ASPECTS REGARDING THE INFLUENCE OF PROCESSING PARAMETERS ON THE GRINDING COEFFICIENT

Alin Rizea¹

¹University of Pitesti, Romania,

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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.

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

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 Δr_s recorded after the processing with formula:

$$V_{s} = \frac{\pi \cdot (2 \cdot D - 2 \cdot \Delta r_{s}) \cdot \Delta r_{s}}{2} \cdot B = \pi \cdot (D - \Delta r_{s}) \cdot \Delta r_{s} \cdot B \quad [mm^{3}]$$
(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:

$$V_p = \frac{M_p}{\rho_p} \qquad \text{[mm^3]},\tag{3}$$



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where, M_{p} and ρ_{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

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

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].

$$q = \frac{mass_of_diamond_worn_off}{mass_of_material_taken} = \frac{M_d}{M_p} \qquad [g/g] \qquad (5)$$

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

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

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

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

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

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

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:

$$M_{p} = \frac{8.8 \cdot 10^{6} \cdot \pi \cdot (D - \Delta r_{s}) \cdot \Delta r_{s} \cdot B \cdot C}{C_{q} \cdot t^{x_{q}} \cdot v_{p}^{y_{q}} \cdot v_{d}^{z_{q}} \cdot K_{q}}$$
(9)

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

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





Table 2

 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		Strue	No of regr.		
prog		X_1	coef.		
P1	1.	+1	-1	-1	
	2.	-1	+1	-1	
	3.	-1	-1	+1	4
	4.	+1	+1	+1	4
	4.	0	0	0	
	6.	0	0	0	

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

Tuble 2. Experimental parameters for the grinning operation coefficient of
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$ZrO_2 - Y_2O_3$	Al_2O_3				
Roughing process with dian	nond disc 1A1 D181 M C75				
$X_1 = v_d$; $X_2 = v_p$; $X_3 = t$, with natural values:	$X_1 = v_d$; $X_2 = v_p$; $X_3 = t$, with natural values:				
$v_d = 16 / 24.7 / 32 [m/s]$	$v_d = 16 / 24.7 / 32 [m/s]$				
v _p = 9 /11 / 13 [m/min]	$v_p = 9 / 11 / 13 [m/min]$				
t = 0.05 / 0.075 / 0.11 [mm]	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.

				ZrO ₂ -	$-Y_2O_3$	Al ₂ O ₃				
	Coded va	alues of ind	ependent	Roughing	g process	Roughing process				
	variables			(D1	.81)	(D181)				
No	X_1	X2	X3	h _{eq}	G	h _{eq}	G			
exp.	Vd	Vp	t	[µm]	[cm ³ /cm ³]	[µm]	[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:

$$Y = A_0 \cdot A_1^{\nu_d} \cdot A_2^{\nu_p} \cdot A_3^t \tag{12}$$

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

Roughing process with diamond disc D181													
Dep. var. Y : grinding coefficient G							Material: ZrO ₂ - Y ₂ O ₃						
				Regression coefficient			nts /	Influence weights of				Maximum	
Progr	Type of	Adecv	Coef	Coe	efficients	significa	gnificance		independent variables			errors	
exp.	determined	model	R ²	A ₀	A ₁	A ₂	A3	\mathbf{p}_1	p ₂	p ₃	p*	abs.	rel %
	Tunction												
	power	adecv	0.990	2754	1.020	0.943	0.001	1.381	0.789	0.577	2.391	117.1	10.9
												2	
P1				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 ₂ O ₃						
	Regression coe			coefficie	efficients / Influence weights of Max					mum			
Progr	Type of	Adecv	Coef	Coefficients sign			ficance independent variables			errors			
exp.	determined	model	R ²	A ₀	A ₁	A ₂	A3	p 1	p2	p 3	p*	abs.	rel %
^	function							•			•		
	linear-log.	adecv	0.988	370.4	547.2	-989.9	-767.3	8771	-3959	-47.2	925	99.04	6.21
P1	_			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						

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

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 ZrO₂ processing and of approximately 22-27% in the case of Al₂O₃ 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)):

$$\frac{D_{D181_ZrO_2}}{D_{181_Al_2O_3}} = 0.265 \cdot v_d^{0.238} \cdot v_p^{-0.131} \cdot t^{-0.248} = 0.63 \dots 0.91$$
(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 $G_{ZrO_2} < G_{Al_2O_2}$

, meaning they are in a reverse order relationship with the hardness and wear resistance (abrasion) of the two materials.

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