Identification of Tool Life and Wear Characteristics of HSS Tools Used in Turning of Ck45

B. Moetakef Imani [1], S.A. Hosseini [2] and A. Baghal Safa[3]
Mechanical Engineering Department, Ferdowsi University, Mashhad, Iran
Corresponding Author E-mail: imani@ferdowsi.um.ac.ir

Abstract
Cutting tools can be used when they do not reach tool life criteria and can produce parts with desired surface finish and dimensional accuracy. When the cutting edge of the tool reaches one of the tool life criterion, the tool should be replaced by a new one or sending it for regrinding [1]. During cutting operations, the cutting tool experiences various stresses such as normal, shear and also thermal shocks. These stresses cause wear and breakage of cutting edge. Tool wear is defined as a gradual loss of tool material at contact zones of workpiece and tool material, resulting the cutting tool reaches its life limit [2]. This research is based on ISO3685 and investigates the flank wear patterns of HSS tools during machining of CK45. It also determines the effects of cutting conditions on Taylor tool life equation.

Keywords: Flank Wear, Tool Life, Machining, Ck45

1 Introduction
In practical situation, the time at which a tool ceases to produce workpieces with desired size, surface quality and acceptable dimensional tolerances, usually determines the end of tool life. Several mechanisms of wear can contributes to the tool life period. The main objective of tool life testing and wear investigation is to determine experimentally how wear affect the useful life of cutting tool. In most cases the tool wears gradually and the work done by the tool becomes less satisfactory. For instance, the roughness of the machined surface becomes too high, cutting forces rise and cause intolerable deflections or vibrations. As the tool wear rate increases, the dimensional tolerances can not be maintained. Various damage and wear of the cutting tool can be developed during cutting process [2]. The various features of turning tool wear, cracks and breakage indicated in Figure 1. There are several different causes and mechanisms of tool wear. Friction on the rake face and on the flank of the tool occurs under a close contact of freshly created surface of the workpiece material. The coolant penetrates into this contact zone only at very low cutting speed. The pressure in the contact zone is at least equal to the yield stress of the workpiece material [1] [2]. The temperatures in the contact zone are high and may reach the melting temperature of the one of the materials in this zone, most often that of the workpiece material.

[1] - Assistant Professor of Mechanical Engineering
[2] - M.Sc. Student of Mechanical Engineering
[3] - B.Sc. Student of Mechanical Engineering

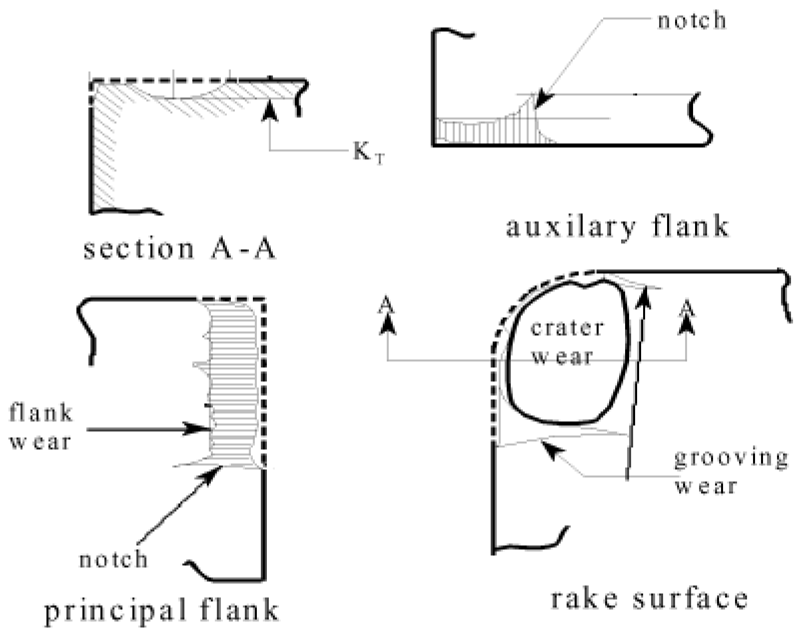

Figure 1: Geometry and major features of wear of turning tools

2 Basic mechanisms of tool wear

The various mechanisms that contribute to wear process are as bellow [2]:

- Mechanical overload causing micro breakages (attrition).
- Abrasion
- Adhesion
- Diffusion

2.1 Attrition

The grains of the various components of the tool material hold together at grain boundaries. Those on the rake face and on the flank are supported on at least half of their surfaces and can therefore be rather easily broken out, embedded in the machined surface and in the underside of the chip, and dragged over the tool surface. Some of them may then break out other grains and produce a kind of chain effect.

2.2 Abrasion

Abrasion is the commonly known wear process in which a harder material scratches a softer material over which it is sliding under normal pressure. This mechanism is significant for tool wear only in those instances where the workpiece material is very hard or contains hard particles: cast iron with grains of cementite, various metal containing hard inclusions like hypereutectic aluminum with SiC grains, steel killed with aluminum and containing Al_2O_3 , and so on. The machined surface is cooler than the tool flank, and it may happen that tool material is softened more than some of the constituents of the workpiece materials, which creates the conditions for abrasion.

2.3 Adhesion

In the conditions of the intimate contact between the tool and the freshly created surfaces on the workpiece and on the underside of the chip, welding of the workpiece surface and of the chip to the tool can often be observed. The extreme case is the built-up edge, which is formed in the low and middle speed range. Layers of workpiece material welded to the tool are found in ductile materials like in ferritic and austenitic steels, titanium alloy, and nickel-based alloys. The welded layers and points are periodically sheared away. This mechanism contributes to flank wear as well as to the formation of the crater.

2.4 Diffusion

Diffusion is an important mechanism and plays a significant role at higher cutting speeds in some workpiece/tool material combinations. The diffusion rate, that is, the amount of atoms of material penetrating into another material, depends on the affinity of the two, very strongly on temperature, and on the gradient of concentration of the penetrating atoms in the solvent material. The latter aspect is very special in cutting, because the chip materials that absorbs the atoms of the tool material is continuously being carried away, and all the time new, virgin, unsaturated material is always arriving. The diffusion rate is highest at the point of highest temperature. This is about in the middle of the chip contact length, and that is where the crater becomes deepest. Diffusion is the most significant factor in crater wear, but it also participates in flank wear. Diffusion rate increases with cutting speed as the temperature at the contact on the rake face and on the flank increases.

3 Basic kinds of tool wear

The above wear mechanisms may occure simultaneously, or one of them may dominate the process. These mechanisms can lead to several types of wear; however, two types of them, which called crater and Flank wear, are most distingushed.

3.1 Flank wear

Flank wear is caused by friction between the flank face of the tool and the machined workpiece surface. Interference of tool flank face with machined surface of workpiece cause tool particle adhere to the workpiece surface and are periodically sheared off. Adhesion of the tool and workpiece materials increase at higher temperatures. Abrasive mechanism of wear occures when hard inclusion of work material or scaped tool particle scratch the flank and workpiece surface as they move across the contact area. Although adhesive and abrasive mechanisms are predominant in flank wear some diffusion wear also exists. Figure 2 shows the rake and flank face of the HSS turning tool and Figure 3 shows the the flank wear on the HSS turning tool.

3.2 Crater wear

Crater wear occurs at the tool-chip contact area where the tool is subject to a friction force of the moving chip under heavy loads and high temperatures. The temperature is greatest near the midpoint of the tool-chip contact length, where the greatest amount of crater wear occurs due to intensive diffusion. As the crater wear approaches the cutting edge, it weakens the wedge and causes chipping of the tool. Figure 4 shows the crater wear on the HSS turning tool.

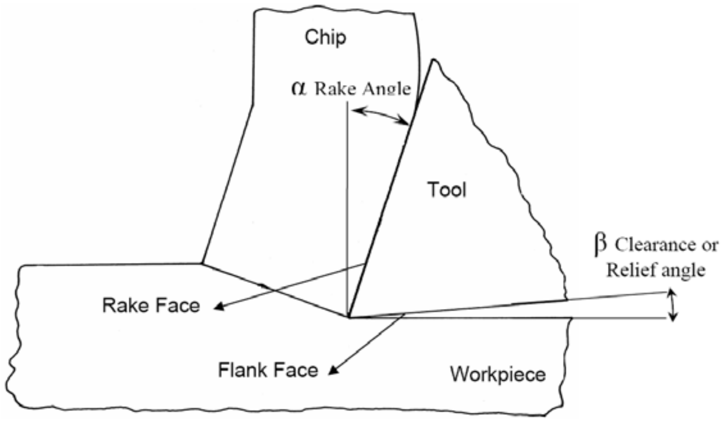

Figure 2: Definition of rake and flank face and tool angles

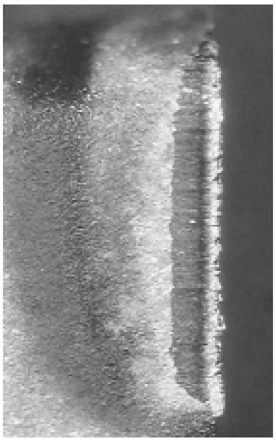

Figure 3: Flank wear

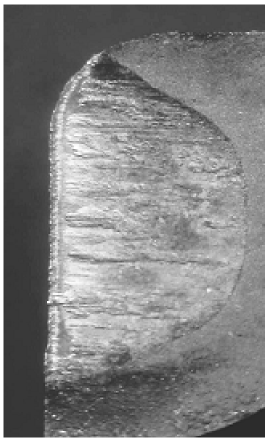

Figure 4: Crater wear

4 Common tool life criteria for HSS tools

The criteria most commonly used for HSS tools are as follows[3]:

- The maximum width of the flank wear land VB_B max=0.6 mm, if the flank wear is not regularly worn, scratched, chipped or badly grooved.
- The average width of the flank wear land VB_B=0.3 mm, if the flank wear land is considered to be regularly worn.
- Catastrophic failure.

Figure 5 shows the flank wear parameters. Flank wear typically increases with the time of cutting, as shown in Figure 6. At the beginning phase 1, there is an initial faster increase that is followed by a steady increase in proportion to cutting time, phase 2.

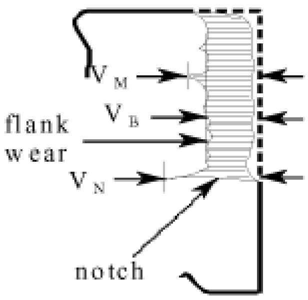

Figure 5: Principal parameters of flank wear

When the wear reaches a certain size, it will accelerate and may lead to a sudden failure of the edge, phase 3 [2].

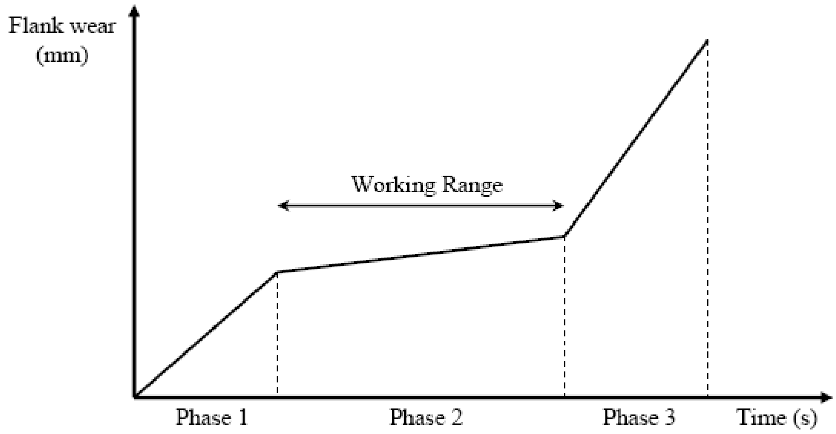

Figure 6: phases of tool wear in HSS turning tools [2] [4]

5 Identification of Taylor tool life coefficient for HSS in machining of Ck45

Taylor [4] suggested an equation which describes the relation between tool life (T_c) and cutting speed (V_c) as bellow.

$$C = V_c \times T_c^{-\frac{1}{k}} \tag{1}$$

C and k are two independent constants. The suggested experiment is designed for determining C and k for a variety of cutting conditions for a certain combination of tool and workpiece material.

5.1 Experiment setup based on ISO3685 standard

The test materials are medium carbonized and hot-rolled bars of Ck45. To prevent undesirable vibrations the lenght (L)/diameter (D) ratio must be smaller than 10. The tools are HSS Uncoated and noncobalt (S2, S4) with the hardness of 69 HRC.
Table 1 summarizes the conditions used for the experiment.

Table 1: Elements of the test

Machine tool	Tool material	Workpiece material	Coolant
TNB Turning center	HSS (S2,S4) Uncoated, Noncobalt	Ck45	Must be used

Figure 7 shows the geometry of tool used in the experiment. Rake and clearance angles of the tool are grounded with acceptable surface finish and tolerances according to ISO 3685. Table 2 shows the cutting conditions used in the experiment.

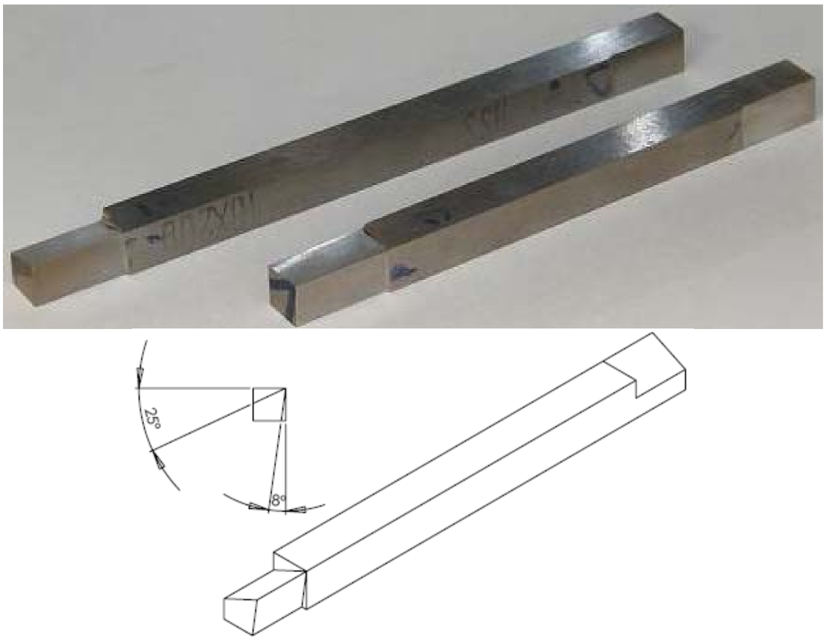

Figure 7: Geometry of the HSS turning tools

Table 2: Cutting condition

Cutting Condition	case	Depth of Cut (mm)	Feed (mm/rev)	Spindle Speed (rpm)	Cutting Velocity (m/min)
A	1	1	0.11	180	21.48
	2	1	0.11	355	40.13
	3	1	0.11	500	53.38
B	4	2.5	0.24	500	56.52
	5	2.5	0.24	355	35.67
	6	2.5	0.24	250	29.83
C	7	2.5	0.4	355	31.21
	8	2.5	0.4	250	29.83
	9	2.5	0.4	180	18.65
D	10	2.5	0.56	250	25.92
	11	2.5	0.56	180	21.49
	12	2.5	0.56	125	11

Each of the 12 cases started with a new tool until it reached its life limit which was then replaced by a new one. During cutting process and after each pass, the tool was unclamped and a CCD image of the flank face was taken using a CCD camera enhanced with a tele-centric lens, further details will be found in [5]. These images are calibrated and then used for measuring the flank wear of the worn tool. Figure 8 shows the calibration gauge and Figure 9 shows the measurement process of the flank width implemented in SolidWorks 2007.

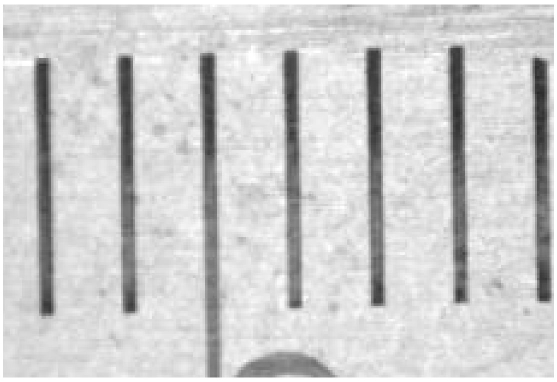

Figure 8: Calibration gauge

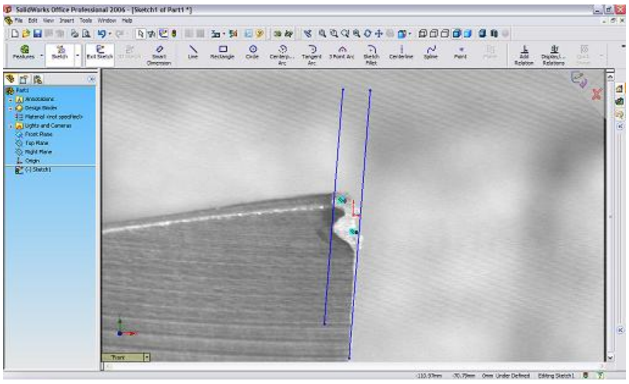

Figure 9: measurement of the flank width

Figure 10 and 11 shows the flank wear of the tool 2 after 13 and 71 minutes machining.

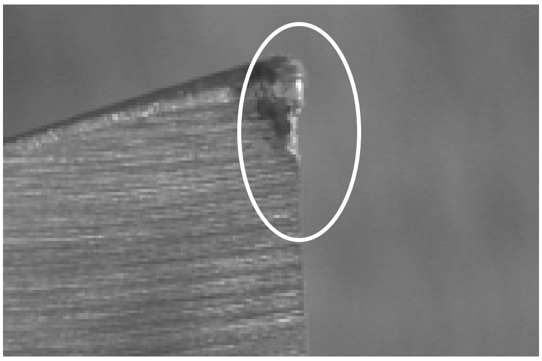

Figure 10: flank wear after 2 minutes

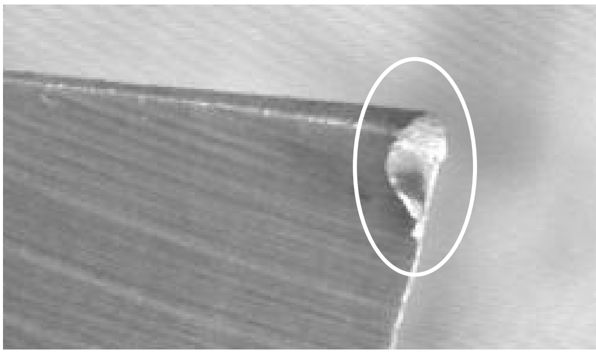

Figure 11: flank wear after 71 minutes

As it can be seen in Figure 12, which is obtained for the case 2, three phases for the flank wear rate can be distinguished which is in accordance to Figure 6.

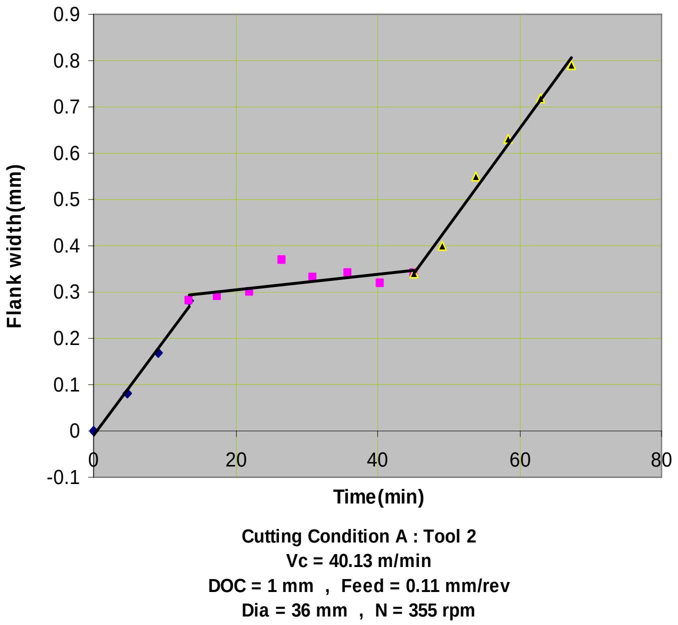

Figure 12: Flank wear versus time

When the tool reaches its life limit it replaced by new one and the process is continued. The process repeated for each case and the tool life reported for that cutting conditions. Using acquired data, Taylor's coefficients are determined based on the method mentioned in the ISO 3685 [3]. The test results such as tool life and Taylor's coefficients for each case reported in Table 3.

Table 3: Cutting condition, tool life and Taylor constant for the tools

Condition	Case	DOC (mm)	Feed (mm)	N (rpm)	Vc (m/min)	Tc (min)	Log (Vc)	Log (Tc)	Taylor Costant	
A	1	1	0.11	180	21.48	183	1.33203	2.26245	K=-2.9512	C=122.83
	2	1	0.11	355	40.13	22.08	1.60346	1.34399		
	3	1	0.11	500	53.38	13.46	1.72737	1.12904		
B	4	2.5	0.24	500	56.52	5.58	1.75220	0.74663	K=-2.8976	C=100.53
	5	2.5	0.24	355	35.67	16.8	1.55230	1.22530		
	6	2.5	0.24	250	29.83	38.5	1.47465	1.58546		
C	7	2.5	0.4	355	31.21	23.37	1.49429	1.36865	K=-0.698	C=3068
	8	2.5	0.4	250	29.83	26.83	1.47465	1.42862		
	9	2.5	0.4	180	18.65	35.05	1.27067	1.54468		
D	10	2.5	0.56	250	25.92	15.67	1.41363	1.19506	K=-1.1015	C=287.09
	11	2.5	0.56	180	21.49	15.23	1.33223	1.1827		
	12	2.5	0.56	125	11	37.4	1.04139	1.57287		

5.2 Measuring the cutting forces

In addition to the wear rate and tool life experiment, the cutting forces are measured for Case 2 in 1, 8 and 12 minutes after the beginning of the cut. The force measurement was performed by experimental setup, which contains load cell for measuring the cutting forces and date acquisition card to get the data, see [6]. The Figures 13-15 illustrates that there is an increasing trend for the average of cutting forces. The average cutting force for 1-minute operation is around 110 N and increased to 125 N for 8-minutes operation and then reached 150 N for 12-minutes operation.

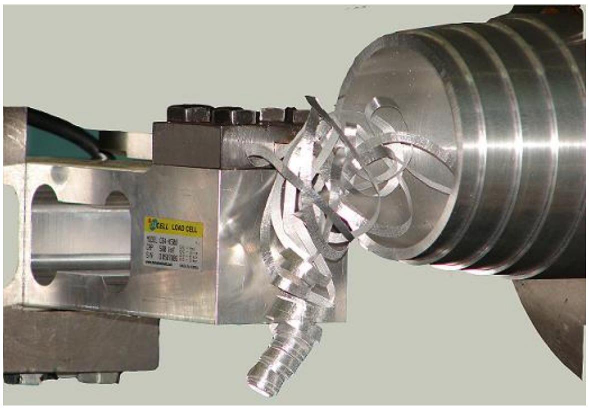

Figure 13: experiment setup for force measurement [6]

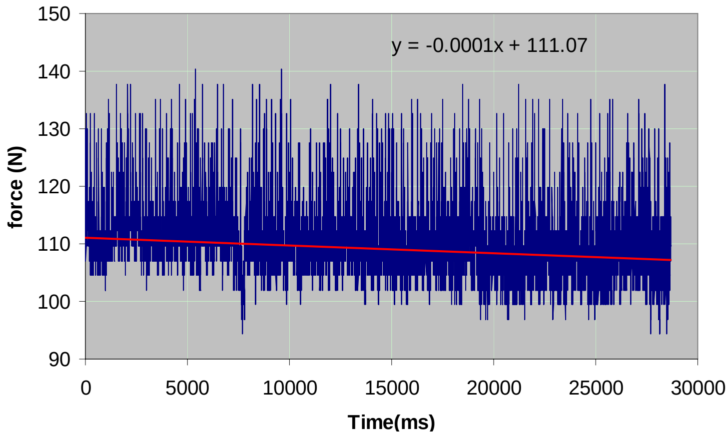

Figure 14: Cutting forces after 1 minute

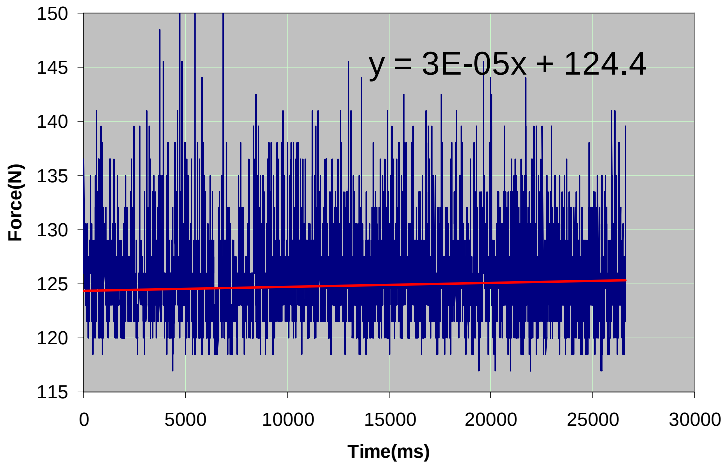

Figure 15: Cutting forces after 8 minute

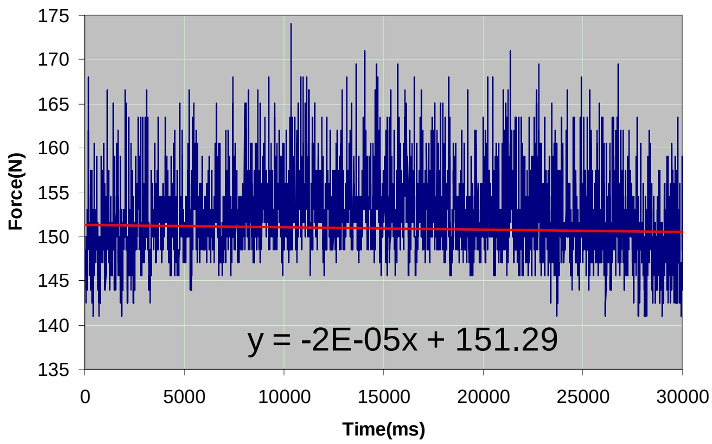

Figure 16: Cutting forces after 12 minute

Conclusion

Tool life of HSS turning tools is modelled using Taylor tool life equation. Taylor's coefficients are derived for the combination of HSS tool and Ck45 work piece material for recommended cutting conditions. The criterion used for tool life prediction is based on ISO 3685 and the average width of flank wear is chosen. Cutting forces are measured during cutting process at certain times. There is a good correlation between the average cutting force and the amount of flank wear. Due to simplicify of force measurement it is recommended to measure the average cutting force instead of measuring the amount of wear which is a time consuming and inefficient.

Acknowledgment
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