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# CORRELATING THE TYPE OF METAL BOND IN DIAMOND SINTERED TOOLS WITH THE MINERALOGICAL NATURE OF PROCESSED ORNAMENTAL STONES

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*Au fost efectuate experimentări sistematice pentru a testa dependența de timp a procesului de tăiere a rocilor ornamentale utilizând scule abrazive diamantate cu liant sinterizat. Pentru a cerceta interacțiunile reciproce între materialul procesat şi constituienții sculei diamantate au fost testate trei sorturi de roci ornamentale de producție indigenă (două sorturi de marmoră şi un sort de granit) şi două tipuri de liant metalic (un bronz bogat în staniu, respectiv un aliaj dur tip Widia) în care au fost încorporate prin sinterizare cristale de diamant sintetic super-tenace din clasa ST. Au fost puse în evidență efecte sistematice clare asupra eficienței procesului de tăiere şi asupra uzurii sculei, efecte exercitate în mod corelativ de natura mineralogică a materialului procesat şi de natura metalurgică a liantului.*

*Systematic experiments have been carried out to test the time dependent efficiency of the cutting process performed on ornamental building stones by means of diamond sintered abrasive tools. To investigate the interaction between the processed material and the constituents of the cutting tool, three sorts of ornamental building stones of indigeneous origin have been tested (two sorts of marble and one sort of granite) and two types of metallic binder (a tin rich bronze and a Widia type hard alloy, respectively) have been used for embedding super-tough ST diamond crystals. Definite systematic effects on the cutting process efficiency and on the tool wear have been put in evidence exerted correlativelly by the mineralogical nature of the processed material and by the metallurgical nature of the binder in the diamond sintered tool.*

**Keywords:** diamond sintered tools, ornamental building stones processing, cutting efficiency

## Introduction

The ornamental building stone processing involving operations like cutting, grinding and polishing is nowadays a prosperous and growing industry, whose development is strongly associated with the availability of sinthetic diamond tools.

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In processing ornamental building stones such as marble and granite, the hard diamond abrasive crystals don't represent an "independent variable". In fact their behavior is to be considered in correlation with the binder that keeps the diamond crystals embedded in the matrix of the cutting tool and also in relation with the nature of the material subjected to the cutting process. It is obvious from Fig. 1 that when the diamond crystal penetrates the material under process, small fragments (or microchips) of this material will themselves act as an abrasive and will erode the binder that holds the diamond grains. Several situations may occur and in each of them the speed of the cutting process as well as the quantity of the processed material will be different:

(a)- if the errosion rate of the binder matrix is adequate, the diamond crystal is expected to stay in the cutting zone all the time, before the diamond crystals become completely blunt; in that case the tool is working with good efficiency;

(b)- if the errosion rate of the binder matrix is too small, the blunt diamond crystals cannot be removed from the matrix; in this case the tool is working poorly;

(c)- if the errosion rate of the binder matrix is too high, the diamond cristals are removed out from the matrix before having become completely blunt; in this case the tool will work with good efficiency, but the overall amount of processed material will be less than in case (a).

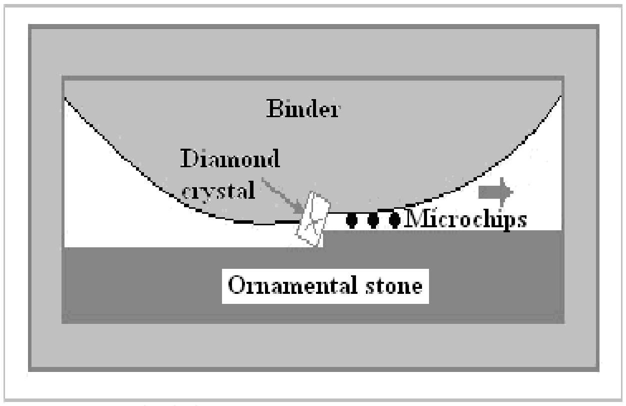

Fig.1.Interaction between "diamond crystal-binder -processed material" during cutting ornamental building stones

Bearing in mind such considerations, the present paper is intended to make a contribution to this complex correlation within the triplet "diamond crystals–binder–processed material", by investigating the behavior of diamond cutting tools of indigenous productions in processing ornamental building stones extracted from Romanian quarries.

## 1. Experimental

The cutting tools under investigation in this paper consisted of diamond abrasive segments 7 mm in height brazed on the periphery of a cutting disk blade with 300 mm diameter. The abrasive segments were obtained by incorporating the diamond crystals in a sintered metallic binder.

The type and dimensions for diamond crystals were ST10 D602 + ST10 D427 in proportion 1:2. According to the Romanian specifications several types and dimensions are obtained in the indigeneous production, by high temperature/high pressure diamond synthesis, followed by physical, chemical and electrochemical processes for separating the obtained diamond crystals. Symbol ST stands for the best diamond crystals of high toughness and perfectly developed cube-octahedral external shape as illustrated in the scanning electron micrograph in Fig.2. Symbols D602 and D427 indicate the size in microns of the individual diamond crystals. The concentration of diamond crystals in the binder matrix was 3.3 carats/cm$^3$ binder [1] (1 carat being equal to 0.2g).

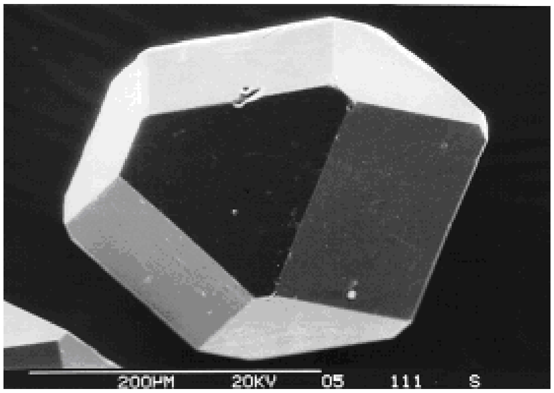

Fig.2 SEM micrograph of a perfect cube-octahedral synthetic diamond crystal of high toughness – ST class

The binder that made up the matrix in which the diamond crystals were embedded was of two types: (i) type BR80 consisting of a sintered metallic powder mixture (80%Cu +20%Sn) and (ii) type A10 consisting of 90%WC+10%Co. Because of the severe conditions imposed during the pressing and sintering process applied to the mixture “diamond crystals + metallic powder” [2] involving pressure of the order 2000 daN/cm$^2$ and temperatures in the range 600$^0$ up to 950$^0$C, rigurous conditions are imposed on the diamond crystals mixed with the metallic powder during sintering. As a result only the best sort of synthetic diamonds belonging to ST class are able to sustain the high pressure and high temperature conditions without undergoing a graphitising damaging process during sintering.

Concerning the choice of the materials subjected to the cutting process, the selection was made on two reasons: (i) first to represent ornamental buiding stones usual in Romanian production, and (ii) to present a large disparity in their mechanical properties on account of their different mineralogical nature.

According to the first criterion two sorts of marble were selected from the well known quarries in Romania, namely Moneasa and Ruşchiţa. The third material that was tested was different namely the granite from Topleţ.

This choice also agrees with the second criterion, marble being a metamorphic rock, while granite is an igneous rock (more specifically a plutonic rock). What makes this choice more meaningful for the purpose of the present study is the large disparity between the mineralogical constitution of the selected rocks. Indeed marble may be considered to be a monomineral rock, consisting of the mineral calcite ($CaCO_3$) whose hardness is $H_M=3$ on the Mohs scale. In contrast, granite is a polymineral rock comprising a variety of minerals of different hardness, such as quartz ($SiO_2$ and $H_M = 7$), feldspar ($KAlSi_3O_8$ and $H_M = 6$, in two polymorphic forms,- orthoclase and oligoclase-), biotite or black mica $K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$ and $H_M = 2.5$-$3$), and in lesser content magnetite ($Fe_3O_4$ and $H_M = 6$), ilmenite ($FeTiO_3$ and $H_M = 5.5$-$6$), amphibole (a mineral group with $H_M = 5$-$6$). According to reference [3] there are large differences in the proportion these various minerals of different hardness enter in the mineralogical constitution of granite, as indicated in Table 1.

*Table 1*

**Mineralogical constitution of granite (in volume percent)**

| **Mineral** | **quartz** | **orthoclase** | **oligoclase** | **biotite** | **magnetite** | **ilmenite** | **amphibole** |
|---|---|---|---|---|---|---|---|
| Vol% | 25 | 40 | 26 | 5 | 2 | 1 | 1 |
| $H_M$ | 7 | 6 | 6 | 2.5-3 | 6 | 5.5-6 | 5-6 |

For a more complete characterisation of the ornamental rocks under investigation we have carried out experimental measurements for their density, resistance to mechanical shocks and resistance to wear. The density was measured by a picnometer method. The resistance to mechanical shocks was measured by means of an apparatus type Foppl by using a hammer of 50±0.5 daN force, on dried cubic samples of edge 50±0.5 mm. The wear resistance was defined according to reference [4] as the ability of the rock sample to opose the wear produced by friction with an abrasive sticked on a rotating disk. The loss of material per unit surface expressed in $g/cm^2$ represents the wear; the reciprocal of this value expressed in $cm^2/g$ is the resistance to wear.

The results obtained for the three rocks under study are summarized in Table 2.

*Table 2*

**Experimental characterization of the investigated ornamental rocks**

| Material | Aspect and colour | Density (g/cm$^3$) | Mechanical shock resistance daNcm/cm$^3$ | Resistance to wear (cm$^2$/g) |
|---|---|---|---|---|
| Moneasa marble | Grey<br>Black<br>Brown-red | 2.75 | 2.9 | 0.2 |
| Ruşchiţa marble | White<br>White-pink<br>White-Yellow | 2.76 | 4.2 | 0.35 |
| Topleţ granite | Grey<br>White-gray | 2.74 | 4.6 | 0.8 |

## 2. Results

To investigate the interactions between the three actors "diamond-binder-processed material", cutting tests have been carried out at 30 m/s peripheric speed of the cutting disc, at constant power (~0.35 kW).

Several effects on the tool and on the processed material have been evaluated after various periods of time, namely the hight $h$ of the worn cutting segment expressed in mm, and the quantity $q$ of processed material expressed in linear meters of cut material. A more meaningful value was calculated from these data, namely the efficiency $\eta$ of the overall cutting operation after various periods of time ($\eta = q/\tau$ expressed in meters per hour). Table 3 summarizes the results.

*Table3*

**Effects recorded during the cutting operation related to binder and to processed material**

**a. Moneasa marble**

| Time (hours) | | 0.1 | 0.5 | 2 | 5 | 7.5 | 10 |
|---|---|---|---|---|---|---|---|
| Binder BR80 | q (m) | 28 | 115 | 208 | 297 | 442 | 581 |
| | η(m/hour) | 280 | 230 | 104 | 59.4 | 58.9 | 58.1 |
| | h(mm) | 6.969 | 6.812 | 6.752 | 6.670 | 6.037 | 5.413 |
| Binder A10 | q (m) | 25 | 98 | 142 | 179 | 230 | 251 |
| | η(m/hour) | 250 | 196 | 71 | 35.8 | 30.7 | 25.1 |
| | h(mm) | 6.991 | 6.919 | 9.883 | 6.473 | 6.012 | 5.996 |

**b. Ruşchiţa marble**

| Time (hours) | | 0.1 | 0.5 | 2 | 5 | 7.5 | 10 |
|---|---|---|---|---|---|---|---|
| Binder BR80 | q (m) | 24 | 103 | 180 | 256 | 368 | 472 |
| | η(m/hour) | 240 | 206 | 90 | 51.2 | 49.1 | 47.2 |
| | h(mm) | 6.898 | 6.665 | 6.212 | 5.901 | 5.099 | 4.422 |
| Binder A10 | q (m) | 21 | 79 | 130 | 167 | 187 | 196 |
| | η(m/hour) | 210 | 158 | 65 | 33.4 | 24.9 | 19.6 |
| | h(mm) | 6.993 | 6.906 | 6.862 | 6.501 | 6.460 | 6.422 |

**c. Topleț granite**

| **Time (hours)** | | 0.1 | 0.5 | 2 | 5 | 7.5 | 10 |
|---|---|---|---|---|---|---|---|
| Binder BR80 | q (m) | 23 | 95 | 166 | 235 | 331 | 426 |
| | η(m/hour) | 230 | 190 | 83 | 47 | 44.1 | 42.6 |
| | h(mm) | 6.869 | 6.233 | 5.894 | 5.112 | 4.466 | 3.814 |
| Binder A10 | q (m) | 13 | 77 | 135 | 193 | 281 | 369 |
| | η(m/hour) | 154 | 130 | 67.5 | 38.6 | 37.5 | 36.9 |
| | h(mm) | 6.991 | 6.872 | 6.751 | 6.664 | 5.809 | 5.217 |

Figs. 3 and 4 present in a graphical manner the main results from Table 3.

## 3. Discussion

The experimental results in Table 3 and Fig. 3 and 4 show a clear dependence of the efficiency and tool consumption in the cutting operation first on the mineralogical nature of the processed ornamental rock and second on the nature of the metallic binder in which the diamond cristals are embedded.

*A.* Concerning *the influence of the binder*, both Fig. 3 and Fig.4 point it to be very important. Thus if Fig.3 is analyzed one sees a decrease in time of the efficiency of the cutting process. This decrease is very abrupt at short cutting times for all processed materials and for both types of binder. At long times ($\tau > 5$ hours) the efficiency tends to stabilize itself at a level that is specific for each processed ornamental rock and for each type of metallic binder. What's remarkable in Fig.3 is a clear and distinct effect exerted by the type of binder. Indeed the sintered tools in which the diamond crystals are bonded by the BR80 binder work at a higher efficiency for all investigated rocks in comparison with the sintered tools in wich a Widia type alloy was used (A10 binder). The BR80 binder having the composition of a hypoeutectoid two-phase bronze [4] (80%Cu + 20%Sn in weight percent), erodes itself in the proper manner to keep the diamond crystals in place until they become completely blunt (as mentioned under head (a) in the Introduction of this paper) and this is in our opinion the reason for its better efficiency. This view is supported by our results reported in Fig. 4. Indeed the erosion rate estimated from the decrease in height of the cutting segment is, as a rule, larger for the binder BR80 in comparison with the binder A10. Indeed binder A10 (a Widia type alloy 90% WC + 10% Co) shows lesser efficiency for all processed rocks as illustrated in Fig.3, and lower errosion rates as illustrated in Fig.4. According to the considerations exposed under head (b) in the Introduction of this paper, this behavior may be associated with a less proper errosion rate having as a consequence the fact that the blunt diamond crystals are not properly removed out of the binder matrix.

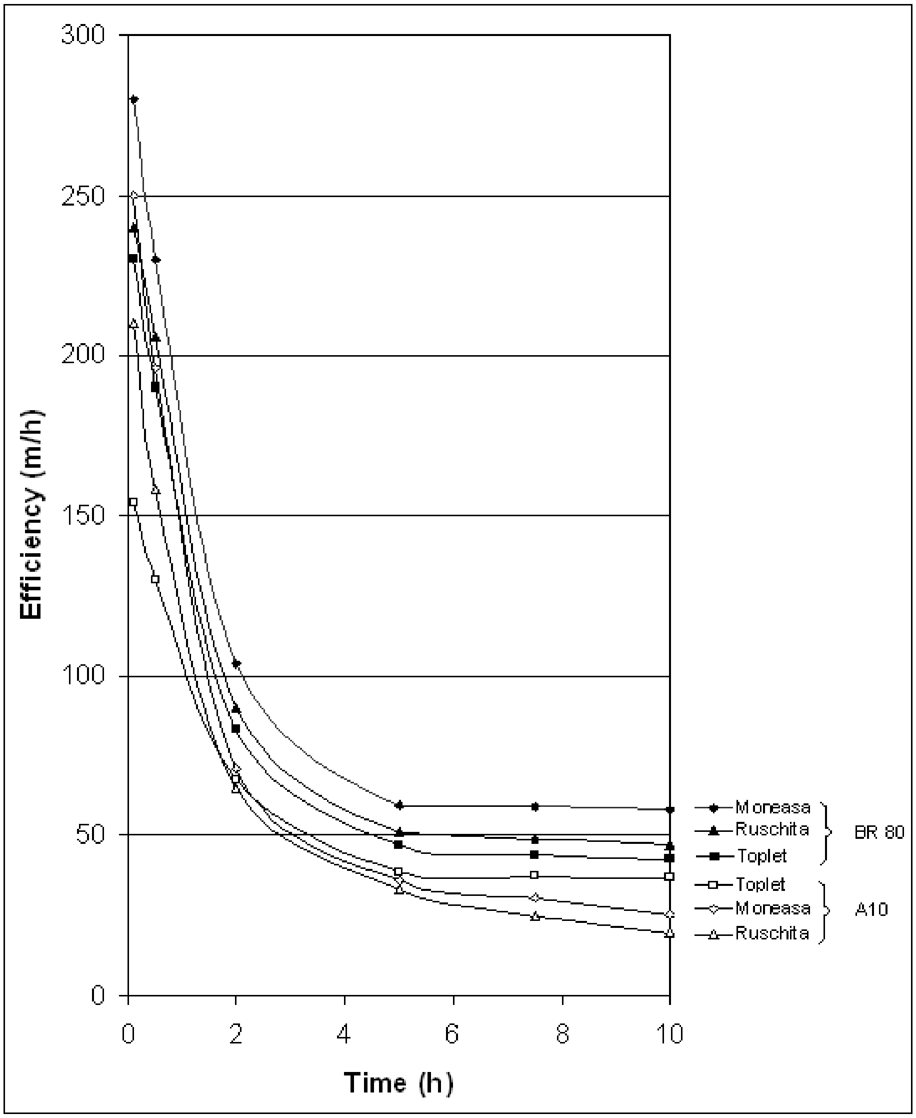

Fig. 3 Efficiency $\eta$ of the cutting operation derived from the cumulated amount $q$ of processed rock at various periods of time

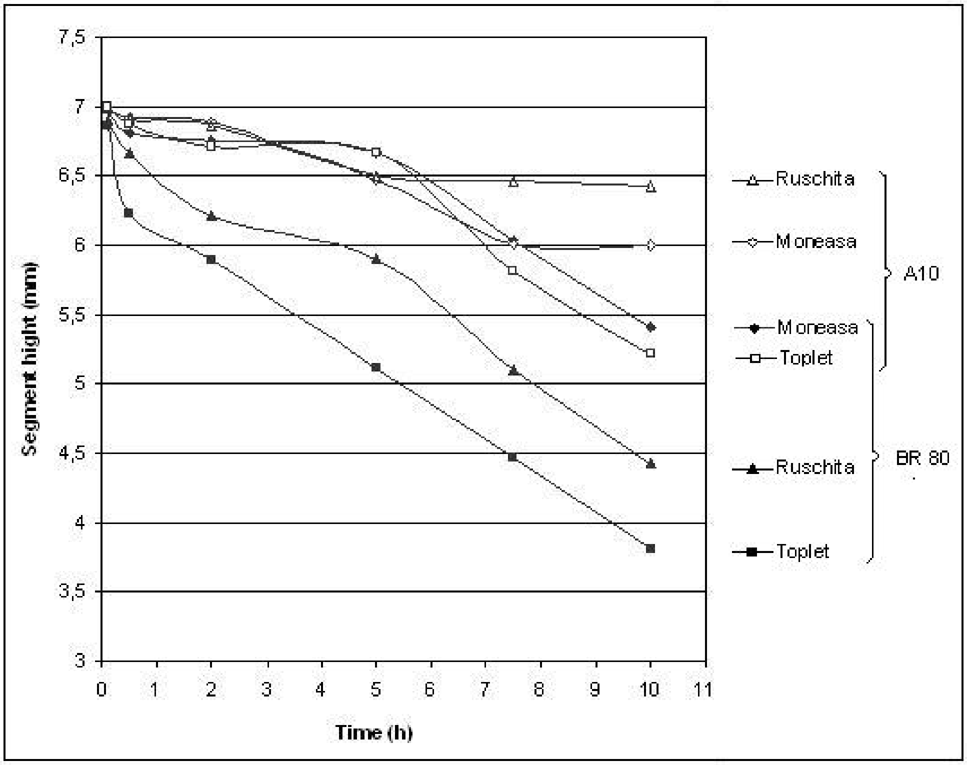

Fig. 4 Tool consumption evaluated by the height of the worn diamond reinforced cutting segment after various cutting periods (original height of the segment h = 7 mm)

*B*. Concerning *the influence of the mineralogical nature of the processed ornamental rock*, Fig. 3 points to well marked effects that have to be considered in corelation with the type of binder. Indeed from the standpoint of processing efficiency the three ornamental rocks under investigation range themeselves in two distinct groups.

In the first group related to the BR80 binder the efficiency is systematically higher and the three rocks range themselves in a sequence that agrees with the expectances: the Moneasa marble shows the higher efficiency and the Topleț granite the lowest one, the Ruşchița marble occupying an intermediate position. If the experimental values for the resistance to wear recorded in Table 2 for the three ornamental rocks are considered, the above mentioned sequence in Fig.3 appears to be the expected one. As a matter of fact the difference in behaviour between the Moneasa marble and the Ruşchița marble may be eventually ascribed to their different degree of metamorphism and texture, the Ruşchița marble being especially compact and showing a sugar-like texture [5].

In the second group in Fig. 3 related to the A10 binder, the sequence is reversed, the Topleț granite exceeding in efficience the two sorts of marble (whose sequence has not changed). A possible explanation may be given in our opinion if the mechanism in Fig. 1 is taken in consideration. Indeed as depicted in Fig. 1 small fragments of the rocks subjected to the cutting process may themselves act as an abrasive (if the rock has a high enough hardness).

*C.* A final comment is concerned with the *different shape of the time dependant curves* in Fig.3 and in Fig.4. Indeed all curves in Fig.3 related to the *efficiency of the cutting process* appear to be monotonous. In our opinion this fact points to a unique mechanism that may be explained in terms of the two parameters we have investigated in this paper, namely the type of metallic binder used in obtaining diamond abrasive sintered tools and the mineralogical nature of the processed ornamental rock. In contrast to this, the curves in Fig.4 related to the wear or decrease in height of the diamond reinforced cutting segment are not monotonous, pointing to different mechanisms put at work during different periods of the cutting process. Further investigations are required to explain such a complex behavior.

## Conclusions

1. Diamond reinforced abrasive sintered tools for processing ornamental building stones have been investigated having in view the efficiency of the cutting process as well as the tool consumption reflected in the cutting segments erosion.
2. Definite effects have been put in evidence concerning the influence of the type of binder in which the diamond crystals are embended during the sintering process.
3. The binder consisting of a two-phase tin bronze (binder type BR80) provided higher efficiency in the cutting operation both in marble processing and granite processing in comparison with a harder binder consisting of a Widia type alloy (90% WC + 10%Co).
4. The mineralogical nature of the processed ornamental building stone was shown to have a strong influence in the cutting operation, acting not as independent parameter but in corelation with the type of binder.

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