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Experimental studies of heat dissipation by a stream of dressing products during dry dressing of conventional ceramic grinding wheels

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ABSTRACT

Part of the energy required to perform the dressing process is converted into heat, which is generated by friction and elastic-plastic deformations occurring in the contact area of diamond grit and the grinding wheel. This heat is diffused by thermal conduction in the direction of the grinding wheel and the body of the dresser, electromagnetic radiation, convection and it is also transferred through the particle stream of dressing products. This article describes the assessment method and the results of the research on the amount of heat accumulated in the stream of the particles of the dressing products. In the presented method, the enthalpy of the stream was estimated based on the measurements of electrical voltage generated by the Peltier module set in a short distance from the point of stream formation, transversely to the direction of its movement. The method of determining the thermal-voltage characteristics of the module necessary to determine the amount of heat released by the particle stream is described. The research of enthalpy streams was carried out during dry dressing of conventional ceramic grinding wheels made of brown and white fused aluminum oxide and green silicon carbide. Dressing studies were performed with a single point diamond dresser using various feed values and dressing depths. Measurements of the Peltier module voltage were carried out simultaneously with measurements of the diamond grain temperature in the dresser and the power of dressing. On the basis of the obtained results, the correlation of the module voltage signals and the diamond temperature is evaluated. Furthermore the influence of dressing parameters and type of grinding wheel abrasive material on the magnitude of stream enthalpy and its share in dressing energy are also evaluated. The studies show that the module voltage remains in almost full, linear correlation ($\rho > 0.95$) with the diamond dresser temperature; the amount of heat carried by the stream constitutes a few percentage points (2%–5%) part of the dressing energy, and the amount of this share increases with the increase of the thermal conductivity of the grinding wheel material and dressing volume capacity.

1. Introduction

Despite the continuous development of machining hard materials that ensure high efficiency and flexibility of the process, grinding still remains the basic process of finishing hardened objects, and allows for achieving high precision of shape and dimensions, low surface roughness and low value of stretching tension in the surface layer of workpieces in a reliable and repeatable way [1]. The above-mentioned functional values of surfaces processed by grinding can only be achieved in properly designed grinding operations, in which, among others, proper selection of grinding wheel characteristics, grinding parameters, the method of cooling the processing zone as well as the frequency and manner of performing the dressing operation has been made. The interaction of the workpiece and the active surface of the grinding wheel occurring during grinding causes a progressive loss of its cutting ability. The grain tips become abraded - which radically reduces the number of active cutting edges, the pores are loading - which prevents the grinding wheel from penetrating into the material and the grinding wheel profile becomes deformed by breakage and pull-out of abrasive grains [2–4]. Restoration of the cutting ability and the required shape of the active surface of the grinding wheel takes place in the dressing process, which in the case of grinding wheels with ceramic or resin bond can be carried out using various types of diamond tools (eg. single and multigrain stationary dressers, rotating dressers). The type of the dresser used and the parameters of the treatment have a significant impact on the cutting ability of the active grinding wheel surface and the grinding result [5–7]. The use of overlap ratio U_d [8], which is the quotient of the active width of the diamond tip b_d and dressing feed f_d, is a commonly used method of supervising operations performed with a single point diamond dresser. Dressing a grinding wheel with a fixed overlap ratio and depth of dressing a_d enables repeatable reproduction of the same state of the active grinding wheel

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surface in consecutive treatments. In the case of using natural diamond dressers, the active width of the dresser b_d changes as a result of progressive wear of the diamond tip, which has an impact on the result of dressing [8], despite the use of the same parameter values U_d and a_d. Therefore, reducing the rate of diamond tip abrasion proceeds contributes to limiting the impact on dressing results and reducing the cost operation. Mechanical and thermal loads that arise through the interaction of the surface of the grinding wheel and the dresser are the cause of diamond wear. During dressing, a significant amount of heat is generated, which activates the processes of oxidation and graphitization of the diamond and causes its mechanical damage due to thermal fatigue or decreasing hardness. Diamond, being a metastable form of carbon, under natural environmental conditions can undergo allotropic transformation as a result of supplying a specific portion of energy. In the atmosphere of oxygen, heating a pure diamond to a temperature of approx. 700 °C, and in the oxygen-free atmosphere up to approx. 1500 °C, causes its transformation into graphite which has considerably lower hardness. The increased pressure that occurs in the contact zone of the diamond with the grinding wheel is also the factor conducive to graphitization. The change in the hardness of the diamond tip of the dresser is not only the result of its allotropic transformation into graphite, but is also due to the properties of brittle materials which become softer under the influence of heating [9]. In both cases, the surface of the diamond tip becomes susceptible to micro-scratching by the abrasive material contained in the grinding wheel. A process of micro-splitting occurs, whereby an increase in tension shears atomic bonds and micro-scratches are formed in the direction parallel to the velocity vector, resulting in the abrasive wear of the tip. Furthermore, cracks and chipping may occur on the surface of the diamond tip. Variable thermal load is reported to be their cause - during the dressing operation, the diamond periodically heats up to high temperatures and then quickly cools, which creates conditions for the occurrence of thermo-elastic stress in the crystal, approaching the level of diamond strength [10]. The oxidation process is another form of diamond wear, which is initiated with air access when the temperature of the diamond exceeds approx. 700 °C. Limiting the impact of the heat generated by the dressing process on the dresser diamond is one of the basic activities aimed at reducing the intensity of tip wear. The standard solution is to perform dressing with the application of intensive cooling using a lubricating coolant fluid [11]. However, it has been shown that the use of coolants has a negative impact on the natural environment and human health [12]. Therefore, a similar effect can be achieved through alternative methods, e.g. by using MQL (minimum quantity lubrication), in which various types of fluids and nanoparticles are used to minimize friction between interacting surfaces [13–15]. More far-reaching approaches include complete elimination of coolant and dry dressing. Here, limiting the diamond temperature increase is achieved by a forced blow of cold air jet into the treatment zone (253 K) obtained from the Vortex tube and placing the single grain CVD diamond dresser in a casing made of material with high thermal conductivity (copper) [16,17].

Positive effects of research on limiting or abandoning the use of coolants in dressing processes justify the search for such solutions where the process temperature will not cause rapid diamond wear and unacceptable thermal deformation of the tool. Knowledge of the energy balance of the dressing process, the causes and conditions of heat generation and the division and routes of its dissipation are the basis for the search for optimal solutions. Energy in the dressing process with the application of stationary dressers (Fig. 1) is mainly related to the decohesion and elastic-plastic deformations of the grinding wheel material and the friction occurring between the particles of crushed grains and binder and the friction arising between the surface of the tip of the diamond grain and the material of the grinding wheel.

The friction and elastic-plastic strains cause heat generation in the contact area of the diamond grain with the grinding wheel [18]. This heat is dissipated in the case of dry dressing by (Fig. 2):

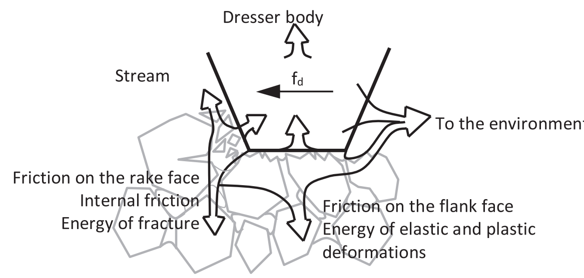

Fig. 1. Energy distribution during dressing with a single point diamond dresser.

- conduction (in the grain volume further through solder to the body of the dresser, the dresser holder and further to the grinder base as well as through the grinding wheel surface to its body and grinding wheel adapter, etc.) – 1 and 5,
- convection (forced by the movement of the boundary layer of air swirling with the grinding wheel) – 2,
- thermal radiation to the bodies from the near and distant surroundings – 3,
- dust of the crushed grinding wheel composite – 4.

The amount of heat produced during dressing depends on the properties of the grinding wheels and the parameters of the process performed. The authors [11] link the amount of heat generated with the frequency of diamond collisions with the abrasive grains. They indicate that a higher temperature of the dresser diamond observed at the higher circumferential speeds of the grinding wheel or using the lower values of the indicator U_d is a consequence of the higher frequency of collision between the diamond grit and grinding wheel grits. In turn, smaller dressing depths according to [11,19] are the reason for the increasing amounts of heat generated due to the greater frequency of contact between diamond and the abrasive grains not leading to their chipping or rupture, but only to the elastic or plastic deformations and thus to the occurrence of intense friction.

Heat dissipation is a phenomenon that counteracts the rising temperature of the dresser grain and thus counteracts its wear intensity. Research results on heat dissipation in the dressing process are presented in [17,20]. Ref. [17] presented thermal model of the dressing process (taking into account two paths of heat dissipation: through conduction and convection) and the methodology for determining the quantity of heat transferred to the dressing tool. It was found that the amount of heat penetrating into the tool in relation to the total heat generated during the process depends mainly on the dressing mechanism. This proportion varies from 0.97 when the friction between the dressing tool and the grinding wheel prevails, up to 0.54 when grain breakage and pull-out occur at higher dressing depths.

This paper presents the research results on heat dissipation through a stream of dust created during dry dressing of grinding wheels with a diamond single grain dresser. In the measurements of the amount of heat accumulated by the stream, a thermoelectric Peltier module was used, whose indications, for a more complete picture of the thermal phenomena occurring were referred to the results of simultaneous measurements of the dresser diamond temperature. The research was performed during the dressing of ceramic grinding wheels made of green silicon carbide and brown and white fused aluminum oxide while using different dressing parameters. Based on the results of the experiments, it was possible to determine the impact of the dressing conditions on the size of heat accumulated in the stream of dressing products and the participation this heat in the energy balance of dressing process.