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METHODS OF MINIMALIZATION OF COOLANT FLOW RATE IN THE GRINDING PROCESSES – THE REVIEW

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Abstract: The article describes the role and types of cooling lubricants used in grinding processes. Conventional methods of coolants delivery into the grinding zone were described, such as: flood method, high-pressure jet method, centrifugal coolant provision method as well as methods method to minimize coolant flow rate: minimum quantity lubrication (MQL), minimum quantity cooling (MQC) and minimum quantity cooling lubrication (MQCL). Against this background, a methods were presented to completely eliminate grinding fluid from the grinding process (dry grinding) like: impregnated grinding wheels and cold air guns (CAG).

Keywords: grinding process, grinding wheel, minimum quantity lubrication (MQL), minimum quantity cooling (MQC), cold air gun (CAG)

1. INTRODUCTION

Due to the dynamic development of the industry, it is necessary to constantly develop new technological processes and improve existing ones, which raises a number of issues related to grinding.

During grinding process the energy supplied to the machining zone is used for elastic-plastic deformation of the material, internal friction occurring during chip formation, friction between chip and abrasive grain, and between the bond and the workpiece surface. During machining, a large amount of heat is generated, which is mainly dissipated by chips. On the other hand, a certain part of it is also transferred to the workpiece material, which increases the temperature of the workpiece surface. Up to 95% of the energy supplied to the grinding zone is converted into heat [20].

The grinding process is associated with a significant increase in temperature in the machining zone. It is known from the literature that the grinding temperature can reach the melting point of the workpiece material. The high grinding temperature may cause such negative effects as: structural changes in the surface layer of the machined part, changes in hardness in the surface layer, development of tensile stresses in the surface layer, formation of microcracks in the surface layer, formation of burnings on the ground surface, thermal deformations of the ground part and rapid wear of abrasive grains [8].

The heat distribution, which is generated in the deformed areas, is uneven, which increases thermal stress in both the grinding wheel and workpiece. The majority of the energy used in the grinding process is converted into heat at the tool's contact point with the workpiece [20], because the intergranular space is relatively small and maintaining high cutting capacity requires it to be free and efficiently support the transport of grinding products from the contact area. Most grinding processes use coolants. The main role of coolants are: lubrication of the grinding wheel contact area with the machined material to reduce friction of grains with unidentified geometry and often negative rake angle as well as cooling of this zone [9].

The selection of the appropriate coolants is extremely important for the proper course of the grinding process due to significant differences in their biological, physical and chemical properties [4, 16]. Coolants contains substances that are hazardous to the environment and their disposal consists in chemical disposal (method of re-refining and thermal cracking) or biodegradation. They can also be incinerated and recovered by cleaning. These processes are costly and often place a significant burden on the environment with their waste products. In addition, many coolants have a negative impact on the health of machine operators, who are exposed to constant contact with them. These negative aspects of coolants have contributed to the modern trend of minimizing their output in grinding processes [9, 15].

2. COOLANT SUPPLY METHODS TO THE GRINDING ZONE

The commonly used basic methods of bringing coolants to the grinding zone are as follows:

- flood method,
- high-pressure jet method,
- using spot nozzles,
- using shoe nozzles,
- centrifugal coolant provision method.

2.1. Flood method

In the flood method, the coolant is pumped to the grinding zone through a nozzle with a slotted hole. Fluid outflow velocities v = 1 m/s. As the contact area between workpiece and the grinding wheel increases, the width of the grinding wheel and the densities of the grinding wheel structure, and as the size of the grinding wheel grains decreases, the delivery intensity of coolant should increase. The efficiency of the coolant in the form of a slow-flow stream into the grinding zone is significantly affected by the rotating air stream, which is caused by the rotating wheel. This is so called air barrier (Fig. 1), which surrounds the wheel around its circumference and already at the peripheral velocity of the grinding wheel v_s = 20 m/s, causes deflection and spray of the fluid stream [1].

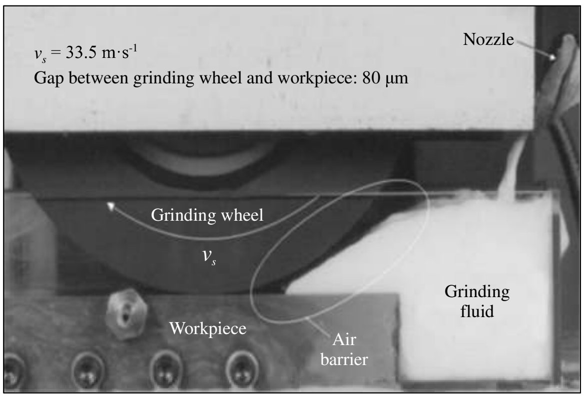

Fig. 1. View of rotating air around the GWAS and limiting coolant access to the grinding zone [1]

The air barrier is the main obstacle for coolant, which hinders its interaction with grinding wheel active surface during machining and limits coolant's access to the grinding zone. One of the effective ways to prevent this phenomenon is to increase the pressure of the coolant to be supplied. In addition, other methods of air barrier elimination have been developed, such as: the use of shoe nozzles, high-pressure jet nozzles or centrifugal coolant provision through the wheel [1, 10, 12, 16, 21, 22].

2.2. High-pressure jet method

The coolant high-pressure jet method differs from the priming method by increasing the pressure of coolant to more than 1-1.5 MPa. High pressure increases the speed of the coolant to be supplied, thus overcoming the resistance of the air barrier. This allows the coolant to penetrate into the grinding zone and significantly increases the lubrication and heat dissipation intensity of the ground surface. In order to achieve better effect of fluid action, the minimum distance of the nozzle from the grinding wheel must be selected and the optimum angle of the nozzle relative to the grinding wheel should be determined [16].

2.3. Spot nozzles

Spot nozzles are a design solution that allows coolant to be delivered into the grinding zone when access to the machining zone is difficult. This is a high-pressure cooling process for hard-to-cut grinding processes used in the aerospace industry.

2.4. Shoe nozzles

Shoe nozzles (Fig. 2) are an alternative design solution that connects the elements responsible for the deflection of the rotating air barrier and very effective fluid distribution in the contact zone between grinding wheel and workpiece surface. Nozzles of this type are precisely shaped to the grinding wheel active surface profile and surround the grinding wheel on three sides. The rotating air barrier is tilted from the grinding wheel at the nozzle inlet, allowing the grinding wheel surface to be completely moistened with coolant in the inner chamber of the shoe nozzle. Rotation of the grinding wheel boosts the coolant to its peripheral speed.

The total amount of coolant delivered can be limited to the volume needed to fill the entire intergranular free spaces of the grinding wheel active surface, as further delivery shows only a negligible influence on the grinding process parameters.

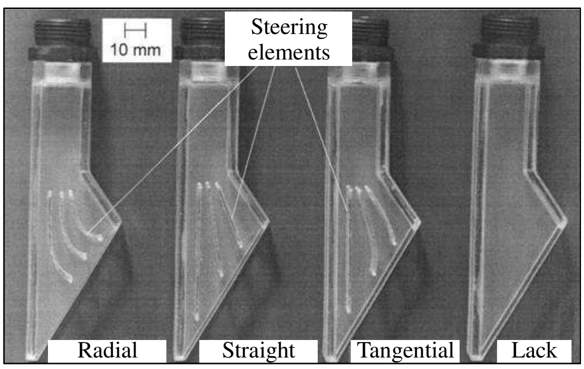

Fig. 2. Various examples of internal geometry of the shoe nozzles [2]

The geometry of the shoe nozzle is determined by the contours of the grinding wheel circumference, so that the shape of the shoe nozzle must be adjusted simultaneously with the change of the grinding wheel size. For this reason, the flexibility of such nozzles is limited. Numerous studies have shown that the application of coolant with shoe nozzles reduces the wear of grinding wheels and the thermal degradation of the workpiece surface layer, with a reduced coolant flow rate, compared to that of the flood method [2, 5].

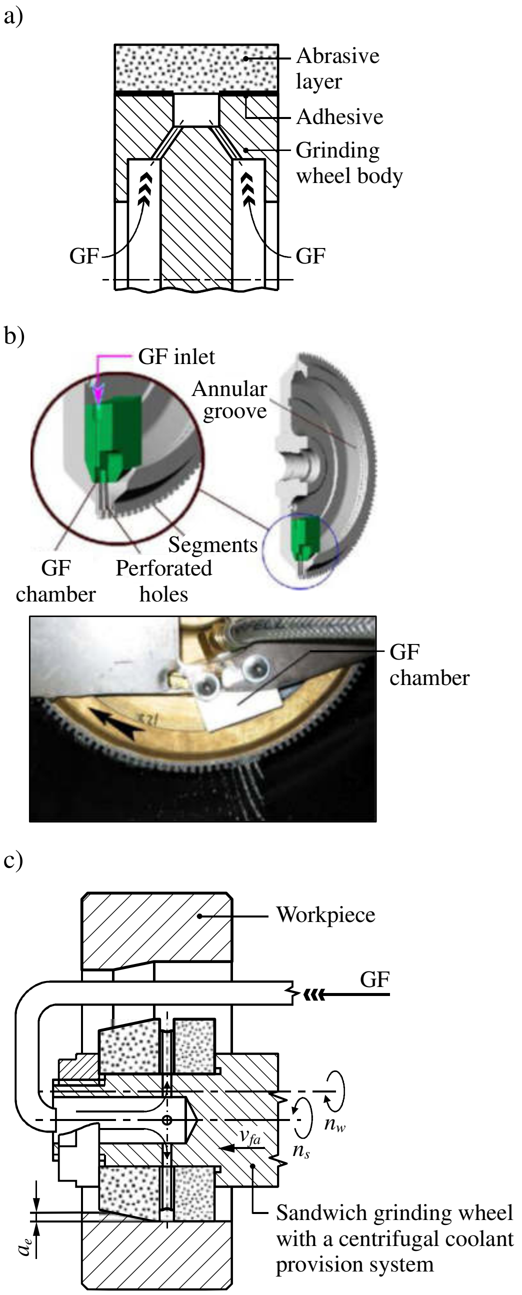

Fig. 3. Examples of centrifugal systems for coolant provision into the grinding zone by [7]: a) channels in the grinding wheel body and abrasive layer [10, 12]; b) channels in the wheel body and spaces between the abrasive segments [1, 22]; c) using special grinding wheel arbor and centrifugal coolant provision system [21]

The development of the shoe nozzle construction is aimed at introducing and modifying the internal shapes of coolant feed elements into the grinding zone [2].

2.5. Centrifugal coolant provision method

Centrifugal supply of coolant (via grinding wheel) is especially recommended for internal cylindrical grinding processes and the best results are achieved when grinding blind openings, openings of a considerable length and when there is limited space between workpiece and grinding wheel arbor [12, 16]. Many centrifugal methods of coolant delivery into the grinding zone are known, both in the case of relatively large grinding wheels in the processes of flat, shaped and external cylindrical surfaces grinding as well as in small-sized grinding wheels designed for the internal cylindrical grinding processes. Selected solutions from this area were shown in Fig. 3 [1, 10, 12, 16, 21, 22].

3. METHODS OF MINIMIZING THE FLOW RATE OF COOLANTS

3.1. Minimum quantity lubrication (MQL)

At the minimum quantity lubrication (MQL) coolant in the form of oil mist, is sprayed on the grinding wheel active surface by compressed air energy. Only a thin layer of oil covers the surface of the grinding wheel before it enters the contact area with the workpiece surface (Fig. 4) [10]. MQL grinding is characterized by a very small amount of fluid involved in the machining process (about 7.2-97.2 ml/h, nearly 1000 times less than with the conventional flood method), which is delivered precisely to the contact area between grinding wheel active surface with the workpiece [10, 19].

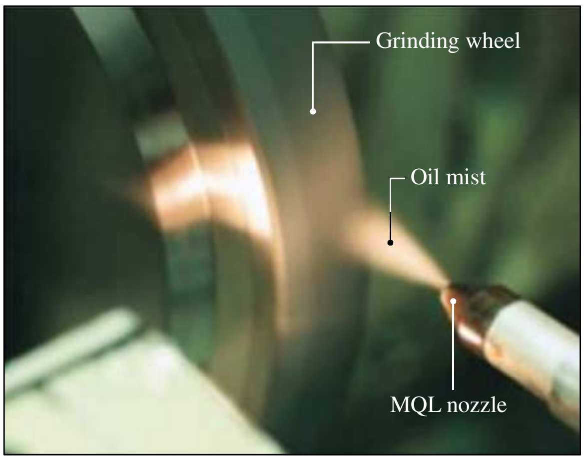

Fig. 4. View of the MQL method in the grinding process [10]

3.2. Minimum quantity cooling (MQC)

Minimum quantity cooling (MQC) method was developed for grinding processes where efficient cooling is required. In this method emulsions in combination with water are used as coolant instead of oil (used in MQL method). The lubricating properties of the emulsion are significantly lower than those of the oil. MQC method is used much less frequently than MQL, but has significant potential in terms of temperature influence on tool characteristics and workpiece surface during grinding processes.

3.3. Minimum quantity cooling lubrication (MQCL)

Minimum quantity cooling lubrication (MQCL) consists in supplying special oil (less often emulsions), in a low temperature environment to the grinding zone (Fig. 5). The coolants used in this method must have a low viscosity and low density at negative temperatures. The air temperature value, which is used to transport coolant droplets, is –30°C, which also influences the decrease of coolant temperature. The MQCL method enables both lubrication in the grinding zone and cooling of the workpiece surface and grinding wheel [22].

When oil is used as a grinding fluid, its good lubricating properties are combined with good cooling ability of the method. As a result, the amount of heat generated by friction is reduced and the workpiece surface as well as grinding wheel are maintained at a lower temperature than in dry machining [3].

4. DRY GRINDING

There are cases where it is not possible to use coolants mainly where it is necessary to keep the workpiece dry. In this cases, the use of air jets can provide better cooling during grinding without any form of cooling liquids. The presence of water vapor in the airflow can be acceptable and can be a useful contribution to cooling. Steam contained in the air improves grinding efficiency and also ensures lubrication. Dust extraction equipment have to be used for dry grinding machines. These devices can be installed above the grinding machine station as a general extraction hood or locally installed at the working zone connected to the central extraction system in the factory floor. The suction unit must be located as close as possible to the grinding wheel area with ground object. It is important that the extraction equipment works properly and effectively, therefore it should be periodically checked by specialists. Grinding of certain materials, e.g. sintered carbides, may be harmful to the respiratory tract (inhalation), digestive tract (ingestion) or cause skin or eye injuries. Complete liquid elimination does not guarantee the best process results in the overall process for all types of machining [18].

4.1. Cold air guns (CAG)

Cold air can be obtained using the phenomenon occurring in the centrifugal tube, where the compressed air stream is divided into two smaller ones, one with hot air and the other one with cold air (Fig. 6) [6].

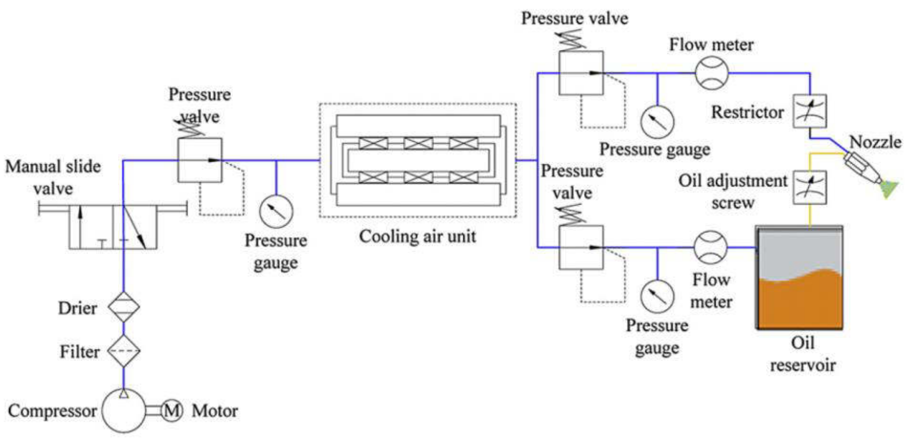

Fig. 5. Schematic diagram of coolant delivery system using MQCL method [22]

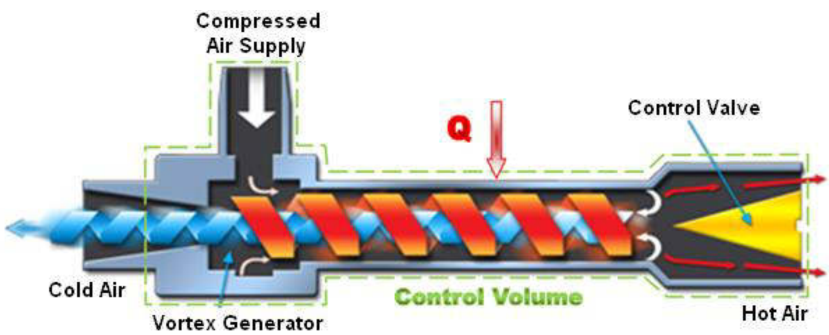

Fig. 6. Air flow diagram in the vortex tube [11]

4.2. Impregnation of the grinding wheels

An important problem in grinding difficult to cut materials is the intensive clogging of the active surface of the grinding wheel with the ductile chips. They result from the adhesion of the chips of the workpiece chips to the abrasive grains caused by high temperature. The cloggings reduces the cutting ability of the grinding wheel, increases the grinding forces and increases the friction rate in the whole process. One of the ways to prevent the formation of cloggings on the grinding wheel active surface in the grinding process of hard-to cut materials is by deliberately introducing chemical actions aimed at lowering the temperature in the grinding zone and preventing the adhesion of chips to the machined surface and grinding wheel. This effect can be achieved, among others, by grinding wheel impregnation by direct insertion of a molten impregnate in the grinding wheel free intergranular spaces. This operation can be carried out by tool manufacturers and their users, adapting the composition of the impregnate to current technological needs [17].

5. CONCLUSIONS

The effort to broaden the knowledge connected with grinding is to reduce the workload and costs of materials used in the process. Based on the analysis of the state of knowledge in the field of the role of coolants and methods of their introduction to the grinding zone, the following conclusions were drawn:

- coolant performs the following roles in the grinding process: reduction of friction between the abrasive grain and the workpiece surface as well as between the bond and the workpiece surface, cooling of workpiece surface and grinding wheel, wetting and cleaning the grinding wheel, rinsing of chips from the grinding zone, corrosion protection for machine tools and workpieces, counteracting bacterial growth, foaming of coolant, etc.;
- the flood method is characterized by a high cooling efficiency, high coolant output ensures systematic wetting and cleaning of the grinding wheel and excellent removal of chips from the grinding zone. This solution is simple to implement but requires the use of a large amount of coolant, which entails production and disposal costs;
- a number of methods have been developed to minimize coolant expenditure: high-pressure jet method allows for precise feed of coolant into the grinding zone and control flow velocity but requires a high energy input for coolant compression; MQL method allows to significantly reduce the coolant output, however, a significant part of heat generated in the grinding process is taken over by workpiece surface, which has a negative impact on the course and results of the grinding process; MQC method allows to significantly reduce coolant flow rate, reduce grinding wheel and workpiece temperature, whereas low temperature negatively influences coolant properties.

To sum up the above conclusions, there is no grinding method that is universal and provides the right conditions in the ecological interface between workpiece surface and grinding wheel. Therefore, it is important for economic and ecological reasons to look for solutions to limit the use of coolants. The method of combining the application of impregnated grinding wheels (impregnate in the form of a solid lubricant) with the simultaneous application of CAG (cooling function) can provide the right conditions for dry grinding processes without using of traditional coolants.

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Biographical note

Wiesław Czapiewski received the title of mechanical engineer (specialization: Computer Aided Manufacturing) in the Faculty of Mechanical Engineering at the Koszalin University of Technology. Since 2000 professionally associated with the automotive industry. He deals with diagnostics and technical evaluation of motor vehicles for the needs of vehicle restitution and repair of communication damages. His professional interests focus on the causes of faults and consequences of road accidents. Scientific interests are directed at improving of technological processes and production methods. He is a co-author of 5 scientific articles in national journals and actively participated in national and international conferences.