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# 3D characterization of cubic boron nitride (CBN) composites used as tool material for high precision abrasive machining processes

S. Fang[a,b,c], L. Llanes[a,b,*], D. Bähre[c], F. Mücklich[d]

[a] CIEFMA-Departament de Ciència del Materials i Enginyeria Metal.lúrgica, Universitat Politècnica de Catalunya, EEBE – Campus Diagonal Besòs, 08019 Barcelona, Spain

[b] Barcelona Research Center in Multiscale Science and Engineering, Universitat Politècnica de Catalunya, 08019 Barcelona, Spain

[c] Institute of Production Engineering, Saarland University, 66123 Saarbrücken, Germany

[d] Chair of Functional Materials, Saarland University, 66123 Saarbrücken, Germany

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ABSTRACT

Cubic boron nitride (CBN) composites are widely used as cutting tool materials for high precision abrasive machining processes. They are composed of super hard CBN abrasives and a softer binder. CBN abrasives are one of the hardest materials. They are embedded in the binder which can be metallic, polymeric or ceramic. The binder supports the abrasives and offers suitable toughness. The two components are consolidated by sintering processes under high pressure and temperature. Hence, abrasive particles exhibit an irregular spatial distribution in terms of size, location and orientation. In this work, X-ray computed tomography (CT scan) is used to investigate the geometrical properties of CBN abrasives in the volume regarding quantity, dimension and shape. A three-dimensional (3D) model is generated and the CBN abrasives are correspondingly characterized. The contribution includes both detailed explanation of CT scan and 3D modeling implementation, as well as quantification analysis of the key microstructural features for CBN composites.

## 1. Introduction

Cubic boron nitride (CBN) is the second hardest substance after diamond [1]. Under high temperature and pressure, the structure of boron nitride is transformed from hexagonal to cubic [2]. Moreover, CBN exhibits not only better wear resistance, but also higher thermal conductivity than diamond. It implies a wider range of applications for CBN compared to diamond [1–3]. It is widely used as the hard phase within cutting tools for industrial abrasive machining processes, such as grinding and honing, and under harsh service conditions, i.e. elevated temperature or high speed [4,5]. CBN composites basically consist of two phases: CBN grains and a binder. According to its chemical nature, binder materials can be classified as metallic, polymeric (resin) and ceramic. CBN composites are sintered by mixing CBN particles and binder material powders under high temperature and vacuum. However, due to the manufacturing processes, the CBN particles are not regularly distributed in the produced composite. In addition, shape, dimension and orientation of the particles are not standardized.

During abrasive machining processes, the emerging CBN grains located on the cutting surfaces work as sharp edges and remove the material of workpiece. Therefore, geometrical properties of CBN grains can strongly influence the quality of the machined workpiece surfaces. For example, the produced surface roughness of the workpiece is, to some extent, determined by the protruding height of the grains [6]. Hence, the surface topography becomes relevant for correlating tool material characteristics and its performance. In a recent work by the authors, a two-dimensional (2D) quantification protocol has been proposed for assessing the geometrical properties of CBN grains on the cutting surfaces of a honing stone [7]. However, 2D characterization methods offer limited information related to three-dimensional (3D) subsurface features. This information may play an important role for understanding wear processes of the material, since the abrasive grains at the cutting surfaces are dynamically changing during the machining processes due to a self-sharpening effect [8]. Therefore, it is relevant to extend the characterization and quantification of these composites, and particularly of the CBN grains, to a bulk-like (3D) perspective. It would enable to foresee the evolution of the cutting surfaces during the machining processes.

There are several advanced techniques to obtain a 3D volume reconstruction of microstructures and/or damage/cracking scenarios involved in materials science: electron tomography [9], atom probe

* Corresponding author at: CIEFMA-Departament de Ciència del Materials i Enginyeria Metal.lúrgica, Universitat Politècnica de Catalunya, EEBE – Campus Diagonal Besòs, 08019 Barcelona, Spain.

*E-mail address:* luis.miguel.llanes@upc.edu (L. Llanes).

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**Table 1**
Properties of the honing stones B151/L2/10/50.

| Honing Stone | Mean grain size (µm) | Max. grain size (µm) | Min. grain size (µm) | Grain concentration (vol %) | Density (g/cm$^3$) |
|---|---|---|---|---|---|
| B151 | 138 | 150 | 126 | 12.5 | 0.44 |

tomography [10,11], focused ion beam tomography [12–15], and X-ray computed tomography [16,17], among others. Considering the length-scale of microstructural features exhibited by the CBN composites investigated, X-ray computed tomography (CT) emerges as the most appropriated technique for 3D microstructure characterization to be used in this study. It uses X-ray to produce 3D images of the scanned object [18,19]. Since its introduction in the 1970s, it has been mainly implemented in medicine as a remarkable development of the diagnosis method. The application of X-ray CT is now widely extended as it is also used in different industries (e.g. Refs. [20,21]). In the field of production engineering, X-ray CT is employed to inspect and characterize material deformation, internal flaws and crack propagation (e.g. Refs. [22,23]). Considering the subject of this paper, CT scan has been used to analyze the geometrical properties of single CBN grains, such as shape and dimension [24]. However, in order to quantitatively characterize CBN composites from a statistical point of view, it is necessary to obtain geometrical information of a large quantity of grains in a given (representative) volume. Within this context, the 3D volume quantification of CBN composites requires extensive data gathering and analysis together with effective modeling, so that the material volume may be reliably reconstructed. Under these conditions, the geometrical properties of a large number of grains could be statistically analyzed on the basis of their features, such as shape, dimension, orientation and phase ratio. This is the main objective of the investigation presented in this paper.

## 2. Material, data analysis and experimental aspects

### 2.1. Investigated CBN composite

The material studied in this paper is a commercial CBN honing stone which is referred to as B151/L2/10/50. The specification (Table 1) of this honing stone indicates the following data: the abrasive nature is Cubic Boron Nitride (B), the grain size is between 126 µm and 150 µm (151), a standard metallic (bronze-like nature) binder type of (L2) is used, the grain structure and quality (10) and grain concentration is 12.5 vol%, i.e. about 0.44 g/cm$^3$ (50) [25,26]. Composite hardness ranges from 250 to 350 Vickers hardness (measured under applied load of 294 N), in agreement with the relative amount of superhard phase embedded in a quite soft metallic matrix. Fig. 1(a) shows the surface image of CBN composite obtained by scanning electron microscopy, and Fig. 1(b) shows the 3D image of a CBN grain obtained by laser scanning microscopy.

### 2.2. Software programs for image processing and quantitative analysis of microstructures

Two software programs are used in the study: 3D modeling and processing software AMIRA 5 (FEI Company) and MAVI (Fraunhofer Institute for Industrial Mathematics). AMIRA 5 is a competent software tool for 3D image processing. It can visualize raw data (2D images) obtained from microscopy or tomography, manipulate and enhance image processing and reconstruct the studied volume by assembling cross-sectional 2D images. MAVI is employed as an additional unit to complement volume image analysis after the bulk reconstruction. It permits to carry out quantitative analysis of the studied microstructures.

### 2.3. 3D volume quantification parameters

The main objective of the investigation is to propose a method to quantify and analyze grain geometrical properties of the honing stone B151 with a 3D statistical perspective. During the investigation procedure, the volume of the studied material is reconstructed with a series of binarized cross-sectional images obtained by the CT-scan. Based on the reconstructed volume, key geometrical properties of the grains in the investigated volume, such as quantity, dimension and form (Fig. 2) are assessed.

#### 2.3.1. Quantity parameters

Four parameters (Table 2) are used to describe the quantity features: grain amount $N_t$, grain volume fraction $f_g$, binder volume fraction $f_b$ and particle density D. Grain/binder volume fraction $f_g/f_b$ is

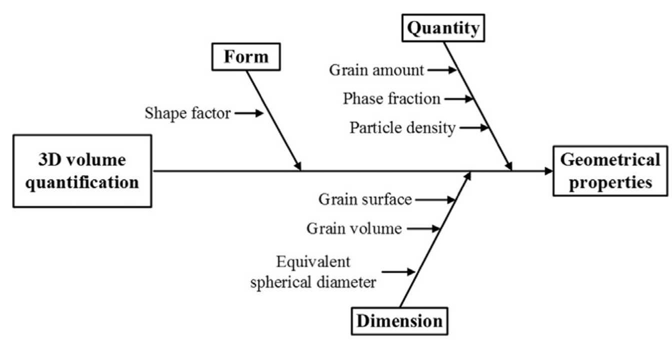


**Fig. 2.** Assessment parameters of the 3D volume quantification of CBN honing stone B151.

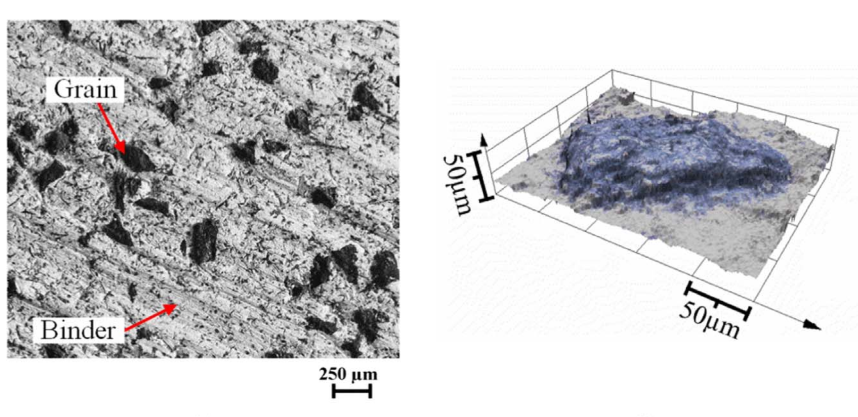


**Fig. 1.** (a) CBN composite surface image obtained by SEM, (b) CBN grain 3D image obtained by LSM.