The Journal of Undergraduate Research

Volume 4 *Journal of Undergraduate Research, Volume 4: 2006*

Article 9

2006

Cutting Force and Temperature Prediction for Turning Processes

Brian Carstensen
South Dakota State University

Aaron Eich
South Dakota State University

Tyler Schroeder
South Dakota State University

Ryan Joens
South Dakota State University

Recommended Citation

Carstensen, Brian; Eich, Aaron; Schroeder, Tyler; and Joens, Ryan (2006) "Cutting Force and Temperature Prediction for Turning Processes," *The Journal of Undergraduate Research*: Vol. 4, Article 9.
Available at: http://openprairie.sdstate.edu/jur/vol4/iss1/9

Cutting Force and Temperature Prediction for Turning Processes

Authors: Brian Carstensen, Aaron Eich,
Tyler Schroeder, Ryan Joens
Faculty Sponsor: Dr. Li Qian
Department: Engineering Technology & Management

ABSTRACT

The machining process modeling software allows researchers to run simulations of real world situations without the costs and risks of operating the machining tool and ruining a work piece or cutting tool. We ran several simulations with combinations of high speed steel, carbide, and cubic-boron-nitride for our tool materials, and 1045 steel, 15-5PH, or Inconel 718 for workpiece material options. The numerical simulations or experiments assumed physical, mechanical, and thermal properties representative of work-piece materials and tool material. Cutting forces were determined in the numerical simulations.

INTRODUCTION

Numerical analysis with finite element method (FEM) is used to find the correct parameters for cutting processes. The types of cutters are high speed steel, carbide, and cubic-boron-nitride (CBN). The workpiece materials are 1045 steel, 15-5PH, or Inconel 718.

Machining process simulation software allows us to put in information for many various types of cutters and cutting materials, which include: depth of cut, length of cut, speed, feed, length of work piece, height of work piece, cutting edge radius, rake angle, relief angle, initial temperature, and coolant. These options save researchers large amounts of money and time because we can run machining situations and it will give us a visual representation of what is happening during the cut for many different parameters that go with the cut.

METHODS

Participants

The members of this study were Aaron Eich, Tyler Schroeder, Ryan Joens, and Brian Carstensen. At the beginning of the experiment we each picked out what part of it pertained the most best to each team personmember and we set certain goals for ourselves.

Materials

For the experiment, we had four different cutting tools and cutting material combinations.

Cutting Tool	**Work Piece Material**
High Speed Steel	1045 Steel
Carbide	1045 Steel
Carbide	15-5 PH
Cubic-Boron-Nitride	Inconel 718

High Speed Steel (HSS) has been the most widely used type of cutting tool for a long time. HSS is tough but not hard, easily re-sharpened, and used with lower cutting speeds (<150 feet per minute) and a lower tool contact temperature (<550 °C). Carbide is an extremely hard and abrasion-resistant material. While it is slightly more expensive than HSS, it can out last it by a factor of 5-10 times depending upon the application. One shortcoming of the cutting tool is that it is considerably more difficult to re-sharpen than HSS. It is used for higher cutting speeds (<400SFM) and higher tool contact temperatures (1200 °C). Cubic boron nitride (CBN) is an artificially synthesized material exceeded in hardness only by diamond. Unlike diamond, however, CBN is stable under conditions of high temperature (up to 1000°C) normally seen when machining hardened ferrous or super alloy materials such as chilled cast iron; hardened forged steel rolls(55-65HRc); HSS tools(60HRc); abrasion-resistant parts (55-65HRc) and Titanium alloy Inconel 718.

1045 is medium tensile, low harden-ability carbon steel generally supplied in the black hot rolled or occasionally in the normalized condition, with a typical tensile strength range of 570 - 700 Mpa and a Brinell hardness range of 170 - 210 in either condition. Steel 15-5 PH is a martensitic precipitation-hardening stainless steel that provides high strength, good corrosion resistance, good mechanical properties at temperatures up to 600°F (316°C) and good toughness in both the longitudinal and transverse directions in both base metal and welds. Inconel 718 is a precipitation hardenable, nickel-base alloy designed to display exceptionally high yield, tensile, and creep-rupture properties at temperatures up to 1300°F.

Procedure

Numerical simulations with FEA were performed using the 2D Lagrangian FE modeling software AdvantEdge [1]. Features to model machining processes in the software include adaptive remeshing capabilities for resolution of multiple length scales; multiple body deformable contact for tool-work interface, and transient thermal analysis. The material properties model contains deformation hardening, thermal softening and rate sensitivity associated with a transient heat conduction analysis for finite deformations. A constant coefficient of friction (0.5) is assumed in the simulations. Detailed information on the FEA model, material model, and friction model can be found in Ref. [2]. Fig. 1 shows the schematic of orthogonal cutting conditions used for the two-dimensional finite element mesh. The cutting tool is characterized by rake angle, clearance angle, and cutting edge radius. The process parameters include feed f, cutting speed V, and depth of cut (doc).

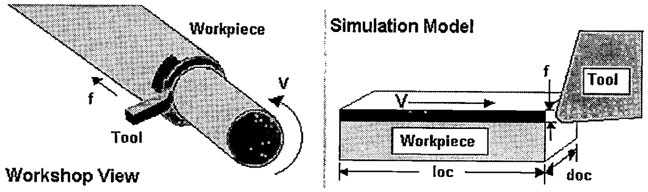

Figure 1. Scematic of Orthogonal cutting conditions for simulation

We ran each of the above tool/workpiece material combinations with different cutting process parameters. The effect of feed, cutting speed, and depth of cut on the cutting performance variables such as cutting forces, and temperature were investigated in those simulations. Table 1 shows the cutting parameters used in the simulations.

Table 1. Cutting Process Parameters in Numerical Simulations

Depth of Cut *(mm)*	.5, 1, 1.25,1.5, 2, 2.5
Speed	Variable
Feed	Variable
Length of Cut	3 mm
Length of Workpiece	50 mm
Height of Workpiece	10 mm
Cutting Edge Radius	0.79375 mm
Rake Angle	6□
Relief Angle	15□
Initial Temperature	20□ C
Coolant	Off

As you can see from the table, depths of cut, speeds, and feeds were variable for each combination. These parameters are determined from one manufacturing handbook [4]. We then ran each of the programs and collected the data that pertained to the information we needed. In the model you can view a graph showing how parameters matched up to other parameters. We then made line-graphs showing what reactions occurred with the combinations.

RESULTS

The information gathered from our experiment was collected and condensed into graphs displaying the relationship between force, depth of cut, and speed. The relationship between this data can be analyzed through the following formula as shown in Fundamentals of Tool Design Textbook [5] :

$$F = k \cdot a_p^{\alpha_1} \cdot f^{\alpha_2} \cdot v^{\alpha_3}$$

This equation shows how depth of cut, speed, and feed affect the force between the cutting tool and the work piece. The exponent Alpha can be compared in Table 2, and expresses the relationship between cutting force (F) and the given variable; depth of cut (ap), feed, (f) and speed (v). As seen by the data in our graphs, speed had a minimal affect and was displayed as virtually a straight line. This illustrates that Alpha 3 is approaching zero. The other two Alpha values had a much greater affect on the force.

Table 2. Factor Coefficients for Various Tool/work piece Material Combinations

Tool/workpiece material combination	DOC □1	FEED □2
HSS/1045	0.8576	0.2375
CARBIDE/1045	0.7252	0.187
CARBIDE/15-5PH	0.852	0.2797
CBN/INCONNEL-718	0.852	0.2137

We found that with these four combinations each one would work well in many cases. No particular combination stuck out as being superior over other combinations. The line trends in each of the cases for the different depths of cuts, feeds, and speeds stayed consistent throughout the experiment.

Fig .2 and Fig. 3 below were from the simulation for the carbide and 1045 combination. Fig.2 shows the temperature distribution with meshed workpiece and cutting tool. Fig.3 shows the predicted cutting forces in the X and Y directions and peak temperature during turning 1045 with one carbide tool.

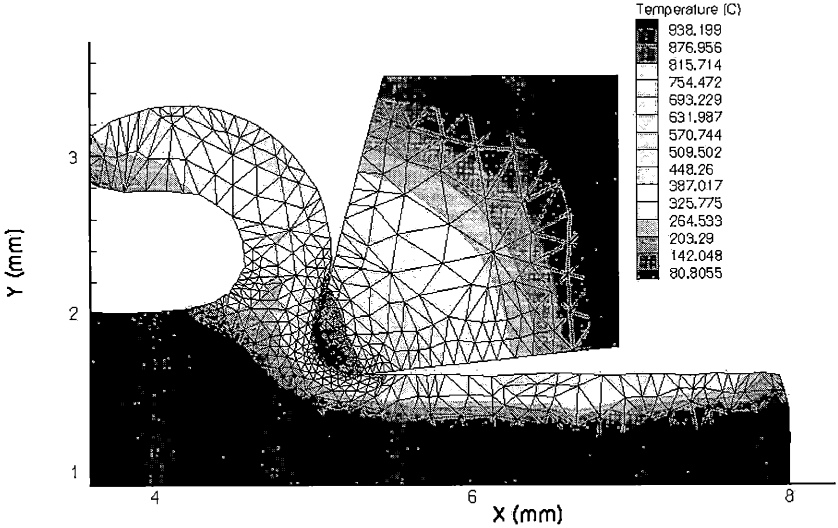

Figure 2. Temperature distribution

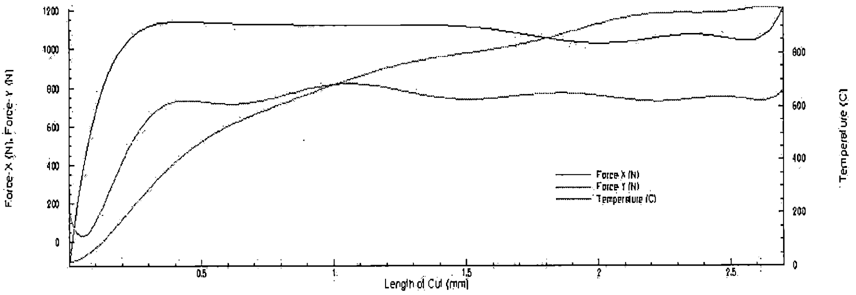

Figure 3. Cutting force and temperature

DISCUSSION

The cutting force/temperature predictions are important for automation and optimization. These factors are related to tool wear and tool life. The combinations are acted nearly the same for all parts of the experiment. Presumably, this was because of the combinations of materials chosen. We used cutting tool materials and cutting work piece materials that would work very well together. Of interest would be the outcome of choosing materials that would not work well together in this same experiment. If we would extend the experiment, we could also look at which combinations would be better for quality and price issues. These concerns are what affect companies the most in deciding which type of tools to use. Many cases of this would be different for all types of companies. Tooling plays a huge role in this instance in helping pick out the tools that are the most efficient for certain operations.

REFERENCES

[1]. Third Wave Systems (2004). Third Wave Systems AdvantEdge User's Manual (Version 4.5). Minneapolis, MN: Third Wave Systems.
[2]. Marusich, T.D. and Ortiz, M., Modeling and Simulation of High-speed Machining," International Journal Numerical Method Engineering, 1995, 38, pp. 3675-3694.
[3]. Marusich, T. D., Thiele, J. D., & Brand, C. J. (2001). Simulation and Analysis of Chip Breakage in Turning Processes. Minneapolis, MN: Third WaveSystems.
[4]. Oberg, E., Jones, F. D., Horton, H. L., & Ryffell, H. H. (2000). Machinery's Handbook (26 ed.). New York: Industrial Press Inc.
[5]. McLelland, M., Csizmadia, R., Quirk, K., Kania, F., & Newberg, J. (2003). Fundamentals of Tool Design (5th ed.). Dearborn, MI: Society of Manufacturing Engineers.