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Modeling of tool wear during hard turning with self-propelled rotary tools

H.A. Kishawy [a,*], Lei Pang [a], M. Balazinski [b]

[a] Machining Research Laboratory, Faculty of Engineering and Applied Science, University of Ontario, Institute of Technology, Ontario, Canada
[b] Department of Mechanical Engineering, Ecole Polytechnique de Montreal, Quebec, Canada

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ABSTRACT

In this paper, an attempt is made to evaluate the self-propelled rotary carbide tool performance during machining hardened steel. Although several models were developed and used to evaluate the tool wear in conventional tools, there were no attempts in open literature for modeling the progress of tool wear when using the self-propelled rotary tools. Flank wear model for self-propelled rotary cutting tools is developed based on the work-tool geometric interaction and the empirical function. A set of cutting tests were carried out on the AISI 4340 steel with hardness of 54–56 HRC under different cutting speeds and feeds. The progress of tool wear was recorded under different interval of time. A genetic algorithm was developed to identify the constants in the proposed model. The comparison of measured and predicted flank wear showed that the developed model is capable of predicting the rate of rotary tool flank wear progression.

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1. Introduction

Turning instead of grinding hardened steel is an economical method to generate a high quality machined surface. During the past few years, there has been a significant industrial interest in using dry machining rather than grinding of hardened steel and other difficult-to-machine materials. As an example, dry hard turning of automotive differential side gears is a successful industrial application of this technology. Dry hard turning reduces both the machining time and the specific cutting energy, and eliminates the health and environmental hazards associated with coolant usage in conventional machining operations. However, severe tool wear has been an obstacle to the application of hard turning. Therefore, the control of tool wear and its effect on the integrity of machined surface have been a major technical challenge. Since the high specific forces and temperatures in the small contact area between the tool and the workpiece have much impact on tool wear, hard turning requires tool materials with high wear and temperature resistance. In addition, indentation hardness of at least three times higher than the workpiece hardness is essential, as demonstrated by Nakayama et al. [12]. Since the tool wear and plastic deformation of the cutting edge affect the quality and integrity of the machined surface, ceramics and CBN tools are commonly recommended for hard turning.

Chip removal and wear mechanism of hard turning using CBN, PCBN and ceramic cutting tools has been studied by many researchers.

Matsumoto et al. [11] performed cutting tests on AISI 4340 steels with various hardness values, ranging from 29 to 57 HRC, using ceramic (Al_2O_3–TiC) inserts. Chip morphology study using scanning electron microscopy (SEM) showed that the 50 HRC is the critical hardness beyond which the segmented chips are produced. They also found that the cutting force decreases with the increase in the hardness from 29 to 49 HRC. However, when the hardness exceeded 50 HRC, the cutting forces suddenly increased.

Lin and Chen [8] carried out the experimental study on the various cutting characteristics of a CBN tool during the turning of AISI 52100 bearing steel (HRC 64). At low cutting speed (44.5 m/min), the flank wear rate is low and not sensitive to the feed rate. However, for the high cutting speed (144.5 m/min), the flank wear rate becomes quite large and sensitive to the feed rate. For the commonly used small depth of cut (0.2 mm) during hard turning, the thrust force was found greater than the cutting force. While for a greater depth of cut (0.4 mm) the cutting force becomes greater than the thrust force. This phenomenon was attributed to the size effects since only the tool nose circle of the cutting chin is engaged in cutting at shallow depth of cut.

Luo et al. [9] studied the wear behavior for CBN and ceramic tools during hard turning of AISI 4340 steels with the hardness values in a range of 35–60 HRC. They found that the main wear mechanism for CBN tools is the abrasion of the binder material by hard carbide particles of the workpiece, while adhesion and abrasion wear mechanisms are dominant for ceramic tools. When the hardness of the work material is less than 50 HRC, the wear rate of both tool materials decrease with the increase in the work material hardness. However, the trend becomes opposite when 50 HRC is reached.

The reason why the tool flank wear rate decreases with the material hardness for softer materials is out of the scope of the

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* Corresponding author.
E-mail address: hossam.kishawy@uoit.ca (H.A. Kishawy).

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