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Review

Recent advances and challenges of abrasive jet machining

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ABSTRACT

Abrasive jet machining (AJM) is a manufacturing technology based on erosion localization and intensification. AJM has a progressively important influence on the machining technology market. Over the past 20 years, there has been an exponential growth in the number of papers that discuss AJM. Various innovations and process developments such as intermittent, submerged, thermally assisted and other jet conditions were proposed. This paper examines AJM's technological advantages and the variety of machining operations in different industries where AJM is utilized. Particular attention is devoted to the micro-texturing capabilities of powder blasting and its application in tribology. New evidence of ductile and brittle material removal mechanisms are reviewed together with recently discovered elastic removal mode. The effects of hydraulic, abrasive and machining parameters on particles kinetic energy, machined surface roughness and footprint size are described in detail. Nozzle wear has a strong dependence on nozzle materials, its geometry, particles size, hardness, and flow rate. The trend of AJM development is a shift from macro to micro scale. Improvements in micro-machining resolution, process controlling and erosion prediction are current challenges facing AJM.

Contents

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Introduction

In the 1930s, a low-pressure water jet system was patented and successfully used to cut paper [1]. Twenty years later, a high-pressure hydraulic seal from aviation industry was adopted to water jet machining, that noticeably increased the process productivity [2]. The continuous increase of working pressure in the next few decades allowed the cutting of hard alloys and carbides. On the other hand, a high pressure led to severe nozzle wear, making abrasive jet machining (AJM) economically non-competitive. From the 1970s, after ceramic nozzles were introduced, abrasive jet systems became commercially available and, within a short span of time, became the industrial mainstream and were mainly utilised for cutting and cleaning purposes. Further developments of AJM technology have been made, mainly based on material science progress and CNC conception. In the 21st century, AJM development deviated its track to technology miniaturization, wherein the nozzle diameter plunged from macro to micro scale. Today, sapphire orifice, super-hard abrasives and reliable high-pressure pumps combined with a 6-axis, precisely manage and process monitored systems, making AJM one of the most promising micro-manufacturing technologies despite the fact that it has been used for a century. In the last 20 years, there is a solid growing trend of industrial interest in micro-AJM. The obvious reflection of industrial demands can be seen in a commutative volume of research activity in the area. Since 2000, there has been an exponential growth in the number of publications displayed by Engineering village and Science Direct databases on the request: “abrasive jet machining”.

Previous articles [3–7] have described the recent technological state of AJM. Nevertheless, the review of Chen et al. [3] focused on polishing capabilities of AJM. Verma et al. [4] and Syazwani et al. [5] reviewed the nozzle wear in abrasive waterjet machining (AWJM) separately. Molitoris et al. [6] reported on developments of abrasive water suspension jets. Kalpana et al. [7] analyzed only the process monitoring methods. Taking this research into account, it is necessary to fill the gaps and provide a comprehensive review on the state of the art of AJM, including its technological strengths and weaknesses, analysis of AJM developments and material removal mechanism, the influence of process parameters on surface integrity, texturing capabilities and nozzle wear in abrasive air jet machining (AAJM).

The aim of this work is to fill the gaps in previous articles, by highlighting the main aspects of the technology and representing the most relevant and latest findings among experimental and theoretical investigations. Firstly, two chapters cover technological advantages, industrial applications, and diversity of AJM approach. Chapters 3–5 give a review of material removal mechanisms, process parameters influence and nozzle wear focusing on AAJM. The structure of the paper forms a general view of AJM’s current technological state and detailed assessment of AAJM. Technology problems, their potential solutions, and future prospects are discussed in the conclusion. This review does not cover the modelling of abrasive jet processes. The authors believe that the progress in particle velocity modelling, prediction of material removal rate and surface evolution are worthy of a separate review.

Approaches of abrasive jet machining

The variety of industrial demands for manufacturing of different parts with a specific geometry, surface roughness, and integrity led to several AJM modifications. Apart from well-known abrasive air and waterjet methods, a magnetorheological jet machining (MJM) was invented for superfinishing of precision optics. To change material removal rate (MRR), an abrasive jet can be assisted by cryogenic or high temperatures, air cavitation, etc. For other purposes, such as deep grooving, noise and pollution reduction or large area machining, corresponding proposals were made on the intermittent and submerged jet conditions or energy jet division. This chapter briefly introduces the AJM approaches, its benefits, and latest advances.

Abrasive air jet machining

Abrasive air jet machining (AAJM) and micro AAJM are generally categorized as blasting [8]. While conventional shot blasting is applied mainly to surface cold-hardening, AAJM is aimed at material removal. When the nozzle exit diameter and machining feature is less than 1 mm, the process can be called