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The reliability analysis of cutting tools in the HSM processes

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ABSTRACT

Purpose: This article mainly describe the reliability of the cutting tools in the high speed turning by normal distribution model.

Design/methodology/approach: A series of experimental tests have been done to evaluate the reliability variation of the cutting tools. From experimental results, the tool wear distribution and the tool life are determined, and the tool life distribution and the reliability function of cutting tools are derived. Further, the reliability of cutting tools at anytime for high speed machining (HSM) is easily calculated from cutting parameters and tool wear limit from the derived reliability function.

Findings: The higher the cutting speed, the sooner the tool flank wear, and the faster the degrade speed of the reliability curve. It means that the sooner the tool flank wear rate, the shorter the tool life, and it is the time to change the cutting tool.

Practical implications: This paper shows that the tool flank wear rate can be described by the reliability degrade rate, the higher the flank wear rate, the steeper the tool reliability degrade rate.

Originality/value: This article is discussing about the tool wear variation of the cutting tool from the point of reliability. From the reliability variation of the cutting tool, we can further predict the tool life, in order to decide the tool replacement time.

Keywords: Reliability assessment; Cutting tool; Tool wear; Normal distribution model; High speed machining (HSM)

PROPERTIES

1. Introduction

Facing the fierce competition and the press of the rising production cost. Besides heading towards to automatic, energy-saving and unmanned. High speed machining is also one of those main methods of increasing production efficiency and shorten machining times. High speed machining (HSM) has become a common trend supplied in manufacturing industry [1-3] since the successful development of high speed spindle and modern material techniques.

But wear happens during the cutting operation of the cutting tool. Since tool wear may cause poor dimensional accuracy, as well as deterioration of surface integrity of the workpiece, and even cause damage of workpiece if neglected [4-6]. Therefore the variation of tool wear of the tools during high speed machining process must be known. If the quantity of tool wear is learned, it is possible to make tool compensation for maintaining workpiece accuracy. And the replacement time of the tool can be determined, in order to prevent the occurrence of workpiece damage [7-11].

Since Taylor [12] presented the tool life equation, there were numerous academic experts had discussed the issue of the tool life. Wu [13] predicted the tool life by surface roughness variation. Wager and Barash[14] found the tool life value in statistical distribution after performing hundreds of tool life test by using high speed steel turning tool. The distribution approaches normal distribution. Rossetto and

Zompi [15] constructed the stochastic tool-life model with probability theory. Ramalingam and Watson[16] derived the single- and multiple-injury tool-life model based on the hazard rate function theory. Kwon et al. [17] found that normal distribution was the most suitable for representing the distribution of both flank wear at a given time and cutting time at a given flank wear.

Although these studies made an important progress in understanding the specific nature of tool life, there still remains some difficult problems[18]. It is needed to study the reliability of useful life of cutting tools from the point of probability theory because the tool life and tool wear have an inherent stochastic nature, in order to predict the tool life values precisely.

Tool wear affects dimension and surface quality of the workpiece and it is also one of the important criteria in determining tool life. Flank wear is a major form of tool wear in metal cutting. Tool flank wear land width is often used to characterize the tool life.

This research is mainly pointing to the reliability analysis of cutting tools based on the tool flank wear values obtained from the high speed turning experiments. From experimental results, the tool wear distribution and the tool life are estimated, and the tool life distribution and the reliability function of cutting tools are derived. Further, the reliability of cutting tools at any time for high speed machining is easily calculated from cutting parameters and tool wear limit from the derived reliability function.

2. Reliability analysis of tool wear

According to the extrapolation of Wager and Barash [14] and Hitomi et al.[18]] presume the average flank wear V_B as normal distribution, then, the probability density function of flank wear distribution $f(V_B)$ can be expressed as:

$$f(V_B) = \frac{1}{\sqrt{2\pi}\sigma}\exp(-\frac{(V_B-\mu)^2}{2\sigma^2}) \qquad (1)$$

Whereas, μ and σ represent average value and standard deviation of average flank wear normal distribution respectively.

If the average flank wear V_B is the function of cutting conditions (cutting speed V, feed rate f and cutting time t), then

$$V_B = \Psi(v, f, t) \qquad (2)$$

And

$$\mu = E[V_B] = E[\Psi(v, f, t)] \qquad (3)$$

$$\sigma = Var[V_B] = E[(V_B - \mu)^2] \qquad (4)$$

Presume there is relationship of exponential function between average flank wear V_B and cutting conditions, thus

$$V_B = cV^{b_1} f^{b_2} t^{b_3} \qquad (5)$$

Whereas, c, b_1, b_2 , b_3 are constant, the value obtained from experiment. After obtaining c, b_1, b_2, b_3, the probability density function of flank wear distribution $f(V_B)$ can be obtained as

$$f(V_B) = \frac{1}{\sqrt{2\pi}\sigma}\exp(-\frac{[V_B - cv^{b_1} f^{b_2} t^{b_3}]^2}{2\sigma^2}) \qquad (6)$$

Damage probability of turning tool occurred before time t:

$$P(\tau \prec t) = \int_0^t f(\tau)d\tau \qquad (7)$$

Whereas, τ is the time of damage occurred to the tool.

If the flank wear when the tool life end is V_B^*, then, the probability of flank wear reach life limit at time t is:

$$P(V_B \geq V_B^*) = 1 - \int_0^{V_B^*} f(V_B)dV_B \qquad (8)$$

Presume $P(\tau < t) = P(V_B \geq V_B^*)$, then:

$$\int_0^t f(\tau)d\tau = \int_0^{V_B^*} f(V_B)dV_B \qquad (9)$$

Input $f(V_B)$ of (6) into equation (9), rearrange and differential the t, get probability density function of tool life f(t)

$$f(t) = \frac{1}{\sqrt{2\pi}\sigma}\exp[-(\frac{T_v - t}{\sqrt{2}\sigma})^2] \qquad (10)$$

Whereas, T_v is time when average flank wear reach V_B^* value. Reliability function R(t) can be obtained from following equation.

$$R(t) = 1 - P(\tau < t)$$

$$= 1 - \int_{-\infty}^{t} \frac{1}{\sqrt{2\pi}\sigma}\exp[-\frac{1}{2}(\frac{x-\mu}{\sigma})^2]dx \qquad (11)$$

Using the above function, the reliability of the cutting tool is as follows[17]:

(1) the mean time of failure-free operation

$$T_0 = T_v \exp[\frac{(\sigma)^2}{2}] \qquad (12)$$

(2) Variance of lifelength

$$Var[\tau] = T_0^2[\exp(\frac{(\sigma)^2}{2}) - 1] \qquad (13)$$

(3) Failure rate of the cutting tool

$$h(T) = \frac{1}{\sqrt{Var[\tau]}\sigma}\exp[\frac{T - T_0}{\sqrt{Var[\tau]}}] \qquad (14)$$

3. Tool wear experiments and discussion

In order to understand the variation condition of the tool flank wear, experiment of tungsten carbide turning tool against S55C high carbon steel dry cutting test for tool life was conducted. The cutting test used disposable tungsten carbide turning tool on CNC lathe to perform machining experiment. The experimental device is shown in Fig. 1. The workpiece is mounted on CNC lathe by three jaw chuck, and supported at tail by life-center. The specification of tool holder was MTJNR2020K16, and the specification of cutting tool was TNMG160404R2G.

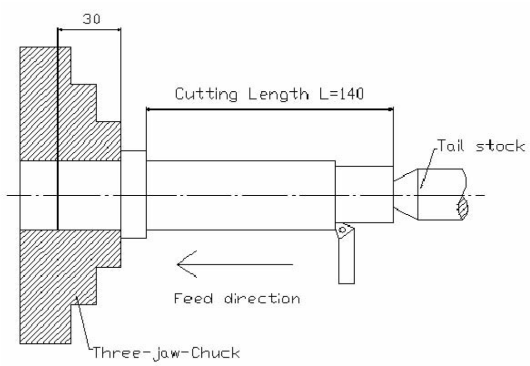

Fig. 1 Experimental set-up

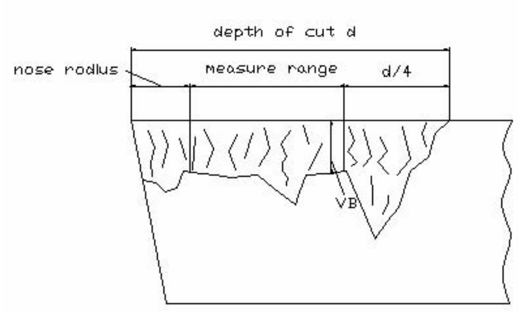

Fig. 2. The measure position of tool flank wear width [19]

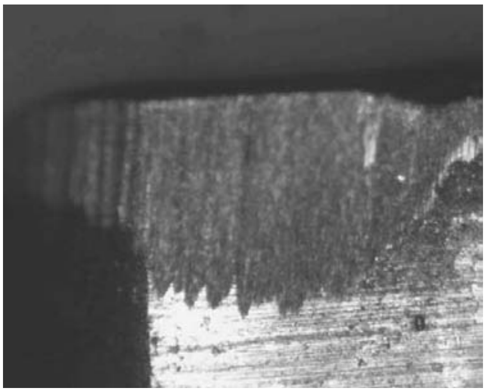

Fig. 3. The tool flank wear condition

Remove the insert at appropriate interval of machining, used the tool microscope(OLYMPUS B202 , made in Japan) to measure the flank wear V_B, the measuring method of flank wear is illustrated in Fig. 2 [19]. The tool flank wear condition through the high speed turning process is as shown in Fig. 3. Using the tool microscope to measure five points flank wear value, and average them then get an average flank wear value. The high speed turning tests were conducted at cutting speed of 350, 450 and 550 m/min and the feed rate were 0.05, 0.15 and 0.25 mm/rev.

The depth of cut was fixed at 1.0 mm. The machining tests would be stopped if the flank wear reached to 0.40 mm or if catastrophic tool failure occurred. Every machining condition had been tested 5 times and calculate it's average and standard deviation.

In this study, taking normal distribution as the tool wear distribution to calculate the tool wear reliability. The preset tool life criterion is that when the average tool flank wear width becomes equal or greater than 0.3 mm, the tool life ends. Fig.4 and Fig.5 present the measured tool flank wear width against cutting time with different cutting speed and feed rate, respectively. The flank wear width will increasing with cutting time. The clear observation in Fig.4 is that tool flank wear rate increased dramatically at condition that had a cutting speed of 550 m/min instead of 350 m/min. As shown in Fig.5, the effect of feed rate on tool life is not so significant compared cutting speed although is shows the improvement of tool life with the decreasing of feed rate.

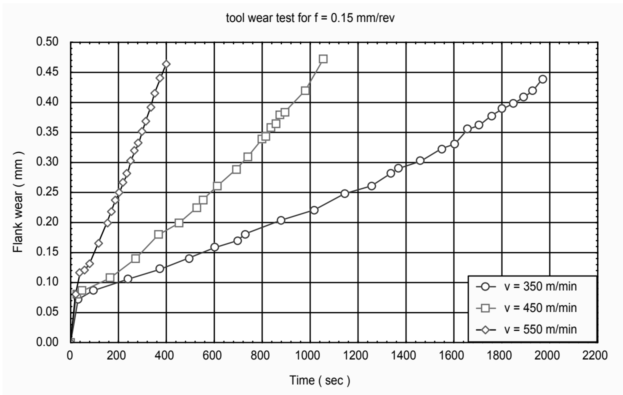

Fig. 4. Tool flank wear variation for different cutting speed

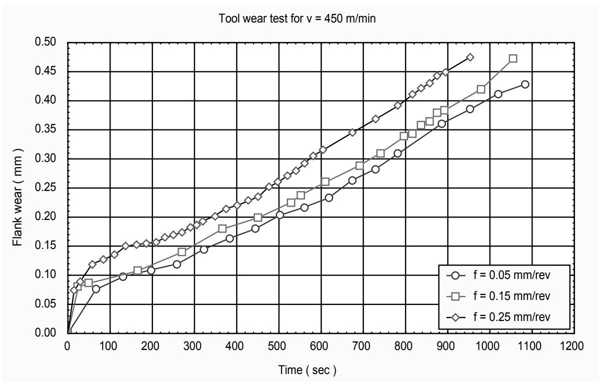

Fig. 5. Tool flank wear variation for different feed rate

When the amounts of tool flank wear become too large, the turning process will occur the unstable condition, and the surface of workpiece may also become very rough. Its means the tool life ends.

The tool wear reliability variation curve were shown in Fig. 6 and Fig. 7. The rapid increase in flank wear rate at 550 m/min gives a rapid fall in reliability in Fig.6. The reliability is less than 10 % beyond 270 seconds. As the cutting speed decreases, the fall is slower so that the reliability remains high for longer times.

At the lower speed of 350 m/min, the reliability is as high as 90 % even at 900 seconds. As a comparison, note that 50 % reliability occurs at 240, 570 and 1100 seconds at speed of 550, 450 and 350 m/min respectively.

As shown in Fig.7, the effect of feed rate on tool wear reliability is not so significant compared cutting speed although is shows the improvement of tool wear reliability with the decreasing of feed rate. 50 % reliability occurs at 224, 250 and 270 seconds at feed rate of 0.25, 0.15 and 0.05 mm/rev. The difference is very small.

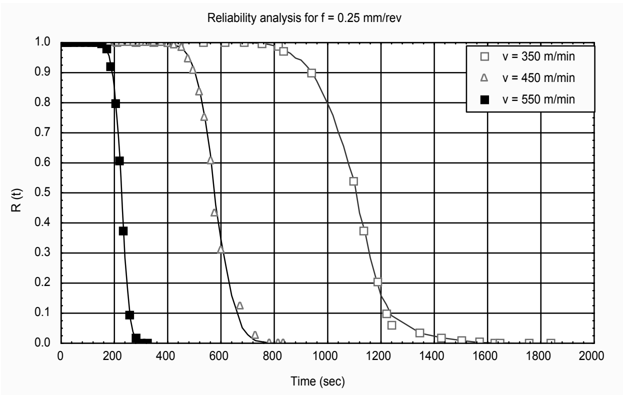

Fig. 6. Tool wear reliability variation for different cutting speed

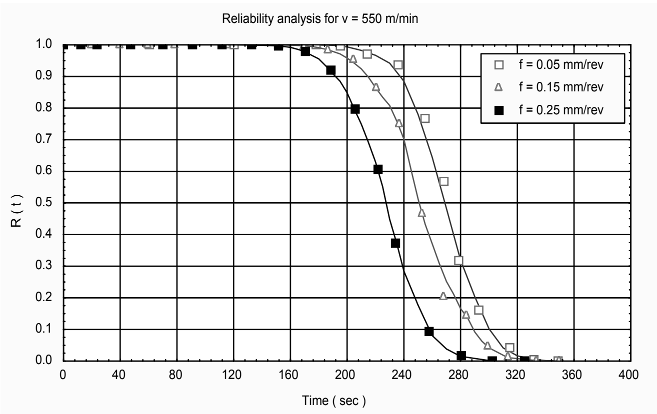

Fig. 7. Tool wear reliability variation for different feed rate

4. Conclusions

Following conclusions are obtained from analysis the above stated experimental results

(1) The tool flank wear width will increasing with cutting time. The results of the experimental studies indicated cutting speed has a more dramatic effect on tool life than feed rate.
(2) The faster cutting speed, the steeper reliability curve of the cutting tool. The faster degradation of the tool reliability, the shorter the tool life.
(3) The effect of feed rate on tool wear reliability is not so significant compared cutting speed.

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