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ORIGINAL ARTICLE

Diamond grinding wheels production study with the use of the finite element method

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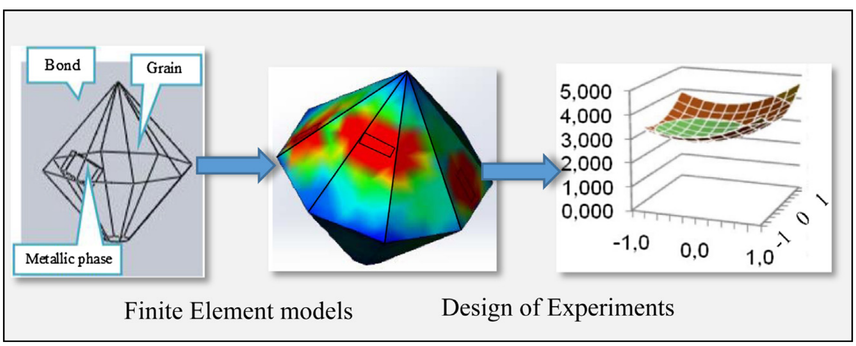
GRAPHICAL ABSTRACT



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ABSTRACT

Research results on 3D modeling of the diamond grain and its bearing layer when sintering diamond grinding wheels are provided in this paper. The influence of the main characteristics of the wheel materials and the wheel production process, namely the quantity of metallic phase within diamond grain, coefficient of thermal expansion of the metallic phase, the modulus of elasticity of bond material and sintering temperature, on the internal stresses arising in grains is investigated. The results indicate that the stresses in the grains are higher in the areas around the metallic phase. Additionally, sintering temperature has the greatest impact on the stresses of

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the grain-metallic phase-bond system regardless of the type of the bond. Furthermore, by employing factorial design for the carried out finite element model, a mathematical model that reflects the impact of these factors on the deflected mode of the diamond grain-metallic phase-bond material system is obtained. The results of the analysis allow for the identification of optimal conditions for the efficient production of improved diamond grinding wheels. More specifically, the smallest stresses are observed when using the metal bond with modulus of elasticity 204 GPa, the quantity of metallic phase in diamond grain of not higher than 7% and coefficient of thermal expansion of 1.32×10^{-5} 1/K or lower. The results obtained from the proposed 3D model can lead to the increase in the diamond grains utilization and improve the overall efficiency of diamond grinding.

Introduction

Grinding is mainly used as a finishing process but also as a process with high material removal rates, in contemporary industry [1,2]. Its efficiency heavily depends on the quality of the tools used, namely, the grinding wheels. In particular diamond grinding wheels are a large part of the tools used in this process and the quest for better quality tools drives the trends toward the overall improvement of the process.

It is necessary to increase the reliability and quality when manufacturing diamond-abrasive tools, which is indispensable to its effective application in manufacturing processes. The operational efficiency of a diamond grinding wheel is determined in extent by factors such as the quality of production of the diamond-bearing layer and its best performance curve. The production process of diamond wheels on various bonds is rather labor-intensive. Foremost, this concerns the sintering process involved in the production of the wheels [3]. At present, there are no scientifically established guidelines for the choice of rational combinations of strength, brand of a grain, graininess and concentration with physical-mechanical properties of wheel bonds. The guidelines that are available in the literature for the use of various bonds in diamond grinding wheels are of general type [4]. This results in damage to the grains during sintering process, which further leads to lower productivity of the abrasive process.

A way to solve the problem of enhancement of diamond abrasive tool production efficiency is to use the modeling techniques for simulation of their production process. Finite Element Method (FEM) is one of the most frequently used methods for the simulation of manufacturing processes [5–7], including grinding as well [8–10]. The advancements in computer technology have also made 3D modeling available [11–13]. These models, although more complicated and computationally intensive in comparison with 2D models, can be completed in reasonable time and hardware resources with modern personal computers. Additionally, commercial FEM software has further simplified the model building and solving procedure; at the same time these software have made modeling more reliable.

Focusing on the modeling of grinding and grinding wheels, two main trends may be identified [14]. In the first one, the grinding wheel-workpiece interaction is macroscopically examined. The actual grinding wheel is replaced by thermal or thermo-mechanical boundary conditions and chip formation is neglected [9]. In the second approach, being a microscopic one, a grain or a group of grains is modeled and their interaction with the workpiece is investigated [15,16]. These models, usually 3D, use shapes of the grain based on optical observations from actual grinding wheels [17]. However, the action between the grain and the bond is neglected. Furthermore, models such as these, pertain only to the operation of the grinding wheel and not to its production.

As a novelty, the microscopic approach is adopted in this paper to describe a diamond grain of the grinding wheel, at the production stage. The methodology is based on numerical modeling of the deflected mode of diamond abrasive tools such as sintering and grinding zone using the finite element method for the introduction of a 3D model. Simultaneously, it is possible to determine the best composition of the diamond-bearing layer of the wheel, i.e. physical-mechanical properties of wheel bond, graininess and concentration of diamond grains and, if necessary, the rational design of the wheel, for specific process conditions, e.g. for high-speed grinding. These tasks are realized without time- and labor-consuming, costly experimental investigations but by means of design of experiments and statistical analysis. Furthermore, the influence of the quantitative composition of metallic phase in diamond grain and the influence of temperature on deflected mode of diamond-bearing layer, when sintering diamond wheels, are investigated.

Finite element model

The question of efficiency enhancement of the diamond grinding processes is still the subject of active research interest. It is anticipated that modern methods of numerical modeling can produce significant results. It is known that during the operation of diamond abrasive tools the coefficient of efficient use of diamond grains does not exceed 5–10% [3]. The remaining percentage of grains is destroyed at the stage of production or in the course of wheel operation. Therefore, at the initial stage of production of a diamond wheel on various bonds, it is important to determine the optimal process conditions for its manufacture, namely pressure, temperature and sintering time, under which the integrity of diamond grains is not disturbed. At the next stage of operation of the sintered wheels, it is necessary to investigate the factors increasing the efficiency of diamond grinding that from now on will allow achieving high coefficient of use of the capability of diamond grains.