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A Study on the abrasive gels and the application of abrasive flow machining in complex-hole polishing

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Abstract

The characteristics of abrasive flow machining (AFM) make it a suitable method to polish complex holes and curved surface. Anyway, the traditional abrasive flowing machining (AFM) methods have difficulty achieving uniform roughness of radial distribution in polishing of complex holes due to the non-uniform abrasive forces. The abrasive media are the key elements that dominate the polishing behavior in AFM process. However, commercial abrasive media are very expensive, and not every user can afford the prices. Therefore, lower-cost and effective abrasive media are developed to improve the surface roughness of the WEDM workpieces in this research. Besides, the application of abrasive gels with a helical passageway is proposed to create a multiple motion of abrasive medium and to obtain the even surface of the complex holes in AFM process.

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Keywords: abrasive flow machining; abrasive gel; a helical passageway; surface roughness

1. Introduction

The benefits of AFM method consist of convenient operation, lower manufacturing cost, complex shape machining, and higher polishing efficiency. It is widely used to deburr, radius, polish, and remove recast layer of the complex geometries and hard materials. However, such as other non-conventional polishing processes, a smoother surface of workpiece is not easily obtained after AFM polishing, since this process had the constraint in the lower rates of material removal. To overcome different limitations of the traditional AFM process, there are many kinds of different skills and methods to be developed. By using AFM as a base process, a lot of hybrid polishing process like magnetic abrasive finishing, magneto rheological finishing, magnetic float polishing, elastic emission machining, etc. have been developed having component and material specific finishing capabilities. A hybrid finishing process like rotational abrasive flow finishing (R-AFF) is one of modifications to raise the radial force and the polishing efficiency in AFM operation [1-3]. R-AFF had an approving performance in terms of better polishing and higher finishing rate, but this method may either rise machining cost or limit the machining shapes to process. Furthermore, Magneto-rheological abrasive flow finishing (MR-AFF) is also one of the improving actions as compared to the common AFM process [4-5]. In MR-AFF, the magnetic field applied to increase the abrasive forces, but this method was limited to the simple geometries of machining workpiece. Recently, a novel conception with inserting a mold core into a machining passageway to enhance the polishing rates was developed. The results indicated that surface roughness of the cylindrical passageway notably decreased to 0.28 μm Ra from an initial value of 1.8 μm Ra after 5 working cycles [6]. Based on experimental study, it was observed that abrasive mesh size and percentage of abrasive concentration in media are the most significant parameters for material removal and improvement in surface roughness. Also viscosity of media was found as significant parameter for material removal for the considered size and shape of the workpiece. Moreover, a

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unique mechanism with a helical mold was created to build helical flowing paths. This design is an easier modification of mechanism with powerful rotation to raise the radial force in AFM process [7-9]. The experimental results indicated that the helical passageways performed better than the original passageways during AFM in terms of efficiency and creating polishing uniformity of the polygonal holes.

Abrasive media plays a major role in AFM because of its ability to precisely polish the selected surfaces along the media flow passageway. Thus, the investigation of different gels is an extremely importance in AFM field. Researchers have attempted to enhance the performance capabilities of AFM and also in development of superior and alternative to commercially available media. Davis et al. [10] investigated rheological study on different medium by homogeneously mixing polyborosiloxane (PBS) with silicon carbide (SiC) grits in varying proportion. Jain et al. [11] demonstrated the same by conducting AFM experiments using medium of different viscosities. Media usually contains two major roles as the carrier and the solid phase. The physical, chemical, material, and rheological characteristics significantly influence the overall performance of the AFM. Sinhg et al. [12] reported the work to model forces responsible for shearing of the roughness peaks during AFM, and their correlation with rheological properties of the medium. It is the complex shear modulus of the medium which governs the magnitude of forces generated in AFM by applying a MATLAB program. Wan et al. [13] performed the CFD simulation of the two-way AFM process during finishing of straight tubes with ellipsoidal cross sections. Final surface roughness of the workpiece is simulated and validated with the experimental result.

In this research, lower-cost and polymer based environmental media are developed to form abrasive gels (PAGs) of various grades and upon trial on AFM setup. This study will evaluate the viscosity of polymer gel; then, a series of AFM experiments were utilized to verify the effects of these abrasive gels. Moreover, a helical passageway is proposed to create a multiple motion of abrasive medium in polishing method to improve the performance of the traditional AFM.

Nomenclature

F_t	tangential force
F_a	axial force
F_r	radial force
F_s	resistance force
RIR	surface roughness improved rate
SR_{origin}	original surface roughness
$SR_{polishing}$	surface roughness after polishing
RU	surface roughness uniformity

2. Materials and Methods

2.1. Gel materials

In this study, a pure silicone rubber (P-Silicone) and silicone rubber with additives (A-Silicone) are chosen as the media. In general, P-Silicone is used to make the plastic mold in metal casting with low melting temperature. This kind of macromolecule gel belongs to high density visco-elastic rubber compound, mainly plays the role of mixed adhesive abrasive in mixed polymer gel and provides flow property, so that it can be deformed by different processing shapes. The composition of the polymer formula is as shown in Figure 1. Moreover, the actual manufacturing process of polymer silicon rubber is the first through the acidification process to destroy the molecular chain. Then, the gel medium is made through the high temperature synthesis of polymer compounds after several repeatable processes. This material is a vinyl-based silicone rubber compounds with several hundred thousand molecules. Figure 2 shows that diagrams regarding (a) the transparent gel of P-Silicone and (b) the gel mixed with abrasive grains.

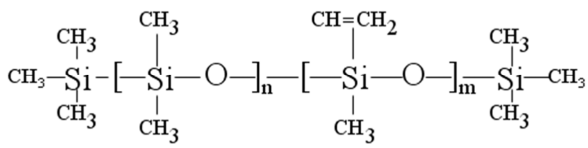

Fig. 1 Composition of the silicone polymer

(a) P-silicone gel without abrasive (b) P-silicone gel with abrasive

Fig. 2 Diagrams regarding the transparent gel of P-Silicone and the gel mixed with abrasive grains

A-Silicone is much like the material of the silly putty which is used for the toy clay. This material is also a vinyl-based silicone rubber compounds but being higher density with several million molecules. These silicone gels have lower flow property and do not stick on the workpiece surface after contact, so that they are the good abrasive media in AFM. The complicated shape can be polished uniformly using this kind of silicone gels. Because the gels have good deformability, the abrasive particles must have high hardness to execute the polishing process. Figure 3 displays that diagrams regarding (a) the orange color gel of A-Silicone and (b) the polymer gel mixed with abrasive particles. Consequently, the silicon carbide (SiC) is chosen as the main abrasive material and uniformly mixed with the silicone gel. Table 1 shows the viscosity of P- and A-silicone without abrasive.

Table 1 Viscosity of three clay gels

Clay	P-Silicone gel	A-Silicone gel
Viscosity (Pa*S)	120	500