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# Investigation of Flank Wear in Multi-coated Layers Cutting Tools

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**ABSTRACT**

The main object of this study is to simulate the progress of the flank wear on a multi coated cutting tool using a special finite element analysis (FEA) software (DEFORM 2D). The modeling of the wear on the cutting tools was depending upon Usui's tool wear model to calculate the wear rate and a sub-routine is developed to update the tool geometry. The coated tool was selected to be (WC) carbide coated with three layers TiC/Al2O3 /TiN with a total thickness (12µ). The results are compared with many relevant papers published in the literature and showed a good agreement with the modeled results.

***Key words:*** **FEM, Tool Wear, Coated tools.**

## 1. Introduction

In the recent decades, with the emergency of more and more powerful computers and the development of numerical technique, numerical methods such as Finite Element Method (FEM), Finite Difference Method (FDM) and Artificial Intelligence (AI) are widely used in machining industry. Among them, FEM has become a powerful tool in the simulation of cutting process because various variables in the cutting process such as cutting force, cutting temperature, strain, strain rate, stress, etc can be predicted by performing chip formation and heat transfer analysis in metal cutting, including those very difficult to detect by experimental method. Therefore new tool wear prediction methods may be developed by integrating FEM simulation of cutting process with tool wear model (Oxley, P.L.B., 1989). (Yen Y.C.et al ,2002) developed a methodology to estimate the tool wear of carbide tool in orthogonal cutting using FEM. Based on temperatures and stresses on the tool face, tool wear may be estimated with acceptable accuracy by using an empirical wear model and using FEM simulation. The methodology proposed by them has three different phases, the first phase includes a development of tool wear model for the specified tool-workpiece pair, the second phase includes, modifications in the commercial FEM code and last phase includes experimental validation of the developed methodology. The wear prediction procedure starts with a coupled thermo-viscoplastic Lagrangian cutting simulation with isotropic strain-hardening using DEFORMR-2D. In order to obtain the cut chip geometry near the steady state, a special simulation module is used. (A. Attanasio et al., 2008) made numerical and experimental tests to predict the tool wear in 3D cutting operation. The experimental tests were carried out on a CNC turning machine and the workpiece was AISI 1045 steel with 100 mm diameter. Uncoated ISO P40 tool was used with tool nose radius of 0.8 mm, rake angle = 0° and clearance angle = 6°. Several experiments were done with different cutting speeds and feed rates. The 3D ALE simulation was carried out using SFTC Deform 3D V. 6.1. A comparison has made between the numerical and experimental work and all the experiments were repeated three times showing an uncertainty of 6–10% (95% confidence interval). Observing these results it is evident the good agreement (the average error is about 6%). (A. Attanasio et al., 2010) made an investigation and FEM-based simulation of tool wear. The experimental tests were conducted to set-up and validate the FEM model; they consisted of turning operations of cylindrical bars made of AISI 1045 with an initial diameter of 90mm. The utilized tips uncoated tungsten carbide (WC) inserts A coupled abrasive–diffusive wear model based on Takeyama and Murata and Usui et al. formulations was implemented into a suitable subroutine of a FEM code. In this way, it was possible to simulate non-orthogonal cutting operations updating the tool geometry as the tool wears. Experimental and simulated results were compared in terms of maximum depth, position and extension of the crater wear. An overall good ability of the FEM model in reproducing the tool wear as the cutting time increases was found. The developed FEM model was validated by comparing the simulated tool craters with the experimental ones. The good agreement between experimental and simulated results is evident showing the ability of the FEM model in forecasting the correct tool worn geometry. (Rajesh K. B. et al., 2010) studied the influence of cutting speed, depth of cut, and feed rate on tool wear during machining. The experiments were conducted on a CNC Turning Machine using tungsten carbide (K10). Flank wear of carbide tool is increased by a factor of 2.4 with the increase in cutting speed from (180 to 240 m/min) at a feed of (0.1 mm/rev) and a depth of cut of (0.5 mm)

## Experimental work:

All experiment tests were done using convential turning machine. The coated tool was selected to be (WC) carbide coated with three layers TiC/Al2O3 /TiN with a total layers thickness (12µ). Cutting conditions were selected to be as in Table (1).

Table 1 Cutting conditions for experimental work

| Workpiece material | AISI 1045 |
|---|---|

| | |
|---|---|
| Cutting speed (Vc) | (55, 70 , 90, 100, 140) (m/min) |
| Feed rate (f) | (0.08 , 0.12, 0.16, 0.2, 0.24) (mm/rev) |
| Depth of cut (DoC) | (1.5) (mm) |

The arrangement of the tool and the workpiece is shown in Figure (1).

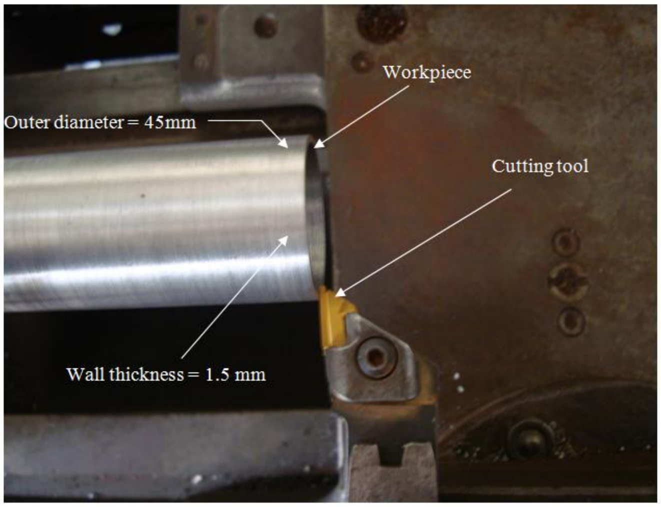


Figure (1) Photograph of the turning machine, showing the workpiece and tool used.

## Tool Wear Measurement

The following steps are done in order to measure the flank wear:

a. The cutting process starts due to orthogonal cutting using the three types of coated tools being mentioned.

b. The cutting conditions are selected as mentioned in Table (1).

c. The flank wear was measured using micro scale and optical microscope, as shown in Figure (2)

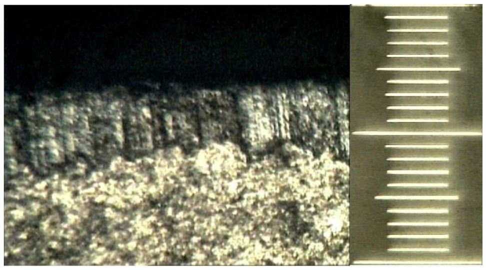


Fig (2): Flank wear of TiN/Al2O3/TiC coated inserts

d. For constant cutting time intervals of (30 sec) till reaching the final wear due to standard in Table (3).

Table (3) the criteria of flank wear

| Tool material | | HSS | Cemented carbide | Coated carbide | Ceramics | |
|---|---|---|---|---|---|---|
| Operation | (mm) | | | | $Al_2O_3$ | $Si_3N_4$ |
| Roughing | $VB_B$ | 0.35-1.0 | 0.3-0.5 | 0.3-0.5 | 0.25-0.3 | 0.25-0.5 |
| Finishing | $VB_B$ | 0.2-0.3 | 0.1-0.25 | 0.1-0.25 | 0.1-0.2 | 0.1-0.2 |

e. The test is repeated of other cutting conditions.

## Numerical work:

### Finite Element Model

The Finite Element model is composed of a deformable workpiece and a rigid tool. The tool penetrates through the workpiece at a constant cutting speed and feed rate. The initial arrangement of both the workpiece and the tool in the simulation model is shown in Figure (3).

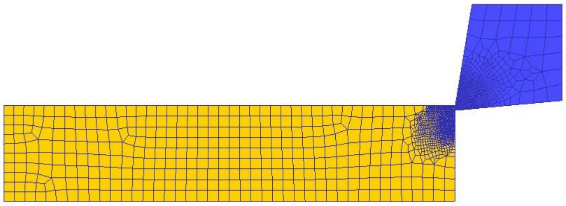


Fig (3): cutting model used in the simulation

### Mesh Generation

Finite Element model used for the plane-strain orthogonal metal cutting simulation is based on the Lagrangian techniques and explicit dynamic, mechanical modeling software with adaptive remeshing. This means that the initial mesh becomes distorted after a certain length of cut. The workpiece discretized by bilinear four-node quadratic. This consists of the following number of nodes and elements. As shown in Figure (4).

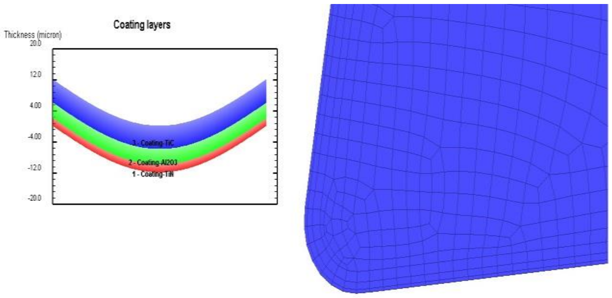


Fig (4): three coated layers cutting tool

There are (1080) nodes and (1025) elements for three layers coated tools models.

### Simulation Strategy

The adopted simulation strategy is schematized in the flow chart of Figure (5).

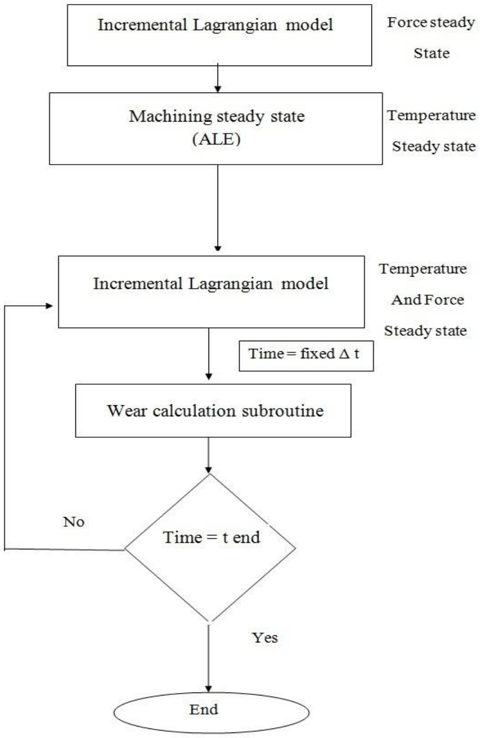


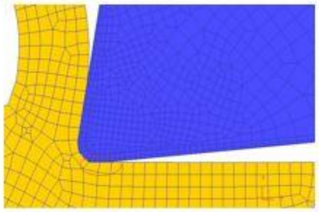
Figure (5) Flow chart of Wear Simulation Strategy

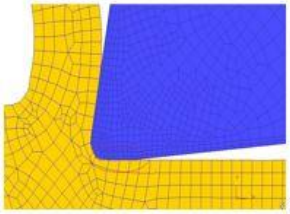
The iterative part of the simulation strategy allows representing the wear development and growth in the FEM model. The wear subroutine is implemented and run for a constant simulation time $\Delta t$ (30 sec) until reaching the total simulation time. Before applying the tool geometry updating sub-routine it is necessary to run the Lagrangian simulation in order to identify the correct temperature and force distributions as the tool wears. The subroutine for tool geometry updating consists of three phases. In the first phase the tool wear rate is calculated, according to Usiu's wear model, for each node of the tool mesh boundary in contact with the chip. After that, the subroutine identifies the mesh nodes movement direction finding, for each identified node, the connected elements and determining the values of their components. At this point, the node movement direction is obtained as vector sum of all the vectors of the connected elements. The third phase initially updates the tool mesh, moving each boundary mesh node along the corresponding movement direction for a distance equal to the calculated wear. After that the software rebuilds the tool geometry starting from the worn mesh.

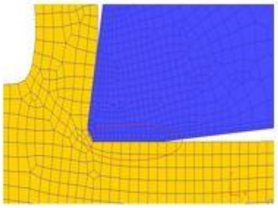
## Results and Discussion

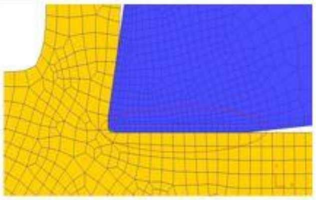
### Flank Wear Modeling

The uses of the developed user routine leads to present the flank wear at the tool. Figure 6 (a, b, c d and e) represents the updating of tool geometry in order to show the criteria of flank wear on the carbide cutting tool coated with (TiC/$Al_2O_3$ /TiN). Corresponding to discrete data points on a flank wear curve, the simulations for a cutting tool with constantly updated flank geometry have shown that it is possible to predict the evolution of tool wear at any given cutting time from FEM simulations by using the mentioned simulation strategy. The ultimate goal is to enable the complete construction of tool wear curves (i.e. $VB_B$ vs. cutting time) and estimate the tool life through a FEM-based technique. With the developed simulation method, the engineering analysis for the effect of cutting conditions on cutting performance is possible. The results of using developed user routine to present the flank wear agree well with those in **(**Yen Y.C.et al ,2002) as shown in Figure (7).


(a) $VB_B$ = 0.014 mm, cutting time = 2 min


(b) VBB = 0.077 mm, cutting time = 4 min


(c) VBB = 0.173 mm, cutting time = 12.5 min


(d) $VB_B$ = 0.293 mm, cutting time = 19 min

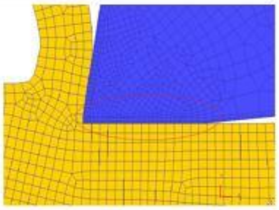

(e) $VB_B$ = 0.365mm, cutting time = 23 min

Figure (6) the stage of cutting tool geometry update to present flank wear (three layers coated tool)

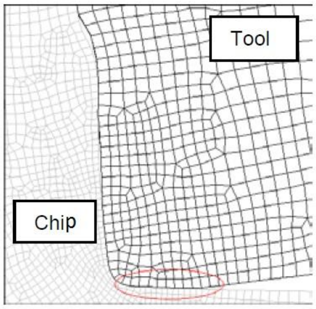


Figure (7) Flank wear progress as predicted by (Yen Y.C.et al ,2002)

## Effect of cutting speed

The increase in cutting speeds leads to an increase in the flank wear. At a cutting speed range of (70 to 100 m/min) the increase or decrease in cutting speed has a small effect on the tool wear for the three types of cutting tools as shown in fig.(8). One of the main reasons for the increase in tool wear as the cutting speed increased may be the increase in heat being generated at tool chip interface region in addition to the effect of friction at higher cutting speed. The experimental and the simulation tests show that the three layer coated tool is less affected in the change of cutting speed and when the cutting speeds increases 45% the flank wear increases at 14%.

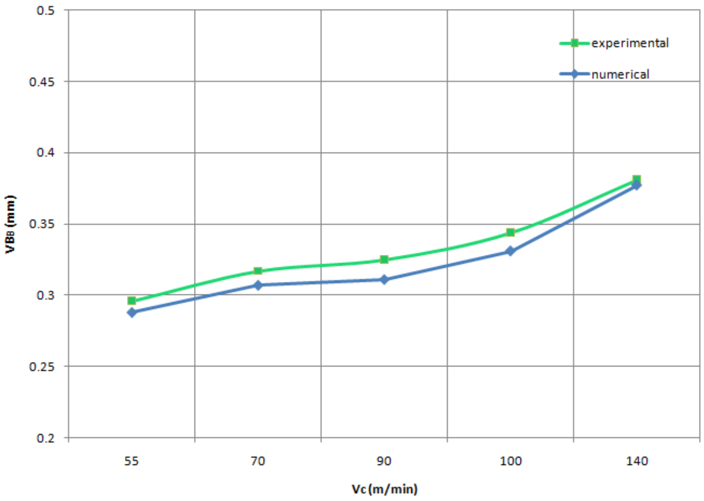


Figure (8) the effect of cutting speed on flank wear

## Effect of Feed Rate

Both numerical and experimental results show that the increase in feed rate leads to increase in tool wear. The results show that as the feed rate increases from (0.08 to 0.24 mm/rev) the tool wear increases by 20.4 % for three layers coated**.** It is obvious that the three layer coated tool is the least affected in the increase in feed rate. This means that the three layer coated tool is the best type when there is increase in the feed rate. The maximum difference between the numerical and experimental results is 5%.

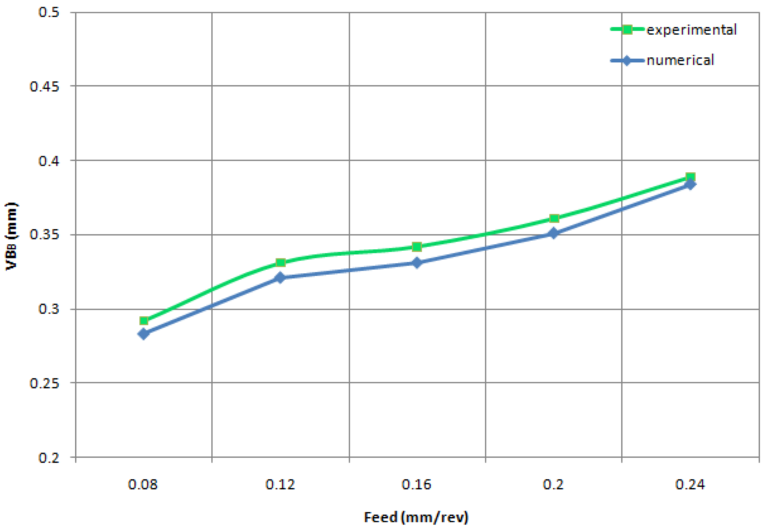


Figure (9) the effect of feed rate on flank wear

## Conclusion

1. The FEA code DEFORM 2D is successfully accomplished in modeling and simulation of the flank wear in cutting tools.
2. Usui wear rate model is a powerful tool to predict the flank wear in the numerical experiments.
3. The cutting speed effect on the tool wear is more dominant than other machining parameters such as feed rate, coated layers and depth of cut.
4. Best values of minimum tool wear are obtained when cutting speed (70 – 100 m/min), feed (0.12 – 0.2 mm/rev) and depth of cut 1.5 mm.
5. The three layer coated tool is the perfect tool to be used when there is a change in the cutting speed and feed rate for cutting speed (50 – 140 m/min), feed (0.08 – 0.24 mm/rev) and depth of cut (1.5 mm).

## References

Oxley, P.L.B. (1989).**The Mechanics of Machining**. Chichester. Ellis Horwood.

Yen Y.C.,Sohner J.,Weule H.,Schmidt J.,Altan T. (2002). Estimation of Tool Wear of Carbide Tool in Orthogonal Cutting Using FEM Simulation. Machining Science & Technology, vol. 6, pp. 467-486.

A. Attanasio, E. Ceretti, S. Rizzuti , D. Umbrello and F. Micari. (2008). 3D Finite Element Analysis of Tool Wear in Machining. CIRP Annals - Manufacturing Technology, vol. 57, pp.61–64.

A. Attanasio, E. Ceretti, A. Fiorentino, C. Cappellini and C. Giardini. (2010). Investigation and FEM-based Simulation of Tool Wear in Turning Operations with Uncoated Carbide Tools. Journal of Wear, vol. 269, pp. 344–450.

Rajesh Kumar Bhushan , Sudhir Kumar and S. Das. (2010). Effect of Machining Parameters on Surface Roughness and Tool Wear for 7075 Al Alloy SiC Composite. Journal of Advance Manufacturing Technology, vol. 50, pp. 459–469.