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Design of bronze-bonded grinding wheel properties

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ABSTRACT

The properties of grinding wheels determine the productivity of the grinding process and the achievable grinding quality. The influences of grain type, size and concentration as well as the type of bond on the grinding behavior are well known. In contrast to this, the effects of the individual properties of the bond on the grinding process have not yet been identified. Furthermore, it remains unknown how to selectively adjust these properties during the grinding wheel manufacturing. This paper demonstrates how the sintering of bronze-bonded grinding wheels influences their bond properties and the resulting grinding behavior.

1. Introduction

The right choice of grinding wheel determines the success of a grinding operation. The properties of the grinding wheel influence the productivity and the achievable workpiece quality decisively in interaction with the process parameters and the workpiece material. Grinding wheel properties include the specifications of the grinding layer such as grain size, type and concentration as well as the bonding type are comprehended [1]. These are typically used to explain and predict the grinding behavior of a grinding wheel. The grain size, type and concentration are considered in variant chip thickness and topography models, which are used to describe the thermal and mechanical load in the wheel-workpiece contact zone and the generated workpiece roughness [2]. The conditioned topography of a grinding wheel depends also on its specification and is described by 3D parameters to predict the possible grinding behavior [3–5]. This knowledge is used to adjust the wheel topography and enhance the grinding efficiency [6,7]. Furthermore, there are also investigations of the grain strength on the grinding behavior [8]. The bond material determines the grinding wheel'skey properties and influences primarily wear mechanism, wear rate as well as thermal conditions in the wheel-workpiece contact zone [1]. Metallic bonds have a high bonding strength and a high thermal conductivity in comparison to other bond systems like vitrified or resin bonds [9]. Several use cases benefit from these advantages, for example the grinding of glass, stone and concrete as well as the profile grinding of gears [10–12]. However, the strength of metallic bonds causes difficulties in dressing operations and they provide no self-sharpening effects such as vitrified bond systems. These negative characteristics are nowadays encountered with hybrid bonding systems [13,14].

Nevertheless the bonding strength between abrasive grain and bond matrix plays a key role in the performance of a grinding wheel. If the bonding strength is too high, the abrasive grain flattens. If the bonding strength is too low, the grain pulls out too early [15]. Both wear mechanisms cause a decrease of the grinding ability so that a good adjustment of the bonding strength in the bond/grain-interface is necessary and important. The bonding strength between a bronze based metallic bond and diamond is well known [16] and is often influenced by a variation of the coating on the grain [17] or a variation of the copper alloy composition [18,19].

Despite the extensive research in this field, it is not possible to predict the grinding behavior of sintered bronze grinding wheels prior to its production. Numerous and iterative grinding tests are necessary to find the suitable grinding wheel properties for a given application. The aim of this study is an approach that allows the targeted manufacturing of bronze bonded grinding wheels in consideration of their expected grinding behavior. To achieve this aim qualified parameters for the description of the bonding properties are derived. These parameters will be used as a missing link between the sintering and the grinding process.

2. Determination of the bonding mechanism

Although the diamond/metal interface has been studied for various alloy compositions before, first of all the bonding mechanisms need to be investigated. This is because the type and exact conditions of sintering may alter the nature of the interface. Cylindrical specimens were used for various investigations as well as grinding wheels that were manufactured by mixing grains and metal powders and by applying subsequent hot pressing using a “Dr. Fritsch DSP 510”. When diamond is brought into contact with metals under elevated temperature and pressure during sintering, there are three possible reactions that could take place at the interface. Those possibilities comprise a graphitization at the diamond's surface catalyzed by metals, the formation of metal carbides, or no chemical reaction at all. The electronic state of the metal determines the possibility of these reaction types. Since the presence of unoccupied d-orbitals is mandatory for a chemical interaction between metal and carbon, no reaction can

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beobserved with main group metals as well as with metals from the copper and zinc-groups. Early transition metals (Ti, V, Cr, Mn) on the other hand show a pronounced tendency to form metal-carbides whereas late transition metals (Fe, Co, Ni) tend to catalyze the graphite formation. However there is a smooth transition between these two alternative reactions. Since copper and tin do not possess unoccupied d-orbitals, no reaction can be expected at the interface between diamonds and a pure bronze bond. With cobalt on the other hand, which is frequently used as a material for metal bonds, a chemical reaction (formation of carbides, graphite or a solid solution) may occur [15]. To investigate the interface properties resulting after hot pressing specimens containing diamond grains in a matrix of bronze and bronze with an addition of 10% cobalt were produced. The samples were sintered at 680 °C and 68 bar for 180 s. SEM micrographs of fractured surfaces of these samples show smooth and unaltered diamond surfaces for both samples (Fig. 1).

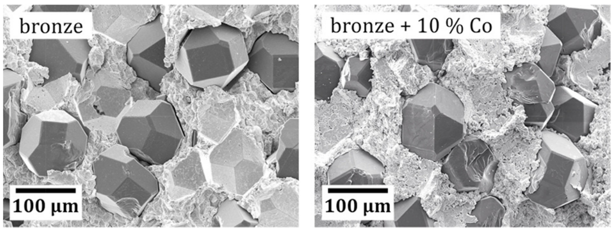

Fig. 1. SEM micrographs of fracture surfaces.

For a more detailed investigation of the interface, focused ion beam milling was used to prepare cuts through the specimen. Fig. 2 shows a high resolution SEM analysis of such a cut through a sample containing 10% of cobalt. Even with the addition of cobalt, a clear distinction between grain and bond is apparent and no reaction zone can be found (Fig. 2b). Tree ring like structures can be found in some regions of the sample (Fig. 2c). This is no hint for a reaction but can be attributed to a redeposition of material that was removed by the FIB during preparation.

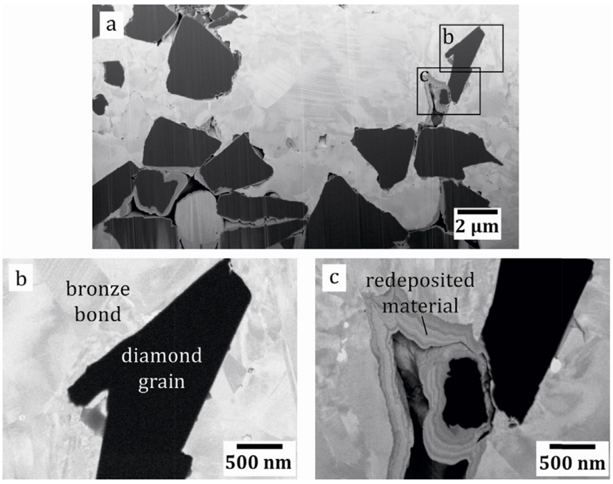

Fig. 2. SEM analysis of the diamond/metal bond interface; a: overview, b: magnification of interface region (BSE image), c: redeposited material in pore (BSE image).

The investigations have shown that the incorporation of the diamonds into the metal matrix after hot pressing is purely mechanical even when cobalt is added as an alloying component. That is why mechanical parameters of the grinding layer are determined as crucial properties of the grinding wheels that can be adjusted during sintering.

3. Grinding layer bond properties

For the description of the macroscopic mechanical behavior of a grinding wheel layer, the pore volume content Φ and the critical bond stress σ_c, are determined on cylindrical grinding layer specimen. The pore volume content is determined by the measured density ρ and the theoretical density ρ_{th} as follows:

$$\Phi = \left(1 - \frac{\rho}{\rho_{\mathrm{th}}}\right) \times 100\%. \tag{1}$$

The theoretical density results from the composition of the grinding layer. The actual density was determined by measuring the cylindrical grinding layer specimen by using a density scale based on Archimedes' principle. The critical bond stress is the critical bending stress of the bond and is determined by a fracture test. The specimen was loaded with a vertical force F_z until it collapsed at a critical bending stress. The force was measured with a Kistler dynamometer 9255C. The critical stress is calculated by taking the dimension of the specimen, like the length l, the diameter d and the height h, into account. With the assumption that $I_y = (d \cdot h^3)/12$ results σ_c as follows:

$$\sigma_c = \frac{3 \cdot F_z \cdot l}{2 \cdot d \cdot h^2} \tag{2}$$

To determine the influence of the sintering process and the grinding wheel specification on the presented properties 16 different grinding layer specimens, according to a 2^{k-1} fractional design with $k = 5$ factors, were prepared. For each factor combination seven cylindrical specimens were manufactured for property testing purposes. The factors are the abrasive size d_g, the grain concentration C as well as the sintering parameters maximum sintering temperature T_s, maximum sintering pressure p_s and the sintering retention time t_s. The respective factor steps are shown in Table 1.

Table 1
Factor steps of the fractional design 2^{k-1}.

Factor	Factor steps	
	−1	1
d_g [μm]	46	107
C [–]	75	125
T_s [°C]	560	720
p_s [bar]	48	68
t_s [s]	120	360

The abrasive grains were FMD 60 diamonds with a medium toughness. The bronze bond material was a 80/20 copper-tin alloy. In addition, the grinding layer contains 21% silicon carbide secondary grains. The size of the SiC grains depends on the size of the used diamond. SiC 120# was used with $d_g = 107$ μm and SiC #280 was used in combination with $d_g = 46$ μm. Fig. 3 represents the significant effect on the pore volume content Φ. Φ is mainly influenced by the diamond grain concentration C, the sintering retention time t_s, sintering pressure p_s and the grain size d_g. Here, C and t_s have a positive and p_s and d_g a negative effect. The effect of the sintering temperature T_s can be neglected.

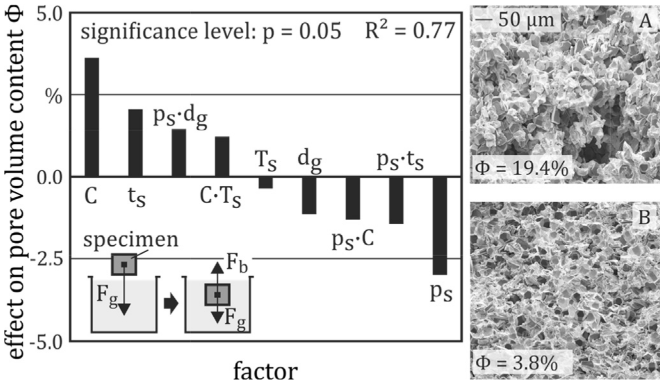

Fig. 3. Significant effects on the pore volume content.

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