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A study of the flow characteristics in micro-abrasive jets

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ABSTRACT

An experimental study of particle velocities in micro-abrasive jets by using the particle image velocimetry (PIV) technique is presented. It has been found that the particle jet flow has a nearly linear expansion downstream. The particle velocities increase with air pressure, and the increasing rate increases with nozzle diameter within the range considered. The instantaneous velocity profile of the particle flow field in terms of the particle velocity distribution along the axial and radial directions of the jets is discussed. For the axial profile in the jet centerline downstream, there exists an extended acceleration stage, a transition stage, and a deceleration stage. For the radial velocity profiles, a relatively flat shape is observed at a jet cross-section near the nozzle exit. Mathematical models for the particle velocities in the air jet are then developed. It is shown that the results from the models agree well with experimental data in both the variation trend and magnitude.

1. Introduction

Abrasive jet micromachining (AJM) has been considered as one of the most appropriate micromachining technologies for hard and brittle materials, such as ceramics and semiconductors [1,2]. Owing to its various distinct advantages, such as negligible heat affected zone, small cutting forces, high machining versatility and high flexibility, AJM has been used in fabricating electronic devices and micro-fluidic channels in recent years, where damage-free micro-part features are required. With this technology, a mixture of abrasive particles and compressed air is expelled through a fine nozzle to form a high velocity abrasive-laden air jet. The abrasive air jet (AAJ) impinges the workpiece surface for material removal and shape generation. Material removal takes place due to the erosive action of the particles impacting the target material.

An increased understanding of the erosion process associated with brittle materials enables the development of more accurate models for the erosion rate and surface integrity etc. as a function of process and material variables [3–9]. For hard and brittle materials, the impact force of the abrasive particle causes localized cracks at the work surface. The target material is removed by the formation and propagation of cracks with the subsequent impact events. However, ductile-mode erosion often exits for brittle materials where the material is eroded by the cutting and ploughing actions of the particles [4]. The component of the impact energy that is normal to work surface is responsible for material removal in the brittle nature, while the component parallel to the work surface contributes to the cutting and ploughing actions. Ciampini et al. [5] studied the interference effects between an incident stream of spheres and those rebounding from a flat surface, and developed a computer model to examine the severity and frequency of inter-particle collisions. Ghobeity et al. [6] extended an existing erosion model to predict the cross-sectional profiles of unmasked micromachined channels in borosilicate, in which the experimentally obtained spatial and velocity distributions of particles in the jet of an AJM were used. In [6], particle velocity across a circular jet was measured using a phase-Doppler particle analyzer. It showed that the velocity decreased linearly from the centerline of the jet to the periphery. It has been reported by Burzynski and Papini [7] that the spatial distribution of particles in an abrasive jet follows a Weibull distribution for the majority of cases. Shafiei et al. [8] developed a computer simulation to predict the time evolution of the eroded profiles of surfaces machined by air abrasive jets. It was indicated that future modeling efforts should focus on implementing more realistic velocity distributions for the high particle flux case. Achtsnick et al. [9] developed a one-dimensional isentropic flow model to calculate the particle velocity at the nozzle exit.

From the above analysis, it is apparent that particle velocity and trajectory are important jet characteristic information required for understanding and modelling the particle erosion process involved in AJM. It is well-known that the kinetic energy of the abrasive particles is crucial to the plastic deformation and crack generation in erosion process. The erosion rates of materials are strongly dependent on the particle impact velocity [10–12]. It has been found that the typical erosion rate is dependent on particle velocity to a power of between 2 and 3 for metallic materials, and with even greater

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