Depth of cut prediction in abrasive waterjet turning using a new finite element model

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Abstract: Abrasive waterjet turning (AWJT) is an advanced machining process that could be used for turning cylindrical workpieces with the advantages of low vertical forces and negligible thermal distortion. Radial-mode AWJT is characterised by better utilisation of jet energy and high material removal rate. However, the prediction of depth of cut (DOC) is difficult due to the interaction of several process parameters. In this paper, a new finite element (FE) model was developed to predict the DOC in radial-mode AWJT. The workpiece material is AISI 4340 alloy steel and it is modelled with Johnson-Cook (JC) constitutive model. Two AWJT parameters: waterjet pressure and abrasive flow rate, were considered in the FE model with three levels for each parameter. A full factorial design was selected to evaluate the combined effect of these independent parameters. The resulting crater profile was utilised to estimate the DOC at each parameter combination. In order to evaluate the model accuracy, the DOC results were compared with published experimental data from the literature at the same AWJT conditions. The comparison showed a good agreement between the FE results and the published experimental results.

Keywords: abrasive waterjet turning; AWJT; radial-mode; finite element modelling; multi-particle impact; depth of cut; DOC.

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1 Introduction

Over the past few decades, abrasive waterjet (AWJ) machining has found its way to become one of the most key machining technologies widely used in modern industries (Saravanan et al., 2020). Owing to its distinctive merits, AWJ is capable of virtually machining all engineering materials without being limited by the phenomenal characteristics usually possessed by such materials that hinder the other competing advanced technologies. In AWJ technology, hard abrasive particles are accelerated within a flexible jet of high pressurised water (up to 650 MPa) which is directed toward the workpiece at high speed up to 1,000 m/s. Upon the impingement of the high energetic particles on the workpiece, the material is removed from its upper surface based on the rapid erosion principle (Ghosh et al., 2015). AWJ is a versatile technology that has been applied competently for cutting, milling, turning, drilling and polishing processes. Recently, much attention has been paid for exploiting this technology at the micro-level by employing reduced scale machining areas, nozzles (down to 254 μm in diameter), abrasive particles (down to 25 μm) and lower pressures (Haghbin et al., 2016; Azarsa et al., 2020). As a result, small features (down to 200 μm) with a centreline roughness below 1.1 μm could be obtained.

Abrasive waterjet turning (AWJT) represents an advanced alternative for turning cylindrical workpieces using a similar configuration of the traditional turning where the AWJ acts as the cutting tool while being axially fed along the rotating workpiece (Hashish, 1987). Being an application of AWJ technology, AWJT is distinguished from traditional turning by its versatility and flexibility in processing different materials, low cutting forces and stresses, no thermal distortion, burr-free surfaces, and simple workpiece mounting. Based on the movement of the nozzle, AWJT can be classified into two modes: radial-mode and offset-mode (Li et al., 2012). In the radial-mode turning, the AWJ nozzle is positioned perpendicularly to the workpiece surface whilst the AWJ acts tangentially to the workpiece in the offset-mode, as shown in Figure 1. It was reported that radial-mode AWJT produces a higher material removal rate (MRR) than that obtained by the offset-mode since it allows the maximum utilisation of jet energy (Li et al., 2013). In a direct comparison between these two modes, it was concluded that the radial-mode could achieve a better MRR of 28% while turning alumina ceramics using waterjet pressure and abrasive flow rate of 250 MPa and 5.5 g/s, respectively (Liu et al.,