STUDY OF DEFORMATION OF COATED TOOLS IN ORTHOGONAL METAL CUTTING PROCESS USING FEA

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Abstracts: The paper presents an investigation into the performance characteristics of electrical discharge machined cemented carbide tool inserts coated with titanium nitride (TiN). In this study, finite element analysis (FEA) software, SolidWorks CosmosExpress was used to study load bearing capacity of the cutting tool extensively. Results from cutting tests indicate increased tool life and better surface finish and reduce power loading by 18% when the tool was operated at 40% faster than the recommended standard speed. When the tool begins to wear out, tool wear characteristics did not affect dimensional accuracy of the work-piece. The surface enhancement, called 'residual island' treatment, produces an undulating surface topography on the tool. As the tool wears, 'islands' of residual titanium nitride remained in the valleys, which continued to provide wear resistance. It is expected that residual island effect would occur for most, if not all, types of coating. It was therefore concluded that TiN coatings if applied to turning tools with crater-like surface structures provide satisfactory lubricating properties which help in providing protection to the tool substrates against friction and wear.

1. Introduction:

It would be difficult to imagine the state of today's industry and the impact that it has had on peoples' standard of living if not for the advances made in metal cutting tool materials. However, today's technology is more focussed at developing hard wear resistant coatings for tool materials and this aspect is of particular relevance to the present work. Turning operation during metal cutting has always been one of the most important machining processes in manufacturing. Turing process parameters are still mainly chosen based on empirical knowledge. Traditionally, experiments are carried out to test the suitability of a process and quality of components manufactured. These experiments are costly and are time consuming. In addition, there are many databases of workpiece material and tool combinations for experimental purposes but these databases lose their meanings because new materials, tools and new faster machine tools are developed all the time. To meet the challenge, finite element analysis (FEA) has been developed to simulate metal cutting processes. Current Improvements of manufacturing technologies such as in metal cutting require better modelling and analysis ability. In order to continuously develop the metal cutting process, better modelling is a requisite in predicting metal cutting processes. This development has helped in selection of cutting tools and process parameters because numerical methods have become efficient tool for investigation of complex phenomenon in metal cutting. Finite element technique as a method for analysing metal cutting is a novel approach and has contributed to a higher level on understanding of metal cutting process and has led to a more in-depth understanding for the selection of cutting tools and process parameters.

Development of analysis of metal cutting process began over sixty years ago. The pioneers were (Merchant, 1945), (Armarego and Brown, 1988) and (Oxley, 1989) who developed analytical models. (Kienzle, 1952) developed an empirical model based on a large number of experiments. Lately, finite element methods (FEM) development to simulate metal cutting process have been reinforced by many researchers among them are; (Massilimani, 2006, Raczy et al 2006, Olovsson, 1999, Özel and Karpat, Y., 2007, Limido, 2007)

2. Forces Acting on a Cutting Tool:

Figure 1(a) below is a model of the 'ideal' turning process that completely suppresses the concept of inhomogeneous strain by assuming the material to behave in a completely homogeneous fashion. The assumptions on which this model is based include the fact that:

i. The tool is perfectly sharp and there is no contact along the clearance face.
ii. The shear surface is a plane extendir upward from the cutting edge.
iii. The load applied is uniform distributed.
iv. The work moves relative to the to with uniform velocity
v. A continuous chip is produced with ı built-up edge
vi. The shear and normal stresses alor shear plane and tool are unifor (strength of materials approach).

To determine the load (force) to be applie in the finite element model, it was importa to ascertain the resultant force. It is knov that when a lathe tool is cutting there a three perpendicular forces acting on These are shown diagrammatically in figu 1(a), where *C* is the vertical cutting force, the feeding force, and *H* the horizontal pressure of the work. By means of vector diagrams we determined the resultant of these forces.

2.1 Procedure

To determine the resultant force of the two forces acting in two planes, the problem was solved in two stages. First it was found out that the resultant of *F* and *C* as shown in the vector diagram *abc* in figure 1(b) and R_{FC}, represented by *ac*, is the resultant, acting in the vertical plane containing *F* and *C*. At this point, the tool is being acted upon by the forces R_{FC} and *H*, acting in a plane inclined at Θ to the vertical as shown at 1(a). Merging these in a second vector diagram, we obtain the final resultant force on the tool (*R*) as shown at figure 1(c). *R* lies in a plane sloping at Θ to the vertical and its line of action is inclined at α to the line of *H*. It is advisable to visualise the conditions as demonstrated in (*d*) which is a diagrammatic sketch of the forces and their resultants.

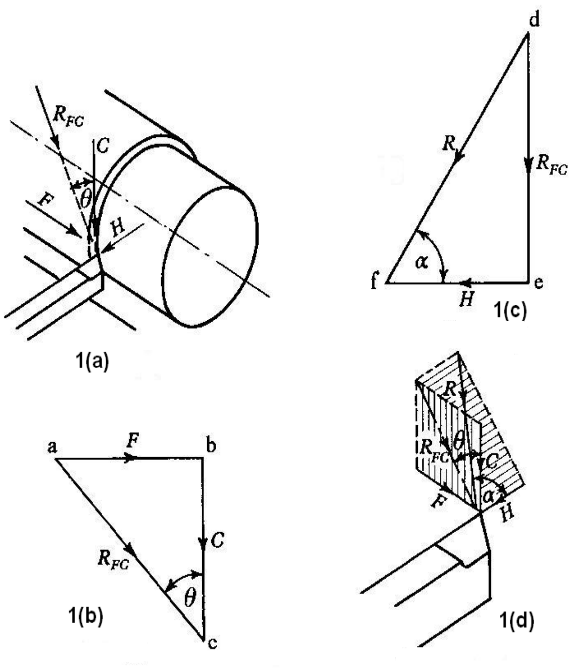

Figure 1 Showing Ideal Turning Process.

To find the resultant force on the tool, data for the forces acting on the lathe tool were obtained from published work of Boothroyd and Knight (1989) in fundamentals of machining and machine tools (10). It was established that for machining mild steel EN3, the cutting force C = 890 N, feeding force F = 667 N and H = 400 N. Thus, to find the resultant force on the tool, we have

$$R_{FC}2 = F^2 + C^2 = 667^2 + 890^2$$

$$R_{FC} = \sqrt{667^2 + 890^2}$$

$$= 1112\,\text{N}$$

$\tan\theta = \frac{F}{C} = \frac{667}{890} = 0.75$, from which $\Theta = 36.9^0$

$$R^2 = R_{FC}^2 + H^2 = 1112^2 + 400^2$$

$$R = \sqrt{1112^2 + 400^2}$$

$$= 1181\,\text{N}$$

$\tan\alpha = \frac{R_{FC}}{H} = \frac{1112}{400} = 2.78$, from which $\alpha = 70^0\,12'$

Hence the resultant is a force of 1181 N, and the angles α and Θ in the figure 1(d) are 70^0 12' and 36.9^0 respectively.

3. Material Properties:

The Tool used was a tungsten carbide (WC) tool insert (Table 1) with crater-like surface topography generated at the cutting point by electro discharge machining (EDM) process and coated with titanium nitride (Table 2) to a thickness of approximately 4 micron.

Table 1: Tool Insert

Tungsten Carbide (WC)		
Property Name	**Value**	**Units**
Elastic Modulus	$1.24e^{+011}$	N/m^2
Poisson's Ratio	0.28	N/A
Mass Density	19000	Kg/m^3
Yield Strength	0	N/m^2

Table 2: The Coating Material

Titanium Nitride (TiN)		
Property Name	**Value**	**Units**
Elastic Modulus	$1.1e^{+011}$	N/m^2
Poisson's Ratio	0.3	N/A
Mass Density	4600	Kg/m^3
Yield Strength	$1.4e^{+008}$	N/m^2

Table 4: The Mesh Conditions

Mesh Information	
Mesher Used	Standard
Automatic Transition	Off
Smooth Surface	On
Jacobian Check	4 Points
Element Size	3.6998 mm
Tolerance	0.18499 mm
Quality	High
Number of Elements	7521
Number of Nodes	12085

4. Results

The Tool was restrained at both the Base and one end Fixed at the hole in order to restrict it from deflection. The results showed that workpiece material experienced Von Mises Stress $4.46232e^{+007}N/m^2$ while the carbide TiN coated tool had Von Mises maximum stress of $1.185e^{+006}N/m^2$

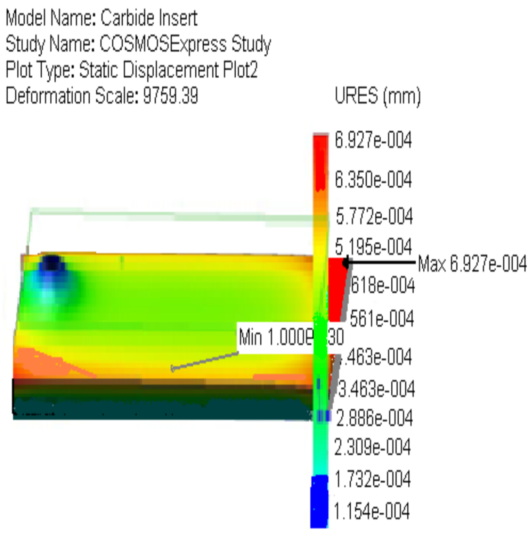

Figure 4.1 Showing the Tool after deformation

4.1 Discussion of Results

Figure 4.2 shows a section of EDMed surface which is represented as a crater-like surface topography. It is easy to visualise it as a 2D having 'grooves' and not craters which implies that the grooves have equal radii so that it looks similar to a turned surface.

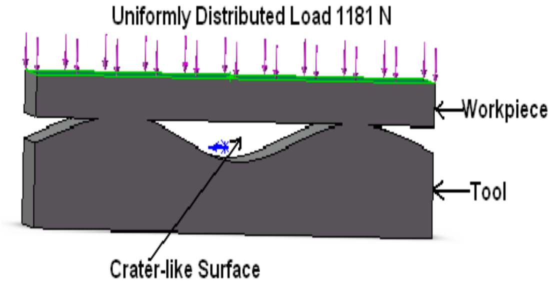

Figure 4.2 Showing Uniform Distribution of Load

To understand this let's apply the concept of chip formation described by Dr. Merchant in his studies of the mechanics of metal cutting. It is idealised in the concept that the workpiece material advances at velocity *V* towards the tool edge, is compressed at the tool rake face, causing failure to occur by plastic shearing along the plane, called the shear plane. Under suitable conditions a continuous and steady rate of deformation occurs along the shear plane and the deformed material slides at a uniform velocity V_c down the rake face of the tool in the form of a continuous chip. Before deformation, the thickness of the chip is t_1 and t_1 = feed/rev when $\Pi = 90^0$; during deformation the cut chip increases in thickness to t_2. The rake angle plays an essential part in the action and shearing occurs along some definite plane, the position of which is given by the shear plane angle Theta. Since t_1 and Gamma are known, and t_2 will be measured with a pointed micrometer.

5. Conclusion

It was noted that heat and stress distribution were greatest at the edges and the top face (rake face) of the tool where the TiN coatings had worn out. The deformation in the side of the insert represents the wear rate of the tool. The design analysis results are based on linear static analysis and the material is assumed isotropic. Linear static analysis assumes that:

i. the material behaviour is linear complying with Hooke's law,

ii. induced displacements are adequately small to ignore changes in stiffness due to loading, and

iii. loads are applied slowly in order to ignore dynamic effects.

Therefore in conclusion TiN coatings if applied to turning tools with crater-like surface structures will provide satisfactory lubricating properties which help in providing protection to the tool substrates against friction and wear. This work was done in linear elastic isotropic deformation mode and it is recommended that more work should be done in plastic deformation to verify the results

6. References

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