UNIVERSITY OF PITESTI
FACULTY OF MECHANICS AND TECHNOLOGY
SCIENTIFIC BULLETIN
AUTOMOTIVE series, year XIX, no.23 B

# ASPECTS REGARDING THE INFLUENCE OF PROCESSING PARAMETERS ON THE GRINDING COEFFICIENT

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*Article history:*
Received: 10.06.2013; Accepted: 20.09.2013.

***Abstract:***
*Grinding with diamond tools is one of the most used chips removing process in the processing of ceramics. The grinding working is necessary when the requirements of dimensional accuracy and of quality of the surface are not satisfied after the compacting and sintering process.*

**Keywords**: grinding, ceramics, grinding operation coefficient G, zirconium, grindability

## Introduction

The development of researches on the grinding process of some ceramic materials was made both experimentally and theoretically in recent years. These researches were dictated by the needs of industrial activity due to the apparition of some new materials used in the automotive industry, among which we find ceramic materials as well.
The criterion to assess workability based on the wear of abrasive tools represents a basic criterion. Usually, the wear of abrasive tools is studied with the help of the parameter "grinding operation coefficient G". Throughout the paper a mathematical model will be developed pointing out the influence of the cutting regime parameters on G, a mathematical model which will further be validated with the help of experimental data.

## THEORETICAL DETERMINATION OF THE ANALYTICAL EXPRESSION OF THE GRINDING OPERATION COEFFICIENT G

Usually, the grindability of a ceramic material is assessed with the help of the grinding operation coefficient G, which is defined by the ratio between the volume $V_p$ of material cut off the surface of the semi-product and volume $V_s$ of material worn off on the diamond tool.

$$G = \frac{Volume\_of\_material\_taken}{Volume\_of\_material\_worn\_off\_on\_the\_tool} = \frac{V_p}{V_s} \quad [mm^3/mm^3] \quad (1)$$

The best workability is considered for the material which has the highest G, in similar processing conditions. Obviously, for the abrasive finishing processes, this criterion has to be combined with the criterion of roughness of the processed surface.
The volume of abrasive material worn off on the tool, $V_s$, is calculated geometrically considering the value of radial wear $\Delta r_s$ recorded after the processing with formula:

$$V_s = \frac{\pi \cdot (2 \cdot D - 2 \cdot \Delta r_s) \cdot \Delta r_s}{2} \cdot B = \pi \cdot (D - \Delta r_s) \cdot \Delta r_s \cdot B \quad [mm^3] \quad (2)$$

where B and D are the width and the diameter of the diamond tools, expressed in [mm].
We will also express the volume of material processed with the help of relation:

$$V_p = \frac{M_p}{\rho_p} \quad [mm^3], \quad (3)$$

where, $M_p$ and $\rho_p$ represent the mass and density of the material removed during the grinding operation.
By combining relations (1), (2) and (3) there will result a new expression for the grinding operation coefficient G

$$G = \frac{M_p}{\rho_p \cdot \pi \cdot (D - \Delta r_s) \cdot \Delta r_s \cdot B} \quad [\text{mm}^3/\text{mm}^3] \quad (4)$$

The specific consumption of diamond q in the working process is determined by measuring the wear of the diamond disc for the processing of a certain amount of material and is defined as the gravimetric ratio between diamond consumption and quantity of material taken with the disc on which the consumption was marked [1].

$$q = \frac{mass\_of\_diamond\_worn\_off}{mass\_of\_material\_taken} = \frac{M_d}{M_p} \quad [\text{g/g}] \quad (5)$$

Knowing the concentration in diamonds of the active layer, according to [1], the mass of diamond worn off is calculated with the formula:

$$M_d = 8.8 \cdot 10^6 \cdot C \cdot V_s = 8.8 \cdot 10^6 \cdot \pi \cdot (D - \Delta r_s) \cdot \Delta r_s \cdot B \cdot C \quad [\text{g}] \quad (6)$$

where C represents the concentration of the diamond.
By combining relations (5) and (6), it will result:

$$M_p = \frac{M_d}{q} = \frac{8.8 \cdot 10^6 \cdot \pi \cdot (D - \Delta r_s) \cdot \Delta r_s \cdot B \cdot C}{q} \quad [\text{g}] \quad (7)$$

In the case of plane grinding, literature [2] offers an empirical formula for the specific consumption of diamond q, as follows:

$$q = C_q \cdot t^{x_q} \cdot v_p^{y_q} \cdot v_d^{z_q} \cdot K_q \quad (8)$$

where $C_q$ represents a coefficient which reflects the properties of abrasive grains and $K_q$ represents a coefficient which reflects the influence of the material of the piece, of the dimensions of the diamond disc, of the type of binder, of the cooling liquid, etc.
By replacing relation (8) in relation (7) it will result:

$$M_p = \frac{8.8 \cdot 10^6 \cdot \pi \cdot (D - \Delta r_s) \cdot \Delta r_s \cdot B \cdot C}{C_q \cdot t^{x_q} \cdot v_p^{y_q} \cdot v_d^{z_q} \cdot K_q} \quad (9)$$

In conclusion, the efficiency of the grinding operation G can be written as follows:

$$G = \frac{8.8 \cdot 10^6 \cdot C}{\rho_p \cdot C_q \cdot t^{x_q} \cdot v_p^{y_q} \cdot v_d^{z_q} \cdot K_q} = K \cdot t^{\alpha_G} \cdot v_p^{\beta_G} \cdot v_d^{\gamma_G} \quad (10)$$

which reflects the influence of the parameters of the grinding regime (t, $v_p$ and $v_d$) on the grinding operation coefficient G.

**METHODOLOGY FOR EXPERIMENTS**

To validate the analytical expressions determined theoretically, a series of experimental processing was performed on two types of oxidic ceramic materials. The first material studied is zirconium oxide

$ZrO_2$ and the second is an alumina-based material $Al_2O_3$. The specimens studied have the shape of rectangular plates with dimensions 80 x 80 x 10 in the case of $ZrO_2$ and 55 x 55 x 10 in the case of $Al_2O_3$.

Diamond discs of the type 1A1 175-10-3 were used for the processing. In order to obtain the grinding discs there were used synthetic diamonds with different granulations (D107 and D181), brittle environment type (DSD-M), diamonds uncovered. The concentration of diamonds used was C75. The diamonds were embedded in a metallic binder of the type Bz 335. The processing was performed with the help of a universal grinding machine of the type Tacchella Machine 6 AP.

## EXPERIMENTAL DETERMINATION OF THE VARIATION LAW OF THE GRINDING OPERATION COEFFICIENT G. ANALYSIS OF RESULTS

As the determinations of the values of radial wear of some diamond discs require a large amount of processes, therefore, a great consumption of time and ceramic material which has to be processed, the experimental plan P1 (tab. 1) which includes 6 experiments, among which two are identical, was used from economic reasons.

Table 1

| No prog | Structure | | | | No of regr. coef. |
|---|---|---|---|---|---|
| | | $X_1$ | $X_2$ | $X_3$ | |
| P1 | 1. | +1 | -1 | -1 | 4 |
| | 2. | -1 | +1 | -1 | |
| | 3. | -1 | -1 | +1 | |
| | 4. | +1 | +1 | +1 | |
| | 4. | 0 | 0 | 0 | |
| | 6. | 0 | 0 | 0 | |

The values of input parameters (coded with +1, -1 and 0) are presented in table 2

Table 2. Experimental parameters for the grinding operation coefficient G

| **$ZrO_2$ - $Y_2O_3$** | **$Al_2O_3$** |
|---|---|
| Roughing process with diamond disc 1A1 D181 M C75 | |
| $X_1 = v_d$; $X_2 = v_p$; $X_3 = t$, with natural values:<br>$v_d$ = 16 / 24.7 / 32 [m/s]<br>$v_p$ = 9 /11 / 13 [m/min]<br>t = 0.05 / 0.075 / 0.11 [mm] | $X_1 = v_d$; $X_2 = v_p$; $X_3 = t$, with natural values:<br>$v_d$ = 16 / 24.7 / 32 [m/s]<br>$v_p$ = 9 / 11 / 13 [m/min]<br>t = 0.06 / 0.085 / 0.12 [mm] |

The results obtained after the processing are presented in table 3 both in the case of zirconium oxide processing and in the case of alumina processing. The analysis of the measurement results was made from a statistical point of view with the help of the regression analysis.

Table 3

| | | | | **$ZrO_2$-$Y_2O_3$** | | **$Al_2O_3$** | |
|---|---|---|---|---|---|---|---|
| | Coded values of independent variables | | | Roughing process (D181) | | Roughing process (D181) | |
| No exp. | $X_1$ $v_d$ | $X_2$ $v_p$ | $X_3$ t | $h_{eq}$ [µm] | G [$cm^3/cm^3$] | $h_{eq}$ [µm] | G [$cm^3/cm^3$] |
| 1. | +1 | -1 | -1 | 0.234 | 1961 | 0.281 | 2314 |
| 2. | -1 | +1 | -1 | 0.677 | 1121 | 0.813 | 1570 |
| 3. | -1 | -1 | +1 | 1.031 | 820 | 1.125 | 1472 |
| 4. | +1 | +1 | +1 | 0.745 | 894 | 0.813 | 1405 |
| 5. | 0 | 0 | 0 | 0.557 | 1152 | 0.631 | 1706 |
| 6. | 0 | 0 | 0 | 0.557 | 1074 | 0.631 | 1594 |

The analysis was meant to determine a dependence relation between the dependent variable G and independent variables $v_d$, $v_p$ and t. With the help of some Excel sheets [86], there were determined the dependence functions of the form:

-polytropic functions:

$$Y = A_0 \cdot v_d^{A_1} \cdot v_p^{A_2} \cdot t^{A_3} \tag{11}$$

-power functions:

$$Y = A_0 \cdot A_1^{v_d} \cdot A_2^{v_p} \cdot A_3^{t} \tag{12}$$

The main results of the regression analysis and of the statistical analysis are presented in table 4.

Table 4. The main results of the regression analysis for G at roughing processes

| Roughing process with diamond disc **D181** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dep. var. Y : **grinding coefficient G** | | | | | | Material: **$ZrO_2$ - $Y_2O_3$** | | | | | | | |
| Progr exp. | Type of determined function | Adecv model | Coef $R^2$ | Regression coefficients / Coefficients significance | | | | Influence weights of independent variables | | | | Maximum errors | |
| | | | | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $p_1$ | $p_2$ | $p_3$ | p* | abs. | rel % |
| P1 | power | adecv | 0.990 | 2754 | 1.020 | 0.943 | 0.001 | 1.381 | 0.789 | 0.577 | 2.391 | 117.12 | 10.9 |
| | | | | S | S | S | S | | | | | | |
| | polytropic | adecv | 0.990 | 197.2 | 0.466 | -0.643 | -0.696 | 1.381 | 0.789 | 0.577 | 1.391 | 73.05 | 6.8 |
| | | | | S | S | S | S | | | | | | |
| Dep. var. Y : **grinding coefficient G** | | | | | | Material: **$Al_2O_3$** | | | | | | | |
| Progr exp. | Type of determined function | Adecv model | Coef $R^2$ | Regression coefficients / Coefficients significance | | | | Influence weights of independent variables | | | | Maximum errors | |
| | | | | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $p_1$ | $p_2$ | $p_3$ | p* | abs. | rel % |
| P1 | linear-log. | adecv | 0.988 | 370.4 | 547.2 | -989.9 | -767.3 | 8771 | -3959 | -47.2 | 925 | 99.04 | 6.21 |
| | | | | S | S | S | S | | | | | | |
| | polytropic | adecv | 0.985 | 746.5 | 0.228 | -0.512 | -0.448 | 1.221 | 0.828 | 0.733 | 1.666 | 69.70 | 4.37 |
| | | | | S | S | S | S | | | | | | |

The influence of independent factors $v_d$, $v_p$ and t, as well as the type of material used, on the dependent variable "grinding operation coefficient G" can be summarized as follows:

- considering the values of the determination coefficient $R^2$, the values of maximum absolute errors, the values of maximum relative errors, as well as the convenience of using them in practice, it is noted that in most cases of all the functions analysed the polytropic function (function 11) models the experimental data the best. This fact points out the correctness of the theoretical model established by relation (10). This is why this type of function will be maintained for all the comparisons which will be made.
- from a statistical point of view the independent variable $v_d$ is a significant independent factor for dependent variable G in all the cases analysed;

This is explained as follows:

-as a result of the increase of the peripheral speed of the disc $v_d$, the dimensions of the chips taken are smaller, which leads to a decrease of mechanical and thermic stress, therefore to a decrease of the value of the diamond disc wear;

-if the peripheral speed of the diamond disc $v_d$ is lower, the abrasive grains remain longer in contact with the processed piece, which leads to the increase of thermic stress, therefore to obtaining a higher wear of the diamond grains and a decrease of the grinding operation coefficient;

- the variation of the tangential speed of the diamond disc $v_d$ on the domain analysed (16-32 [m/s]) produces an increase of the values of the grinding coefficient of approximately 38-45% in the case of $ZrO_2$ processing and of approximately 22-27% in the case of $Al_2O_3$ processing.
- from a statistical point of view, the independent variable speed of longitudinal mass feed $v_p$ is a significant independent factor for the dependent variable G at the roughing process of both materials. The negative influence of the speed of the longitudinal mass feed is explained by its direct

proportionality to the size of the chips taken, thus, its increase leads to the increase of mechanical stress in the cutting process and therefore to the increase of wear.

- from a statistical point of view, the independent variable t is a significant independent factor for the dependent variable G for both materials. The increase of the value of the cutting depth t leads to the decrease of the values of the grinding coefficient G. This dependence appears at both materials analysed.
- the influence of the multiple ($v_d$, $v_p$, t) leads to increases of the value of G with 122-139% in the case of zirconium oxide processing and with 66-67% in the case of alumina processing when passing from multiple ($v_{d\_max}$, $v_{p\_min}$, $t_{min}$) to multiple ($v_{d\_min}$, $v_{p\_max}$, $t_{max}$), on all variation domains considered;
- in order to point out the influence (from a quantitative point of view as well) of the type of material processed on parameter G, there were compared the extreme values of parameter G at the variation of independent values on the domains studied (the polytropic functions determined were used for the analysis (10)):

$$\frac{D_{D181\_ZrO_2}}{D_{181\_Al_2O_3}} = 0.265 \cdot v_d^{0.238} \cdot v_p^{-0.131} \cdot t^{-0.248} = 0.63 \ldots 0.91 \qquad (12)$$

## CONCLUSIONS

After the mathematical modelling and the experimental researches performed to validate the theoretical model the following conclusions can be drawn:

- The use of diamond discs to process ceramic materials provides, on the one hand, good productivity of the grinding process and, on the other hand, high sustainability of the tools, in general. The use of diamond discs with metallic binder to grind ceramic materials allows reaching high grinding efficiency.
- The polytropic functions proved to be adequate from a statistical point of view.
- The independent variables taken into account have different influences.
- As for the type of material, it was noted that dependent variables are in order $G_{ZrO_2} < G_{Al_2O_3}$, meaning they are in a reverse order relationship with the hardness and wear resistance (abrasion) of the two materials.

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