ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume VII (XVII), 2008

THE ANALYZE OF THE TOOL WEAR MECHANISMS

Carmen TACHE[1], **Dumitru DUMITRU**[1]
[1]VALAHIA University of Târgovişte,
Faculty of Environment Engineering and Biotechnology
e-mail: carmen_tache@yahoo.com, ddumitru@valahia.ro

Keywords: wear mechanisms, cutting, tool wear

Abstract: Cutting tools experience various forms of wear during machining. Tool wear is defined as a gradual loss of tool material at workpiece material and tool contact zones [1].
There are several wear mechanisms that may occur simultaneously, or one of them may dominate the process. This paper identifies the main wear mechanisms of the cutting tool and analyzes the specific elements of them. For the analyzed mechanisms it is presents a model for the wearied tool.

1. INTRODUCTION

Cutting tools can be used only when their edges produce parts with specified surface finish and dimensional tolerance. When the quality of the cutting edge is lost due to wear, the tool reaches its limit and must be replaced by a new one.
In this paper, we will discuss about the mechanisms that lead to the tool wear.
Presently, no viable theories exist for predicting tool wear on the basis of properties of tool and work material. Optical and electronmicroscopic and autoradiographic observations suggest that the tool wear phenomena occurs at microscopic and atomic levels.
Each tool wear location such as wearland, crater, nose, notchand trailing (see Fig.1) involves a different wear mechanism. This is because the temperature, sliding velocity and stresses are different at each location [3],[8].
Also, the applicable mechanism for each location may be different for different tool materials, work materials, and machining speeds, feed, depths and cutting fluid. This multiple nature of tool wear phenomena has led to a number of possible mechanisms but, however, no predictive theories have evolved as yet.

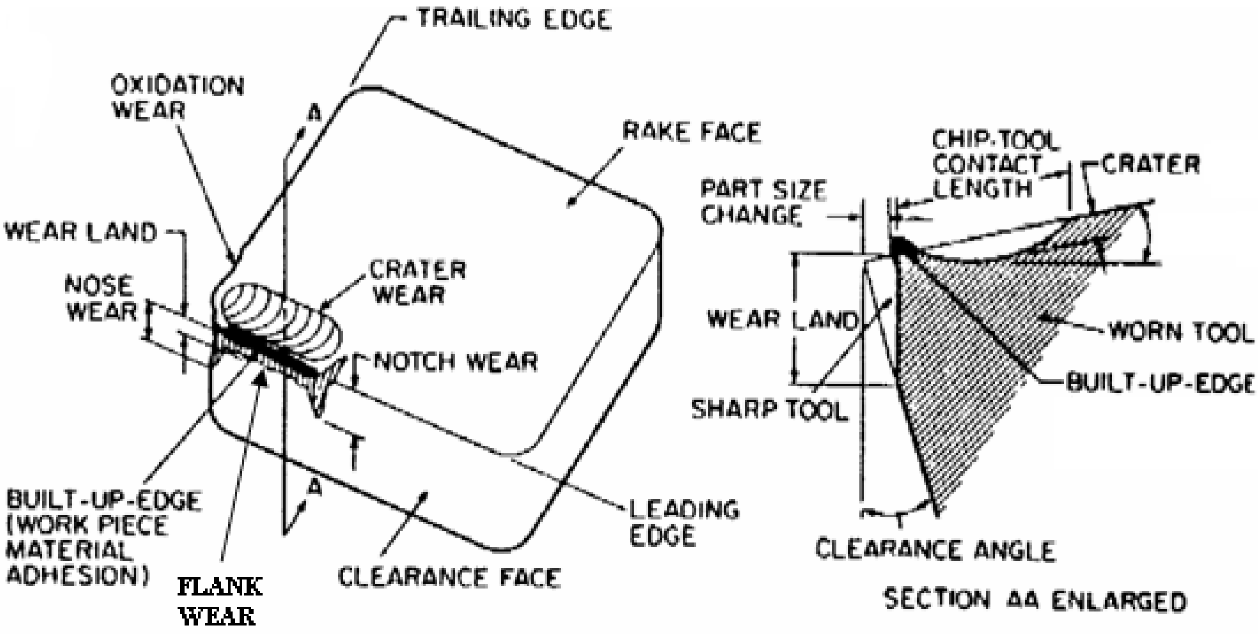


Figure 1: Typical wear patterns of turning tool (carbide insert)

Lim and Ashby consider that two major forms of wear are commonly observed on a cutting tool: flank wear and crater wear [3]. This is illustrated in Fig.1. Flank wear (occuring on the major and minor flank of a tool) generally causes an increase in the cutting force and the interfacial temperature, leading normally to dimensional inaccuracy in the workpieces machined and to vibration which makes the cutting operation less efficient. Crater wear takes place on the rake face of the tool where the chip moves over the tool surface. A crater is ussualy formed at some distance from the cutting edge (Fig.1) and it is most frequently observed when cutting steels and other high-melting-point metals at relatively high cutting speeds [4]. This crater gradually becomes deeper with time and may lead to the breakage of the cutting edge, rendering the tool useless.

2. THE WEAR MECHANISMS

Holmberg and Matthews [2] develop four main mechanisms of tool wear namely adhesive wear, abrasive wear, delamination wear and wear due to chemical instability, including diffusion, solution and electrochemical wear as shown in Fig.2.

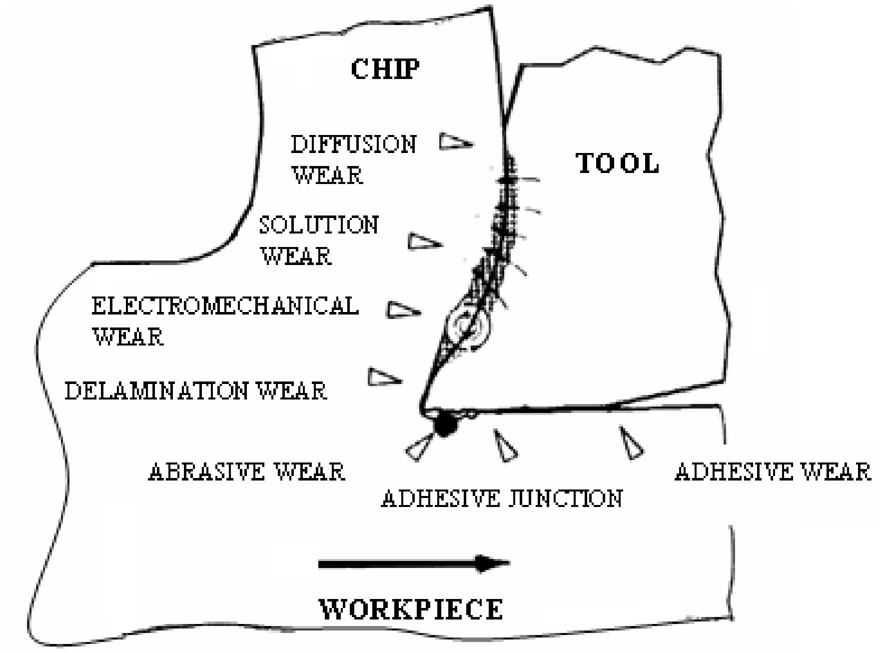
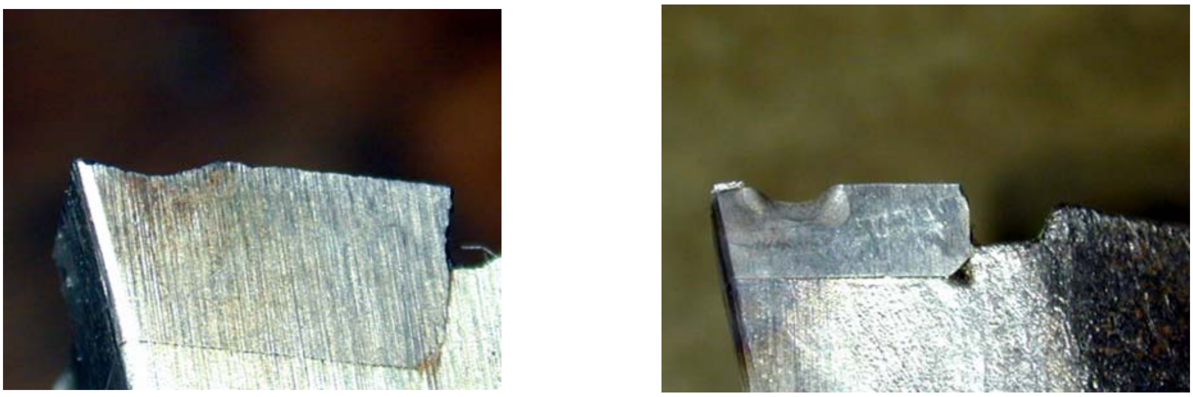


Figure 2: The different mechanisms of tool wear

Adhesive wear is caused by the formation of welded asperity junctions between the chip and the tool faces and the fracture of the junctions by the shearing force so that tiny fragments of the tool material are torn out and adhere to the chip or the workpiece (Moore, 1975). This kind of wear may occur at the flank face in low speed cutting when the contact temperatures are not so high. It may involve oxidation of the tool surface, or other chemical interaction with the surrounding atmosphere, followed by mechanical removal of the products of the reaction (Trent, 1979: Suh, 1986; Thangaraj and Weinmann, 1992).

Another point of view regarding the adhesion wear is presents by Yusuf Altintas [1] and represents the analyze making by Oxley [5]:

When there is a relative motion between the two bodies that are under the normal load, fragments of softer workpiece adhere to the harder tool. The adhered material is unstable, and it separates from the cutting tool and tears small fragments of the tool material. The typical example in metal cutting is a built-up edge, which usually occurs at low cutting speeds when part of the chip material welds to the cutting edge. Depending on the size and stability of the built-up edge, either the forces decrease because the effective rake angle becomes positive or the lumped built-up edge dulls the tool and increases the forces. An unstable, large built-up edge occurs close to the cutting edge at low speeds where the tool-chip interface temperature is low. The material is still strong at this point and difficult to move over the rake face. As the chip moves over the rake face, the chip-tool interface temperature increases, leading to a softer chip, which is easier to move. As the cutting speed is increased, the magnitude and length of the built-up edge becomes smaller and localizes close to the cutting edge. Predicting the tool chip interface tempreature is therefore important in identifying cutting speeds where the built-up edge is minimum.



Flank wear ***Tool wear because of built-up edge***

Figure 3: The wear of cutting tool determined by adhesion and built-up edge

Abrasive wear on the tool surface is caused by hard particles in the work material. Their effect on the tool wear can be explained theoretically by three abrasion models, these are micro ploughing, micro chipping and micro cracking (Knotek, 1993). Many work materials (cast iron, steel), contain particles of phases which have a hardness that is much higher than of the workpiece. The particles can typically be carbides or oxides, particularly Al_2O_3, but also silica and some silicates (Trent, 1979).

The particles may also be highly strain-hardened fragments from an unstable built-up edge on the tool (Moore, 1975). In particular the wear at the flank face may be attributed to abrasive wear. In abrasive wear the influence of tool surface hardness is considerable (Budinski, 1980; Kramer, 1986; Konig and Kammermeier, 1992).

Figure 4: Abrasive wear of the cutting tool

Abrasion [1] occurs when a harder material (the tool) shears away small particles from the softer work material. However, softer work material also removes small particles from the tool material although at a smaller rate. The hard tool particles are caught between the hard tool and soft workpiece, and this causes additional abrasion wear. Tool and workpiece contain carbides, oxides, and nitrides with hard microstructures; these cause abrasion wear during machining.

Diffusion wear characterizes the material loss due to diffusion of atoms of the tool material into the workpiece moving over it. Requirements for diffusion wear are metallurgical bonding of the two surfaces so that atoms can move freely across the interface, a temperature high enough to make rapid diffusion possible, and some solubility of the tool material phases in the work material (Trent, 1979; Subramanian, 1993).

In a theoretical model of diffusion wear proposed by Kramer and Suh (1980) and Kramer (1986) the wear rate is considered to be controlled by the mass diffusion rate. However, tool wear prediction according to the model is not in agreement with experimental results reported by Sproul (1987), Ono and Takeyama (1992) have shown that in diffusion wear at the minor flank (relief face) of the tool the chemical reaction taking place at the interface has a major effect on wear. They showed that oxygen gas accelerates the formation of oxide layers that are continuously torn off resulting in increased wear, whilst wear is decreased by an environment of argon gas.

From the analyze proposed by Altintas (2000), the diffusion wear appear when the temperature of the tool and workpiece increase at the contact zones, the atoms in the two materials become restive and migrate to the opposite material where the concentration of the same atom is less.

Typically, in a tool material such as tungsten carbide (WC), where carbide (C) provides the hardness, while cobalt (Co) binds the WC grains, carbon diffuses to the moving steel chips, which have less concentration of the same atoms. Progressive diffusion of the tool materials into the chip gradually leads to a weakened cutting edge and eventual chipping or breakage of the tool.

Figure 5: Diffusion wear of the cutting tool

Solution wear describes the wear mechanism taking place when the wear rate is controlled by the dissolution rate rather than by convective transport (Kramer, 1979; Kramer and Suh, 1980).

Electrochemical wear is due to a thermoelectric emission generated at the chip-tool junction causing electric currents to circulate resulting in the passage of ions from the tool surface to the workpiece material. This may result in breakdown of the tool material and scaling of the tool surface at the tool – chip interface (Moore, 1975). The thermoelectric current is formed at the chip-crater contact and at the flank-workpiece contact and its intensity has been found to be as high as 5A with the tool being of negative polarity (Opitz, 1975: Shan and Pandey, 1980; Uehara, 1992).

Delamination wear is due to plastic deformation of the surface leading to subsurface crack nucleation propagation and the liberation of tiny flakes from the tool surface. This has been observed when high speed tools soften due to annealing during machining (Suh, 1986).

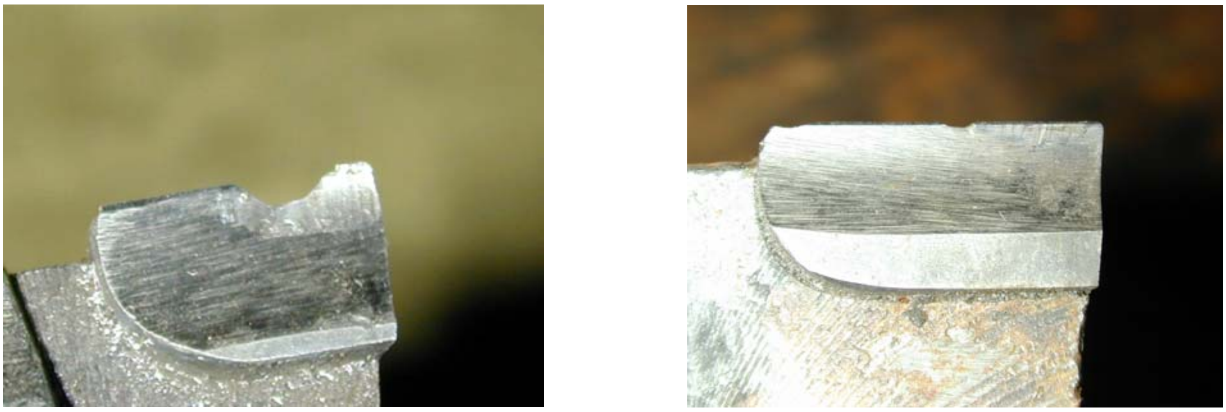


Figure 6: The wear of the cutting tool determined by electrochemical instability

3.CONCLUSIONS

The most typical models of tool wear in metal cutting are the ***flank wear*** at the front of edge of the tool and ***crater wear*** at the tool face.

Flank wear is caused by friction between the flank face (primary clearance face) of the tool and the machined workpiece surface. At the tool flank-workpiece surface contact area, tool particles adhere to the workpiece surface and are periodically sheared off. Adhesion of the tool and workpiece materials increases at higher temperatures. Abrasive wear occurs when hard inclusions of work material or escaped tool particles scratch the flank and workpiece surface as they move across the contact area. Although adhesive and abrasive wear mechanisms are predominant in flank wear, some diffusion wear also exists [1]. It is the dominating wear mode at low cutting speeds (Thangaraj and Weinmann, 1992).

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. At higher speeds, the temperature on the rake face of a carbide tool may reach over 1,000°C. At these high temperatures, the atoms in the tool continuously diffuse to the moving chip. 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 [1]. Crater wear is caused primarily by the dissolution of tool material by diffusion or solution wear since it occurs in the region of maximum temperature rise (Subramanian, 1993).

Crater wear is the formation of a groove or a crater on the tool face, typically some 0.2 to 0.5 mm from the cutting edge, at the place where the chip moves over the tool surface.

Crater wear can be minimized by selecting a tool material that has the least affinity to the workpiece material in terms of diffusion.

Mapping of wear data for flank or crater wear of uncoated high-speed-steel (HSS) cutting tools, during dry turning operations is presents by Lim (1993), (Fig.6).
The map for flank and crater wear for HSS tools can be useful because shows that by suitable choice of cutting parameters a safety zone with low wears can be reached.

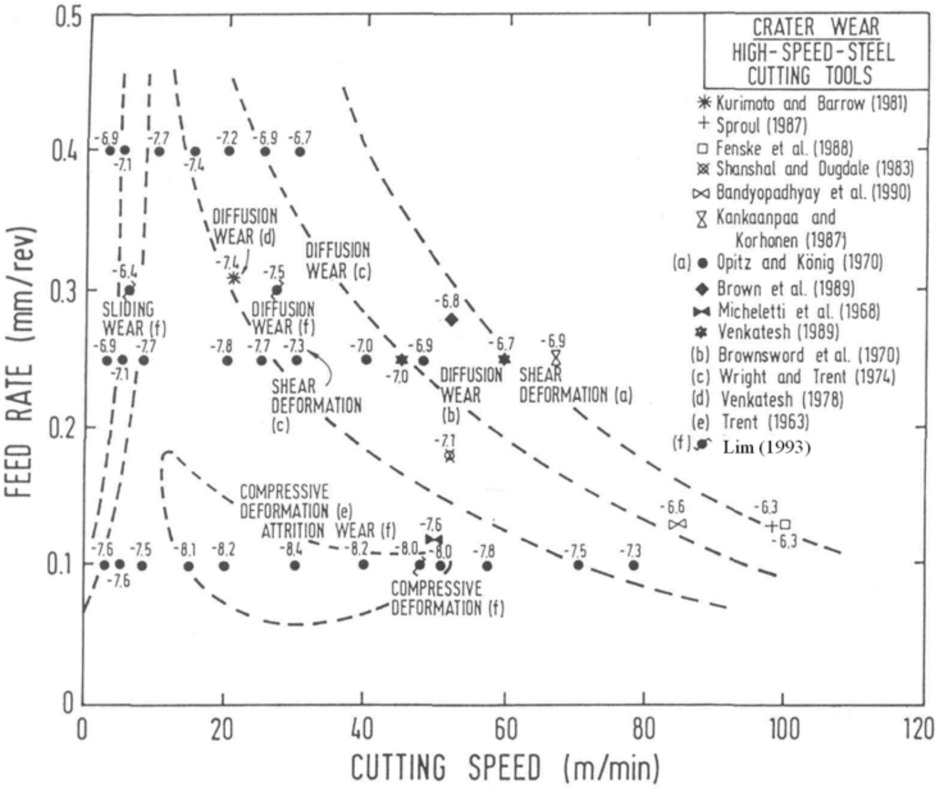


Figure 6: The wear map of uncoated HSS cutting tools during dry turning operations [4]

REFERENCES

[1] Altintas, Y., (2000), *Manufacturing Automation-Metal Cutting Mechanics, Machine Tool Vibrations, and CNC Design.* Cambridge University Press, ISBN 0-521-65973-6, Cambridge, pp.54-59.

[2] Holmberg, K., Matthews, A., (1994), *Coatings Tribology – Properties, techniques and Applications in Surface Engineering*. Tribology Series, no.28, part II, United Kingdown, pp.354-358.

[3] Lim, S.C., Ashby, M.F., (1987), *Wear Mechanism Maps*. Acta metall, Vol. 35, No.1, pp. 1-24.

[4] Lim, S.C., Lee, S.H., and al., (1993), *Wear maps for uncoated high-speed steel cutting tools*. Wear, no.170, p.137-144.

[5] Oxley, P.L.B., (1989), *The Mechanics of Machining.* Ellis Horwood Limited.

[6] Petre, I., Tache, C., (2001), *Sinteză privind modele de uzare termomecanică a sculelor aşchietoare*. Lucrările Sesiunii Anuale de Comunicări Ştiinţifice cu Participare Internaţională, IMTOradea, 24-26 mai, Analele Universităţii din Oradea, Fascicola Mecanică, Secţiunea: Mecanisme, Organe de Maşini, Tribologie, ISSN 1222-5517, pp.131-135.

[7]Tache, C.,(2002), *Contributii privind studiul uzurii termomecanice a sculelor cu aplicatii la* strunjire. Teza de Doctorat, Universitatea Politehnica Bucuresti.

[8] Tache, C., (1999), *The models of wear mechanisms*. Analele Universităţii Valahia, Târgovişte, Vol.II, Nr. 9, ISSN 1453-8202, pp. 165-175.

[9] Tache, C., Tudor, A., Tache, A., (1999), *A Synthesis concerning the wear mechanisms of the turning cutting tools*. The 3rd International Conference of Tribology, BalkanTrib'99, 2-4 iunie, Sinaia, România, Buletinul Universităţii "Petrol-Gaze"Ploieşti,Vol.LI-1999, Nr.3, ISSN 1221-9371, pp. 63-70.

[10] Trent, E., M., (1983), *The tribology of metal cutting.* Industrial tribology, The Practical Aspect of Friction, Lubrication and Wear, Elsevier, Amsterdam, pp.446-470