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Section 1: Single crystal materials

CHARACTERIZATION OF DACIA SYNTHETIC DIAMOND FOR SAWING APPLICATIONS

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Selection of the most efficient diamond type for various sawing applications is a very important and not easy to solve problem. Intended to provide a guide to grit selection for toolmakers and endusers, a saw grit indicator system has been developed, based on: diamond strength, thermal stability and structure. A graphical representation system for the most characteristics of Dacia saw grits is proposed in the paper.

Keywords: Diamond powder, Saw grit indicator system

1. Introduction

The outstanding properties of diamond make him an invaluable material in abrasive applications. Each application demands crystals with specific characteristics, in order to obtain the desired lifetime of the diamond tool. To supply grits with such characteristics, special methods for selection and characterization of the extreme diversity of synthetic diamond particles resulted by industrial synthesis must be employed.

The crystal's behaviour in different applications is actually determined by their structure. Structure is a direct result of the crystal growing process and determines all the characteristics discussed usually in the characterization of the synthetic diamonds.

The structure of a crystal comprises, from the physical point of view, the constituent particles of the crystal (in the case of pure diamond – carbon atoms) and the way in which they are distributed – the lattice (the basic diamond cell can be pictured as a face - centred cube). The diamond crystals obtained by catalytic synthesis are not perfect: besides carbon atoms synthetic diamonds contain nitrogen and other elements, mainly from the metallic solvent catalysts used in the synthesis; the lattice is not a perfect face – centered cube due to the impurities and the other defects of the lattice. The synthesis conditions (pressure, temperature, kinetics and chemical environment in which the crystal grows) are determinant for the structure of diamond crystals.

The real structure of the crystals is very hard to characterize. In the diamond industry, crystals are described by the measurable macroscopic characteristics determined by their structure: shape and dimension, colour, transparency, surface quality etc.

An other used way to deduce the structure is by characterization of crystal's behaviour in controlled mechanical tests, with or without a previous heat treatment.

A special field of industrial applications of synthetic diamond is sawing of natural stone. Diamond saw tools are manufactured with special grits, named "saw grits". These crystals are exposed generally to very hard conditions in the tool manufacture process and, lately, in the specific application. The crystals should have a near perfect structure. The saw grits are commercially presented as "blocky, very uniformly cubo – octahedral shaped diamond crystals with extremely high toughness and thermal stability, transparent, with smooth faces and a yellow to green – yellow colour".

From DACIA Synthetic Diamond Factory range of products, the ST20®, ST10®, T30®, T20®, T10® grades cater for this specific field of applications. Depending on the hardness and abrasivity of the machined stone and on the working conditions, the proper grade from the saw grit range can be selected.

2. The characterization of saw grit crystal's structure

Synthetic diamond crystals of good quality are usually symmetric cubo - octahedrons with sharp edges and smooth, well – defined faces. The granulation of those populations of near – spherical particles can be well measured by sieving methods.

The morphology of synthetic diamonds varies as a function of synthesis thermodynamic conditions [1]. Depending on the relative rates of growth of crystal's cubic faces, the crystal shape can range from a pure cube to a pure octahedron. Yamaoka et al [2] demonstrated that the octahedron is the stable morphology at high synthesis temperatures whereas the cube forms at the low temperature end of the diamond stable region in the carbon pressure – temperature phase diagram.

The most common shapes of DACIA grit crystals are represented in Fig. 1 (a – d).

The morphology studies by SEM demonstrate that DACIA saw grit crystals with cubo - octahedral shape, sharp edges and smooth, well – defined faces represent approximately 80% in the total number of crystals (for ST20 type), to 60 % (for T10 type). The asymmetry degree increases from ST20 to T10. The other crystals to 100 % are generally twins and, in small proportions, irregular shape or fractured crystals. Synthetic diamonds exhibit a variety of colours due to the incorporation of point defects in crystal lattice, which depend on growth conditions and further treatments. The nitrogen atoms randomly distributed throughout the lattice give the typical golden colour of synthetic diamonds. Depending on the catalysts used in diamond synthesis, on the reaction kinetics and on the chemical elements eventually incorporated into crystals during growth under high temperature and high pressure conditions, crystals may bear different hues (yellow, blue, green, brown) [3]. Crystals grown from Ni as catalyst – like DACIA synthetic diamonds – exhibit a yellow-green colour.

The spectro-photometric method allows an objective characterization of diamond's colour. A strong correlation was found [4] between the colour values in CIE – L*a*b* system and quality of diamonds, and, for crystals of the same quality, between the colour values and sample granulation. Thus, "better" and bigger crystals have a deeper colour than smaller and poorly quality crystals. The luminosity of the samples increases with decreasing granulation, and the colour changes from yellow to green-yellow.

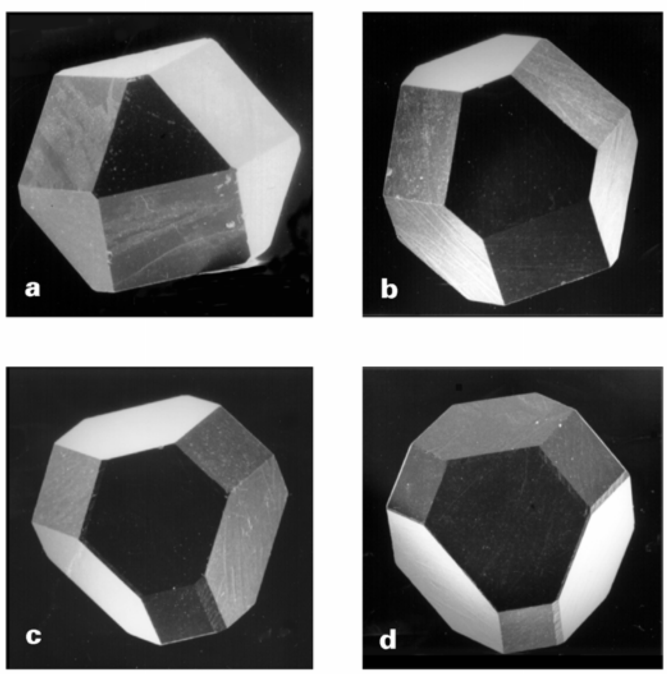

Fig. 1. The usual DACIA saw grit crystal forms from "half cube –half octahedron" (a) where wither the cube nor the octahedral faces predominate, to truncated octahedron (d) were octahedral faces predominate.

The most popular language of diamond grits characterization is, perhaps, those of the tenacity / friability of the crystals.

Tenacity is a measure of the impact strength of diamond abrasive grit under specific conditions, based on the breakdown of a proportion of the particles to a smaller size. Tenacity index (TI %) represents the proportion of diamonds resting on the breakdown sieve. Friability index (*FI* %) is the proportion of particles passing thru the breakdown sieve (*FI* = 100 – *TI*).

Various methods can be used for assessing the impact strength, some of them being standardized [5, 6]. These methods have the disadvantage that they not inform about the strength of individual particles. Furthermore, *TI* depends on the shape and other structural atributes of the crystals. Comparing the diamonds only on the basis of their strength is not efficient. Anyway, *TI* can be used to compare the diamonds with the same type of structure, for example saw grits.

Thermal stability of diamonds can be assessed comparing the *TTI* value of a grit – tenacity index of crystals exposed to a heat treatment at 1100^{o}C, in controlled conditions – with *TI* value. Thermal stability is very important for the diamonds used in sawing applications. These crystals are exposed to high temperatures during tool manufacture and in applications. Stability depends mainly on the quantity of inclusions and the distribution of them into crystal lattice.

The way in which crystals fracture under repeated mechanical shocks in the friability tests depends on their structure.

So, blocky particles with sharp edges are generally microchipping. A new particle geometry appears, and the crystal size reduces. Weaker diamonds fracture into bigger chips because of internal defects – inclusions, cracks, pores and other stress concentrators (Fig. 2).

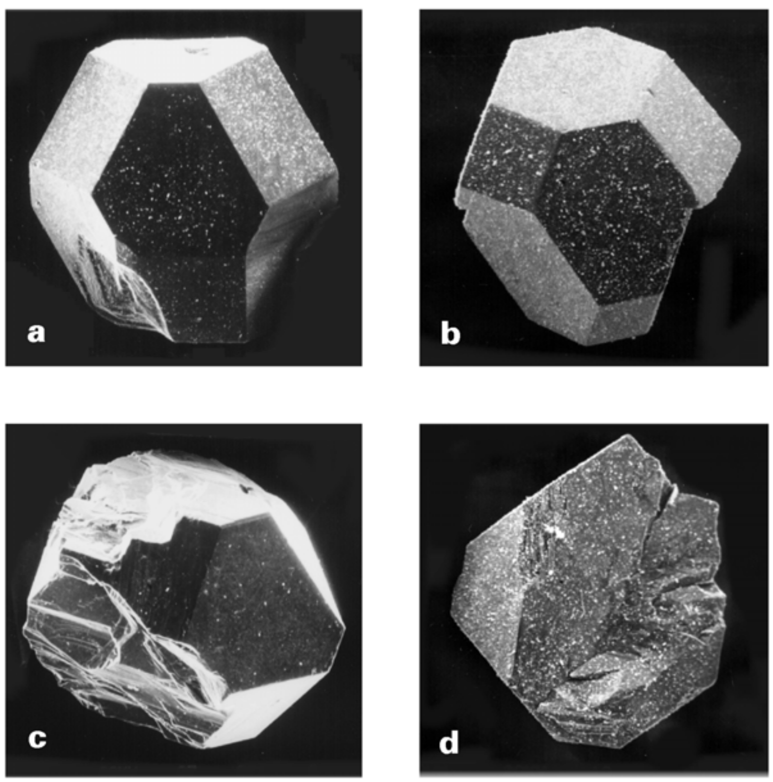

Fig. 2. Diamonds fractured under mechanical shocks: ST20 crystal; (b) ST20 crystal heat treated before mechanical test; (c) T10 crystal; (d) T10 crystal heat treated before mechanical test.

3. A proposed comparative system for DACIA saw grits

Depending on the parameters discussed above (shape, faces, colour, strength), Dacia saw grits structure can be comparatively characterized. To facilitate the selection of one saw grit type for a given application, a saw grit comparative system has been developed, based on:

1. Crystal's structure – shape, faces quality, colour.

A structural index *S* was defined, based on the proportion of crystals with cubo-octahedral shape, smooth faces and sharp edges, the proportion of twins with smooth faces and sharp edges and the intensity of crystal's colour. This proportions was determined on representative samples of DACIA saw grits with different granulations, using the SEM technique.

The index is calculated relative to ST20, for which *S* is assumed to be 100%. The values of *S* are the same for each granulation. The *S* values for DACIA saw grits are given in Table 1 and are determined by the following relationships:

$$S_x = \frac{F_x}{F_{ST20}} \cdot \frac{C_x}{C_{ST20}} \cdot 100 \quad [\%] \qquad (1)$$

where
$$F_x = \frac{\alpha + \frac{1}{2}\beta}{N_x} \qquad (2)$$

and
$$C_x = \sqrt{(a^*)^2 + (b^*)^2} \qquad (3)$$

where S_x is the S value for the saw grit type x;

α is number of "perfect" cubo-octahedral crystals in sample x;

β is number of twins in sample x;

N_x is total number of crystals in sample x;

a^*, b^* are the colour values of saw grit x in CIE-L*a*b* system.

2. The second index by which the comparative system is based on is the *T raport between TI and Δ(TI),* where *TI* is the toughness index at 20°C and Δ*(TI)* is the difference between TI and the toughness index measured after a heat treatment of diamonds at 1100°C *(TTI):*

$$T = \frac{TI}{\Delta(TI)} = \frac{TI}{TI - TTI}$$

The values of *T* are greater for very good quality diamonds, with highest toughness index and highest thermal stability - lowest Δ*(TI)* - and decreases with decreasing the toughness and the thermal stability of the grits. So, the mechanical properties of a diamond sample can be rapidly characterized using only one value *(T),* instead of two values (*TI* and *TTI*), taking in consideration the fact that, for saw grits, Δ*(TI)* decrease with increasing *TI* values.

In the comparative system, *T* value for ST20 was considered 100%. The relative *T* values for DACIA saw grits are given in Table 1, and are the same independent on the granulation.

Table 1. The relative T values for DACIA saw grit.

	S	*T*
ST20	100	100
ST10	90	59
T30	80	41
T20	74	29
T10	61	23

In Fig. 3 are represented *S* and *T* values for DACIA saw grits. As mechanical properties of the crystals depend on their structure, the *T* values increases with the structural index *S*.

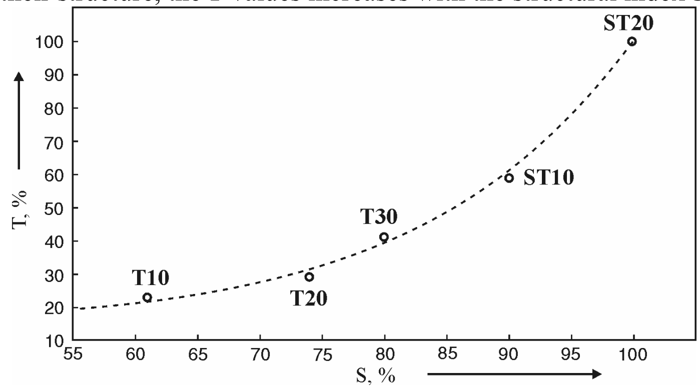

Fig. 3. S, T values for DACIA diamond saw grit.

4. Selection of saw grit type for sawing applications

In the manufacture of metal bond diamond tools for machining of natural stone, a great attention must be payed to the selection of: - the proper diamond grit, with structural properties, toughness and thermal stability depending on the physical properties of machined material, especially strength and abrasivity; - the proper metal bond, depending on the diamond type that will be used; - the working parameters, who determine temperatures at the tool – workpiece interface.

Although it is impossible to provide a complete guide for selection of proper diamond grit, metal bond and working parameters for any given application, some schematical recommendations are given in Table 2. The final decision in this selection must always be taken after several working tests on the workpiece material.

Table 2. Schematic recommendations for selection of diamond grit, metal bond and workpiece material.

Work material	Stone properties	Diamond properties	Recommended diamond type	Recommended bond properties
- hard granite - dense hard refractories - fused cast refractories	- hard materials - the amount of swarf generated is not very large	- diamond crystals must be strong and sharp, the pressure on them being substantial	ST	- metal bond processed at less than 1000°C
- sandstone - concrete - reinforced concrete	- friable work materials - easy desintegrate into abrasive swarf	- strong, thermally stable, very well crystalized diamonds	ST	- very resistant tool bonds - high processing temperatures
- marble - softer granite - refractories - asphalt	- soft, easy to cut materials - swarf is not very abrasive	- the forces on the diamond crystals are smaller	T	- medium temperature metal bonds

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