Elaboration and Optimization of Pellets Used for Precise Glass Grinding

N. Belkhir, A. Chorfa, and D. Bouzid

***Abstract*—**In this work, grinding or microcutting tools in the form of pellets were manufactured using a bounded alumina abrasive grains. The bound used is a vitreous material containing quartz feldspars, kaolinite and a quantity of hematite. The pellets were used in glass grinding process to replace the free abrasive grains lapping process.

The study of the elaborated pellets were done to define their effectiveness in the grinding process and to optimize the influence of the pellets elaboration parameters.

The obtained results show the existence of an optimal combination of the pellets elaboration parameters for each glass grinding phase (coarse to fine grinding). The final roughness (rms) reached by the elaborated pellets on a BK7 glass surface was about 0.392 µm.

***Keywords*—**Abrasive grain, glass, grinding, pellet.

I. Introduction

CONVENTIONAL lapping technology was performed by loose abrasive lapping (slurry lapping). The significant loss of time and grains has contributed to the use of the bonded abrasive in several applications [1]-[3], this process is commonly called fixed abrasive grains grinding or pellets grinding. In this process, the abrasive grains (typically alumina or diamond) are incorporated into small pellets using metal, vitreous, or resin as bond. During the grinding operation the pellets are fixed on cast iron machine platens.

The ground surface during pellets grinding is formed by the top surfaces of all the pellets. In most cases, the difference between the pellets used in grinding process is the abrasive grains nature (alumina, diamond, silicon carbide…), the cost and the manufacturing simplicity. The nature of abrasive grains used in elaboration of pellets depends on their use. Indeed, alumina pellets are efficiency in the glass lapping and diamond is better in the metals and ceramics finishing [2].

The grinding process is necessary to eliminate the form deviations and the surface roughness of the surface to be prepared for polishing.

Material removal by abrasion in brittle materials is still not fully understood. The interactions of process parameters complicate the comprehension of grinding. Some authors [4]-[7] explain that during the grinding operation, the biggest asperities on the surface are eliminated by brittle fracturing causing microcracks with contribution of the glass hydrolysis.

Demirci [8] in his study on the influence of the grinding process parameters, has indicate that three different damage regimes are observed: the first one is the partial ductile with cutting action accompanied by chip formation, the second is the crushing or fragmentation regime and the third one is the partial ductile by plowing action with the displaced material.

The bond plays a very important role, as it is responsible of retaining the rigid inclusions against pull out mechanisms. The different binders are used in order to meet certain requirements as the surface roughness or the form accuracy. However, the satisfaction of these requirements can generate disadvantages. Indeed, the resins are employed for obtaining surface with lower roughness however it presents a very fast wear of the pellets [9]-[12].

Several other parameters of the pellets are very important for the understanding of the grinding process such as the density, repartition and shape of grains, nature and grains wear. The surface quality of ground glass is correlated with wear of abrasive grains [13] and obtained roughness is linked with wear of abrasive grains [14].

It has been shows that the effectiveness of the pellets grinding process is particularly influenced by several manufacturing parameters as the compacting pressure, firing temperature and its duration, the binding material kind and the abrasive grains content [15],[16].

In our study and for practical application of the grinding process, the grinding performance of the pellets and optimization of their composition was investigated.

II. Experimental Procedure

A. Pellets Elaboration

The elaboration of the pellets was done using a-alumina abrasive grains type (ABRALOX, Quality E, Supplier Pieplow & Brandt GmbH) and a vitreous bond. Two grain sizes of the commonly used sizes in the glass grinding operations were chosen. These are the grains sizes about 80 µm for the coarse grinding and 28 µm for the fine grinding. The chemical composition and the characteristics of the used abrasive grains are illustrated in Table I and their morphology is shown in Fig. 1. The chemical composition of the binding material and its characteristics are presented in Table II.

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TABLE I
CHEMICAL COMPOSITION AND CHARACTERISTICS OF ALUMINA ABRASIVE GRAINS

Elements	%	Characteristics		
Al2O3	95.96			
TiO_2	2.5	Pellets	P80	P28
SiO_2	0.85	Grinding stage	Coarse	fine
ZrO_3	0.21	Mean diameter grain(µm)	80	28
		Specific Surface (m²/g)	0.361	1.119
Fe_2O_3	0.20			
MgO+CaO	0.27	Density (g/cm3)	3.93	
Na_2O	0.01			

TABLE II
CHEMICAL COMPOSITION AND CHARACTERISTICS OF THE BOND

Chemical composition		characteristics	
Elements	%		
SiO_2	61.52	Mean diameter (µm)	0.1
Al_2O_3	23.51		
Na_2O	6.59	Specific surface (m²/g)	5.448
Fe_2O_3	3.80		
K_2O	2.40	Fusion temperature (°C)	1200
CaO	2.18		

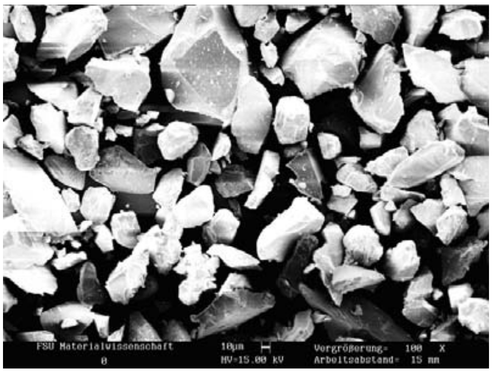

Fig. 1 SEM micrographic of the used alumina abrasive grains (∅80µm)

The elaboration of the pellets was made in several steps. The first step was the mixture of the abrasive grains and the binding material powders. The second one was the mixture forming which was done by hydraulic press in a closed die using uniaxial compression. Then the product was sintered.

The choice of the elaboration parameters was done on the basic of preliminary experiences. The obtained pellets were visualized by SEM and LSM (Laser Scanning Microscope) and their porosity was measured by porosimeter. The elaboration parameters and the measured porosity are summarized in Table III.

TABLE III
ELABORATION PARAMETERS AND POROSITY OF THE ELABORATED PELLET

Pellet	Compression presser (Mpa)	Firing temperature (°C)	Firing duration (H)	Porosity (%)	Diameter (mm)
P80	157 - 314	1200	2	23	10
P28	157 - 314			16.16	

B. Grinding Process

The elaborated pellets were used in grinding process (see Fig. 2) on a grinding machine using the parameters summarized in Table IV. During grinding 9 pellets were fixed on the lap to form the grinding tool. The glass samples of BK7 Schott were ground.

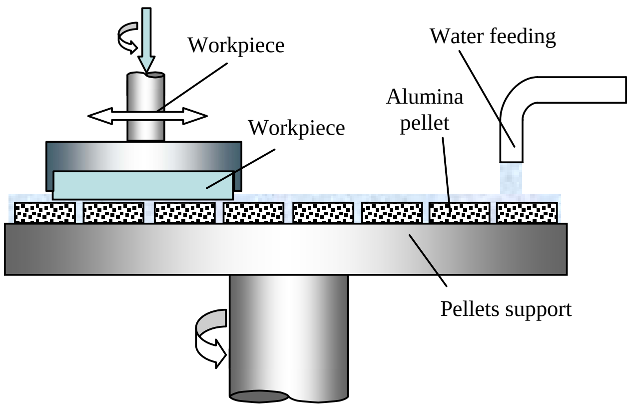

Fig. 2 Principle of glass pellets lapping

TABLE IV
GRINDING PARAMETERS

Grinding parameters	
Tool rotation speed	132 rpm
Sample rotation speed	450 rpm
Oscillation amplitude	10 mm
Water Feeding	500 ml/mn
Additional grinding charge (N)	Without additional charge

C. Characterization

During the grinding process, the quality and the efficiency were characterized. The glass surface quality described by the quadratic roughness (rms) was measured using the mechanical profilometer Form Talysurf (Taylor-Hobson). However, the sample weight loss was measured by precision balance to evaluate the efficiency. In addition, the pellets wear was characterized by the thickness loss which was measured by optical microscopy.

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D.Empirical Modeling

The obtained results were used to define empirical models describing the relation between the pellets manufacturing parameters and the grinding efficiency. In addition, the pellets manufacturing and the process parameters were optimized. The empirical models were obtained by a numerical approximation using NEWTON and LAGRANGE polynomial forms. The approximation coefficients were calculated using established software.

The first empirical models describe the variation of the roughness (rms) and the pellets wear according to the grinding time (t_l). The obtained empirical numerical models are given by equation 1 and 2.

$$\Delta h = A_0 + \sum_{i=1}^{n} A_i t_l^{\,n} \quad \text{(i=n)} \qquad (1)$$

$$rms = B_0 + \sum_{i=1}^{n} B_i t_l^{\,n} \quad \text{(i=n)} \qquad (2)$$

where: *Δh*: Pellets wear (thickness decrease for grinding time)

rms: Quadratic roughness of the sample surface.

t_l : Grinding time

(*A0,…A6*) and (*B0,…B6*): Approximation coefficient which values are given in Table V.

The second empirical models describe the variation of the pellets wear and the roughness (rms) versus the compacting pressure and the firing duration together. The empirical models are given by equation 3 and 4 respectively.

TABLE V
VALUES OF THE COEFFICIENTS FOR THE DIFFERENT GRINDING PHASES

Coef.	Coarse grinding	Fine grinding	Coef.	Coarse grinding	Fine grinding
	Δh			rms	
A0	-	-	B0	4.475	1.265
A1	0.55	-	B1	-2.12	0.277
A2	-0.151	0.035	B2	4.702	-1.02
A3	0.020	0.003	B3	-3.82	0.638
A4	-0.001	-	B4	1.39	-0.164
A5	-	-	B5	-0.232	0.019
A6	-	-	B6	0.014	-

$$\Delta h = C_0 + C_1P_c + C_2t_f + C_3P_ct_f + C_4P_c^2t_f + C_5Pctf^2 + C_6P_c^2t_f^2 + C_7P_c^2 + C_8t_f^2 \qquad (3)$$

$$rms = D_0 + D_1P_c + D_2t_f + D_3P_ct_f + D_4P_c^2t_f + D_5Pctf^2 + D_6P_c^2t_f^2 + D_7P_c^2 + D_8t_f^2 \qquad (4)$$

where: Δh: Pellets wear (thickness decrease for grinding time)

rms: Quadratic roughness of the optical surface.

Pc : Compacting pressure

tf: Firing duration

(C0,…C8) and (D0,…D8): Approximation coefficients which values are given by Table VI.

TABLE VI
VALUES OF THE COEFFICIENTS FOR THE DIFFERENT GRINDING PHASES

Coef.	Coarse grinding	Fine grinding	Coef.	Coarse grinding	Fine grinding
	Δh			rms	
C0	13.156	1.561	D0	-3.603	4.607
C1	6.131	-0.383	D1	0.023	-1.122
C2	-0.119	-5.2×10^{-3}	D2	0.076	-0.014
C3	-0.029	1.42×10^{-3}	D3	-0.035	4.33×10^{-3}
C4	0.022	-	D4	0.00423	-
C5	-2.2×10^{-5}	-	D5	1.24×10^{-4}	-
C6	-2.7×10^{-5}	-	D6	-2.2×10^{-5}	-
C7	-3.341	-	D7	0.590	-
C8	3.13×10^{-4}	-	D8	-1.9×10^{-4}	-

III. RESULTS AND DISCUSSION

A. Pellets Quality

The micrographics of the elaborated pellets obtained by SEM and LSM are shown in Fig. 3 and 4 respectively. The micrographics show that the abrasive grains have not undergoes a big change in their morphology after the elaboration process, where the abrasive grains have always sharp edges (see Fig. 3). On the other hand, the distribution of the abrasive grains and the bound is homogenous in the pellet, which permits the contribution of the entire pellet in the material removal during the grinding process. The porosity is also distinguished on the pellets (see Fig. 4) and consequently the grains detachment will be possible during their use in the grinding process. Nevertheless, measured porosity (see Table III) indicates that the pellets elaborated with the finer grains have a lower porosity, which can influence the wear of the pellets according to the grains size. In all cases, the elaborated pellets appear of good quality which allows their use as tools in the precision grinding of the glass.

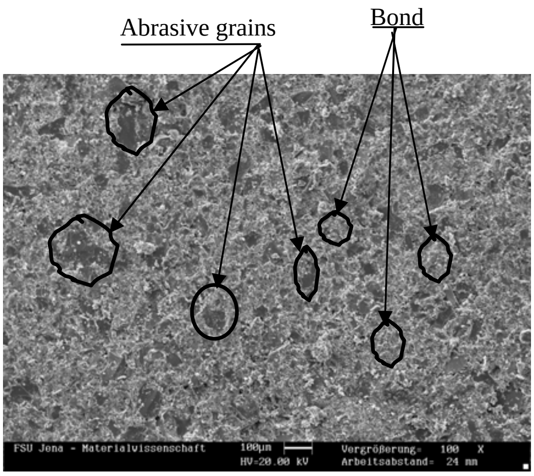

Fig. 3 (a) SEM micrograph of the bounded abrasive grains distribution on the pellet surface (P80) after forming

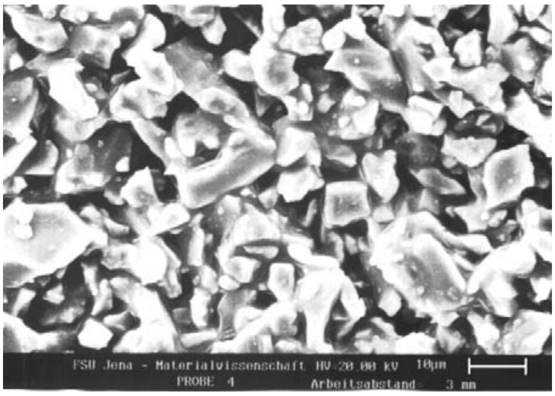

Fig. 3 (b) SEM micrograph of the abrasive grains morphology after sintering of the pellet P80

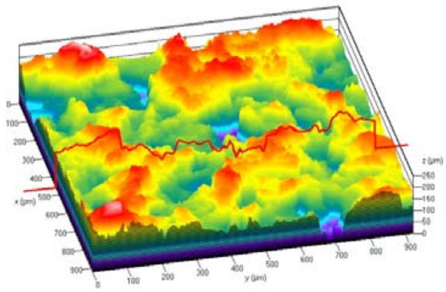

Fig. 4 (a) LSM micrographic of the porosity distributuion in the pellet (P80)

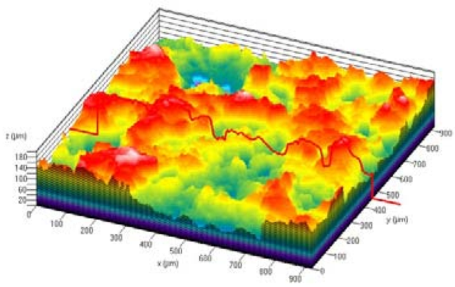

Fig.4 (b) LSM micrographic of the distrubution of the bounded abrasive grains in the elborated pellet (P80)

B. Effect of the Pellets Elaboration Parameters on the Surface Quality

Fig. 5 shows the roughness (rms) variation over grinding time. The results obtained of the two types of used pellets indicate that the roughness decreases proportionally to the grinding time. A minimum of roughness called the optimal roughness is reached in a time considered as the optimal grinding time. After this time the roughness increases. The roughness evolution can be explained by the fact that the abrasive grains of the pellet remove the macro defects of the glass surface in the first time of lapping. When the optimal time is reached, then the abrasive grains reach their limit of macro defects removal and this coincides with the optimal roughness. After this time the grains scratches the surface and cause its degradation.

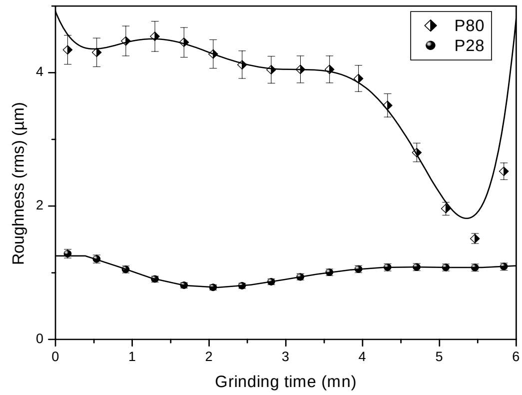

Fig. 5 Variation of the roughness (rms) vs. the grinding time

Fig. 6 shows the evolution of the pellets wear versus the grinding time. It is to be noticed that the wear variation is nearly linear. Also, the wear of the pellets P80 is more important than the pellets P28. Indeed, during grinding by the P80 pellets where the abrasive grains size is bigger their detachment causes an important wear in the pellet. Nevertheless, the higher wear of the pellets can be beneficial for the material removal rate which will be more important according to the abrasive grains detachment from the pellets.

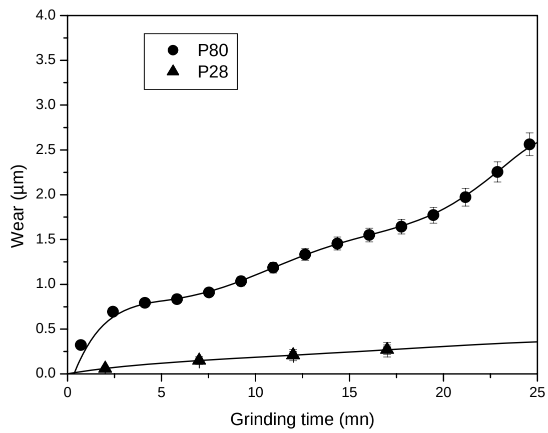

Fig. 6 Variation of the pellets wear vs. the grinding time

The results of the compaction pressure and the firing duration effect on the roughness and the pellets wear are shown in Fig. 7 and 8 respectively.

The results in Fig. 7 showed the influence of the compaction pressure and the firing duration on the sample surface quality. The results illustrate that the best results of optimal roughness are obtained by the pellets elaborated at low compaction pressure and an average firing duration. Indeed, the higher compaction pressure can produce the fracture of the grains which can change the abrasive grains size and makes them inadequate for their grinding phase and then can influence the produced surfaces quality. On the others hand, the longest and the shortest duration of firing produces a harder or softer bonding of the grains in the pellets and the grains detachment can be variable and consequently influence the grinding process and the surface roughness.

Fig. 8 shows that the pellets having the weakest wear are those elaborated by medium compaction pressure and Firing duration. Effectively, pellets elaborated in medium parameters (compacting pressure and firing temperature and duration) will have a slow detachment of the grains.

The grains detachment influences the wear rate and consequently the pellets lifetime can be longer than pellets realized in others parameters combinations.

According to the previous results it was noticed that during pellets grinding process, the difficulty was the choice of the elaboration parameter combinations. Indeed, it was found that the best surface quality can be obtained by pellets elaborated in low compacting pressure and medium Firing duration, at the same time the pellets with higher lifetime are those elaborated in medium compacting pressure and Firing duration.

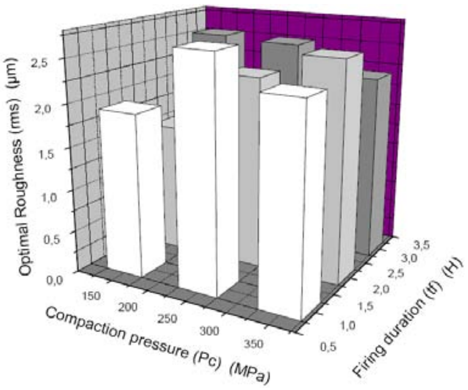

Fig.7 Effect of compaction pressure and Firing duration on the roughness during grinding by P80 pellets

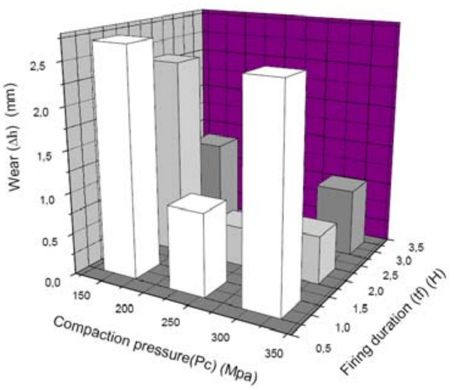

Fig. 8 Effect of compaction pressure and Firing duration on the pellets wear during grinding by P80 pellets

C. Optimization of the Roughness and the Grinding Time

Using the found empirical models (Eq. 1- 4), the optimal roughness and grinding time are computed and compared to those obtained experimentally; results are shown in Fig. 9 and 10. It is found that the calculated optimal roughness is lower than the measured one which can be due to the measuring errors. The calculated optimal time is also different of the measured, which can be related to the difficulty of the measurement of seconds during the grinding process which is easier by calculation.

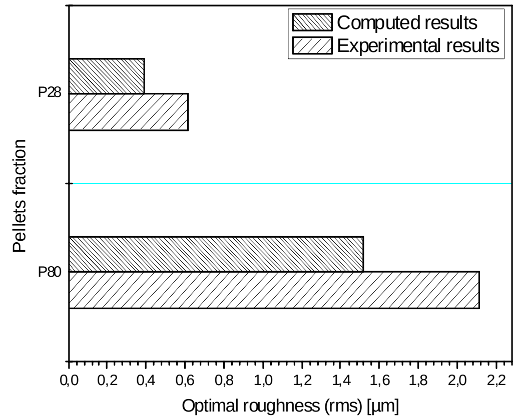

Fig. 9 Optimal values of roughness (rms) in two grinding phases

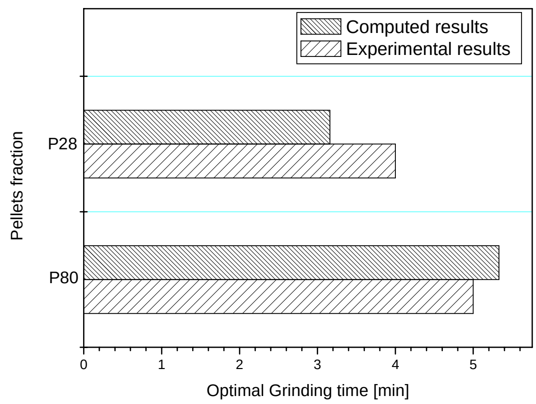

Fig. 10 Optimal values of grinding time (tl) in two grinding phase

IV. Conclusion

In this study pellets tools were elaborated using different parameters, and optimized. The elaborated alumina pellets tools can be easily used for the glass grinding process to prepare surfaces for polishing. The most important elaboration parameters of the pellets are the compaction pressure. It permits the densification of the pellets and consequently the influence on the grains detachment during their use. The firing temperature and its duration are also important elaboration parameters. Their choice is closely related to the conservation of the initial size and morphology of the abrasive grains.

The optimization of the elaboration parameters of the pellets can be possible by a number of pellets manufacturing tests. This remains however, insufficient to obtain a tool with optimal efficiency. It is in fact; difficult to simultaneously take into account all of the manufacturing parameters.

The grains sizes, the compaction pressure and the firing duration have an influence on the quality of the ground surface and the pellets wear. The optimization of the pellets elaboration parameters can contribute to the determination of their lifetime and effectiveness. These parameters are interdependent.

The found empirical models have permit to establish a relationship between the pellets manufacturing parameters and their wear and the effectiveness of the grinding process.

Optimal value of the roughness and the grinding time can be calculated for any combination of pellets manufacturing parameters during grinding process.

It was concluded that during pellets lapping process of glass, the difficulty is to define the adequate combination of pellets to obtain best efficiency of the process and higher lifetime of the pellets.

It can be deduced that optimal pellets manufacturing parameters are medium compacting pressure and firing duration.

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