IMPROVED RETENTION OF SURFACE TREATED DIAMONDS IN SINTERED TOOLS FOR PROCESSING ORNAMENTAL STONES

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Pentru a îmbunătăţi încastrarea şi a preveni smulgerea prematură a cristalelor de diamant fixate în liantul metalic al sculelor sinterizate s-a imprimat o rugozitate controlată pe suprafaţa externă perfect plană a cristalelor de diamant sintetic super-tenace cub-octaedrice. In acest scop au fost efectuate experienţe de corodare prin imersia cristalelor de diamant în topituri de nitraţi alcalini,. rugozitatea rezultată fiind observată prin microscopie electronică SEM. Teste de tăiere pe o marmură dintr-o importantă carieră din România, au fost efectuate în mod comparativ utilizând două tipuri de segmenţi sinterizaţi conţinând diamante ne-tratate, respectiv tratate superficial. Efectul rugozităţii controlate produsă prin tratament a fost evaluat măsurând scăderea în timp a înălţimii segmenţilor.

To improve the retention and avoid premature pull-out of saw grit diamond crystals from their metallic binder in sintered cutting tools a controlled roughness was imposed on the perfect plane external surface of cube-octahedral super-tough synthetic diamonds. To this purpose experiments have been carried aut by immersing the diamond crystals in molten alkaline nitrates and the resulting roughness has been observed by SEM examination. Cutting tests have been performed on a marble from an important quarry in Romania by using two types of segments containing either non-corroded or corroded saw grit diamond crystals. The effect of the controlled roughness produced by surface treatment was evaluated by measuring the decrease in time of the segments height.

Keywords: diamond retention, sintered cutting tools, surface roughness, surface corroding treatments

Introduction

In a previous paper [1] we have put in evidence some experimental correlations between the nature of the metallic binder in diamond reinforced sintered tools and the mineralogical constitution of the processed ornamental building stones. Such correlations manifested during the cutting process may be

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explained having in mind two facts. First, the efficiency of the cutting operation and the durability of the cutting tool will be at their best if the erosion of the metallic binder will be such as not to release the diamond crystals before they are no more able to do their cutting job on account of blunting. Second, the microchips of processed stone that are formed during the cutting operation make an important contribution to the erosion of the metallic binder in which the diamond crystals are embedded. As a corollary it is to be expected to have the cutting process work at its best if a proper matching exists between the mechanical properties (e.g. hardness) of these two materials, namely the metallic binder of the sintered tool and the ornamental stone subject to the cutting operation.

In the present paper we continue this investigation by considering a new factor , namely the strength of the mechanical bond that retains the diamond crystals embedded in the binder of the sintered tool.To this purpose experiments have been performed to evaluate the influence of the smoothness of the diamond crystal faces by modifying the latter in a controlled manner by applying surface treatments to the diamond crystals[2-4].

1. Considerations on the mechanical bond in diamond reinforced sintered tools

According to reference [5] the metallic binder in sintered tools retains the diamond crystals by a mechanical action (surface interlocking). On the other hand during the cutting operation several forces are developed that may influence diamond retention. As depicted in Fig.1a reproduced from [5] the diamond crystal is stressed by a vertical force F_v which tends to embed it in the binder giving rise to the penetration tendency T_p . At the same time the diamond crystal is stressed by a tangential force F_t which produces a moment with a tendency T_r to rolling the diamond crystal in its cavity. The difficulty in penetrating the binder gives the tip of the diamond crystal a protrusion able to cut the processed stone without causing friction between the diamond crystal and the binder. At its turn the prevention of rolling avoids premature pull-out of the diamond crystal from its cavity. Both actions are favourable to a proper behaviour of the cutting tool and are guaranteed by a low deformability of the binder.

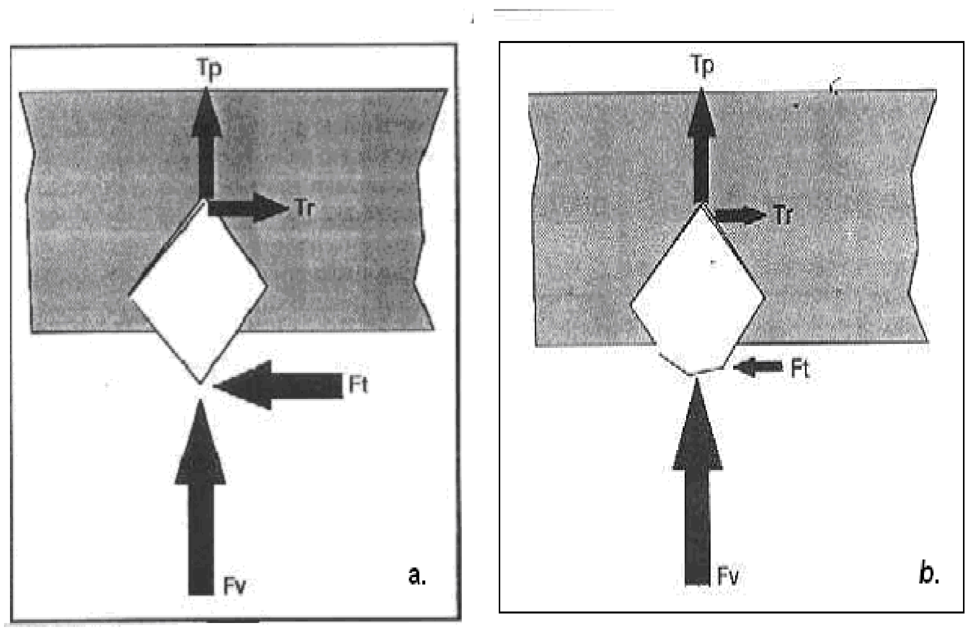

Fig. 1 Forces acting on the diamond crystal embedded in the metallic binder
a. original sharp diamond crystal
b. blunt diamond crystal

A second phenomenon that has to be taken into account is depicted in Fig.1b. The diamond crystal, especially if put to cut high hardness stones such as granite of high quartz content, can in the long term lose its initial sharpness with a tendency to glazing (becoming round or blunt). In these new circumstances the two forces F_v and F_t change and this fact has important consequences. Indeed the increase in F_v is unfavoutable because it tends to embed the blunt diamond crystal deeper in the binder. On the other hand the increase in F_t may be useful because it allows the pull-out of the blunt diamond crystal. Unfortunately if the toughness of the binder is too high the pull-out of the glazed diamond crystal will be difficult and the latter will continue to flatten, finally disappearing into the binder with no further possibility of contributing to the cutting action.

This complex picture describing the diamond crystals retention as well as their glazing and pull-out during the cutting operation may be influenced by acting on the smoothness of the free surfaces of the diamond crystals that are in contact with the binder. As we have mentioned in paper [1] on various reasons the diamond crystals intended to be embedded in the binder of sintered tools should be of the best quality belonging to the ST(super-tough) or to the T (tough) types. What matters for the the purpose of this paper is the highly smooth faces of the cube-octahedral ST and T diamond crystals. On this account their mechanical bond with the binder is not very strong. Increasing the strength of this bond by introducing a certain roughness on the free surfaces of the ST synthetic diamond crystals is just a straightforward idea. This is possible by applying a surface treatment that doesn't affect the bulk properties of the saw grit diamond crystals, keeping their most important property, -the toughness- almost as high as before the surface treatment [2].

2. Materials and methods

Concerning the saw grit diamond crystals and the sintered tools

A surface treatment was applied to saw grit diamond crystals by immersing them in an oxidizing melt consisting of alkaline nitrates. The thermal decomposition of the nitrate provides the free oxygen responsible for the surface corrosion of the diamond crystals according to the following reactions at $T>500^{o}C$

$$2KNO_3 \rightarrow 2KNO_2 + O_2 \quad \text{or} \quad 2NaNO_3 \rightarrow 2NaNO_2$$

$$C_{diamond} + O_2 \rightarrow CO_2$$

$$2\,C_{diamond} + O_2 \rightarrow 2CO$$

The diamond crystals subjected to the corroding surface treatment were of the best surface perfection, namely super-tough ST10 of Romanian production. The size of the crystals was either D602 μm or D427 μm. To obtain the sintered cutting tool these two dimensional sorts were mixed in a ratio D602 μm / D427 μm = 1:2. The binder used in the sintering process was BR80 (80Cu-20Sn). As shown in paper [1] this binder was in a good compatibility with marble (the stone intended to be processed in the present paper). The concentration of the saw grit diamond crystals for both types (corroded or non-corroded) was 75% that represents 3.3 carats / cm^3 binder (1 carat=0.2g). Two sorts of cutting tools have been manufactured denoted type B and type A respectively, in which the saw grit diamond crystals have been or have not been subjected to a previous corroding surface treatment as described before. The sintered tools consisted of cutting segments having an initial height h_o =7mm which have been brazed on the periphery of a cutting disk (300 mm diameter).

Concerning the selection of the processed ornamental stone

The choice has had in view the results obtained in our previous paper [1]. Because among the three ornamental rocks of Romanian origin investigated in paper [1] namely the granite from the Topleț quarry and two sorts of marble (from the Moneasa quarry and from the Ruşchița quarry), the Ruşchița marble has manifested an intermediate behaviour during the cutting tests it was selected for the purpose of the present investigation.

This choice was also motivated by the economic value of the Ruşchiţa marble explained by the geological conditions in which this deposit was formed. The Ruşchiţa marble is a metamorphic monomineral rock consisting of crystallized pure calcite ($CaCO_3$), its impurity content not exceeding 1%. According to [6] these impurities contribute to give an ornamental value to marble, the iron salts giving it a red colour, the manganese salts a brown colour and dispersed graphite a gray colour. The Ruşchiţa marble is found in various colours , but its most prized sort is the rosy one almost unique in Europe. Also prized is its white statuary sort completely devoid of impurities.

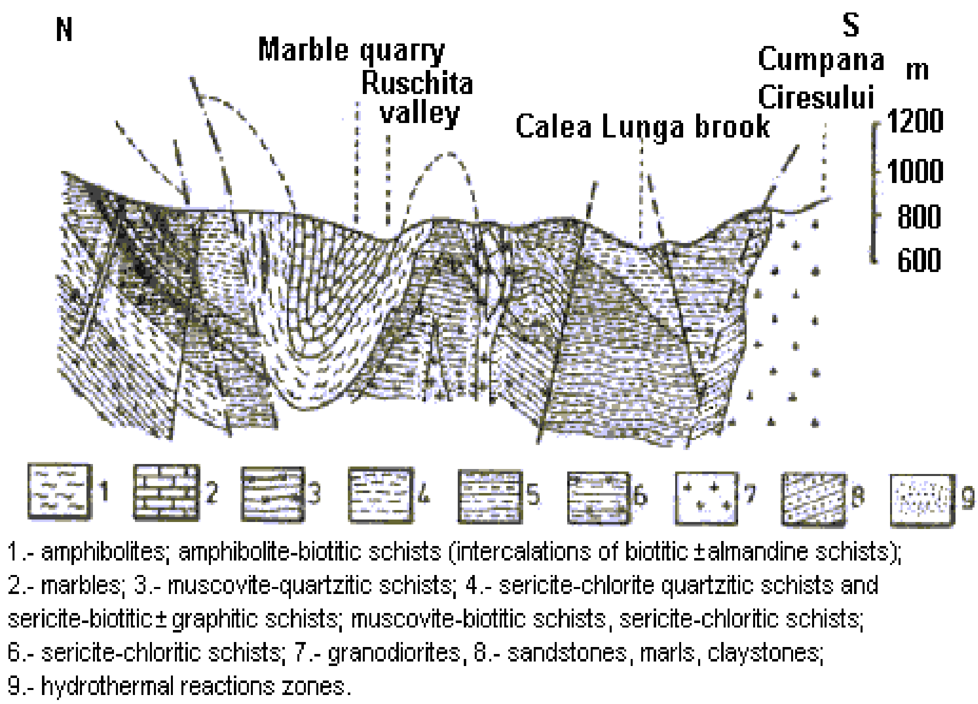

Fig.2 Geological cross –section N-S in the Ruşchiţa region

The economic value of Ruşchiţa marble (exploited since 1886) is additionally connected with the size of its geological deposit located North to Rusca-Montana [6,7].According to the geological cross-section in Fig.2 the main marble lense comprises three zones, each of them extending on 2-3 km^2 and a depth of about 100 m which allow the extraction of blocks up to 25 tons.

3. Results and Discussion

Concerning the surface corroding treatment of the saw grit diamond crystals

Experiments have been performed by immersing the ST10 super-tough diamond crystals in a molten nitrate bath for different periods of time at two different temperatures.The effect of the surface corroding action was ascertained by scanning electron microscopical examination. Also determined were the losses in weight and toughness of the corroded saw grit diamond crystal.l Fig.3 amd Table 1 summarize the results.

The SEM micrographs in Fig.3 show at lower magnification the perfect cube-octahedral shape of the diamond crystal subjected to the corroding treatment and at high magnification the severe roughness produced on its free surface.

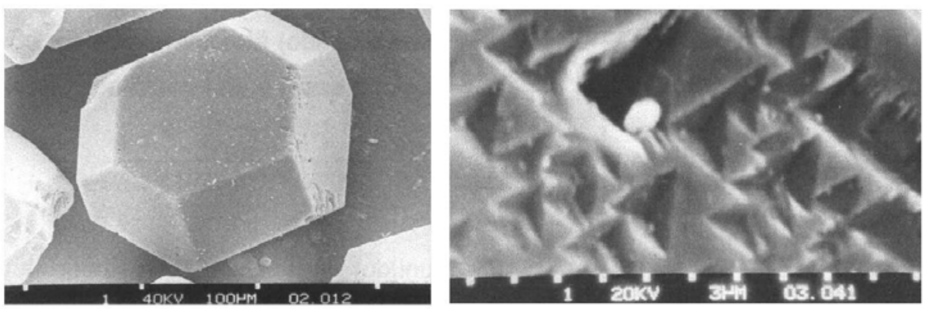

Fig3. SEM micrographs recorded at different magnification of an ST10 diamond crystal corroded for 2 hours at 600°C in molten $NaNO_3$

Table 1

Effects of time and temperature during the surface corroding treatment applied to ST10 saw grit diamond crystals

Nature of the corroding melt	Corrosion time (hours)	Temp. (°C)	Corrosion intensity	Loss in toughness (%)	Loss in weight (%)
$NaNO_3$	1	500	•	0.8	0.4
		600	••	1.4	0.9
	2	500	••	1.7	1.1
		600	•••	4.9	2.5
KNO_3	1	500	•	0.6	0.3
		600	••	1.25	0.75
	2	500	••	1.8	1.25
		600	•••	4.8	2.6

• mild •• moderate ••• strong

If the desirable surface roughness is not considered separately but in correlation with other effects such as weight and toughness losses of the corroded diamond crystals, the results in Table 1 indicate as a good compromise the time and temperature conditions for which a moderate corrosion intensity is obtained. A closer examination of the values for these parameters recorded in Table 1 shows that even in severe conditions the loss in toughness is acceptable but the loss in weight may become critical for strong corrosion if the high price of saw grit diamond crystals is taken into consideration. Given the importance of the weight losses, we have measured them for a wider time-temperature range in a separate experimental run performed on MT20 saw grit diamond crystals (medium tough, size D427 μm). The results are presented in Fig.4 and they point to a dramatical increase in the weight losses of the diamond crystals when the temperature of the corroding surface treatment is augmented.

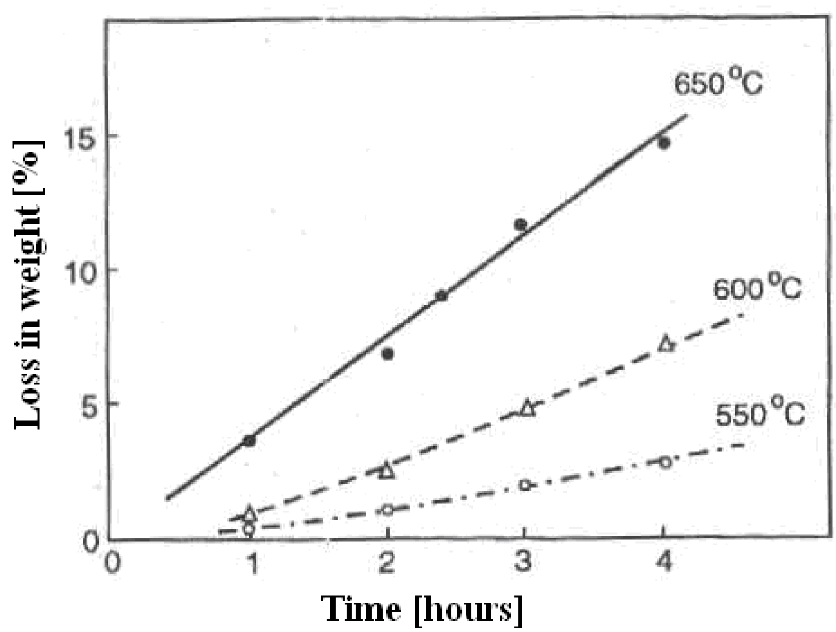

Fig.4 Time and temperature dependence of the weight losses during the surface corroding treatment in molten $NaNO_3$ of MT20 saw grit diamond crystals

Concerning the cutting tests

Experiments similar to those performed in paper [1] have been carried out but this time the aim was to compare the performances of the diamond reinforced sintered tools with or without previous surface treatment of the saw grit diamond crystals. To emphasize more pregnantly the effect of the surface roughness induced by the surface treatment severe conditions were applied namely 600^o C for 2 hours in molten $NaNO_3$.

For both types of sintered cutting segments (type A= non-corroded saw grit diamond crystals, type B= corroded saw grit diamond crystals) the peripheric speed of the cutting disk was the same namely 30 m /s. The power absorbed from the driving motor was adjusted so as to maintain an almost constant amount of processed material per hour. The processed material was the Ruşchiţa marble.

Measurements were made at each 1 hour time interval for the height *h* of the cutting segments (expressed in mm) and for the cumulated amount *q* of processed stone (expressed in linear meters). The actual efficiency *η* of the cutting operation was calculated as η= q / τ (expressed in linear meters per hour).

The results are summarized in Table 2.

Table 2

Effect of the surface roughness of the diamond crystals induced by surface treatment on the cutting operation when processing Ruşchiţa marble

Time (hours)		1	2	3	4	5
Cutting segments type A (non-corroded diamonds)	q(m)	79	164	265	324	410
	η(m/h)	79	82	88.33	81	82
	h(mm)	6.882	6.494	5.925	5.533	5.201
	Δh(mm)	0.118	0.506	1.075	1.467	1.799
	Δh/h (%)	1.69	7.23	15.36	20.95	25.70
Cutting segments type B (corroded diamonds)	q(m)	84	179	261	335	417
	η(m/h)	84	89.5	87	83.75	83.40
	h(mm)	6.896	6.659	6.445	6.210	5.896
	Δh(mm)	0.104	0.341	0.555	0.790	1.104
	Δh/h (%)	1.48	4.87	7.92	11.28	15.77

As intended the actual cutting efficiency η was almost constant during the whole period of time up to 5 hours. The average value for η was nonetheless slightly higher for the cutting segments type B (η =85.53 m/hour) as compared to the cutting segments type A (η =82.46 m/hour).

What matters in the results presented in Table 2 is the effect of the diamond surface treatment exerted on the tool wear. Indeed the wear of the cutting segments reflected in the decrease in time of their height *h* is systematically lower for the segments type B incorporating corroded diamond crystals than for the segments type A incorporating non-corroded diamond crystals . This difference in behaviour increases with cutting time and as pointed out by the percent values $\Delta h/h_o$ in Table 2 it reaches 10% after 5 hours, indicating a better durability of the tool if the saw grit diamond crystals have been previously surface treated.

This benefic effect of the controlled corrosion of the diamond crystals is undoubtfully produced by the surface roughness (put in evidence in Fig.3) that results in a better retention of the saw grit diamond cristals in the metallic binder of the sintered tool.

Conclusions

1. Experiments of surface corrosion have been performed in molten alkaline nitrates baths at 500-600^o C for 1-2 hours aiming at producing a controlled surface roughness on the free surfaces of super-tough saw grit diamond crystals that was supposed to improve the diamond retention in the metallic binder of sintered tools. SEM examination has put in evidence mild up to strong corrosion effects depending on time and temperature.

2. The loss in toughness of the corroded diamond crystals was acceptable (0.6-1.8%) for mild and medium corrosion increasing to 4.8% for strong corrosion.

3. The loss in weight was to be taken in account more carefully because of the high price of the saw grit diamond crystals. It was acceptable for mild and medium corrosion (< 1.25%) but it doubled (~2.5%) for strong corrosion.

4. Cutting tests performed on marble by using sintered cutting segments brazed on the periphery of a cutting disk in conditions of constant cutting efficiency (linear meters/hour) have put in evidence the superiority of the sintered tools incorporating surface corroded saw grit diamond crystals. The controlled surface roughness induced by corroding super-tough ST10 diamond crystals in a $NaNO_3$ melt at 600^o C for 2 hours has resulted in a better diamond retention in the metallic binder of the sintered cutting segments. The corollary of this better retention was a decrease in segments wear in time. For 5 hours cutting time the improvement in wear resistance was ` 10%

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