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Modeling Flank Wear Progression Based on Cutting Force and Energy Prediction in Turning Process

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Abstract
Flank wear of cutting tools is often used as the tool life criterion because it has high impact on the diametric accuracy of turning. Accurate prediction of tool wear is important for optimizing tool change and other cutting parameters. In this work, a tool wear model is proposed based on the prediction of the cutting force and the energy consumption in turning process. Based on the cutting force prediction using a validated mechanistic force model, the energy consumption in turning can be estimated. A tool flank wear model is developed using the prediction of the cutting energy consumption and considering the impact of the cutting speed. By using the distribution of the cutting force on tool edge and the energy consumption for each revolution of the workpiece, the wear volume distribution on the tool edge for each revolution is predicted. The flank wear (VB) is further calculated using the tool geometry information. The model prediction of flank wear is validated by using tool wear data published in literature. The comparison shows that the model prediction agrees well with the experimental results.

Keywords: Cutting force, Force intensity, Energy consumption, Tool wear, Wear model, Turning process

1 Introduction

Tool wear is a critical problem in metal cutting. It not only increases the production cost but also degrades the product quality. In addition to resulting in poor work surface finish and the work dimension variations, the tool wear also affects the machining dynamics and thus can be monitored by measuring cutting forces and torques and so on (Cheng, 2009). The useful tool life can be defined in terms of the progressive wear. Progressive tool wear mainly includes the wear on the tool rake face (crater wear) and that on the clearance face (flank wear). Flank wear is often used to define the end of effective tool life. As the flank wear land width (*VB*) has grown to a certain level, it will influence the dimensional accuracy and surface finish of the part as well as the stability of the machining process.

It is helpful to be able to predict the tool wear and tool life and as a result to optimize machining process parameters to reduce manufacturing cost and improve product quality. A wear model describes

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the relation between the machining time and the attained tool wear amount (flank wear VB) for different cutting condition parameters. In the past over thirty years, much work has been contributed to the tool wear modeling. A well-known model for the tool wear rate was developed by Usui et al (Usui & Shirakashi, 1984), and it is based on the idea of contact mechanics and wear. The most famous tool life model is Taylor's model in which the tool life depends mainly on the cutting speed and a constant determined by materials of the tool and the workpiece, feed rate, etc. (Taylor, 1906).

Choudhury et al (Choudhury & Srinivas, 2004) developed a mathematical tool wear model including some important factors like the index of diffusion, wear coefficient, and the hardness of tool, etc. The developed mathematical model was used to relate the wear to the input parameters for a turning operation. Based the prediction results, the authors claimed that the flank wear model is reliable and could be used effectively for tool wear prediction.

Huang et al (Huang & Liang, 2004) studied wear mechanism of Cubic Boron Nitride (CBN) cutters in finish turning of hardened parts and presented a methodology to analytically model the CBN tool flank wear rate as a function of tool/workpiece material properties, cutting parameters. It is shown that adhesion is the main wear mechanism over common cutting conditions.

Yen et al (Yen, Jörg, Lilly, & Atlan, 2004) developed finite element model for tool wear prediction. Based on temperatures and stresses on the tool face predicted by the finite element analysis simulation, tool wear was estimated with acceptable accuracy using an empirical wear model.

Kannan et al. (Kannan, Kishawy, & Surrapa, 2005) presented an energy based analytical model for predicting the tool wear during orthogonal cutting of particulate metal matrix composites (PMMC). The model accounted for the particulate size effect, cutting conditions, material and cutting tool hardness and cutting tool geometry.

Luo et al (Luo, Cheng, Holt, & Liu, 2005) studied the intrinsic relationship between tool flank wear and operational conditions in metal cutting processes using carbide cutting inserts. They proposed a new flank wear rate model combining cutting mechanics simulation and an empirical model. A good agreements between the predicted and measured tool flank wear land width show that the developed tool wear model can accurately predict tool flank wear to some extent.

Marksberry et al (Marksberry & Jawahir, 2008) presented an extended Taylor speed-based dry machining equation to predict tool-wear/tool-life performance in near dry machining (NDM). The validation of the model was performed in an automotive production environment in the machining of steel wheel rims. Tool-wear measurements obtained during the validation of the model showed that NDM can improve tool-wear/tool-life over four times compared to dry machining which underlines the need to develop sustainable models to match current practices.

Attanasioa et al (Attanasioa, Cerettia, & Giardinib, 2013) compared response surface methodology (RSM) and artificial neural networks (ANNs) fitting techniques for tool wear forecasting. Tool life tests on turning of AISI 1045 steel were conducted. Both flank (VB) and crater wears (KT) of the tool were monitored. The comparison shown that ANNs model provides better approximation than RSM in the prediction of the amount of the tool wear parameters.

Mathematical/analytical models are either inaccurate or with difficulties in determining coefficients and they may work well in controlled and well-defined laboratory conditions. The difficulty of these models is the adaptability and validity under industrial conditions. Empirical models rely on lots of experiments and are very time consuming. In this work, a semi-empirical flank wear model based on prediction of cutting force and energy consumption is developed for turning operations. The wear model is based on our previously developed turning force model in which the prediction of the force intensity and energy intensity can be made (Zhang & Guo, 2015). The predicted energy intensity, together with the cutting speed is used to develop the flank wear model. The model is able to predict instantaneous wear volume for each workpiece revolution and the accumulated flank wear VB at a time instance.