

Chipping of Sintered Cutting Tools - Mechanism and its Prediction -

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1. Introduction

The geometrical irregularity of cutting edge due to chipping is a significant factor that affects the quality of surface finish in precision machining. The single crystal diamond cutting tools are widely used for precision machining of aluminum and copper. The reason of the use of single crystal material is to assure the smoothness of the cutting edge. Besides, the sintered polycrystalline cutting tools are also used increasingly in an extended field of precision machining such as cutting of hardened steel. The cutting edge of sintered tool is tends to chip in this case because the cutting force is big and the cutting tool has a heterogeneous structure. Chipping of cutting edge is a significant problem for to assure the quality of surface finish in this type of machining.

Many research works (e.g. [1],[2],[3]) have been reported on the phenomena and the mechanism of chipping of cutting tools so far, and also many on-line methods that detects tool wear and chipping have been reported. Most methods use a monitoring principle that detects the abnormality of cutting signals such as cutting force. A big problem of this principle is that the monitoring equipment acts after chipping occurred. It has been pointed out that an important cause of tool chipping is the deterioration or the fatigue of the tool material in interrupted cutting [1],[2]. The deterioration of tool material at the cutting point should accompany the change of physical and chemical properties of the tool material at the same point.

From this point of view, the authors have contrived and tested a prediction method of chipping that measures the electric contact resistance between the tool point and an electrode [4],[5]. In this method, the detection is done prior to the occurrence of chipping. Afterwards, this method has been improved and a new non-contact method that measures the impedance of high frequency coil has been contrived. The object of this paper is to clarify the mechanism of the deterioration of the tool material through finite element analysis and microscopic structure observation, and to propose two prediction methods that detect chipping before its occurrence.

2. Finite Element Analysis

Most sintered cutting tools are composite material that is consisted of hard particles and ductile binding metal. A finite element analysis was carried out assuming that the principal cause of the deterioration or the fatigue is the in-homogeneity of the structure of sintered cutting tools.

Fig.1 shows the nose part of the cutting tool schematically. In the plane A, the normal stress σ and shear stress τ will act at the under part of contact zone when the cutting tool is exposed to the cutting force. Similarly,

the normal stress σ will act in the plane B. The finite element analysis was applied to these sections assuming that the stress distribution is uniform when the structure of the cutting tool is homogeneous. Fig.2 shows the finite element model used in this calculation. It was confirmed that the result of calculation agrees well with the theoretical one when the material is uniform, and when loading and supporting conditions are given as is shown in the figure. Fig 3 shows some results of the calculation. In these figures, ① shows the binding material, and ② shows the hard particles. The material constants are as follows:

- ① $E=210000 \text{ N/mm}^2$, Poisson's ratio: 0.3.
- ② $E=550000 \text{ N/mm}^2$, Poisson's ratio: 0.2.

The calculation is carried out as a problem of plane stress though the plane strain condition is also tried. The result of the calculation shows that the in-homogeneity of the structure of sintered cutting tool induces tensile stress near the grain boundary and inside of the hard particles. The generation of the tensile stress is repeated by interrupted cutting. Thus, the fatigue phenomenon or the deterioration of the structure will proceed. They are, the formation of cracks, development of cracks, formation of vacant places (holes) in the structure. These changes of the structure bring about the change of physical and chemical properties. This is the result and the implication of the finite element analysis.

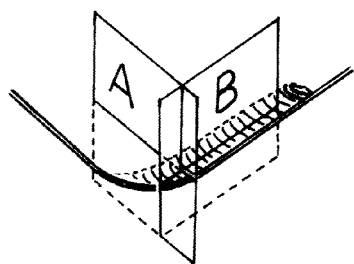


Fig.1 Nose of the cutting tool

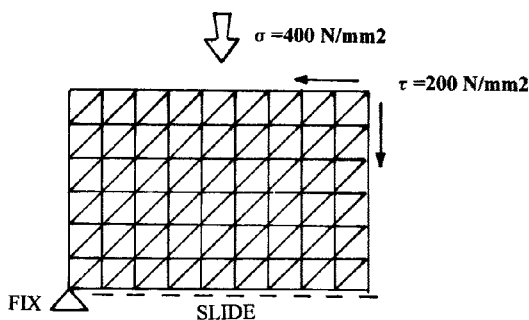


Fig.2 Model of Finite Element Analysis

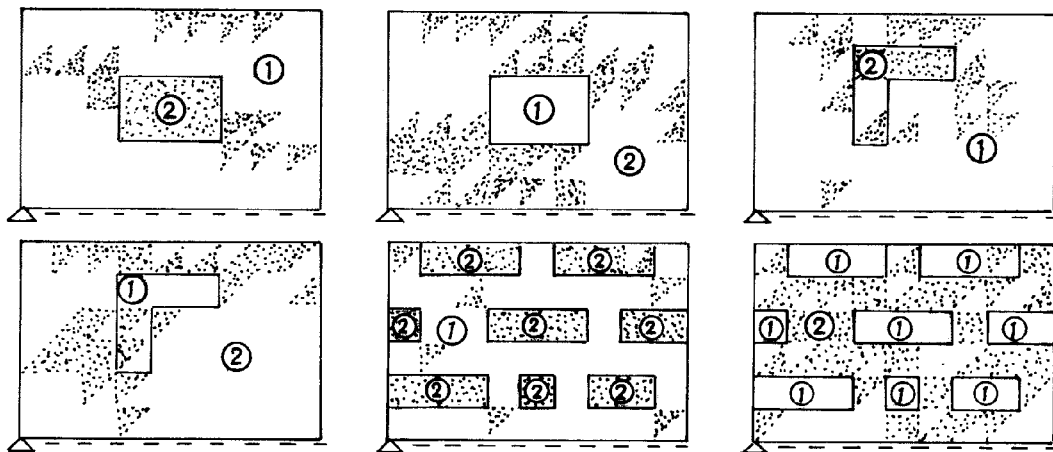


Fig.3 Results of calculation (at section A, Dotted Zone: $\sigma > 100 \text{ N/mm}^2$)

3. Change of Microscopic Tool Structure in Interrupted Cutting

The chipping phenomena and accompanied change of tool structure was examined with wide combination of tool materials and cutting conditions. In the test, the interrupted turning test was carried out using 0.55% carbon steel round bar as the work-piece. Four longitudinal grooves of 5mm width were cut on the work-piece previously for the above purpose. The cutting tool materials used in the tests are: (1) sintered carbide P10, (2) sintered carbide K10, (3) TiC,TiN cermet, (4) Al₂O₃, TiC ceramic and (5) TiCN coated tool.

The tool geometry and cutting conditions are as follows:

Tool geometry: -6,-6,6,6,15,45,0.8mmR, Cutting speed: 95, 135,200 and 300m/min.,

Feed: 0.1mm/rev., Depth of cut: 1mm, Cutting fluids: none.

The cutting test is stopped when chipping is observed, the rake face of the cutting tool is then polished by abrasive paper of #3000 slightly and examined under an Scanning Electron Microscope. A typical result of these tests is shown in Fig.4. In this case, the P10 tool is used and cutting speed is 300m/min, the cutting time is 2.4minutes.

According to the pictures, the change of the tool structure is clearly observed near the fractured part, that is, the formation of small cracks and vacant parts (many small holes) are observed as is predicted by the finite element analysis. This phenomenon is observed widely in the above combinations of cutting tools and cutting conditions.

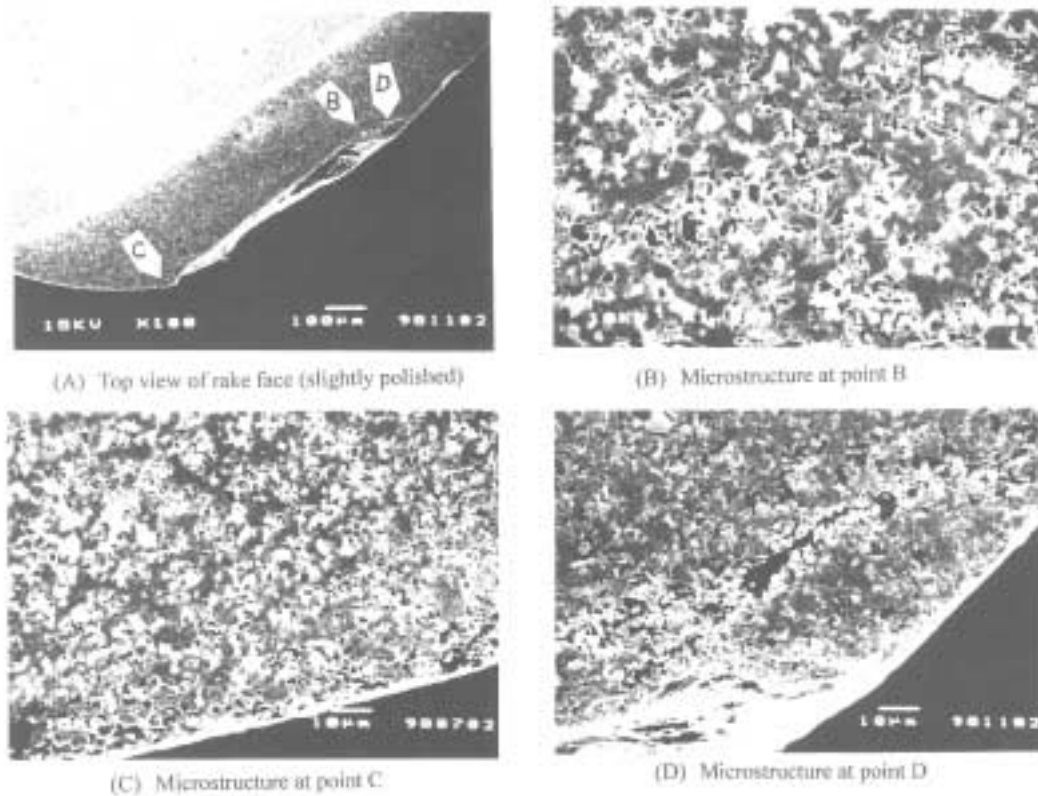
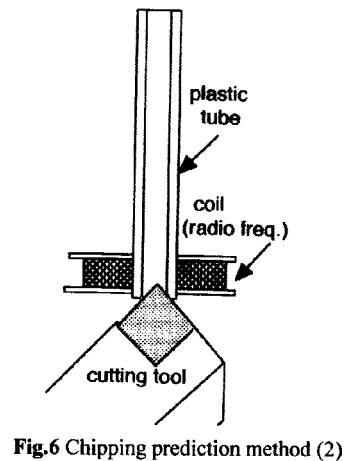
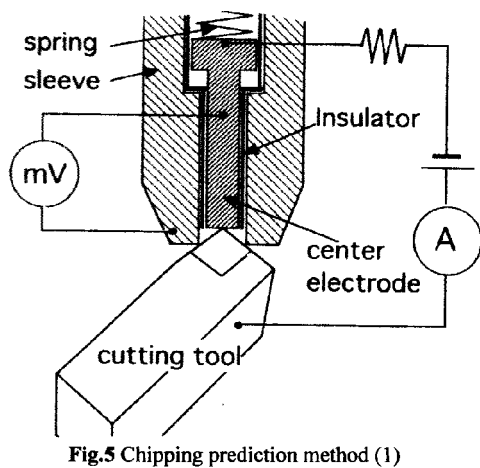


Fig.4 Microstructure of chipped cutting tool (rake face)

4. Prediction of Chipping

Two prediction methods are contrived and tested based on the above stated results. The change of the structure of cutting tools at tool point should accompany the increase of the electric resistance at that point. To detect the increase of the electric resistance, two methods were tested. The first one is a method that measures the electric contact resistance as is shown in Fig.5. The performance of this method was already reported in the literature [5]. According to the test, this method has high sensitivity to the deterioration of cutting tools, however, it is not suitable for coated cutting tools. The second method is then tested. This is shown in Fig.6 schematically. The tip of the cutting tool is inserted in the center hole of a detecting coil. The high frequency electric current (e.g. 300KHz) is applied to the coil and its impedance is measured. A bridge circuit is used for detecting the difference of the impedances of two coils. According to the test, it is found that this method has many advantages but it is important to raise the sensitivity by focusing the magnetic field.



5. Conclusions

The mechanism of chipping of sintered cutting tools in interrupted cutting is clarified through finite element analysis and microscopic observations. It is verified that the deterioration of the tool structure is the significant cause of tool chipping. Two chipping prediction method are proposed based on the above findings.

6. References

- [1] Uehara K., Kanda Y, On the Chipping Phenomena of Carbide Cutting Tools, *Annals of the CIRP*, 25/1, 1977.
- [2] Shirakashi T. et al., Analytical Prediction of Cutting Edge Chipping in Interrupted Turning Operation, (5th report), *J. of the Japan Soc. of Precision Engineering*, 48/10, 1982.
- [3] Bouzakis K.D. et al., Experimental and FEM Analysis of the Fatigue Behavior of PVD Coatings on HSS Substrate in Milling, *Annals of the CIRP*, 47/1, 1998,
- [4] Uehara K., Takeshita H., Prognostication of the Chipping of Cutting Tools, *Annals of the CIRP*, 38/1, 1989.
- [5] Uehara K., Obitsu N, Relationship between Catastrophic Fracture and Electric Resistance of Cutting Tools, *Proc. of the American Society for Precision Engineering*, Vol. 12, 1995.