 \tag{7}$$

5. Discussion

In this research machining of ST-37 steel is carried out with high speed steel tool in coolant and non-coolant cases. Variations of tool's long lasting with cutting speed is shown in Figure 2. According to this figure, the long lasting of tool decreases rapidly in high cutting speed conditions but, in amounts of less than 20 mm/min it is optimized and varies very slowly. The reason is that, in high cutting speeds, the heat concentration near the tool's tip area increases and afterwards, the mass material in boundary grains are loosed and easily released. Figure 3 shows that with using coolant materials, the long lasting of tool can be noticeably increased in comparison with non-coolant case. Since the heat concentration around the cutting zone of tool's tip can be easily conducted via these coolant materials. Therefore, the contact surfaces of the cutting tool will preserve their strength with temperature in higher amount of cutting speed, so that, the optimized cutting speed in this case reaches to 40 mm/min. Figure6 shows the microscopic picture of the cutting zone of the tool in this case. According to this picture the absence of crater related to the heat affect in comparison with the previous case confirm the deficiency of the heat on the tool tip in the cutting zone.

6. Results

In this research wear phenomenon of HSS tip tool in coolant and non-coolant turning conditions are analyzed. The results are as follows:

- The tool is damaged in high cutting speeds according to higher temperature concentration.
- The tool is damaged in lower cutting speeds according to friction wear.
- Tool's which are damaged with friction wear have higher long lasting times. Therefore, an optimized cutting speed can be chosen to have high long lasting time.
- In coolant turning with HSS tool, the optimized cutting speed is 20-30 mm/min.
- In non-coolant turning with HSS tool, the optimized cutting speed is 30-40 mm/min.

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Biography

Ramezan Ali Mahdavinejad received his B.S., M.S., and Ph.D. in Mechanical Engineering from Tehran University, Iran in 1981, 1991 and 1999, respectively. Prof. Mahdavinejad is currently a Professor of the School of Mechanical Engineering, Engineering Faculty of Tehran University, Iran. His research fields are Advanced and Non-Traditional Manufacturing.