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CUTTING LIFE IMPROVEMENT OF MACHINE TOOLS

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ABSTRACT

Machining without the use of any cutting fluid (dry machining) is becoming increasingly more popular due to concern regarding the safety of the environment. Because of this demands for increasing tool life without use of coolants are arising. This paper is an attempt to review the different techniques employed to improve the tool life. The paper begins with reviewing tool wear, different methods to measure wear, and different approaches employed to improve tool life such as tool geometry, machining parameters, edge honing, and thin film coating

Keywords: cutting tool, tool wear, edge honing, and coating.

INTRODUCTION

In industrial production, selection of appropriate manufacturing operation plays an important role in achieving better quality and economical benefits. Most of the manufacturing operations deal with metal shaping and processing with specified geometric dimensions and tolerances. Therefore, enhancing the performance of machining operations economically is an important goal. In machining operations, the cutting tool is the key component which limits the performance because of exposure to different stresses. Many studies have been focused on improving the performance of machine system by modifying tribological conditions. Many attempts have been made to improve machining performance by revamping the tool geometry, material, edge honing, using coolants, optimizing machine parameters and applying thin film coating. The use of coolants is not taken for the review as coming researches are leading towards dry machining or MQL [1].. Even coolants have shown some adverse effect on the environment and human health. Before beginning to approaches to improve tool life, first we have to know wear occurring at the tool surfaces.

TOOL WEAR

Tool wear is a combination of physical and chemical processes which remove small parts of material from the edge of the tool. According to standard DIN 50320 the cutter wear is defined as “forced diminishing of the cutting material resulting from the contact between the cutter and the cut part and from relative motion of the tool against workpiece”. Tool wear has a large influence on the economics of the machining operations. Prediction of tool wear is complex because of the complexity of machining systems. Tool wear in cutting process is produced by the contact and relative sliding between the cutting tool and the workpiece and between the cutting tool and the chip under the extreme conditions of cutting area; the temperature at the cutting edge can exceed 1000°C. Thus, knowledge of tool wear mechanisms and capability of predicting tool life is important and necessary in metal cutting. It is estimated that 50% of wear is caused by abrasion, 20% by adhesion and 10% by chemical action, while the remaining 20% is comprised of all the other mechanisms (especially diffusion). Establishing the point at which the tool is considered worn is important, since after this point, machining results are no longer acceptable. Ingle et al. [2]

The real cause and exact percentage of wear from each source are very difficult to ascertain. Wear is a negative phenomenon on the cutting tool and depends on:

- Cutting tool/workpiece material combination,
- Cutting parameters (speed, feed, and depth of cut),
- Cutting fluid,
- Temperature at the cutting edge.

TOOL LIFE EVALUATION

In manufacturing tool life measured in terms of time, length of path travelled, or no of components produced, it depends on application. Evaluation of tool life in machining operation is a key task some time it needs skill of operator also. According to DIN 6583 standard, the tool life criterion under the influence of tool life conditions, tool life parameters are used. Tool life parameters are time, quantities or paths achieved in chipping under specified conditions until a tool life criterion is reached. These parameters include:

- The tool life
- The tool life travel path
- The tool life volume
- The tool life quantity

Tool life is a measure of wear takes place at cutting edge surfaces, which can be measured directly or indirectly by various means[4]. Indirect method wear is measured by seeing rake and flank surfaces under microscope. Indirect methods for determining wear are correlating with process parameters such as surface finish of workpiece, cutting forces, acoustic emission, temperature, vibration, spindle motor current, cutting conditions, torque, strain and snapshot images of the cutting tool etc are different ways. Out of these direct wear measurement is mostly convenient andaccurate. Michelet have discussed the direct and indirect methods of tool wear measurement using various tool wear sensors, radio isotopes as tracers, chemical analysis of tool particles carried by chip, detection probe microscope, and weighing of the tool before and after machining, etc.

Torque, drift and feed force together with strain measurement are all measures of cutting forces, change in cutting forces is observed as tool wear progresses[6], [7]. Spindle motor and feed drive current are also closely related to forces generated in machining, so they can also treat for measuring wear. D. Cuppini et al. correlated tool wear with the power required for cutting in turning [8].Luis Alfonso Franco-Gasca described a driver current signal analysis to evaluate the tool condition by using the discrete Wavelet Transform in order to extract the information from the original cutting force, and through an autocorrelation algorithm evaluate the tool wear in the form of an asymmetry weighting function[9].The current is monitored from the motor driver to give a sensor-less approach.

Researchers have also shown that AE, which refers to stress waves generated by the sudden release of energy in deforming materials, has been successfully used in laboratory tests to detect tool wear and fracture in single point turning operations. The relationship between the AE signal and tool wear is complex [10]. Monitoring tool wear with the help of analyzing tool vibration and workpiece surface roughness are also reported [11].

TOOL MATERIAL

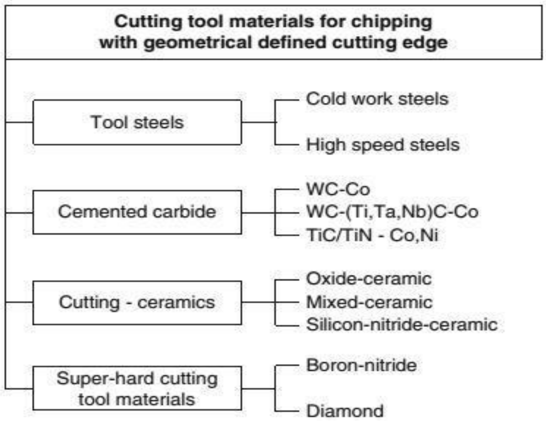
Cutting tools influence the production costs significantly in dependence of their properties as hardness, strength, ductility, wear resistance and reliability. Increasing application of high strength steels and of austenitic steels in automobile industry lead to an increasing wear (abrasion and adhesion) cutting tools. It is necessary to develop tools without and with coatings to shield them against the higher wear load. The cutting tool materials can summarize as follows [12]

- Tool Steel
- Cemented Carbide
- Ceramics
- Boron Nitride and Diamond.

Steel is further categorized under cold working, hot working and high speed steel group. Cold and hot working steel are used under 200ºC. High speed steel can be used temperature range up to 600 ºC. Main alloying element in steel are Tungsten(W), Molybdenum(Mo), Vanadium(V),Chromium(Cr), Cobalt(Co) and Carbon(C). Amount of alloying element influences cutting properties of HSS.

- Cemented Carbides

In 1927, Cemented Carbides were first introduced as new high performance cutting tool materials at the Leipzig Trade Fair under the name WIDIA. This was a revolutionary development at the time, opening up completely new dimensions in cutting technology. Materials such as chilled cast iron, which had been very difficult to cut with HSS tools, could be machined easily with the new cutting tool material. Machining long chipping material like steel was difficult for WC-Co because of its high crater wear, but alloying with TiC made it easy. Further development of cemented carbides in the following years led to continuous improvement of their composition, production and cutting performance. By reducing WC crystallite size to under 1μm, both hardness and bending strength could be increased with the same amount of binder makes it applicable for high variety of task [1], [10]



Classification of cutting tool materials for machining

The cemented carbides are divided in hard metals, which contain only carbides (WC, TiC, TaC, NbC) in a Co or Ni matrix and cermets which contain in addition nitrides in a Co or Ni matrix. In comparison with WC cemented carbides the cermets have a higher chemical resistance at high temperature and higher cutting speed. There exist according to DIN ISO 513 six groups (P, K, M, N, S, H). These groups indicate the cutting conditions and the application possibilities: P = long chip (steel and cast steel), K = short chip (cast iron), M = mixture (stainless steel, austenitic steel, duplex steel), N (non iron metals), S (special alloys, ex. titanium), H (hard materials, e.g. hardened steel). The number after the letter describes the wear resistance and the toughness. A higher number means lower wear resistance and better toughness.

- Ceramics

The main application field of ceramics is the rough machining and the finishing of cast iron and high temperature resistant nickel alloys. To reach a very high cutting speed, low wear and high tool life it is possible to use ceramics. The ceramics are divided in oxides, nitrides and carbides with combinations e.g. Al_2O_3, ZrO_2, Si_3N_4, TiC, TiN etc.

- Diamond and C-BN

Diamond tools, i.e. polycrystalline or mono crystalline diamond, are ideal tools for machining non-ferrous materials and are widely used in metal cutting, aluminum and composite machining. Diamond has the highest hardness, E-modulus and thermal conductivity of all hard materials. However, diamond exhibits some disadvantages, which are mainly its poor fracture toughness, high chemical affinity to ferrous materials and thermal instability beyond 700ºC. C-BN is the second hardest of all known materials, has a high wear resistance and a high thermal stability – this material is very promising for a broad range of applications, especially for cutting tools (milling), both as bulk and as a coating material.

TOOL GEOMETRY

The geometry of cutting tool gives an idea about uncut chip thickness and width, direction of chip flow, cutting forces and surface finish. The geometry of the cutting tool affects tool life directly as this geometry defines the magnitude and direction of the cutting force and its components, sliding velocity at the tool-chip interface, the distribution of the thermal energy released in machining, the temperature distribution in the cutting wedge, etc.

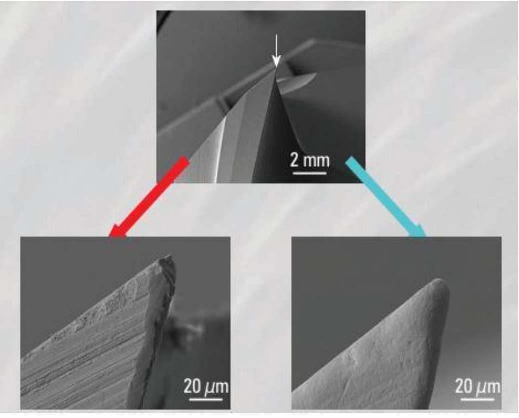
Very often in research papers and books, it is almost never mentioned what kind of angle is listed (Normal, or Orthogonal Rake) and in what particular system (T-hand-S, T-mach-S or T-use-S) is considered. Little attention is paid to the fact that many parameters of tool geometry are interrelated. For example, when one studies the influence of the drill (reamer) point angle, the T-hand-S normal rake and flank angles remain the same in such a study. However, the fact that the T-mach-S (T-use-S) rake and flank angles change significantly with the drill point angle is normally neglected. A direct relationship between tool geometry and wear is not widely reported. To know the influence of cutting edge angles on the tool performance many attempts have been made. Makarow found that there is a relation between major cutting edge angle (k_r) and optimum cutting temperature. The minor cutting edge angle (k_{r1}), it was found that being varied in the practically used range of 5–45◦, this angle has negligibly small influence on the optimal cutting speed and tool wear rate. The cutting edge inclination angle (λ_s) defines the orientation of the tool rake face with respect to the cutting speed vector and decides chip flow direction. The flank angle (α) does not affect the cutting temperature directly; it does affect the dimension wear rate. The tool wear rate increases as flank angle increases.

MACHINING PARAMETERS AND STRATEGY

For a given combination of the tool and work material, there is a cutting temperature referred to as a optimal cutting temperature, at which minimum tool wear occurs as said by Makarow [12]. This optimum temperature is obtained by selecting correct cutting speed and feed. Many attempts have been made to obtain this optimal cutting temperature [18]. In milling, the tool performance is also depends on the path of the cutting tool which is employed machining. The movement of tool path in which the machining is carried is called machining strategy. The machining strategy also improves the tool life, the surface quality of workpiece and substantially reduces the machining time, if employed correctly. There are three main cutter path strategies that are commonly employed in industries namely, offset, raster and single direction raster. The analytical analysis on the cutter path strategies has been mainly on the evaluation and determination of the best cutting angle orientation on a plane surface. A substantial amount of literature study focuses on the entrance and exit effects when the cutter enters or exits a corner. In inclined machining, it can be concluded that tool life is optimum when machining in a vertical upward orientation at an inclined workpiece angle of 15º. When machining at a workpiece inclination angle of 45º, or above, the general consensus is that downward orientation in particular the horizontal downward orientation is preferable in terms of longer tool life [19].

EDGE HONING

The sharp cutting edge is highly prone to fracture due to stress concentration and micro cracks left after grinding. When a radius is applied to the edge, coatings adhere properly to this transition surface between the rake and flank faces. This is particularly important for the chemical vapor deposition (CVD) process, so the edge must be rounded before this final manufacturing step. There are two types of edge hone shapes used currently in industry Radius Hone and Waterfall shape. The main benefit of a waterfall-shaped hone is that the honing process leaves more tool material directly under the cutting edge, which further strengthens the corner. Edge honing increases the tool life by 40% in Ti-Al alloy machining (cc). Although cutting edge preparation type and its geometry has significant (up to 400%) influence on tool life and quality of machined parts [21], these are rarely reported in the known studies. Below figure shows improved surface finish after edge honing.



Coating Machining efficiency is improved by reducing the machining time with high speed machining. When cutting ferrous and hard to machine materials such as steels, cast iron and super alloys, softening temperature and the chemical stability of the tool material limits the cutting speed. Therefore, it is necessary for tool materials to possess good high-temperature mechanical properties and sufficient inertness. The machining of hard and chemically reactive materials at higher speeds is improved by depositing single and multi-layer coatings on conventional tool materials to combine the beneficial properties of ceramics and traditional tool materials. Schintlmeister et al had summarized the effect of coatings in the following statements:

1. Reduction in friction, in generation heat, and in cutting forces
2. Reduction in the diffusion between the chip and the surface of the tool, especially at higher speeds (the Improving Cutting Tool Life a Review 70 coating acts as a diffusion barrier)
3. Prevention of galling, especially at lower cutting speeds.

SURFACE FINISH

Surface roughness and tolerance are among the most critical quality measures in many mechanical products. As competition grows closer, customers now have increasingly high demands on quality, making surface roughness become one of the most competitive dimensions in today’s manufacturing industry. There are several measurements that describe the roughness of a machined surface. One of the most common is the arithmetic average (AA) value usually known as Ra. The AA value is obtained by measuring the height and depth of the valleys on a surface with respect to an average centerline. The higher the AA value is, the rougher the machined surface. Figure shows a magnified cross section of a typical machined surface. Where h is the peak to valley height, hCLA the centre line average roughness, f the feed and R the nose radius. This show that surface roughness is primarily dependent on feed rate and tool nose radius. However, the above equations give ideal surface finish values under satisfactory cutting conditions. The tool wear influences the surface roughness of the work piece and the value of surface roughness is one of the main parameters used to establish the moment to change the tool in finish turning. Carbide tool wear may occur by the mechanical detachment of relatively large fragments of tool material (attrition wear). This causes the surface roughness to increase significantly and promote the formation of ridges. The geometry of tool wear also causes a change in surface roughness as machining time elapses. Flank wear is along with groove wear are the types of wear that most influence this change in surface roughness. Some studies have claimed that the change in surface roughness is primarily caused by cutting-tool flank wear.

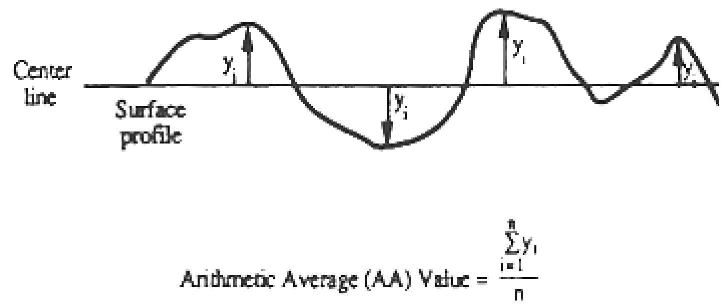


Figure 2- 3 Illustration of surface roughness [30]

CONCLUSION

This paper gives a state-of-art and the recent developments towards dry machining. At optimum cutting temperature tool gives better tool life. Machining performance can be enhanced by selecting proper cutting parameters and machining strategy. Tool life is optimum when machining in a vertical upward orientation at an inclined workpiece angle of 15º. When machining at a workpiece inclination angle of 45º or above. Further, the edge honing of cutting edge will leads to improvement in tool life. Edge honing for carbide drills and end mills have shown 40-60% improvement in tool life. Some research needs to carry in the direction to decide optimum cutting edge radius with respect to work materials. The thin film coating is an emerging field which aims to reduce the cutting temperature and prevent the different wear occurring at the tool surfaces. New developed super hard coatings from nano-composite have shown greater hardness, better wear resistance and lower coefficient of friction.

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