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Burr height model for vibration assisted drilling of aluminum 6061-T6

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ABSTRACT

Vibration assistance has seen increasing application in metal removal processes. One application of this technique is vibration assisted drilling. This method typically induces high-frequency and low-amplitude vibration in the direction of drill feed during drilling, and has the potential to reduce thrust forces and reduce exit burr height. Note that this cutting process is distinct from ultrasonic machining/drilling. Predicting exit burr height accurately is important for determining the favourable vibration conditions for burr height reduction. This paper presents a novel analytical burr height model to predict the exit burr height in vibration assisted drilling of aluminum 6061-T6. This model also improves upon the existing analytical burr height model for conventional drilling. The results of 72 drilling experiments with TiN coated standard twist drills are reported. The predictions from the developed burr height model are compared with the experimental results. The results demonstrate that the proposed model improves the accuracy of the existing burr height model for conventional drilling by up to 36%, and also predicts the burr heights for VAD within a 10% deviation from the mean values of the experimental results. A fast analytical method for predicting the favourable vibration conditions for minimizing burr height is also presented.

1. Introduction

Cutting forces generated in metal cutting can produce undesired deformation of workpiece material. One common deformation occurs at the exit surface of the workpiece, and is known as a burr. Burr formation reduces the quality of the machined component. Large burrs require deburring which can significantly increase the total production cost. There are various methods to reduce burr formation. These include using suitable coating on the tool; using suitable (typically reduced) material removal rate (MRR); or even laser assisted machining, which alters the mechanical properties of the workpiece material. One recent and promising technique is known as ultrasonic assisted or vibration assisted machining.

Vibration assisted machining is a pure mechanical process that does not reduce MRR or alter the mechanical properties of the workpiece material. This technique typically induces high-frequency (>1000 Hz) and low-amplitude (<0.015 mm) vibration in the feed direction of a cutting process. This technique has the potential to reduce thrust force and reduce burr height. One application of vibration assisted machining is vibration assisted drilling (VAD) (Lin and Shyu [1], Okamura et al. [2], Takeyama and Kato [3], Zhang et al. [4], Wang et al. [5], and Chang and Bone [6]). Takeyama and Kato [3] studied VAD experimentally and found that it reduces thrust force and burr height in drilling aluminum. They also concluded that the higher the vibration frequency and amplitude are, the larger the reduction is. However, previous studies [4,5], including our own work [6], have shown that a range of favourable vibration conditions exists. At the current time no analytical methods exist in the published literature for determining this range of vibration conditions. Finite element model modeling of the dynamics of the drill in VAD has been developed (Thomas and Babitsky [7]). Their work can be extended to perform FEA study to predict thrust force and burr height. However, running numerous finite element simulations is a very time consuming approach for finding the favourable vibration conditions. There is a need for an analytical method that can rapidly predict this condition.

The contributions of this paper are: a novel analytical burr height model that is applicable to both conventional drilling and VAD, and a fast analytical method to predict the favourable vibration conditions. Section 2 presents the details of the burr height model. Sections 3 and 4 present the experiment setup and a comparison of the model with experimental results, respectively. In Section 5, a fast analytical method to determine the favourable vibration conditions is described. Conclusions are given in Section 6.

2. Burr height model

In this section, the development of an analytical model for burr height prediction is presented. One crucial factor affecting burr height in drilling is the mean thrust force (Kim and Dornfeld [8]).

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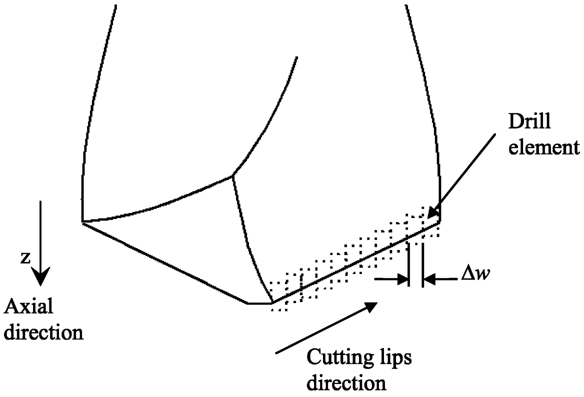

Fig. 1. Each cutting lip of a drill is divided into elements.

The proposed model consists of two parts: a thrust force model for VAD and a burr height model for VAD. Note that this model can be applied to conventional drilling by setting the vibration frequency and amplitude equal to zero. Zhang et al. [4] and Wang et al. [5] presented an analytical model for predicting the thrust force in VAD. Their model is being used in this study and is summarized in Section 2.1. Kim and Dornfeld [8] have developed an analytical model to predict burr height for conventional drilling. Their model, which neglects the effects of temperature, strain rate, and tool wear, is presented in Section 2.2. The model developed in this study, presented in Section 2.3, used a similar burr height modeling approach, with two important modifications. These modifications extend the capability of Kim and Dornfeld's model to predict burr height for VAD, and improve its accuracy for conventional drilling.

2.1. Thrust force model

When predicting cutting forces in a metal removal process, the cutting geometry of the cutting tool is very important (Trent and Wright [9]). Because the effective (also known as dynamic) cutting geometry of a drill varies with its radius, a drill is typically divided into elements along the cutting lips direction (see Fig. 1) and analyzed individually using a conventional mechanistic cutting model. The total thrust force is obtained by summing all the thrust force components of individual elements (Winiyacosol and Armarego [10], Armarego and Wright [11], and Watson [12–13]). A crucial factor in VAD is the instantaneous uncut chip thickness. Because of the vibrations, the instantaneous uncut chip thickness varies with time.

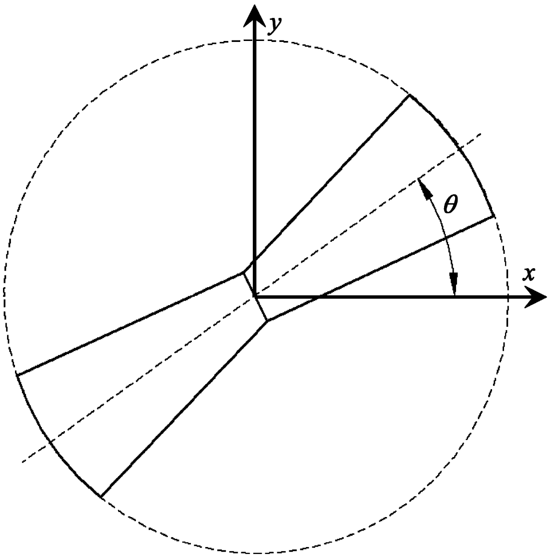

Fig. 3. Rotational location of a cutting lip of a drill.

Following Wang et al.'s [5] methodology, the instantaneous uncut chip thickness for VAD can be estimated by studying the instantaneous displacement and velocity of the tool. The displacement equals the summation of the displacement due to the feed, Fnt, and the displacement due to the vibration, $A\sin(2\pi ft)$, as follows:

$$z(t) = A\sin(2\pi ft) + Fnt \qquad (1)$$

where A and f are the vibration amplitude (mm) and frequency (Hz), respectively; F is the feedrate (mm/rev); n is the spindle speed (rev/s); and t is the time (s). Similarly, the instantaneous velocity is:

$$\dot{z}(t) = 2\pi fA\cos(2\pi ft) + Fn \qquad (2)$$

To determine the axial uncut chip thickness, which is a critical factor in cutting force modeling, it is necessary to monitor the maximum depth of removed material at the rotational location of interest, $z_{\max}(\theta)$ (see Fig. 2). For the definition of θ see Fig. 3. Transforming the independent variable from time (t) to rotational angle of the drill (θ) by substituting $\theta = 2\pi nt$ into Eq. (1) gives:

$$z(\theta) = A\sin\left(\frac{F\theta}{n}\right) + \frac{f\theta}{2\pi} \qquad (3)$$

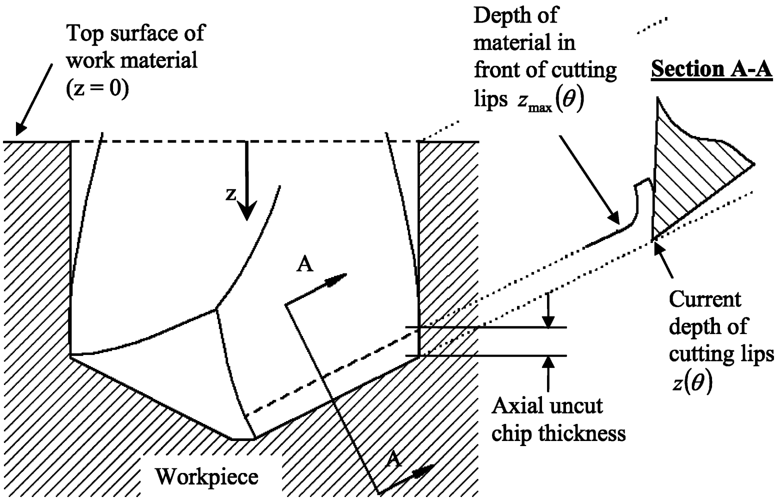

Fig. 2. Schematic of determining axial uncut chip thickness.