Research on the Failure Analysis for Coating Cutters of PVD by the Finite Element

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***Abstract*-In order to study the failure cause of the wear and breakage of coating cutters, model of coating cutter is built by the Pro/ Engineer, and model file is imported into Ansys software so as to carry out the post-processing by the finite element, and subsequently mechanics, thermal and kinetic analysis of coating cutters are conducted. The failure reasons of coating cutters are also discussed which has certain reference value on the rapid development and to improve the durability for the coating tools.**

Keywords- Coating Cutter; Finite Element; Wear; Breakage; PVD

I. INTRODUCTION

Physical vapor deposition (PVD) plays an important role in improving the tool performance. More and more coating tools are used and therefore found the failure cause, which has an important effect on the improvement of tool performance [1-3].

Coated tools have many characteristics, such as high surface hardness, resistance of wear, stable chemical performance, better heat resistance to oxidation, low friction factor, and low thermal conductivity [4]. As the main cutters, coated high-speed steel cutters have accounted for more than 80%, in which, the PVD technology, with its low processing temperature, usually has low effect on the performance of base material of cutters. Furthermore various kinds of process style have quite wide range of use [5]. After coating to cutters, it reduces the diffusion and chemical reaction between the cutter and workpiece, thereby reduces the wear of crescent slot [6].

In cutting process, because of the workpiece material inhomogeneity, the vibration of the workpiece and machine tool etc., the wear and tear for coating cutters are serious. The generation of micro cracks for cutters, then expansion of crack, and eventually resulting in coating cutters breakage, etc. Scholars both at home and abroad think that the emergence of above has the close relation with the stress of the coating tool, vibration and temperature change during the cutting process. The paper analyzes the reasons for the failure of coating cutter by finite element method. Finite element method based on variational principle, and modern computer technology combination with mechanics, which is an object discretization process of approximate solution at present. This study mainly uses Pro/ENGTNEER software to establish a cutters model, using Ansys software by finite element post-processing [7-10].

II. ANALYSIS ON PROCESS OF FINITE ELEMENT FOR COATING CUTTERS

In Pro/Engineer, the establishment of full-scale mock-up mainly includes the creation of coating cutter's entity model, definition of coating cutter's unit, coated cutter, body material of cutter, definition of constraints, finite element mesh loading, as well as definition of the finite element and file output. Using the command of adding materials, tensile to create the initial model of the cutting tools, and then using Boolean operations or turning and cutting process to machining the flute and flank of the cutting tools, then create the coating cutter entity PRT files. The unit of coating cutter parts are created as mmNs, setting the body material of cutter as hard alloy of WC-TiC-Tac-Co [11, 12].

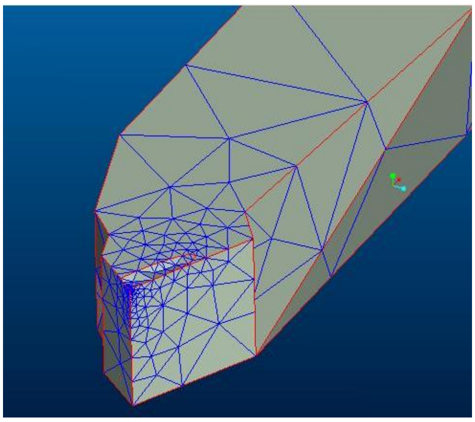


Fig. 1 Meshing of coating cutters

Click MECHANICA menu manager in the Pro/Engineer: Structure/model/constraints/new structure, selecting constraints type, four sides and the rear surface of the cutter body are made translational and rotational constraints. Then, in turn, click on the “structure”, and “new constructure”, enter the “new constructure analysis” dialog box. The type of analysis selects “structure, thermal, modal” [13, 14]. Then, click on the “structure”, “grid”, “control”, and meshing unit type selects “hybrid”, the tip part is carried on the refinement algorithm, the model of the cutter after meshing is shown in Fig. 1, the attribution of cutter material is defined as follows: hardness of HRC63-66, the flexural strength of 3.2-5.2 Gpa, elastic modulus of 550 GPa, and Poisson’s ratio of 0.3. Then loading to the cutter in the direction of X, Y, Z as follows: cutting force of 5000 N, feeding force of 1100 N, back force 1200 N.

III. ANALYSIS RESULTS OF FINITE ELEMENT

A. Statics Analysis of Coating Cutters

Coating cutters are loaded after definition of the attribution of the cutters, cutter body constraints, then analysis result of finite element can be given, and the stress contour map of coating cutters and the strain contour map of coating cutters are shown in Figs. 2 and 3.

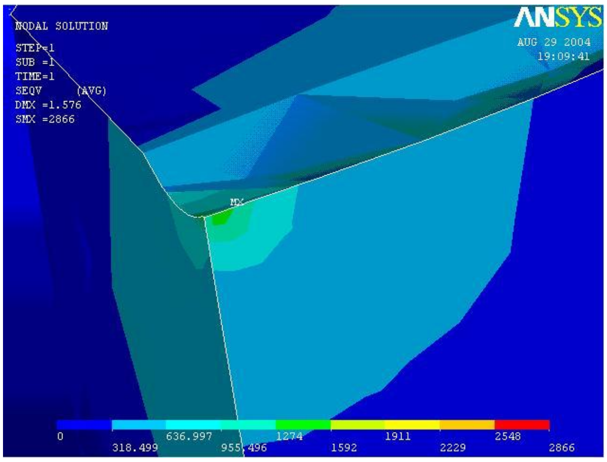


Fig. 2 Equivalent stress diagram of coating cutters

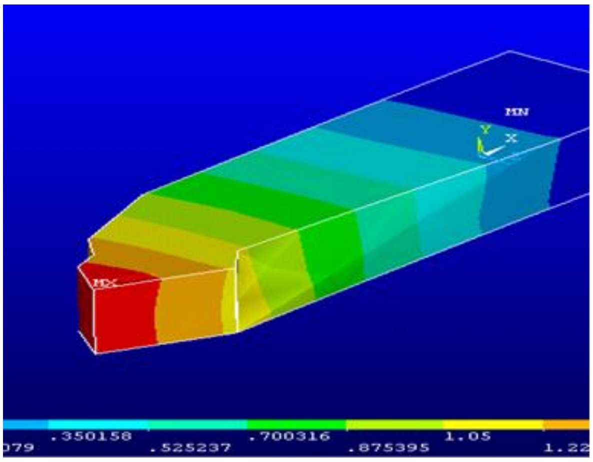


Fig. 3 Elastic strain diagram of coating cutters

From Figs. 2 and 3, the largest stress and strain is the part of cutter point, which decreases along the blade section. During actual operation, the coating surface of coated cutter point part is damaged under the role of tensile stress firstly, and then such damage is gradually expanded, leading to generation of transverse cracks on the coating surface, finally resulting in cutter failure.

B. Thermodynamic Analysis of Coating Cutters

Setting the thermal conductivity of the coated cutting tools to 26.5W/m·℃, thermal expansion coefficient to 1.65×10^{-5} /℃, the preset temperature at the flank of the cutting tool is room temperature 20℃, the temperature at the tip of the cutting tools set to 450℃, then create the thermal analysis finite element file, temperature, heat flow and other thermal analysis results shown in Figs. 4 and 5.

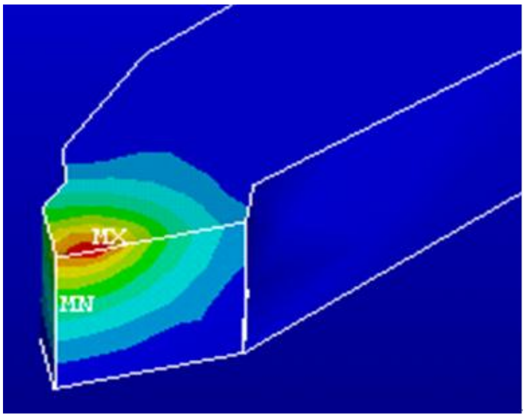


Fig. 4 Coating cutters' temperature distribution diagram

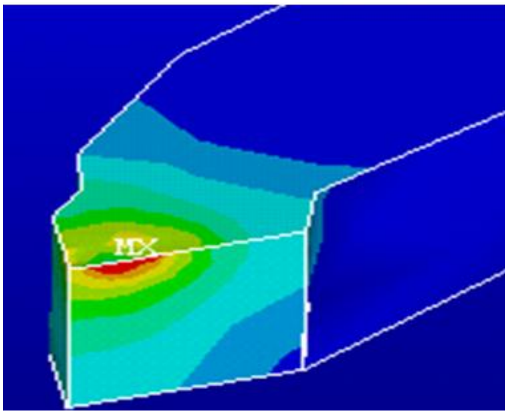
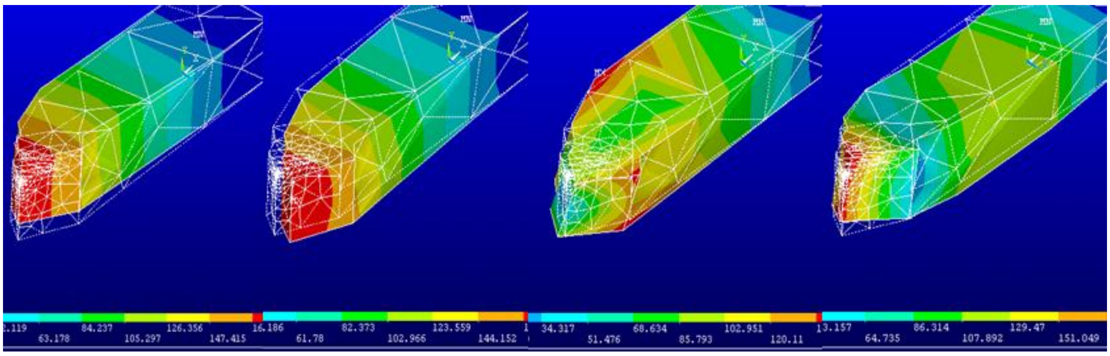


Fig. 5 Heat flow distribution diagram of coating cutters

It can be obtained from Figs. 4 and 5, coated cutter near the tip part of the main cutting edge has the highest temperature, and heat will flow to the cutter body. While coated cutters are cut, the temperature of main cutting edge rises sharply when cutting in the cutters, and when cutting out, the sharp decreasing of temperature or cooling by cutting fluid makes the coating cutters producing severe temperature change at a short period of time, and accordingly bigger thermal stress is generated, which caused coating spalling and failure, leading to wear and breakage of cutters.

C. Modal Analysis of Coating Cutters

During machine tool is processing to the workpiece, coating cutters is suffering a large load change, and it is easy to cause the cutter vibration, and such vibration reduces the durability of cutters, service life, and also the surface quality of workpiece, so it is also very important to analyze the natural frequency and type of vibration. In the cutting process, the maximum of kinetic energy directly determines the cutters' natural frequency of vibration, and the maximum of each vibration mode and natural frequency of vibration is inversely proportional, so the high frequency takes smaller effect than low frequency. Because of phase difference, and the positive and negative counteracted partially, the frequency reaches the maximum value, but other types of vibration don't reach the maximum value, so the first vibration mode plays the leading role. In order to ensure the accuracy of modal analysis, here four vibration modes are outputted, and the modal analysis results of coating cutters as shown in Fig. 6.



(the first vibration mode) (the second vibration mode) (the third vibration mode) (the fourth vibration mode)

Fig. 6 Coating cutters' modal analysis diagram

Fig. 6 gives the first to the fourth order of vibration mode of a cutter, natural frequency of each order for the cutter system is also shown in the figure, and it can be seen that the vibration of the machine tool is one of the main reasons for the failure of coated cutter. But after getting the natural frequency of the cutter, when cutting of machine tool, selecting cutting parameters of cutters, for example, spindle rotation speed of machine tool is much higher than the natural frequencies of the cutter, then the cutter can be effectively avoided resonance phenomenon, so as to improve the durability of coating cutters.

IV. FAILURE ANALYSIS OF COATING CUTTERS

Figs. 2 to 6 give the analysis results of finite element, that is, in the cutting process, the stress and strain of the cutter point and cutting edge part reach the maximum, and the temperature of cutter point is also the highest temperature, the temperature and the heat can transfer from cutter point and cutting edge parts to the cutter body. The vibration of cutter point is most intense, so the wear and breakage of coating cutters have a great relationship with above factors. The result conforms to the actual working condition of the cutter failure. As can be seen from the figures, the cutter is gradually wore and the crack generated thereafter, further leading to the wear of main cutting edge, front cutter surface and flank, and eventually resulting in the failure of the cutters. Figs.7 and 8 are given the failure form for two kinds of coating cutters.

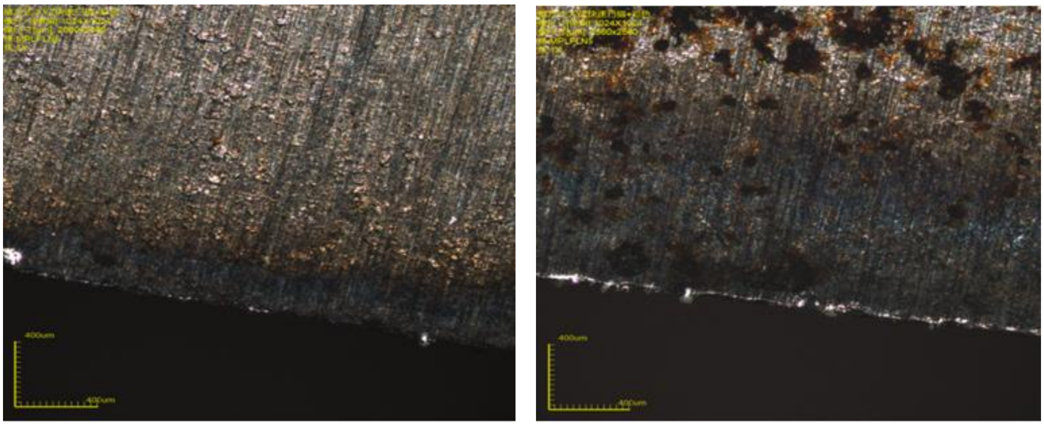


Fig. 7 Wear and tear of coating cutters

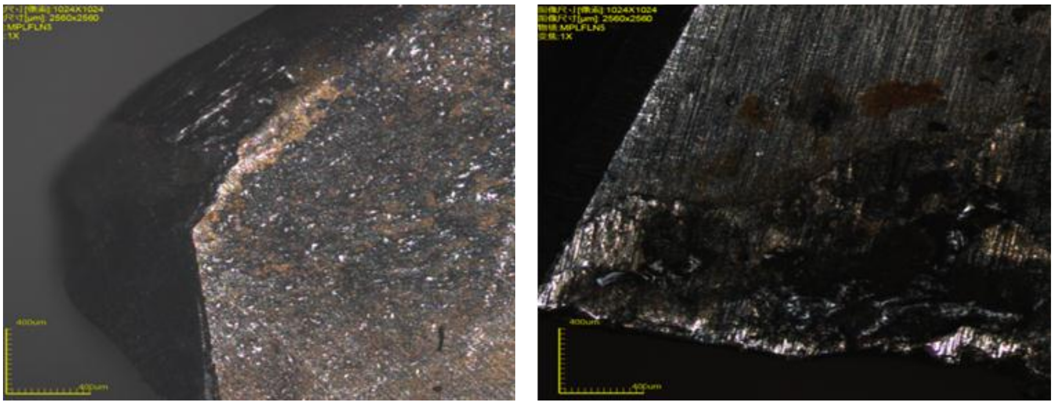


Fig. 8 Breakage of coating cutters

V. CONCLUSION

Finite element model of the coating cutters is established by the Pro/ENGTNEER, and the model is imported into the professional Ansys software, combined with the actual working conditions of the coating cutters in the process of cutting. By analysis of statics, thermodynamics and modal for the cutters, it can be found that the stress, strain and thermal wear in the cutter point and the cutting edge parts in the cutting process reach the maximum, and it is easy for the coating cutters to produce wear in this position, and also produce damage, where is stress concentration area. By finite element analysis, it can analyze the failure cause of coating cutter, as a result, it has a certain significance to predict and prevent machine tool from wear and breakage when cutting, and further to improve the durability and life of the coating cutters.

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