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Magnetic Assisted Finishing of Internal Surfaces †

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Abstract: Surface quality is one of the most important things to think about when using precision equipment. Inadequate surface quality in engineering products can result in a number of issues, such as excessive wear, failures, improper geometry, and more. Traditional finishing techniques are neither flexible nor economical when it comes to finishing complex geometries. When it comes to finishing with low tolerances and no surface topography degradation, magnetic assisted finishing systems rank among the best. This chapter discusses the types of magnetic assisted finishing techniques, including BERMP, UAMAF, and MAF, and how they are used to finish internal surfaces.

Keywords: magnetic assisted finishing processes; magnetic field; magnetic abrasive finishing; internal surface finishing

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1. Introduction

Internal surface precision finishing is always an issue because it is labor-consuming and difficult to manage. Finishing of internal surfaces is in huge demand for a variety of applications in the aerospace, semiconductor, automobile, medical, and chemical industries. Examples include oil pipelines, catheters, gas missiles, sanitary pipes, engine manifolds, and other items with functional internal surfaces [1]. Abrasives with several tiny cutting edges are frequently used to obtain the preferred geometrical precision and qualities of a surface by eliminating undesirable excess material from the surface of a workpiece. All conventional finishing procedures (lapping, honing, grinding, etc.) work via this finishing mechanism. With the advent of new arduous-to-machine materials as well as complicated geometrical shapes of engineering components, existing conventional finishing procedures are inadequate for generating the needed level of quality and other features [2]. Although such approaches are feasible, they necessitate costly equipment and a huge workforce, making them economically ineffective.

In recent decades, advancements in advanced finishing techniques have resulted in a reduction in tool hardness requirements and limited the predetermined relative velocity of cutting edges with regard to the surface of workpieces. Some examples of such processes include electrochemical machining (ECM), abrasive jet machining (AJM), laser beam machining (LBM), ultrasonic machining (USM), electric discharge machining (EDM), and others. A significant barrier regarding finishing intricate geometries is the pre-decided relative velocity of the cutting edge with regard to the workpiece surface.

Another significant aspect of precise finishing with small tolerances and without destroying the topography of a surface is the precise control of finishing forces. The major limitations in existing finishing techniques are incapable of controlling abrasive forces to achieve the final surface finish. Magnetic assisted finishing is an advanced fine finishing technology in which abrading forces are carefully controlled [3]. Magnetic assisted finishing processes have the capability to finish complex or internal geometries up to the nano level. This paper summarizes the various trends in the research literature on magnetic assisted processes with respect to internal surface finishing.

2. Magnetic Assisted Finishing Processes (MAFP)

In magnetic assisted finishing processes (MAFP), the goal is to improve the surface qualities of a workpiece by applying precise finishing forces. The forces of finishing applied to the abrasive particles in the MAFP can be regulated externally. In these processes, the magnetic field (MF) is the main controlling factor. The forces applied to the abrasive particles can be regulated by adjusting the MF, which in turn, regulates the finishing action on the workpiece surface [4]. These processes can finish to the nanoscale or even the angstrom level by accurately controlling finishing parameters such as abrasive particle sizes, magnetic particle size, magnetic field, carrier medium viscosity, and others. Magnetic assisted finishing processes (MAFP) include magnetorheological abrasive flow finishing (MRAFF), magnetic abrasive finishing (MAF), and magnetorheological finishing (MRF), etc.

3. Current Research

For the purpose of polishing the inside surfaces of alumina ceramic components, Yamaguchi et al. (2004) [5] introduces a novel method, which they name magnetic field assisted finishing. According to their investigation, the final surface of alumina ceramic components is extremely dependent upon the amount of lubricant used, the sizes of the ferrous particles, and the grain sizes of the abrasive material. The procedure is able to generate surface, finishes with a roughness of surface (Ra) as low as 0.02 μm, and imparts only a little amount of extra residual stress to the surface. However, the roughness of surface was best improved by the 0–1 μm diamond-based abrasive material, and the final Ra was 0.02 μm after 20 min. The experiments conducted with iron particles measuring 330 μm demonstrated the most efficient finishing performances. The amount of lubricant used is extremely important for abrasive contact the tube's inner surface, which in turn determines the features of finishing.

Yun et. al. (2016) [6] introduces a novel technology called ultrasonic-magnetic abrasive finishing (UAMAF). When compared to MAF, the UAMAF exhibits significant improvements in terms of both the amount of material removed and the Ra as the rotation of the finishing trajectory. The Ra in UAMAF is reduced from 1.1 to 0.03 μm after being finished for 50 min. Hence, when the speed of workpiece increases to 2000 rev/min, the Ra is higher than when it is 600 rev/min. The frequency ranges from 0 to 19 kHz: the greater the frequency, the more material is removed and the better the surface quality. The lower the frequency, the less material is removed. The surface has an optimal roughness of 0.03 μm after fifty minutes of finishing, and 485 mg of material is removed.

The impact of finishing time, tool rotation speed, and abrasive mesh number on internal spiral groove surface roughness in aluminum cylinders was investigated by Khalaj et al. (2017) [7]. Their study used analysis of variance (ANOVA) and a full factorial design approach to assess experimental trial outcomes. Their investigation found that magnetic abrasive finishing (MAF) fitted the surface's geometrical restrictions and enhanced surface quality by 70. To achieve the greatest Ra improvement (from Ra = 1.12 μm to Ra = 0.32 μm), the best variables were 120 abrasive mesh number, 2400 rpm, and 180 min finishing time. The highest material removal occurred at parameters of 2400 rpm, 180 min, and 50 abrasive mesh.

A new magnetically driven polishing tool for internal surface finishing was studied by Zhang et al. (2018) [1]. This cutting-edge technology employs a spherical magnetic and abrasives, regulated by external bar magnets, to remove material from inside a tube. It differs from the current magnetic abrasive finishing (MAF). The current research focuses on using a developed polishing tool to smooth internal surfaces, like the tubes and manifolds of non-ferromagnetic materials. The best Ra of 53 nm was attained by using sphere magnets without MAPs (magnetic abrasive powders). Nevertheless, as a trade-off, material removal during this condition is reduced. This state could be considered as the last phase before creating an incredibly fine surface polish. When added to the magnetically driven polishing process, MAPs can significantly boost the material removal and produce a surface quality that is relatively good. Using MAPs during section polishing resulted in a notable 86% improvement in surface roughness, with 0.557 μm being the best possible roughness of surface (Ra). The goal of this research is to enhance the effectiveness and texture of traditional MAF that is applied to the inner surface of alumina ceramic tubes.

Patel et al. (2022) [8] explored the magnetic field-assisted finishing (MFAF) method for the finishing of alumina ceramic tubes. The MFAF setup was designed and built using a traditional lathe machine; varying the operational constraints had an impact on the surface finish's quality. The parameters studied in this study are the speed of chuck (rpm), iron power, machining time, and quantity of diamond abrasive. The rotating chuck speed had a major effect on the Ra, and increasing the tool speed enhanced the surface quality. A highly polished surface with a Ra of 1.114 µm was obtained after 60 min of machining time at 1025 RPM and its initial surface roughness was 1.5 µm.

In order to complete the blind cavities and grooves in the internal channel of additively manufactured parts, Wang et al. (2022) [9] proposed a novel technique called bias external rotating magnetic pole (BERMP). A novel BERMP method was proposed, based on the principle of vibration-assisted magnetic abrasive finishing (VMAF). In this experiment, the speed of workpiece spherical steel grit (SG) is used as the magnetic abrasive to rub, impact, and extrude the workpiece's surface to achieve finishing. In their experiments, the RSM (response surface methodology) technique of statistical analysis was used to examine the impact of the vibration frequency, processing clearance, vibration amplitude, and magnetic pole speed on the Ra. It was observed that processing efficiency and quality were effectively increased when vibration was used.

In this experimental work, 1 mm of processing clearance, 0.2 mm of vibration amplitude, 800 rev/min of magnetic pole speed, and 15 Hz of vibration frequency provide optimal processing conditions. The Ra may be reduced from the initial Ra 12.60 µm to the final Ra 1.25 µm with a 90% reduction.

Yang et al. (2022) [10] focused on the internal surface finishing of a thick-walled tube. In order to achieve this, the authors developed a new technique called magnetic abrasive finishing, which involved the use of an auxiliary magnetic machining tool. The results of the study suggested that the overall quantity of abrasive particle and powder of iron, respectively, influenced surface roughness and roundness. Furthermore, the findings revealed that a considerable decrease in the relative revolution velocities led to an increase in surface irregularity, and a decline in roundness occurred. Following a finishing time of 105 min, the roughness of surface was decreased from 4.1 µm to 10 nm. An improvement in roundness from the initial measurement of 270 µm to 10 µm was achieved through the implementation of a refining technique comprising multiple stages.

4. Conclusions

This study presents an analysis of the finishing of internal surfaces using magnetic assisted finishing methods. Using various methods in which finishing forces can be controlled precisely through the externally applied MF, the internal surfaces can be finished without many difficulties. Studies explored the finishing capabilities of MAF, UAMAF, and BERMP, etc., to finish the internal surfaces of various materials. These processes aim to improve surface quality by applying precise finishing forces to abrasive particles. The magnetic field is the main controlling factor in these processes, which can be adjusted externally to regulate the finishing action on the surface of workpieces. Several studies have explored the MFAF method for the finishing of alumina ceramic tubes, and a novel method of bias external rotating magnetic pole (BERMP) for blind cavities and grooves was investigated for use in additive manufacturing parts. This study found that vibration can increase processing efficiency and quality, reducing the roughness of surface from 12.60 µm to 1.25 µm with a 90% reduction. This article summarizes the various research studies on the magnetic assisted finishing of internal surfaces.

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