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Wear of abrasive media and its effect on abrasive flow machining results

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ABSTRACT

Abrasive media were examined before and after application in abrasive flow machining to evaluate the wear of media due to the machining process. Both media were tested on workpieces under the same working conditions to study the effect of abrasive media wear on the results of the machining process. With the help of rheological and granulometric characterisation methods, it has been shown that alterations of rheological behaviour and composition of the abrasive medium as well as particle shape and size are responsible for the degradation of the abrasive efficiency. The increasing viscosity of the abrasive medium and progressing rounding of the large abrasive particles as a result of the machining process are the main factors that cause a decreased material removal rate and reduced surface quality.

1. Introduction

A multitude of industry branches (e.g., manufacturing of medical, automotive and aerospace components or mechanical engineering) utilise abrasive suspensions for cutting or finishing high-performance elements. A detailed description of the applications of abrasive flow machining was provided by Yadav et al. [1]. Abrasive flow machining (AFM) is an advanced finishing process applied to deburr, polish or radius edges and surfaces of internal, difficult-to-reach workpiece geometries, and it employs special viscoelastic abrasive media. One of the first studies of this advanced machining process was conducted by Rhoades, who explained the process principle in detail [2]. In abrasive flow machining, two opposing cylinders clamp the workpiece between them and seal the machining passage. Hydraulically operated pistons inside the cylinders repeatedly extrude the abrasive medium back and forth through or across the workpiece to be finished (see Fig. 1). One up-and-down motion of the pistons amounts to a working cycle.

Spur et al. [3] also described the process in general as well as the abrasive medium that is utilised in abrasive flow machining. The semisolid abrasive medium consists of abrasive particles with a concentration of up to 40 vol% and a polymeric carrier medium. The viscosity of the abrasive medium can be adjusted by the addition of oil and other additives. Usually, silicon carbide, aluminium oxide or boron carbide are applied as abrasive materials.

Roughness or burrs are removed by the alternating movement of the abrasive suspension along the workpiece surface and edges. The rheological behaviour of the abrasive medium supports the material removal. On one hand, the carrier medium transfers the pressure of the pistons to the abrasive particles. On the other hand, the viscoelastic material hardens at mechanical strain-for example, at a constricted opening-and steadies the abrasives. The abrasive medium absorbs the abraded workpiece material and transports it away from the location of removal.

A large variety of parameters influence the process abrasive flow machining and results in complexity and difficulty in predicting process results. The input parameters can be assigned to three different groups-machine, workpiece and workpiece fixture, abrasive medium-which are described by Mali and Manna [4] and are listed in Fig. 2.

The process and medium parameters significantly affect the results of the machining process-namely, material removal rate and surface quality. The results are controllable by the variation of these parameters. Numerous studies examine the influence of the input parameters on the machining results. For example, Sankar et al. [5] found

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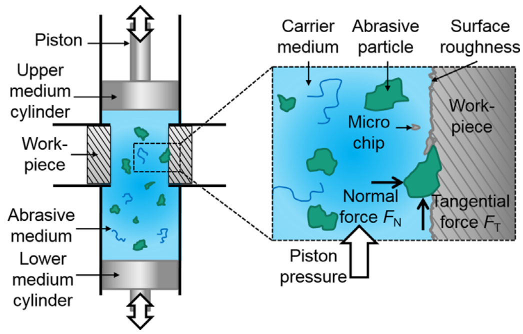

Fig. 1. Schematic depiction of the working principle of the abrasive flow machining process.

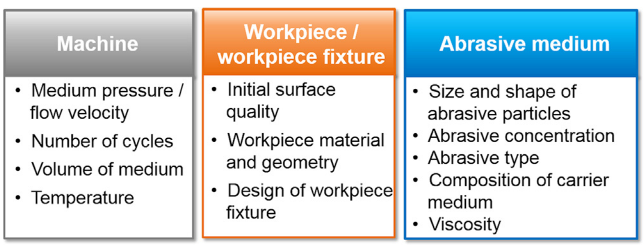

Fig. 2. Input parameters in abrasive flow machining.

in their study that the viscosity of the abrasive medium and the size of the abrasive particles directly determine the removal rate of the workpiece material. A high viscosity and large particles lead to an increased material removal rate but also a reduced surface quality. Rajesha et al. [6] stated that the rheological behaviour of the abrasive medium is the main input parameter, whereas Kar et al. [7] found that the number of cycles and the concentration of abrasives are the basic input parameters. Some studies conduct empirical modelling of the machining process to predict the process results as presented by Jain et al. [8]. In other studies, essential elements of the machining process are theoretically modelled and validated by experimental results. For instance, Walia et al. [9] examined the forces acting on the particles and the number of active abrasive particles in the process, and Uhlmann et al. [10] addressed the modelling of the viscoelastic materials' behaviour.

Consistent process efficiency and quality of results are ensured only by invariable input parameters. However, the properties of the abrasive medium change because of wear in the machining process. Until now, these alterations of medium properties have not been systematically examined or documented except in a previous study of our own [11].

In this study, the rheological properties of new and used (for 420 h) abrasive media are characterized and compared. In addition, further features are quantified that generally affect the rheological behaviour such as composition of the abrasive medium, particle size and shape. Furthermore, the performance of both media in the machining process is tested by utilising them under the same process conditions on test workpieces with the same initial surface qualities. Finally, a conclusion is drawn about the process results with reference to the changed medium properties.

2. Material and methods

2.1. Abrasive media

In this study, an abrasive medium by the company Micro Technica Technologies GmbH is characterized before and after utilisation in an abrasive flow machining process. The abrasive medium was applied to the machining of surfaces and rounding of edges with a total machining time of 420 h.

The carrier medium consists of polyborosiloxane with addition of hydrocarbon oil and metal soap to adjust the viscosity of the mixture. The carrier medium contains three different sizes of silicon carbide particles (see Table 1) with a total abrasive concentration of 58.4 wt%. According to [12,13] the particle sizes are divided into different FEPA-grits.

2.2. Experimental methods

2.2.1. Characterisation of the abrasive media

The rheological analysis of the abrasive media is performed by oscillation and creep tests (rotational and oscillatory rheometer MCR 301, Anton Paar GmbH). A profiled plate–plate measurement system with a diameter of 25 mm and a measurement gap of 2.55 mm is used. For each sample, an amplitude sweep, a frequency sweep and a creep test are conducted at a temperature of 25 °C. The amplitude sweep ($\gamma=0.01$ 100%; $\omega=10$ 1/s) serves as a test to determine the linear viscoelastic range (LVE) in which the frequency sweep and creep test should be performed; this is not discussed in the results of this study. The results of the frequency sweep ($\gamma=0.01\%$; $\omega=100$ 0.1 1/s) and creep test ($\tau=10$ Pa; $t=5$ min) characterize and quantify the viscoelastic behaviour of the abrasive medium.

In addition, the abrasive media are analysed by an infra-red spectrometer (670-IR, Varian) to determine whether the carrier medium has chemically changed because of the machining process.

2.2.2. Characterisation of the abrasive particles

The abrasive particles are separated from the carrier medium by dissolving it in acetone. The particles are divided by wet screening into two particle fractions: particles <200 µm and ≥ 200 µm. For each particle fraction, the size, shape and oxygen content are analysed.

The size of the abrasive particles is measured by laser diffraction (Mastersizer 2000, Malvern). Static image analysis is the best method for analysing the particle shape of abrasive particles because of the high resolution even for small particles. In this analysing technique, the particles are embedded in a resin and prepared by multi-level grinding and polishing processes. A FESEM image of the polished section is generated, and with the help of the software ANALYSIS, the particles are detected by grey scale analysis. The evaluation of the particle shape is conducted by the parameter circularity (also called form or roundness factor) according to ISO 9276-6, which represents the similarity between the real particle area and an ideal circle area. The parameter is defined with the help of the projection area A and the perimeter P of a particle [14]

$$\text{Circularity}=\frac{4\pi A}{P^2} \tag{1}$$

The more the circularity located at a value of one, the rounder the particle. For statistical validation of this measurement method, 1000–3000 particles per sample and size fraction are analysed.

The quantitative determination of the oxygen content is conducted with the help of hot-gas extraction (TCH-600, LECO).

Table 1
Summary of the particles used in the abrasive media.

Ratio in wt%	FEPA-grit	Mean particle size in µm
28.6	F24	745
42.8	F36	525
28.6	F400	17