International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-6, August, 2019

A Simple Mechanistic Model Used For Tool Wear in Turning AISI 4340 Steel

Ramesh Chandra Mohapatra, Ananda Rabi Dhar, Nilrudra Mandal , Shibendu Shekhar Roy

Abstract: ***Determining correct tool life is a key to efficient machining, which makes tool wear extremely important. Development of new and exotic tool materials like ceramics, carbides, nitrides, cermet, diamonds, etc. has intensified research activities in the area of modeling and optimization of turning process. Building an ideal theoretical model is considerably complex because of involvement of multiple physics and absence of readily available data on material property. This paper describes an attempt of building a simple mechanistic model for turning AISI 4340 steel by an uncoated carbide insert using a commercial package ABAQUS/CAE. The tool wear rate is computed using USUI's wear model on the results found after running simulation. The predicted tool wear data were found in close agreement with the experimental findings.***

Keywords**:** ***Turning, tool wear, mechanistic model, simulation.***

I. INTRODUCTION

Turning on lathe is known to be one of the most basic machining operations carried out in industries. Designing process parameters is very important to ensure maximum tool life which is a key to achieve efficiency and sustainability in today's manufacturing industries. Recent advances in the cutting tool technology in the form of development of new and exotic tool materials like ceramics, carbides, nitrides, cermet, diamonds, etc. created new surges of interest in the area of modeling and optimization of turning process. Enormous efforts have already been invested in this direction using various techniques like statistical methods and finite element-based and soft computing-based approaches [1-4, 6-8].The design and development of finite element-based mechanistic model is extremely complex and challenging because of involvement of multiple physics like solid mechanics, rigid body dynamics, thermodynamics, material science, etc. The material properties of the work piece and the tool material pertaining to elasticity, plasticity, and thermal and various other fields of interest need to be obtained beforehand for setting up such a model. The lack of experimental data in the literature for the new tool material makes this a more difficult proposition.Alternatively, by using some well-established tool wear model like USUI's [6] wear model and relevant data from the simulation results, the wear rate of the new tool material can be indirectly computed considering a rigid tool without bothering any tool wear in the simulation.

This paper describes a simple finite element-based mechanistic modelexploring the alternative approach for studying wear behaviour in turning AISI 4340 steel with uncoated carbide (WC) tool insert by using a commercial software package ABAQUS/CAE. Experimental investigations are carried out at constant feed rate with varying cutting speed and depth of cut on a lathe. Each trial run is performed for a stipulated time and tool flank wear length and maximum width are measured using a tool makers microscope. The measured data is converted into equivalent volume loss rate for the tool in the USUI's wear model and the results of simulations are validated accordingly.

Revised Manuscript Received on October 30, 2019.
* Correspondence Author
Dr. Ramesh Chandra Mohapatra, Mechanical Engineering Department, Government College of Engineering Keonjhar-758002, Odisha, India
Ananda Rabi Dhar, Mechanical Engineering Department, National Institute of Technology, Durgapur – 713209, West Bengal, India
Nilrudra Mandal, [3]Materials Processing & Microsystems Laboratory, CSIR-Central Mechanical Engineering Research Institute, Council of Scientific & Industrial Research (CSIR), Durgapur 713209, West Bengal, India
Shibendu Shekhar Roy, Mechanical Engineering Department, National Institute of Technology, Durgapur – 713209, West Bengal, India

II. PROPOSED METHODOLOGY

A. *Experimental setup*

A round bar of 140 mm diameter of AISI 4340 steel, heat treated up to harness of 32 HRC, is rotated at a varying spindle speed to meet the required surface speed of 120, 180 and 240 m/min.The feed rate of the tool setup is kept constant at 0.08 mm/rev. Uncoated tungsten carbide (WC) tool insert with designation SNMG120408 of make SANDVIK is fitted in the tool holder(Fig. 1) maintaining ORS tool signature of "-6, -6, 6, 6, 15, 15, 0.8".The negative rake angle is to ensure strength to the cutting edge of comparatively brittle carbide tool insert.The tool flank wear is measured by tool makers microscope (make: Leica, Germany) with 30 to 150 magnification and1µm resolution. Three levels of depth of cut are used as 0.4, 0.6, and 0.8 mm. For each experimental run, a fresh single corner of the tool insert is dedicatedly used for a fixed cutting time of two min. With one replica, the total number of experimental runs required is 18, thereby requiring minimum three tool inserts. The mean of the observed data for each experimental run is also calculated.

a b c d

Fig. 1. a. Experimental setup on lathe, b. Tool makers microscope, c. Uncoated carbide tool insert, d. Tool flank wear observed in microscope

Density (kg/m^3)	Elastic modulus (GPa)	Poisson's ratio	Thermal conductivity (W/mK)	Specific heat capacity (J/kgK)	Melting point (K)	Thermal expansion co-efficient (µm/mK)
7850	207	0.29	44	475	1700	12.3

Table 1. Material properties of AISI 4340

B. Mechanistic model

ABAQUS/CAE [5] is a well-known finite element-based simulation package extensively used in industries and research organizations. A simplified 2D geometry of work piece and tool is used for developing the model using this software. A dynamic-temperature-displacement solver is employed. The thermo-mechanical properties of AISI 4340 steel are entered in the material sectionof the model, some of which are also indicated in Table 1 [2, 3]. Johnson-Cook model is applied for modeling plastic deformation. Both ductile damage and shear damage with a sample evolution data are specified. A linear explicit temperature coupled displacement element type with quadrilateral shapes is opted for meshing. The boundary condition assumes a rectangular work pieceencastered at bottom and left hand side assembled with a desired tooling with specified inclination of rake and flank face. A chosen reference point on the tool geometry to which the tool is also connected by a rigid body constraint is provided with a linear velocity of desired value, which isvaried across simulations. The tool tip is also placed accordingly in assembly so asto provide with different values of depth of cut as specified. The interaction is selected as of penalty due to hard surface to surface sliding friction. The step time is kept synchronous with the current speed of the tool reference point and the available length of the work piece for cutting. Contact pressure, slip velocity, and nodal temperature are selected as field output responses along with others.The wear volume loss is calculated by the simple formula specified in Eq. (1)applying USUI's wear model [6], and the relationship between flank wear width and volume loss rate as indicated in Eq. (2) [7], wheredW indicates the volume loss rate due to wear, VB_{max} is the maximum value of flank wear width,$\sigma_s$denotes contact pressure for the tool and work piece interface considering specifically the flank face,$V_s$denotes sliding velocity for the tool and work piece interface, T is the interface temperature, and$l$is the contact length (flank wear length), α_n andγ_n are the normal relief angle and normal rake angle respectively. The values for the angles are +6°and +44.84° respectively assuming an orthogonal cutting. *A* and *B*areconstants and their values are computed as0.000638and 1054.818respectively by equating with wear values from the first two experimental results. Using the values of *A* and *B*, the predicted values are obtained for the remaining simulation runs.

$$dW = A.\sigma_s.V_s\exp(-B/T) \quad (1)$$

$$dW = \frac{1}{2}.\ VBmax^2.l.\frac{(tan\alpha_n)}{(1+\ \tan\gamma_n.\tan\alpha_n)}$$

III. RESULTS AND DISCUSSIONS

The additional field output responses like contact pressure, sliding velocity, and nodal temperature as requestedfor the nodes lying on the contact edge of the flank side for the analysis.The mean values for the entire set containing all the node points of interest are calculated. From the experimental observations, it is found that the actual flank wear length and maximum wear land width values are very close. Hence, for the sake of simplification of the computation, the flank wear length and maximum flank wear width are assumed to have identical values. The mean values of the field outputs along with the actual and predicted tool flank wear land width for nine simulation runs are tabulated in Table 2. The RMSE is calculated as 0.0197. The R^2 value of the prediction system is found to be 96.55%, which is quite satisfactory considering the simplified model and the dynamic nature of the problem. In this simplified model, the constants *A* and *B*and coefficient of friction in interaction section of the model are the only variables that need to be wisely selected based on the experimental observations to fit wear results for different tool material and different feed rates.

Table 2. Results showing actual experimental findings and predicted flank wear of simulation runs

Sample Simulation Run	Cutting Speed (m/sec)	Depth of Cut (mm)	Contact Pressure (10^5Pa)	Contact Sliding Speed (m/sec)	Contact Temperature (K)	Actual Wear Width VB_{max} (mm)	Actual Wear Length l (mm)	Predicted Wear Width VB_{max} (mm)
1	2	0.4	0.9	1.8	510	0.14	0.14	0.14
2	2	0.6	2.3	1.7	565	0.18	0.25	0.20
3	2	0.8	8.1	1.6	720	0.32	0.34	0.34
4	3	0.4	3.1	2.9	645	0.28	0.30	0.29
5	3	0.6	4.7	2.7	678	0.31	0.33	0.33
6	3	0.8	8.4	2.5	791	0.38	0.41	0.42
7	4	0.4	5.6	3.8	750	0.42	0.43	0.41
8	4	0.6	7.1	3.6	787	0.43	0.45	0.45
9	4	0.8	8.9	3.4	830	0.47	0.49	0.48

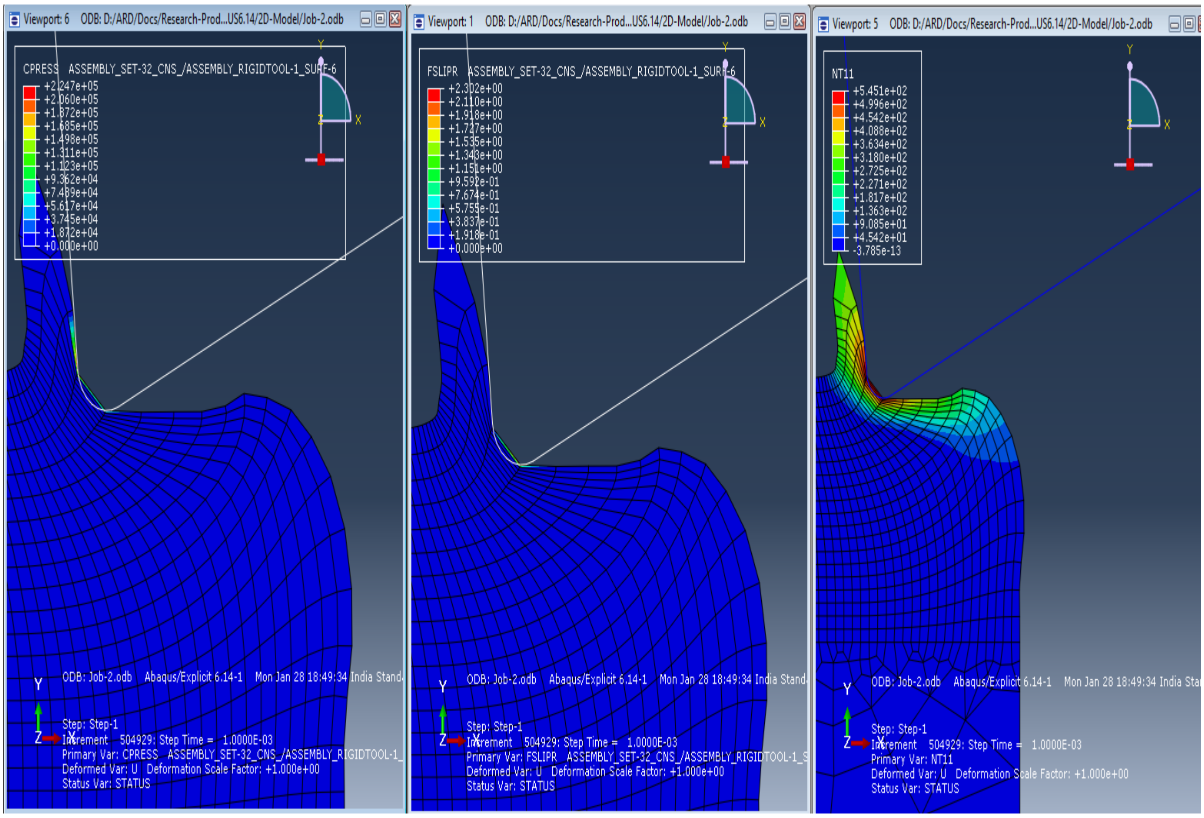

Fig. 2.Screenshot showing simulation results for a sample setup

IV. CONCLUSIONS

In this work, a simple mechanistic model for predicting tool flank wear is developed using ABAQUS/CAE software package. Experimental investigations are conducted by turning AISI 4340 steel with uncoated carbide tool insert on a lathe. The predicted values of tool flank wear maximum land width are found to be in good agreement with the actual observed responses. This should be clearly mentioned that the model uses an oversimplified geometry, for which it may fail to produce expected output, given different tool materials, feed rates, and other changing configurations. Besides replacing this with a 3D model of tool and work piece, the analysis itself can be improved by updating the model of interaction and size and element type of meshing. The assumptions of the matching values of flank wear maximum land width and flank wear length are merely based on experimental findings, which need to be corrected in future work.Most importantly, the tool should not be considered rigid as in this case. If the tool material properties including the failure and damage related properties are obtained and mesh is also generated for tool geometry, the wear rate can be directly obtained from simulations [8] and there will be no need of any additional wear model.

REFERENCES

1. ÇYDAŞ, U. Machinability evaluation in hard turning of AISI 4340 steel with different cutting tools using statistical techniques. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture;2010. 224, 1043-1055.
2. SURESH, R., BASAVARAJAPPA, S. & SAMUEL, G. Some studies on hard turning of AISI 4340 steel using multilayer coated carbide tool. Measurement;2012. 45, 1872-1884.
3. Chinchanikar S., Choudhury S. K.. Investigations on Machinability Aspect of Hardened AISI 4340 Steel Different Levels of Hardness Using Coated Carbide Tools, Int. Journal of Refractory Metals and Hard Materials; 2013, vol.38, pp. 124-133.
4. Wang, X., Wang, W., Huang, Y., Nguyen, N., & Krishnakumar, K.. Design of neural network-based estimator for tool wear modeling in hard turning. Journal of Intelligent Manufacturing; 2008.Vol. 19(4), pp. 383–396.
5. Smith M. ABAQUS/Standard User's Manual, Version 6.9. Providence, RI: Simulia, 2009.
6. Usui E, Shirakashi T , Kitagawa T. Analytical Prediction of Cutting Tool Wear. International Journal of Wear; 1984. vol. 100, pp. 129-151.
7. Zhang, G. and Guo, C. 2016. Modeling Flank Wear Progression Based on Cutting Force and Energy Prediction in Turning Process. United Technologies Research Center (China), Shanghai, China, Procedia Manufacturing, 2016, Vol. 5, pp. 536–545.
8. Vijayaraghavan, V.; Garg, A.; Gao, L.; Vijayaraghavan, R.; Lu, G.: A finite element based data analytics approach for modeling turning process of Inconel 718 alloys. J. Clean. Prod; 2016. Vol. 137, pp. 1619– 1627.

AUTHORS PROFILE

Dr. Ramesh Chandra< Mohapatra was born in Orissa, India in 1969. He graduated from Department of Mechanical Engineering of UCE, Burla, now VSSUT, Burla, Orissa, India. He received the degree of M.Tech in Thermal Engineering from Department of Mechanical Engineering of Indian Institute of Technology (IIT), Kharagpur, Orissa, India and PhD in Mechanical Engineering from Utkal university,Vanivihar, Bhubaneswar, Orissa, India. He is presently working as Associate Professor & HOD of Mechanical Engineering Department in Government College of Engineering, Keonjhar, Orissa, India *Corresponding Author Email Id- rameshmohapatra75@gmail.com