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# Advanced approach for a demand-oriented fluid supply in grinding

C. Heinzel (2)*, D. Meyer, B. Kolkwitz, J. Eckebrecht

*University of Bremen, Foundation Institute of Materials Science, Department of Manufacturing Technologies, Bremen, Germany*

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ABSTRACT

The productivity of grinding processes is often limited by the risk of thermal damage of the workpiece surface layer. Therefore, the control of thermal conditions in the grinding arc is of utmost importance for both, industrial practice and academia. In order to optimize the application of the metal working fluid in grinding, devices and methodologies are needed which can assure the measurement of temperatures in grinding or within set-up mode and the control of demand-oriented fluid supply parameters (nozzle angle, nozzle height, nozzle outlet area, fluid jet velocity). The systematic use of such devices and methodologies for fluid supply optimization is enabling reliable and economic grinding processes.



## 1. Introduction and state-of-the-art

In grinding, most of the heat generated due to high friction between the abrasive grains and the workpiece material is dissipated through the surface layer of the workpiece [1] and causes major challenges for the generation [2] and assessment of favourable surface integrity [3]. If the thermal load of the workpiece exceeds certain limits, thermal damage of the workpiece material (grinding burn) occurs which is accompanied by a decrease in hardness, a change in microstructure or a change in the residual stress state [4]. Thus, the efficient supply of metal working fluids (MWF) in grinding plays a key role in controlling the thermal conditions in the grinding arc. However, the suitable MWF supply in grinding is dependent on various parameters which are the MWF flowrate, the jet velocity, the jet shape, the nozzle position [5], and the wheel specifications (especially the wheel porosity) [6]. Regarding the required MWF flowrate, different suggestions have been presented in literature: a comparably simple flowrate model based on the spindle power $P_s$ during the grinding process has been suggested by Silliman [7] who proposes a specific MWF flowrate of 8–10 l/(min·kW), but neglects aspects like wheel speed, MWF type as well as type of abrasive or mode of grinding process. Based on the investigations of Ott [8], Metzger [9] presented a model for the prediction of a minimum MWF flowrate $Q_{MWF}$ in grinding which considers in addition to the spindle power $P_s$ the nozzle efficiency $\eta$, the specific heat capacity $C$ of the used MWF and its density $\rho$ as well as its tolerated temperature rise $\Delta\theta$. Webster et al. [4] reviewed the mentioned MWF flowrate models and compared them with results obtained by using an experimental procedure for the evaluation of MWF supply conditions in grinding. It can be concluded that in addition to the MWF flowrate, the wheel speed has an influence on the avoidance of grinding burn. Independent from the wheel speed, a specific flowrate of at least 4 l/(min·mm) was sufficient to achieve the desired surface integrity of the ground parts. In general, the models and methods developed within the recent studies are useful for rough estimations to ensure the prevention of grinding burn.

Also many research activities in the past have been focussed on the nozzle design. Besides the traditional tangential or free flow nozzle, different nozzle designs (e.g. the nozzle profile by Rouse et al. [10]) have been developed to maintain the jet's initial shape over long distances [11]. Also, the jet-speed/wheel-speed-ratio has been addressed which should match a value between 0.8 and 1.0 to achieve a sufficient MWF supply [5].

A further aspect influencing the MWF supply conditions in grinding is the adequate positioning of the nozzle. Engineer et al. achieved best results with a nozzle position as close as possible to the contact area [12]. Vits [13] and Ott [8] recommended that the MWF jet should hit the grinding wheel tangentially at approximately 10°–25° in front of the contact zone. However, this large range for the recommended nozzle angle carries the risk of substantial variations of the thermal impact affecting the workpiece material.

To summarize this review of influencing factors regarding MWF supply in grinding, a lot of generalized recommendations for MWF flowrate, jet velocity, nozzle design and nozzle position can be derived from literature. However, the different methods and models do neither consider real temperatures in the contact area nor can they ensure the lowest thermal load in grinding. Thus, to determine optimal MWF supply conditions for a given grinding process, devices and methodologies to control the MWF supply parameters are needed. Ideally, these devices adapt the supply parameters to the needs of the specific grinding process by using in-process information like forces, power or grinding temperature. This paper presents an approach which eases practical application making use of a stepwise procedure explained in Section 2. By optimizing the MWF supply in grinding, economic and environmental aspects are addressed simultaneously as optimized MWF supply conditions allow for an increased productivity and energy efficiency as well as a reduction of the amount of MWF needed.

* Corresponding author.
*E-mail address:* heinzel@iwt.uni-bremen.de (C. Heinzel).

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## 2. Approach towards an optimized MWF supply in grinding

Aim of the research approach presented within this paper is the development of an automated device to identify and to control the best possible and demand-oriented MWF supply conditions in grinding by means of an optimizing algorithm (cf. Fig. 1). For this purpose, a stepwise procedure has been set up: in a first step, the optimal nozzle design has been selected with regard to jet coherency and jet speed by using high-speed imaging techniques (cf. Section 2.1). These techniques allow for the assessment of the jet coherency in a qualitative and of the jet speed in a quantitative way.

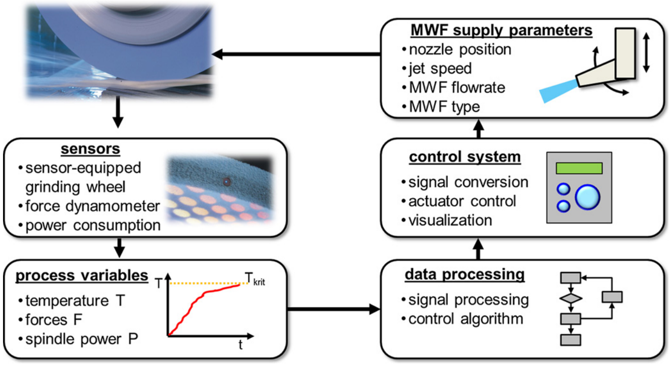


**Fig. 1.** Control loop for demand-oriented MWF supply in grinding.

After the evaluation of the nozzle design, the optimal coupling between the MWF jet and the rotating wheel has been studied with a test rig in set-up mode (cf. Section 2.2). This test rig can be used to determine the optimal nozzle position regarding distance to the grinding arc, nozzle height, nozzle angle, and MWF jet speed/MWF flowrate. For the reliable positioning of the MWF supply nozzle and setting of MWF jet speed/MWF flowrate an automated motor-driven system has been realized (cf. Fig. 2).

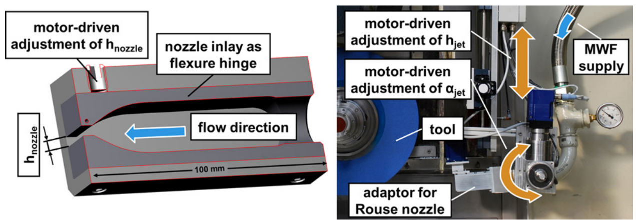


**Fig. 2.** Left: flat jet nozzle with an inner profile based on Rouse (designed as flexure hinge). Right: automated motor-driven MWF supply system.

Finally, an infrared-(IR)-sensor equipped tool (Thermo-Grind-system) has been used to prove if the MWF supply conditions obtained within the two steps described above allow for the lowest possible thermal impact in grinding (cf. Section 2.3). The Thermo-Grind-system enables monitoring of the thermal impact on each workpiece and verification of the optimal MWF supply parameters.

### 2.1. Design of MWF supply nozzle

As mentioned above, the selection of an appropriate nozzle design in grinding has a major impact on the MWF supply conditions to the grinding arc due to the associated jet quality. To characterize the jet quality and according to this, the effectiveness of different nozzle designs, high-speed imaging techniques can be used. For this purpose, two different nozzle designs have been investigated: a traditional (tangential) nozzle was compared with a flat nozzle design based on Rouse. The Rouse nozzle with a width of 30 mm has been designed as a flexure hinge so that the nozzle outlet height $h_{nozzle}$ can be varied in a range of 0.5–1.5 mm (cf. Fig. 2). Thus, varying MWF jet flowrates respecting constant MWF jet velocities can be set and ensured. As a result, the nozzle with an inner profile based on Rouse is characterized by a higher jet coherency over a long distance after the nozzle orifice without any visible jet dispersion or widening independent from MWF flowrate and jet speed. Thus, this nozzle design has been used for the investigations described within this paper.

### 2.2. Test rig for analysing the MWF supply in the set-up mode

Based on the investigations of Powell [14], a test rig which enables a temperature measurement beneath the contact area between the grinding wheel and the workpiece under very similar conditions compared to a real grinding process was developed [15]. The grinding wheel is plunged and thus replicated into a workpiece which is mounted on a heating plate. After reaching the specified area which is heated up electrically, the translational motion between the grinding wheel and the test rig is stopped ($v_{ft}$ = 0 m/min), whereas the rotation of the grinding wheel is continued (cf. Fig. 3). Furthermore, a thermocouple is placed slightly beneath the grinding arc in the middle of the heated area to log the temperature change during the trials. A change of the MWF supply conditions will result in a change of the measured temperature at constant electrical heating power. Thus, the differing MWF supply parameters which are to be set during the investigations can be directly correlated with the temperature evolution below the grinding arc.

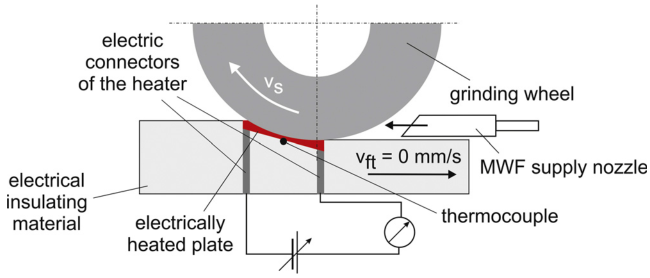


**Fig. 3.** Test rig to analyse MWF supply conditions (schematic).

Although the described system is limited to the use in the set-up state of grinding processes at comparably low temperatures, it represents a quick and effective approach to generate knowledge how MWF supply conditions can be improved. Hence, influences of the MWF supply parameters, of the MWF type as well as of the nozzle design can be observed without performing real grinding operations.

### 2.3. In-process temperature measurement

A key approach to obtain in-process information about the influence of the MWF supply conditions on the temperature in the contact area is the usage of sensor-equipped grinding wheels. From the first studies which have shown the ability of a tool-integrated temperature measurement to gain in-process information directly from the contact zone, the measurement technique has been constantly improved. Today, a fast IR-photodiode detects the IR-radiation from the contact zone via an optical fibre (cf. Fig. 4), both embedded in the grinding wheel [16].

The data received from the IR-sensor are filtered, transformed into temperatures (after calibration) and condensed by a data box directly on the wheel. The data are transmitted wireless to an evaluation box or a PC for monitoring purposes. In view of the

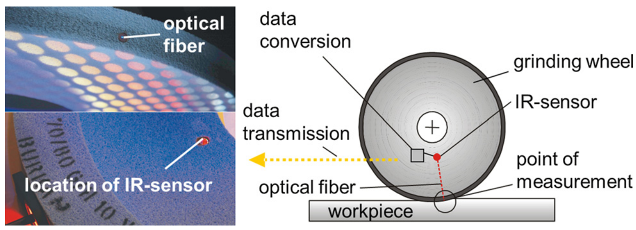


**Fig. 4.** Sensor-equipped grinding wheel for temperature measurement (Thermo-Grind-system).