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An analysis of centrifugal MQL supply system potential in the internal cylindrical grinding process

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ABSTRACT

In the article the state of knowledge regarding the functions and supply methods of the cooling liquid into the grinding zone were presented. The new system for centrifugal supply of oil mist was described. The results of experimental investigations conducted into the internal cylindrical grinding process were given. The life of the wheel, machined surface roughness, grinding power and temperature in the machining zone were analyzed. Experimental results showed that compared to flood cooling, this new system provides double the lifespan of the wheel, significantly reducing the volume of wheel wear and enabling the slightly reduced roughness of machined surface and grinding power. Using a new coolant supply method caused an increase in the workpiece temperature, compared to the flood cooling.

1. Introduction

Grinding of modern materials such as alloys of nickel, aluminium, magnesium or cobalt is a high energy process. Most of the energy used in the process of machined material removal is transformed into heat [1,2]. In so-called conventional grinding using vitrified bonded wheels as much as 75% of heat may be transmitted into the chip, 18% of the energy is processed into heat in the place of contact between the chip and the tool, while the rest of the energy is heat energy absorbed by the workpiece, or energy processed into heat in the place of contact between the workpiece and the tool [3,4]. High temperatures in the machining zone may be the cause of faster wear of the

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abrasive tools and creation of grinding defects on the workpiece surface such as [4]:

- grain growth, precipitation, softening;
- phase transformations leading to re-hardening;
- thermal expansion and contraction, cracking and tensile residual stresses;
- chemical reactions leading to burn marks;
- adhesion wear on the grinding wheel active surface (GWAS)
- wheel clogging/loading/smearing.

Cooling liquids (CLs) are used in order to decrease the temperature in the grinding zone and therefore to improve the cutting ability of the tools. The CLs are usually various oils, emulsions (obtained by mixing oils with water), microemulsions, synthetic liquids (obtained through chemical processes), machining pastes and gases [4].

Liquids are present in the grinding process mostly to cool the abrasive tool and the workpiece, as well as to lubricate the contact zone of the cutting vertexes, the workpiece and chips. Moreover, the cooling liquids cleanse the machining zone of chips and other grinding products and protect the workpiece surface against corrosion [4]. Application of the CL, however, does not always bring about the desired effects as the method and technique of their introduction into the area of contact between the grinding wheel and the workpiece are equally important. What is crucial in this context is aiming at maximization of the CL being applied directly into the grinding zone. The most frequently used method of applying the CL is the so-called flood method, which consists of directing the cooling liquid stream, under low pressure but with high expenditure, into the direct vicinity of the grinding zone [5].

In the case of internal cylindrical grinding, the flood method does not guarantee an even provision of the CL, whose effectiveness decreases as the grinding wheel moves deeper into the opening. Moreover, only a small amount of the liquid gets to the machining zone, as a result of which, the CL properties are used inefficiently. There are numerous more effective methods of providing the coolant into the grinding zone, such as application of shoe nozzles [6], jet nozzles [7], atomizer and spray nozzles [8], other nozzles [9], as well as the MQL method [10,11]. Due to the small size of the grinding wheel and its limited working zone, they have not been, however, so far used in the internal cylindrical grinding processes. It is, however, possible to use the systems of centrifugal coolant provision through the arbor and the grinding wheel intergranular free spaces [12], or the special channels shaped in the wheel [13], directly into the grinding zone.

2. An alternative solution for grinding fluid delivery

Today many articles about grinding fluids have been published, because the usage of conventional flood coolants has become more problematic by virtue of economy, environmental pollution and the health of employees [11]. As the costs of using the machining fluids, which according to Tsai and Jian [14] constituted 7–17% of the total production costs (including the purchase, functioning and recycling of the CL), as well as the growing environmental protection requirements, new alternative solutions are sought to replace the conventional cooling liquid provision methods. The aim of these works is to suggest methods that are both more cost-effective and environmentally friendly and that contribute to increasing the process efficiency, while maintaining the high quality of the workpiece surface layer.

One of the possible solutions is the realization of the lubricating function by substances in a solid state such as graphite, molybdenum sulphide (IV), various silicones, sulphur, paraffin, resins and others. These substances are labelled as impregnates or fillers, depending on the production stage during which they were introduced into the grinding wheel structure; generally they are nontoxic and easy to apply and most of all, they substantially reduce the machining cost [15]. The impregnation of a grinding wheel depends on its porosity. Open-grain wheels allow impregnation of the whole abrasive tool, and close-grain wheels in turn allow impregnation only of the active surface. These actions might be taken by producers [14] and also by the users themselves [16,17]. They would adjust impregnate compositions to the technological needs of the tools [16,17]. As solid lubricants graphite, molybdenum disulphide, silicones, sulphur, waxes, resins, etc. could be used [15]. The most popular, available on the market lubricants (Norton Company (USA), Super Abrasives (India), Systec Segments (USA), etc.) are sulphur, waxes and resins [18–20]. Due to its anti-adhesive properties, sulphur has been used as a substance for influencing conditions in the zone of contact between the grinding wheel and the machined material since the 1920s [21]. Nowadays many articles concerning graphite as solid lubricant have been published. Saji and Radhakrishnan [8] used graphite as a lubricating paste, Tsai and Jian [14] as a filler used during a grinding wheel production process. The effect upon the grinding wheel active surface condition when impregnating with sulphur, graphite and amorphous carbon during internal cylindrical grinding of Titanium Grade 2® alloy was widely described by the authors as well [22].

The MQL (*minimum quantity lubrication*) is another method which has become increasingly popular. It consists in providing the cooling liquid into the grinding zone in the form of an aerosol (oil mist). It allows for a considerable reduction of the CL expenditure while maintaining the high efficiency of the lubricating function [10,11]. Compared to the conventional flood cooling, the flow rate of the grinding fluid is about 3–4 orders of magnitude lower and amounts to 50–500 ml/h [1]. Unfortunately, examples highlighted in the literature regarding application of this method demonstrate that the aerosol has to be used pointwise in the MQL method, which limits its application considerably due to its requiring free access into the grinding zone (which occurs in processes such as grinding flat surfaces or external cylindrical grinding). This solution cannot be, however, used in the described form in internal cylindrical grinding as this type of machining is characterized by a long contact path between the grinding wheel and the workpiece, as well as a highly limited space around the grinding wheel. This problem encouraged the authors to develop an innovative method of applying the cooling liquid using adapted approach to MQL.