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ScienceDirect

Procedia Manufacturing 10 (2017) 136 – 146

Procedia MANUFACTURING

45th SME North American Manufacturing Research Conference, NAMRC 45, LA, USA

Analysis of Surface Finish Improvement during Ultrasonic Assisted Magnetic Abrasive Finishing on chemically treated Tungsten substrate

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Abstract

In the era of globalization, the demand of new products with advanced material and process technologies is increasing. Conventional manufacturing techniques are not capable to process the advanced engineering materials with stringent properties. This paper presents a novel approach to finish some advanced engineering materials with stringent properties, which is a challenge for existing conventional machining processes. In this study the positive outcomes of Magnetic Abrasive Finishing (MAF), Chemical-Mechanical Polishing (CMP), and ultrasonic vibrations have been integrated and a novel finishing process Chemo Ultrasonic Assisted Magnetic Abrasive Finishing (CUMAF) has been developed. The machining performance has been enhanced with the process resulting in better surface finish and reduced finishing time. In order to establish the process, an experimental study was done to analyze the influence of five different process variables on surface roughness of workpiece. The response surface methodology and analysis of variance was used to design the experiments and analyze the results respectively. A regression model was also developed and validated, to foresee the process response. Optimization of the model was carried out at the end to obtain the best performance.

Peer-review under responsibility of the organizing committee of the 45th SME North American Manufacturing Research Conference

Keywords: Hybrid magnetic abrasive finishing; surface finish; chemo mechanical polishing; ultrasonic vibration

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Peer-review under responsibility of the organizing committee of the 45th SME North American Manufacturing Research Conference
doi:10.1016/j.promfg.2017.07.040

1. Introduction

Increasing customer demands and market competition is forcing manufacturing industries to produce precise products with stringent design requirements. Modern manufacturing industries such as aircraft, aerospace, medical, electronics and semiconductor, tools and dies etc. widely use advanced engineering materials such as Titanium alloys, ceramic materials, tungsten, composite materials etc. These non-conventional materials possess some superior characteristics like high wear resistance, toughness, hardness, and better strength. Finishing operations of materials having high hardness values are most precarious, sometimes uncontrollable, and costly phase of entire production process. It is a challenge for modern manufacturing industries to machine these materials precisely to complex shapes with high surface quality [1][2]. Abrasive finishing is widely adapted by manufacturing industries to achieve good quality in terms of precision, accuracy, surface integrity, and form [3]. The conventional abrasive finishing processes utilize a rigid tool that imparts high normal stress to the work-piece. This may cause micro-cracks in the finished surface and affect strength and reliability of the machined parts. Therefore they may be less productive in terms of time, cost and quality. This has led to development of various advanced finishing processes.

MAF is widely used finishing process to obtain highly finished surfaces. In MAF process, abrasive particles are forced against the target surface using magnetic forces causing removal of very fine chips from the workpiece surface. MAF has several advantages in terms of productivity and high surface finish but it is not efficient for processing hard materials like ceramics and high carbon steels [4], [5]. Several attempts have been made to explain the mechanism of MAF and to improve its performance by integrating one or more finishing processes to it. The relevant research papers have been discussed below.

Some researchers [5][6][7][8][9] studied the influence of various process variables such as working gap, voltage supplied to the magnet, magnet rotation and grade of abrasive particles on performance of MAF [6]. Singh et al. [7] conducted an experimental study to explain the mechanism of material removal and wear for magnetic field assisted abrasive flow machining. They reported that the MRR and surface quality was improved due to magnetic field for non-ferromagnetic work materials. Pashmforoush and Rahimi [10] studied the material removal mechanism of MAF on BK7 optical glass. They observed that the most significant factor to affect the process was the size of magnetic and abrasive particles. Jiao et al. [11] also conducted a study to enhance the quality and integrity of sample surface by imparting the rotary motion to the magnetic abrasive brush (MAB) and concluded that improving the trajectory of MAB led to improved surface homogeneity, surface quality and significant increase in the valid finishing region. Singh and Singh [9] performed MAF on cylindrical pipes using sintered magnetic abrasives to study the process characteristics. Lee et al. [12] combined planetary motion and vibrations within magnetic abrasive polishing to improve the efficiency of the abrasives and reported significant improvement in surface quality. Mulik and Pandey [13] successfully finished an AISI 52100 sample with ultrasonic assisted MAF. They concluded that with the application of ultrasonic vibration during MAF tangential force increased, which resulted in improved surface quality. In another study by Kala et al. [14], copper alloy was polished using ultrasonic assisted double disk MAF. They reported that magnetic flux density was increased while using two magnetic disks, which consequently increased the finishing force and improved the surface finish. Zhuo et al. [15] incorporated ultrasonic vibrations with MAF for machining titanium and reported 40% improvement in the process efficiency. Kala and Pandey integrated the ultrasonic vibrations into double disk magnetic abrasive polishing process and found that higher magnetic flux density can be attained by using magnetic poles on either side of the workpiece [16]. Yin and Shinmura applied horizontal, vertical and compound vibration during processing a SUS 304 sample using MAF and reported that providing vibration along the direction of feed and perpendicular to the feed together resulted in improved surface finish with reduced finishing time [17].

Chemo Ultrasonic Polishing is another process used to finish plane surfaces using mechanical and chemical forces together. This process integrates chemical oxidation and abrasive finishing. CMP has disadvantage of low material removal rate (MRR) when applied to hard materials. Wang Z. et al. [18] studied the influence of two main parameters namely process temperature and concentration of slurry abrasive, in the removal mechanism of CMP for tungsten. The removal rate was observed to increase linearly with the process temperature and to be linear to the cubic root of the slurry abrasive concentration. Judal and Yadava [19] proposed a hybrid abrasive finishing process which combines electro-chemical reaction with magnetic abrasive machining (C-EMAM). Forsberg [20] studied the variation in MRR with change in process parameters during CMP of Silicon. He reported that the material is