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Review of Effect of Tool Geometry Variation on Finish Turning and Improving Cutting Tool Life

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Abstract

The effect of cutting tool geometry has long been an issue in understanding mechanics of turning. Tool geometry has significant influence on chip formation, heat generation, tool wear, surface finish and surface integrity during turning. This article presents a survey on variation in tool geometry i.e. tool nose radius, rake angle, groove on the rake face, variable edge geometry, wiper geometry and curvilinear edge tools and their effect on tool wear, surface roughness and surface integrity of the machined surface. The cutting tool is an important basic tool required in the machining process of a part in production. It not only performs the cutting action but helps in getting required surface finish and accuracy of the part. In order to perform these tasks the tool has to be strong enough to withstand wear resistance and serve for long period of time to produce more number of components with the same accuracy. Machining is important in metal manufacturing process to achieve near-net shape, good dimensional accuracy and for aesthetic requirements. In modern machining process and using the CNC machine tools the cutting tool will play a vital role in machining process and in improving the surface finish. Many reputed cutting tool manufacturing organizations globally with their rich experience of research and development, invented different ways of enhancing the life of cutting tool in order to optimise the rate of the production and to reduce the cost of production, which is highly acceptable to the manufacturing Industry. This paper deals with the ways of improving the tool life by various coatings on tungsten based cemented carbide cutting tool.

1. Introduction

Stringent control on the quality of machined surface and sub-surface during turning is most important consideration a part from considering the tool life. In order to attain sufficiently high production rates at minimum cost, optimization of cutting tool geometry is necessary. Users expect to have more and more productivity in their machining processes (high removal rate of work-material) and low wear of their cutting tools (long tool life). These demands require major improvements in the design of cutting tools: new substrates, new coatings, cutting tool geometry and materials etc.

According to tool manufacturers, the manufacturing procedures of their cutting tools, especially the micro-geometry preparation (cutting edge etc.), have a major influence on their performance and on their reliability. It is important to consider the tool-edge effect in order to better understand the chip formation mechanism and accurately predict machining performances, such as cutting forces, cutting temperatures, tool wear, surface finish and the machined surface integrity. The methods commonly employed include experimental, analytical, and numerical methods.

From the literature it is clear that in order to enhance the turning productivity in terms of tool life, surface finish and surface integrity, variation in tool geometry is one of the major parameter to be considered. As mentioned in Figure 2 rake angle variations, groove on rake face, edge radius variations and curvilinear edge, approaching angle and side cutting edge variation in tools

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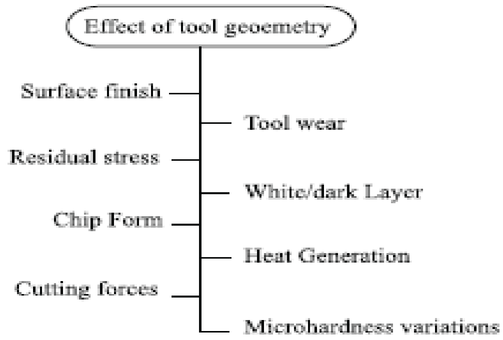

Fig: 1. Effect of tool geometry on performance parameters in turning

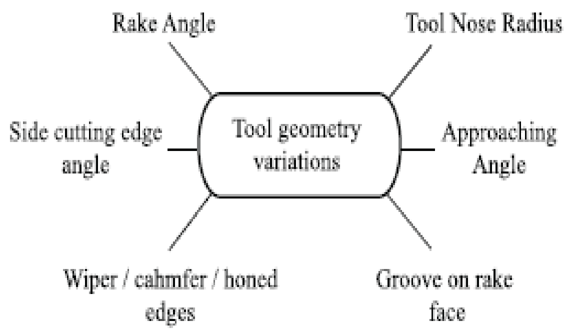

Fig: 2. Tool geometry variation

In addition to increasing the tool life, hard coating deposited on cutting tools allows for improved and more consistent surface roughness of the machined work piece. The surface roughness of the machined work piece changes as the geometry of the cutting tool changes due to wear, and slowing down the wear process means more consistency and better surface finish. It is to improve the effect of different types of coating materials on the performance of carbide cutting tools. To achieve this goal, turning tests were conducted with a CNC lathe using commercially available carbide cutting inserts with different coating materials. The performance of the cutting tools is evaluated by considering the progression of tool wear and the surface finish of the work piece.

The specific objectives of this research study included:

1. Study the flank wear progression on each of the cutting tools used.
2. Study the change of surface finish throughout the tool life of each cutting tool.
3. Assess and analyze the results obtained for each tool, and evaluate their performance based on the effects of the coating materials used.

2. Tool Edge (Curvilinear Edge Or Wiper Geometry)

The design of cutting edge geometry and its influence on machining performance have been a topic of research in metal cutting for a long time. Emerging machining techniques such as hard turning and micromechanical machining, where the uncut chip thickness and the tool edge dimension are in the same order of magnitude, require cutting edges which can withstand high mechanical and thermal stresses, hence wear resistance, for a prolonged machining time. The chamfered/honed tool is recommended to prevent the chipping of the cutting edge and to impart strength to the cutting edge .Wiper geometry tools perform better than the conventional tools for improved surface finish. Tools with chamfered edge are used for machining hard materials due to their high edge strength. In hard turning, as the material is harder, specific cutting forces are larger than in conventional turning. Because of this the small cutting depth required and cutting takes place on the nose radius of cutting tools thus the tools are prepared with chamfered or honed edges to provide a stronger edge geometry that is less prone to premature fracture. Cutting with chamfered or honed edge equates to a large negative effective rake angle, while neutral or positive rake angles are typical in conventional machining. The large negative rake angle yields increased cutting forces compared to machining with positive rake tools and also induces larger compressive loads on the machined surface. As shown in Figure 3 .Cutting forces increase with the increase of the chamfer angle. The passive forces (Fp) in the passive direction are higher than the primary cutting forces (Fc) in cutting direction and increase more rapidly with the increase in chamfer angle.

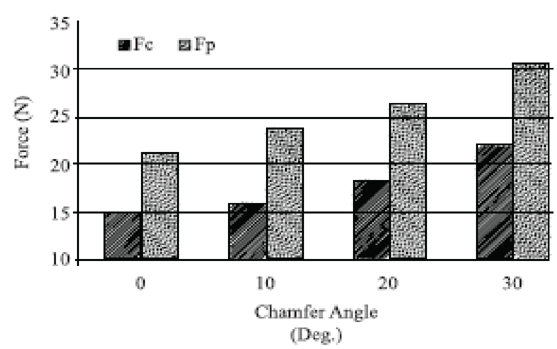

Fig: 3. Correlation of cutting force and chamfer angle

In finish hard turning there is an optimum value of chamfer angle where the tool life is maximum. Results indicated that tool life reaches to its maximum up to 15º-chamfer angle and after that it reduces drastically. The tool life was measured up to the value of 0.2 mm flank wear, in order to avoid excessive white layer induced on the workpiece surface due to the higher temperature under the large flank wear. As per FE analysis the cutting edge with 15° chamfer angle has the smallest value of flank wear as compared to other cutting tools

3. Tool Nose Radius Variations

Nose radius is a major factor that affects surface finish of the machined surface. A larger nose radius produces a smoother surface at lower feed rates and a higher cutting speed. Large nose radius tools have, along the whole cutting period, slightly better surface finish than small nose radius tools. study reveals that large tool nose radii only give finer surface finish, but comparable tool wear with small nose radius tools. Specific cutting energy slightly increases with tool nose radius. Tool life based on flank wear increases with increase in nose radius. However, reaches a constant at nose radius greater than 0.4 mm. On the other hand, tool life based on surface finish shows a local maximum at 0.8 mm nose radius. It was suggested that large nose radii result in severe groove wear, and therefore, poor surface finish. Other than surface finish aspects, tool nose radius also affects uncut chip geometry, and thus, ratio of uncut chip thickness to edge radius that may affect plowing forces in the hard turning process. More interestingly, the distance from the cutting edge to the nominal machined surface changes across the cutting edge and is a strong function of tool nose radius as shown in Figure 4.

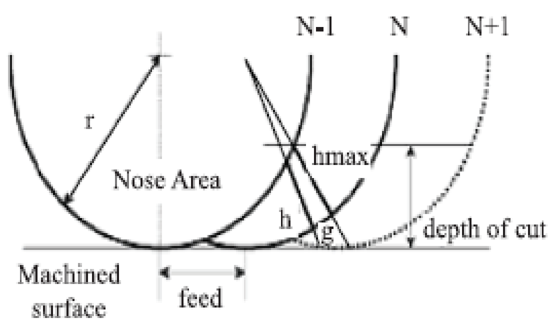

Fig: 4. Tool nose area showing uncut chip thickness (h) and the distance (g) from the cutting edge to the final machined surface

4. Rake Angle Variation

For single point cutting tool most important angle is back rake angle. The back rake angle affects the ability of the tool to shear the work material and form the chip. It can be positive or negative. Positive rake angles reduce the cutting forces resulting in smaller deflections of the workpiece, tool holder, and machine. If the back rake angle is too large, the strength of the tool is reduced as well as its capacity to conduct heat. In machining hard work materials, the back rake angle must be small, even negative for carbide, PCBN and diamond tools.The higher the hardness, the smaller the back rake angle shall be used. The magnitude of rake angle has significant effects on the performance of the cutting tool and the surface integrity generated during machining and negative rake angle tends to generate compressive residual stress whereas positive rake angle tends to induce tensile residual stress. Further it is suggested that creating a chamfer on the cutting edge has a similar effect as creating a negative rake angle, by which the maximum compressive residual stress in the subsurface can be increased.

5. Wear

The prediction and control of wear is one of the most essential problems emerging in the design of cutting operations [13]. A useful definition for a worn out tool is: “A tool is considered to be worn out when the replacement cost is less than the cost for not replacing the tool” [14]. Tool failure is said to occur when the tool no longer performs the desired function whereas total failure (ultimate failure) is defined as the complete removal of the cutting edge, a condition obtaining when catastrophic failure occurs [15]. Therefore, in machining operations, tools are considered to be worn out and are changed long before total failures to avoid incurring high costs associated with such catastrophic failures. Some of the tool life rejection criteria presented in ISO 3685 is listed below [16]: 1. Average flank wear = 0.4 mm 2. Maximum flank wear = 0.6 mm 3. Notching = 1.0 mm 4. Nose wear = 0.5 mm 5. Surface roughness (Ra) = 6.0 μm.

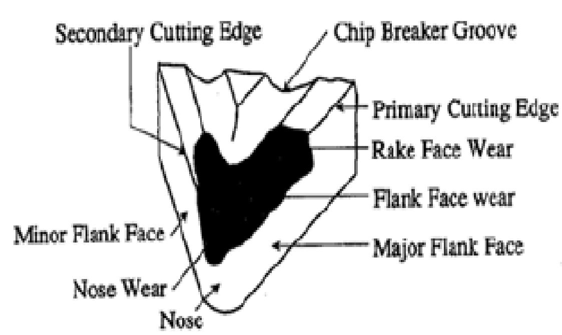

Fig: 5. Typical wear pattern and pertinent technology

Flank wear is observed on the flank or clearance face of a metal cutting insert and is caused mainly by abrasion of the flank face by the hard constituents of the work piece. This failure mechanism is commonly observed during machining of cast irons and steels where the abrasive particles are mainly Fe3C and non-metallic inclusions. Crater wear is observed on the rake face of cutting tools and is caused by

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chemical interactions between the rake face of a metal cutting insert and the hot metal chip flowing over the tool. Depth of cut notching is attributed to the oxidation of the tool material. Nose wear or tool tip blunting results from insufficient deformation resistance of the tool material. Fracture is the least desirable mode of tool failure because it is unpredictable and catastrophic. When machining using carbides under typical cutting conditions, the gradual wear of the flank and rake faces is the main process by which a cutting tool fails. However, flank wear is the preferred mode because it progresses gradually and can easily be monitored. Most tool material development work is focused on minimizing flank wear and preventing unwanted tool failure modes such as catastrophic fracture, gross plastic deformation, built up edge and crater wear. Severe abrasion occurs at the flank face because of the lower temperature, the more rigid work piece relatively to the chip, and the constraint in the movement of the work piece and tool. The intimate contact between the flank of the tool and work piece, high compressive and shear contact stresses acting on the flank of the tool and cutting temperature of around 850oC can encourage atomic dissolution-diffusion wear. Cemented carbide tools worn off by dissolution/diffusion exhibit smoothly worn through carbide grains. In many previous studies, a very smooth surface at the worn flank face possessing voids between carbide grain boundaries was observed on a carbide insert. This smoothly worn surface topography is a characteristic of dissolution/diffusion wear

6. 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 coating acts as a diffusion barrier).
3. Prevention of galling, especially at lower cutting speeds

7. Coating Materials

The majority of inserts presently used in various metal cutting operations are cemented carbide tools coated with a material consisting of nitrides (TiN, CrN, etc.), carbides (TiC, CrC, W2C, WC/C, etc.), oxides (e.g. alumina) or combinations of these. Coating cemented carbide with TiC, TiN and Al2O3 dramatically reduces the rate of flank wear. A primary contributor to the wear resistance of the coating materials is that they are all much less soluble in steel than WC at metal cutting temperatures. High hardness is beneficial in resisting the abrasive wear. Retention of hardness even at higher temperatures is very important since the tool bit experiences a temperature in the range of 300-1000°C depending on the machining parameters and the materials to be machined. Micro hardness values of different coatings measured at different temperatures are shown in Figure 6. They all exhibit a decrease with an increase of temperature, and the decrease of hardness was much more pronounced in the case of TiC. Interestingly, the micro hardness of Al2O3 was significantly lower than TiC at room temperature but retained almost 40 % of its room temperature hardness at 1000 °C.

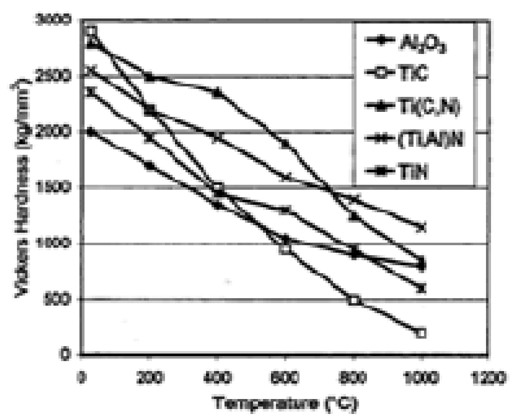

Fig: 6. Temperature dependence of micro hardness

Thus, having a coating layer of Al2O3 over an under layer of TiC help decrease the dissolution/diffusion wear at the TiC coating layer. This enhances the performance of the cutting tool, by including the TiC layer with a low wear rate and protecting it with a layer of Al2O3 to decrease the effect of diffusion/dissolution wear. The softer TiN outer layer helps in reducing the propagation of cracks into the inner coating layers, in addition to decreasing the welding of the chips to the cutting tool. Another reason for having the TiN as an outer layer, as opposed to inner layer, is that at higher temperatures of oxidation, the growth of TiO2 (rutile)

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under layer may affect the performance of the protective alumina over layer of the oxide.

8. 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 7 shows a magnified cross section of a typical machined surface.

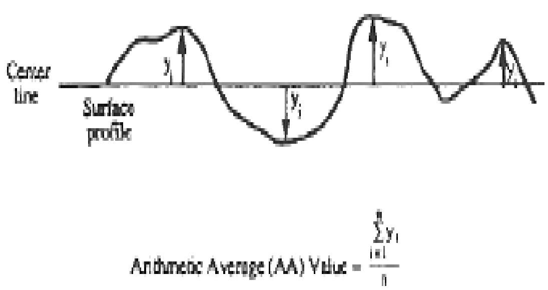

Fig: 7. Illustration of surface roughness

Many factors influence the formation of surface roughness in the turning process. These factors include chip deformation and side flow, vibration of the machine-tool fixture work piece system, geometrical contribution of the feed and tool nose radius. Classical surface roughness related equations calculate geometrical contribution:

$h = f^2/ 8R$, , $hCLA= f^2/ 18\sqrt{3}R$

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 [20]. 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.

9. Conclusions

1. Large edge hone tools produce statistically higher forces in the axial (feed) and radial (thrust) directions than small edge hone tools. Further large edge hone tools produce higher surface roughness values than small edge hone tools. However, feed dominates surface roughness. The chamfer angle has a great influence on the cutting force and tool stress. All cutting force components increase with an increase in the chamfer angle, especially the level of passive force. Further an increase of chamfer angle will increase tool life up to certain value, after that the tool life decreases. This increase of tool life is due to the increase in wedge strength of the PCBN tool. Also higher value of chamfer angle produces low surface roughness at higher cutting speed.
2. Curvilinear edges (chamfer+ honed) are to protect the cutting edge from chipping, to improve its impact resistance, and to increase surface area for heat transfer from the cutting zone. Curvilinear edge preparation affects chip formation mechanism due to increased cyclical plastic deformations along the face of these edges. Further the magnitude of all the cutting forces is lower at higher cutting speed than at lower speed, it means the honed and chamfered cutting edge geometry influences the cutting forces only when the MRR is low.
3. During finish hard turning increase in the rake angle or the chamfer angle as well as the hone cutting edge radius allowed an increase in the compressive residual stress in the subsurface. Further the increased radius of a cutting tool will produce larger compressive residual stress beneath the machined surface. Further large edge hone tools promote continuous white layer formation at feeds above 0.05 mm/rev (0.002 in/rev). While small edge hone tools cause over-tempered regions at feeds above 0.05 mm/rev (0.002 in/rev).
4. Size of tool edge radius is an important factor and it affects the mechanics of cutting. Edge radius must be selected according to cutting conditions. Large edge radius is not suitable for machining low uncut chip thickness. The ratio of uncut chip thickness to edge radius, which is app. equal to three, seems to be an appropriate ratio for edge preparations used in the cutting tests. In finish hard turning white layer depth decreases with increasing nose radius. Further large tool nose radii seem to only have the advantage of finer surface finish, yet tool wear is comparable and specific cutting energy is slightly higher.
5. Variable edge preparation inserts perform better than uniform edge preparation, Tool wear is

6. Decreased with the use of a variable micro-geometry inserts. As this variable micro-geometry tool design reduces the heat generation along the tool cutting edge. Further this edge induces less plastic strain on the machined workpiece in comparison to uniform edge.
7. The nose radius of tool affects the roughness of machined surface, residual stresses of machined surfaces, chip morphology and forces arise during cutting. Further the ratio of the thrust force to cutting force and the ratio of the thrust force to feed force increase with the increase of the tool nose radius. Large tool nose radii seem to have only the advantage of finer surface finish. In comparison to small tool nose radii the large tool nose radii cause almost equal tool wear and a slightly higher specific cutting energy. Large nose radius tools generate shallower white layers in new tool cutting; however, leave deeper white layers when cutting by worn tools. Thus for deciding the life of tool with large nose radius white layer parameter should also be considered a part from flank wear.
8. The failure of grooved tools is mainly due to improper groove utilization by the chip and this has been resulting from.
9. Either poor chip-groove design or inappropriate application of the cutting conditions for a particular chip-groove. Further it is suggested that secondary edge form of wear can be averted, by causing the chip-flow angle to be larger (e.g. by reducing depth of cut, etc.), so that the chip strikes the backwall instead of the minor edge.
10. The tool-chip friction τ/k decreases with increasing absolute value of negative tool rake angle and with increasing
11. Cutting speed. A greater negative rake angle gives higher compressive stresses as well as a deeper affected zone below the machined surface.
12. Increasing the nose radius has a direct effect on cutting forces, leading to a significant increase in the ploughing effect in the cutting zone.
13. The tool chip breaker geometry causes influence on specific cutting energy behavior. Even small modifications on cutting edge geometry affect the cutting force levels and specific cutting energy values.
14. The tool coatings were found to improve upon the wear resistance of the cutting tool. This was shown by the decrease in wear on the flank face of the coated tools compared to that of the uncoated tool. The wear of the TiN coated tool was around 12% lower than the wear observed on the uncoated tool. TiN/Al2O3 coated tool showed a decrease of around 65% compared to the uncoated tool. The decrease in wear was due to the wear resistance properties of the TiN and Al2O3 materials and the high chemical stability of the Al2O3 layer.
15. The TiC/Al2O3/TiN coated tool produced the lowest average surface roughness during the 60 cuts with a decrease of around 38% compared to the uncoated tool. The Al2O3 coated tool produced the second lowest average surface roughness with a decrease of around 23% compared to the uncoated tool. The TiN coated tool produced the third lowest average surface roughness with a decrease of around 7%. While on the other hand, the TiN/Al2O3 coated tool produced the highest average surface roughness with an increase of around 21%. The surface roughness increased while oscillating for all the cutting tools used except for the TiN coated tool in which surface roughness oscillated around a constant value and produced more consistent surface roughness that was not affected by the flank wear of the tool.

References

[1] Dhar, N. R. Paul, S., Chattopadhyay, A. B., The influence of cryogenic cooling on tool wear, dimensional accuracy and surface finish in turning AISI 1040 and E4340C steels, Wear, 249, pp.932–942, 2001
[2] Mustafa Gunay, Ersan Aslan, Ihsan Korkut, Ulvi Seker, Investigation of the effect of rake angle on main cutting force", International Journal of Machine Tools & Manufacture, 44, pp. 953-959. doi:10.1016/j.ijmachtools.2004.01.015, 2004
[3] Zhou, Li., Machining Chip-Breaking Prediction with Grooved Inserts in Steel Turning, 2001
[4] Hughes J. I., Sharman A. R., Ridgwayk, C., The effect of cutting tool material and edge geometry on tool life and workpiece surface integrity, Proceedings of the Institution of Mechanical Engineers. Part B. Journal of Engineering Manufacture, 220(2), pp.93-107, 2006
[5] Haron, C. H., Ginting, A., Goh, J. H., Wear of coated and uncoated carbides in turning tool steel, Journal of materials processing technology 116 (2001) 49-54
[6] Abdullah, A., Machining of aluminium based metal matrix composite (MMC), Ph.D. Thesis, University of Warwick, Warwick, UK, 1996
[7] ISO, ISO 3685 – Tool life testing with single point turning tools, 2nd Edition (1993).