니켈 선삭에서 다이아몬드 공구마모의 통계적 예측방법 연구
Diamond tool wear in turning micro-prism pattern on Ni-P alloy

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1. Introduction

Over the last two decades, ultra precision turning with diamond tools has become a relatively mature technology, competing not with other technology but itself. Nickel phosphorus alloys are the most attractive materials for diamond turning, compare to aluminum, gold or copper alloys [1], in fabrication of recent optical, optoelectronic, mechanical and biomedical components [2]. Previous works reveal an evolutionary development of ultra precision diamond turning technology; experiments are expensive and time consuming, until recently, there has been relatively little academic research in this area. Thus, users are heavily influenced by tool wear. Cost of tool wear is an acceptable term of the value of the product. Thus, the areas of useful optical surface generated, micro fluid channel, etc, are limited by tool wear.

The study is an attempt to explore the diamond tool wear mechanism in turning Ni-P alloys, including mechanical and chemical wear, in other to improve diamond turning quality in micro-prism pattern. A new experiment-based statistic method in mapping and predicting wear size is also proposed in correlation with turning conditions: cutting depth, speed and percentage of phosphorous in Ni-P alloys. Finally, optimization software for turning micro-prism pattern is developed. The benefits of the software are: improving productivity, extending tool life, customizable critical wear point, and friendly graphical user interface.

2. Diamond tool wear mechanism

Tool wear is well known as two main categories: mechanical and chemical wear. Diamond tool mechanical wear behave almost same mechanism as steel tool [1,3]:

- Adhesion and formation of a built-up edge;
- Abrasion, micro chipping, fracture and fatigue;

But diamond tools are more sensitive with chemical reactions because of their carbon element and crystal structures. During the cutting, if there are changes of temperature, pressure or cutting conditions, diamond properties could be changed and react with the surrounding environment or the workpiece directly. So diamond chemical wear need to be discussed deeper, compared to well known mechanical wear, in further details.

In Gubbels's work [4], diamond tools can be oxidized if the tool surface temperature reaches to critical point. Wilks [5] stated that critical value is around 800^0K. It possibly happens in turning micro-prism pattern. Thus, the oxidation or graphitization turns the diamond bound around the tool tip into graphite and produces carbon mono oxide (CO), carbon dioxide (CO_2), depending on specific condition. That is so defined as initial point where chemical wear begins and can be called as oxidative wear [4]. Next, carbon atoms C are separated from tool and diffuse into roll mold. Nickel and Nickel mono oxide (NO) from the surface of the mold could react with CO and CO_2 in certain conditions, which can cause tribo-chemical wear [1,4]. In fact, this is just an ideal sequence which is not interfered by mechanical wear. Corrosion or adhesion can effect in between the chemical wear mechanism which make micro wear in diamond tool a complex and incomplete research until now. Further experimental observations and research need to be carried out to enhance the knowledge about these theories.

3. Tool life prediction

As mentioned above, predicting a variable, that is controlled by many others variables, is really a challenge in mathematical research. Statistical method raises a possibility of solving this wear case. Conventional statistical tool or method is related to large scale of data. But in diamond ultra turning with Ni-P plated mold, doing many experiments to get data is very difficult. Diamond tool is expensive; Ni-P plated technique is unstable and difficult to control the percentage of P [6] and time costing. A new prediction method is come up in combination of standard Taylor's equation, previous wear behavior experience and current wear experiments data. Cardenas and Pramanik's works [7,8] show that the relation of wear and cutting distance is almost linear. Fig. 1 visualizes wear behavior with cutting distance, and linearized approach to assume wear rate is constant.

And the original Taylor's tool life is

$$TV^n = C \tag{1}$$

Modified tool life model

$$LV^aD^b = C$$
$$CLV^aD^b = 1 \tag{2}$$

Wear rate model is shown in Fig. 2

$$\dot{W} = C_W V^a D^b \tag{3}$$

Fig. 3 shows the current experiment results and Lee's work [9] of turning micro-prism pattern on Ni-P plated drum. The idea is to find the average wear rate plane base on the real wear rate plane from experiment. Each average equation of wear rate and cutting depth, wear rate and cutting speed are found.

$$\dot{W} = 5\times10^{-9} V^{3.454}$$

$$\dot{W} = 2\times10^{-6} D^{3.332}$$

Then, average wear rate plane can be built

$$\dot{W} = 2.3\times10^{-13} V^{3.454} D^{3.332} \tag{4}$$

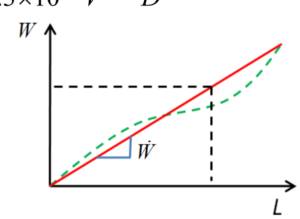

Fig. 1 Wear vs. cutting distance

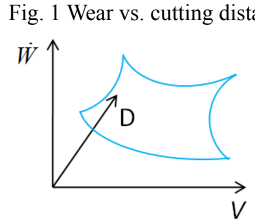

Fig. 2 Wear rate plane model

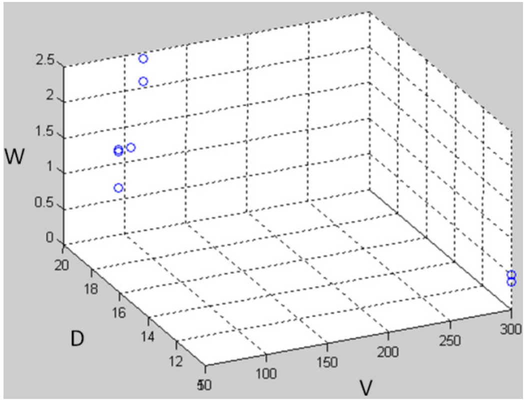

Fig. 3 Wear vs. cutting depth and cutting speed

Because this algorithm is built base on average assumption and experiment values, so reliability is not one hundred percent. Weibull probability density function is derived, to answer the question about reliability of the predicted results, with standard deviation of wear rate

$$\sigma_{\dot{W}}^2 = \frac{\sum_{i=1}^{n}\left(\dot{W}_i - \dot{W}(V_i, D)\right)^2}{n} \Rightarrow \sigma_{\dot{W}} = 0.0135 \qquad (5)$$

For example, in case of D = 20µm, V = 95m/min, L=25km,

$$W_m = L\dot{W}_m = 0.8425\mu m$$

$$\sigma_W = L\sigma_{\dot{W}} = 0.3375$$

And Fig. 4 shows the graphical model of predicting wear and reliability. Average wear 0.8425µm cut the weibull density area at the middle. Here the safe wear is set at 1µm and it cut the density area at the point that shows the reliability of the 1µm wear. This point is found by assuming normal distribution for the weibull curve.

$$N(W_m, \sigma_W^2) : f(W) = \frac{1}{\sigma_W\sqrt{2\pi}} e^{-\frac{(W-W_m)^2}{2\sigma_W^2}}$$

Standard normal distribution:

$$N(0,1^2) : \varphi(W) = \frac{1}{\sqrt{2\pi}} e^{-\frac{W^2}{2}} \qquad (6)$$

Probability area:

$$P(0 \le Z \le z) = \int_0^z \varphi(W)dW = 0.19 \qquad (7)$$

with

$$z = \frac{W - W_m}{\sigma_W} = 0.4667$$

It means the 1µm wear size target can get 69% reliable and the other 31% is unreliable.

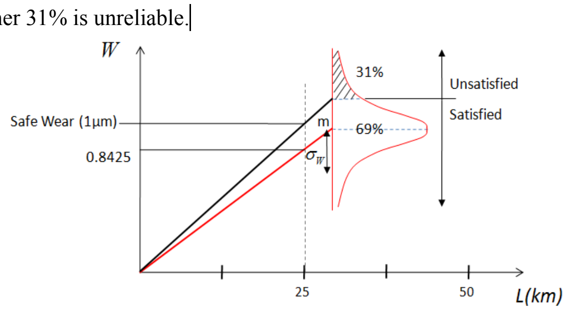

Fig. 4 Reliability with Weibull density probability

4. Optimal condition proposal

Again at Fig. 4, 1µm wear is the predefined maximum acceptable wear. From that point we can calculate the maximum cutting speed that satisfies the tool wear condition:

$$\dot{W}_{max} = \frac{W_{max}}{L} = \frac{1}{25} = 0.04$$
$$V_{max} = \left(\frac{\dot{W}_{max}}{2.3\times10^{-13} D^{3.332}}\right)^{1/3.454} = 99.8(m/\min) \qquad (8)$$

So, in case of 25km cutting distance, safe wear 1µm, maximum cutting speed is estimated about 99.8m/min with well known reliability 69:31.

5. Conclusion

The paper is studied about diamond tool wear mechanism and tool life prediction. Chemical wear is main wear in SCD tools. Base on characteristics of SCD tool wear and experiments data, a new tool life prediction method is proposed. And optimal cutting conditions, which are satisfied the manufacturing purposes, are also suggested with a reliability factor. It is necessary to modify the predicting model with more suitable designed experiment conditions. Furthermore, completed optimization software can be developed to enhance the productivity of ultra precision turning process.

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