

“Review of Different Approaches to Improve Tool Life”

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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.

I. 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.

II. 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] investigated crater wear, which is a major contributor to tool wear.

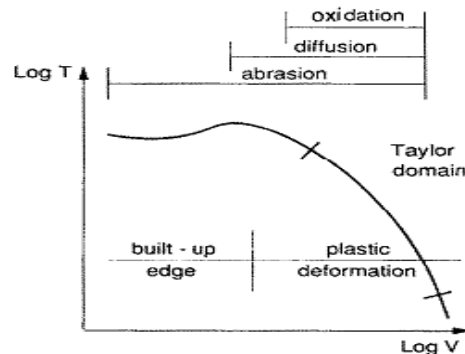


Figure 1: Tool life vs speed for hard metal tools and possible mechanism of tool wear [3].

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.

Total wear is a result of mechanical (physical) and chemical interactions of the tool with the workpiece and can be written as:

$$W_{tot} = W_{mech} - W_{chem}$$

Where,

W_{mech} is thermodynamic wear (mostly abrasion) and

W_{chem} is thermo-chemical wear resulting from chemical interactions between the tool, workpiece and environment.

Tool wear mechanisms in metal cutting include abrasive wear, adhesive wear, solution wear, diffusion wear, oxidation wear, etc. .

III. 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 [DIN6583]:

- The tool life,
- The tool life travel path,
- The tool life volume, and
- 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. In direct method wear is measured by seeing rake and flank surfaces under microscope [4]. 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 and

accurate. Micheletti et al.^[5] 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].

IV. 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 200°C. High speed steel can be used temperature range up to 600 °C. 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]}.

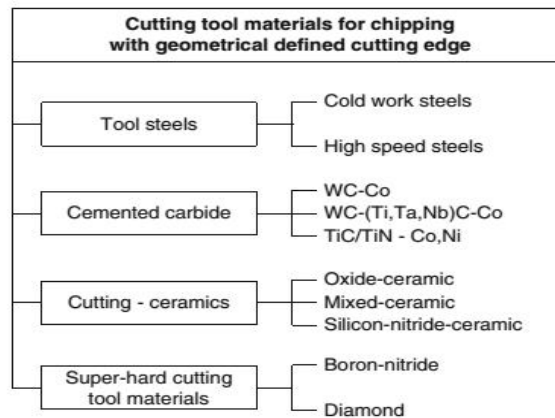


Figure 2: Classification of cutting tool materials for machining ^[13].

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. Al₂O₃, ZrO₂, Si₃N₄, 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 700°C. 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.

V.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^[14]. A direct relationship between tool geometry and wear is not widely reported^[15]. To know the influence of cutting edge angles on the tool performance many attempts have been made. Makarow found^[16] 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^[17].

VI.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 (θ), 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 in 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 15°. When machining at a workpiece inclination angle of 45°, or above, the general consensus is that downward orientation in particular the horizontal downward orientation is preferable in terms of longer tool life^[19].

VII.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^[20]. 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. Figure 3 shows improved surface finish after edge honing.

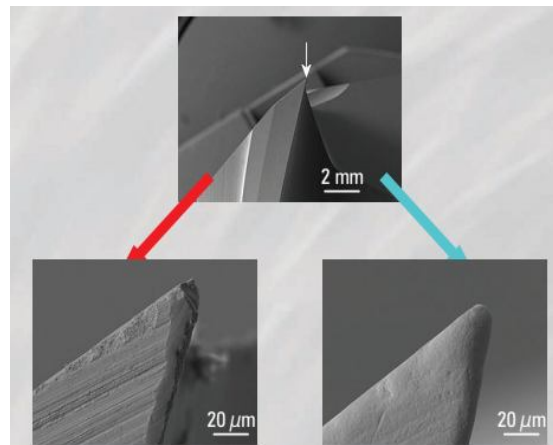


Figure 3: A Typical Cutting Edge picture of Cutting tool before and after Edge honing ^[22].

VIII.COATING

The surface coating improves the tribological, thermal and mechanical performance of cutting tool. It is already reported that coated tools shown better performance compared to uncoated ^[23], ^[24]. There are two types of coating techniques PVD (physical vapour deposition) and CVD (chemical vapour deposition). The majority of carbide cutting tools in use today employ CVD or PVD hard coatings. The high hardness, wear resistance, and chemical stability of these coatings offer proven benefits in terms of tool life and machining performance. Following their introduction in the late 1960s, chemical vapor deposition CVD technologies have advanced from single layer to multi-layer versions combining TiN, TiCN, TiC and Al₂O₃. Coating the tool directly with very hard material like diamond can result in shattering of the diamond coating because of the hardness gradient between the tool and coating. To reduce this effect an interlayer, such as TiC/TiN can be introduced which also enhances adhesion between the tool and coating Modern CVD coatings combine high-temperature and medium-temperature processes in complex cycles that produce excellent wear-resistant coatings with a total thickness of. The coatings are tailored for specific machining applications and workpiece materials. In addition, PVD coatings deposition temperature 400°-600°C are gaining greater acceptance in the marketplace²⁵. Over the last decade, they have been successfully applied to solid round carbide tools as well as carbide and cermet metal cutting inserts. PVD coatings offer performance advantages in applications involving interrupted cuts and/or those requiring sharp edges, as well as in finishing and other operations. Improvements in these technologies, such as high-ionization magnetron sputtering or new cathodic arc processes, have further increased the performance of PVD coated tools ^[26], ^[27].

The first PVD coatings were TiN but more recently developed coatings includes CrN, TiAlN, TiCrN, AlCrN and TiAlSiN, which offer higher hardness, increased toughness and improved wear resistance ^[28], ^[29] and ^[30].

The performance of binary nitrides can be improved by addition of second metal element like Cr, Al, Hf, and Zr. The (Ti, Al) N coating system has shown improved oxidation resistance, hot hardness and wear-protection when compared with binary nitride. Similarly, an addition of Cr to TiN has shown better results in terms of wear resistance, corrosion resistance and abrasion resistance while machining. The performance of coatings generally depends on properties like composition, microstructure, thickness and the process used for coating, surface preparation, etc.. The property requirements for coating vary widely from application to application.

IX.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 15°. When machining at a workpiece inclination angle of 45° or above. Further, the edge honing of cutting edge will lead 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.

REFERENCES

- ¹ P.S. Sreejith, B.K.A. Ngoi, Dry Machining: Machining of The Future, Journal of Materials Processing Technology 101 (2000) 287-291.
- ² S.S. Ingle, Micro-mechanisms of Cemented Carbide Tool Wear, Ph.D. Thesis, McMaster University, Hamilton, Ontario, 1993.
- ³ D. Mari and D. R. Gonseth, A New Look at Carbide Tool Life, Wear, 165 (1993) 9-17.
- ⁴ Viktor P. Astakhov, Tribology of Metal Cutting, Elsevier ISBN-13: 978-0-444-52881-0.
- ⁵ G.F. Micheletti, et al., In Process Tool Wear Sensors For Cutting Operations, Ann. CIRP 25 (1976) 483-495.
- ⁶ A. Thangaraj, P.K. Wright, Computer-Assisted Prediction of Drill Failure Using in-Process Measurements of Thrust Force, Journal of Engineering for Industry, Transactions of the ASME 110 (1988)192-200.
- ⁷ S.C. Lin, C.J. Ting, Tool Wear Monitoring in Drilling Using Force Signals, Wear 180 (1-2) (1995) 53-60.
- ⁸ D. Cuppini, G. D'errico, G. Rutelli,, Tool Wear Monitoring Based On Cutting Power Measurement, Wear, 139 (1990) 303-311.
- ⁹ Erkki Jantunen, A Summary of Methods Applied to Tool Condition Monitoring in Drilling, International Journal of Machine Tools & Manufacture 42 (2002) 997-1010.
- ¹⁰ Xiaoli Li, A Brief Review: Acoustic Emission Method For Tool Wear Monitoring During Turning, International Journal of Machine Tools & Manufacture 42 (2002) 157-165.
- ¹¹ R.M. Sundaram and B.K. Lambert, Surface Roughness Variability of AISI 4140 Steel in Fine Turning Using Carbide Tools, International Journal Production, 17 (3) (1979) 249-258
- ¹² T. Bell, Surface engineering: its current and future impact on tribology, Journal of Physics Department: Applied Physics, 25 (1A) (1992) A297-A306.
- ¹³ Fritz Klocke, Manufacturing Processes 1, Springer ISBN 978-3-642-11978-1.
- ¹⁴ Viktor P. Astakhov, Geometry of Single-point Turning Tools and Drills fundamentals and Practical Applications, Springer ISBN 978-1-84996-052-6.
- ¹⁵ W.J. Endres, R.K. Kountanya, The Effects of Corner Radius and Edge Radius on Tool Flank Wear, Journal of Manufacturing Processes, 4 (2002) 89-96.
- ¹⁶ Makarow, A.D., Optimization of Cutting Processes (in Russian), Machinostroenie, Moscow,1976.
- ¹⁷ Viktor P. Astakhov, Tribology of Metal Cutting, Elsevier ISBN-13: 978-0-444-52881-0.
- ¹⁸ Turgay Kivak, Gurcan Samtas, Adem Cicek, Taguchi Method Based Optimization of Drilling Parameters in Drilling of AISI 316 Steel with PVD Monolayer and Multilayer Coated HSS Drills, Measurement 45 (2012) 1547-1557.
- ¹⁹ C.K. Toh, A Study of The Effects of Cutter Path Strategies and Orientations in Milling, Journal of Materials Processing Technology 152 (2004) 346-356.
- ²⁰ Shaffer WR, Cutting Tool Edge Preparation, SME paper MR99-235, (1999).
- ²¹ Agnew J, The importance and methods of carbide edge preparation.SME paper MR73-905, (1973).
- ²² Platit Compendium 2013, 51st Edition
- ²³ S. Sharif, E.A. Rahim, Performance of coated- and uncoated-carbide tools when drilling titanium alloy-Ti₆Al₄V, Journal of Materials Processing Technology 185 (2007) 72-76.
- ²⁴ F.-R. Weber, F. Fontaine, M. Scheib, W. Bock, Cathodic Arc Evaporation of(Ti,Al)N Coatings and(Ti,Al)N, TiN Multilayer Coatings Correlation Between Lifetime of Coated Cutting Tools, Structural and Mechanical Film Properties, Surface and Coatings Technology 177-178(2004),227-232.
- ²⁵ D.T. Quinto, A.T. Santhanam, P.C. Jindal, Mechanical properties, structure and performance of CVD and PVD coated carbide tools,International Journal Refractory and Hard Material, 8 (2) (1989) 95-101.
- ²⁶ A. Mubarak, E. Hamzah, M. R. M. Toff, Review of Physical Vapour Deposition (PVD) Techniques for Hard Coating, Jurnal Mekanikal (2005), No. 20, 42-5.

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²⁷ Denis Levchuk, Plasma Assisted Techniques for Deposition of Super hard Nano-composite Coatings, Surface & Coatings Technology 201 (2007) 6071–6077.

²⁸ J. Vetter, Vacuum Arc Coatings for Tools: Potential and Application,

²⁹ Yueh-Jaw Lin, Ashutosh Agrawal, Yunmei Fang, Wear Progressions and Tool Life Enhancement with AlCrN Coated Inserts in High-Speed Dry and Wet Steel Lathing, Wear 264 (2008) 226–234.

³⁰ H.G. Prengela, P.C. Jindal, K.H. Wendt, A.T. Santhanam, P.L. HegdeR.M. Penich, A New Class of High Performance PVD Coatings for Carbide Cutting Tools, Surface and Coatings Technology 139 2001 25-34.