USE OF THE PIN-ON-DISK WEAR METHOD FOR THE CHARACTERISATION OF THE RESISTANCE TO DEEP ABRASION OF CERAMIC MATERIALS

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1. INTRODUCTION AND OBJECTIVE OF THE WORK

The wear of materials of a ceramic nature is a key property to be taken into account when it comes to determining their resistance in service.

The main objective of the present study consists of the implementation of the wear technique with a pin-on-disk tribometer for the tribological characterisation of materials of a ceramic nature, and of its subsequent correlation with microstructure, mechanical properties, and surface roughness.

2. MATERIALS AND TEST METHODS

A selection was performed of ceramic materials of different chemical and microstructural nature, which are liable to abrasion processes: ceramic glazes (transparent glazes: **T1** and **T2**; matt glazes: **M1** and **M2**; and opaque glazes: **O1** and **O2**), traditional ceramic material (porcelain tile: **P1-P4** and extruded stoneware: **E1**); and advanced ceramics ($\mathbf{Al_2O_3}$ and $\mathbf{Si_3N_4}$). In addition, different glasses were selected (soda-lime glass: **V1**; and boron-calcium glass: **V2**) for comparative purposes, since these are homogeneous glassy materials.

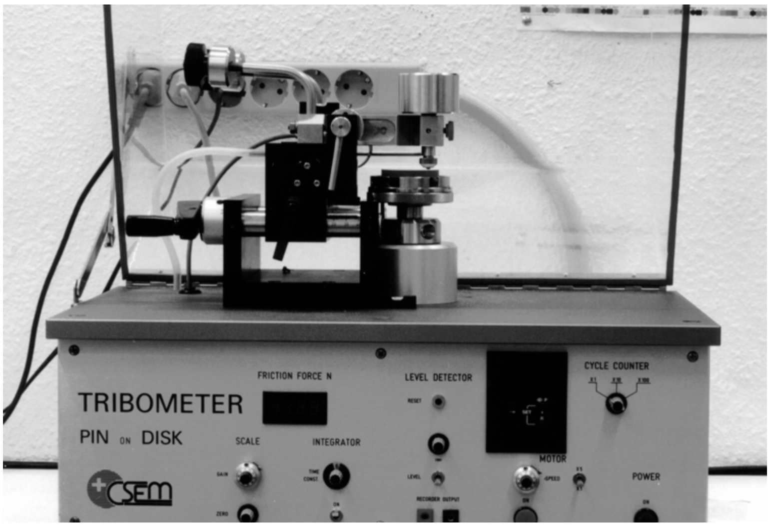


Figure 1. Pin-on-disk tribometer.

With a view to characterising each of the samples tribologically, wear resistance was evaluated with a CSEM pin-on-disk tribometer. With regard to their mechanical features, the surface toughness and brittleness index of the studied materials were calculated using a Micromaterials Nanotest nano-indenter. The crystalline phases were analysed in a BRUKER Theta-Theta model D8 Advance diffractometer.

3. RESULTS AND DISCUSSION

Figure 2 presents, comparatively, representative graphs of the evolution of wear in each tested material as a function of the number of revolutions across its surface. It may be observed that the sample that displays the lowest wear resistance is the extruded stoneware, since it is really the performance of the body that is being analysed, owing to the thinness of the glaze layer produced during the firing process. This material exhibits significantly lower mechanical and tribological properties than the ceramic glazes. On the other hand, the advanced ceramics undergo a lower degree of wear owing to their finer grain size and practically zero porosity. The glasses, ceramic glazes, and porcelain tile display intermediate wear resistances between the previous two products. In these types of products, opaque glazes and porcelain tile have lower specific wear rates. This is because of the presence of small-sized crystalline phases that are homogenously distributed throughout the matrix in the case of the opaque materials, and of the high hardness of the embedded crystalline phases in the case of porcelain tiles.

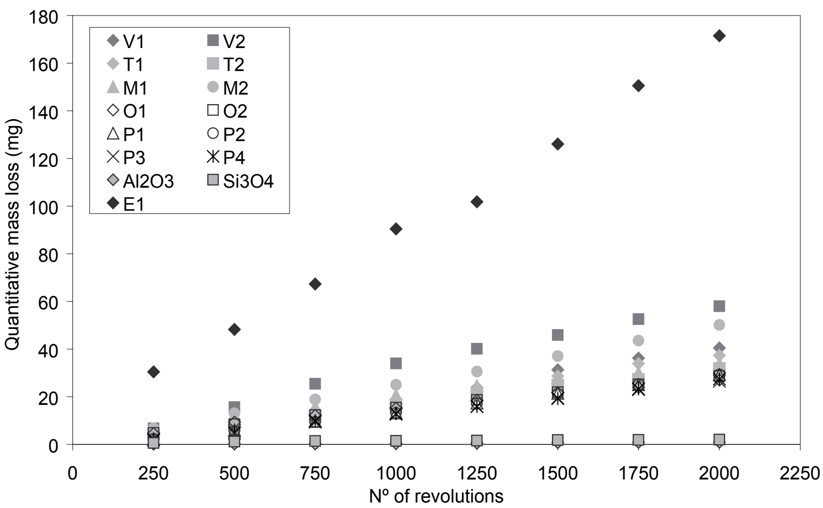


Figure 2. Representative graph of the wear resistance of the tested materials.

Among the glasses, the soda-lime glass displays better resistance than the boron-sodium glass because the tempering treatment that the latter has undergone favours cohesive failure of the material, more readily generating circular cracks and spalling.

Table 3 presents a summary of the test data, with the toughness values, brittleness index, roughness, glassy phase percentage, specific wear rate, and ordinate at the origin of the straight lines of the variation of wear resistance obtained from figure 2.

Sample	K_{IC} ($MPa \cdot m^{1/2}$)	B ($(m^2) \cdot 10^3$)	R_a (μm)	Glassy phase percentage (%)	V_e (μg/N·m)	OO (μg)
V1	**0.58** ± 0.02	**12** ± 1	**0.01** ± 0.01	100	**21.2** ± 0.1	-1.25
V2	**1.00** ± 0.02	**7** ± 1	**0.01** ± 0.01	100	**24.8** ± 0.2	11.2
T1	**0.74** ± 0.09	**10** ± 1	**0.03** ± 0.01	100	**19.6** ± 0.8	-1.66
T2	**0.98** ± 0.01	**9** ± 1	**0.04** ± 0.02	97	**17.4** ± 0.3	0.28
M1	**1.1** ± 0.1	**9** ± 1	**0.9** ± 0.1	72	**17.4** ± 0.3	0.49
M2	**0.7** ± 0.1	**10** ± 1	**1.2** ± 0.1	65	**26.1** ± 0.4	0.44
O1	**1.12** ± 0.09	**7** ± 1	**0.04** ± 0.01	72	**14.2** ± 0.8	2.5
O2	**1.3** ± 0.1	**7** ± 1	**0.04** ± 0.01	73	**14.3** ± 0.1	1.75
P1	**1.3** ± 0.2	**6** ± 1	**0.2** ± 0.1	62	**15.7** ± 0.1	-1.77
P2	**1.1** ± 0.1	**7** ± 1	**2.0** ± 0.1	59	**17.4** ± 0.7	-2.05
P3	**1.3** ± 0.1	**7** ± 1	**1.3** ± 0.1	79	**14.5** ± 0.3	-1.09
P4	**1.3** ± 0.1	**8** ± 2	**2.9** ± 0.5	74	**15.6** ± 0.7	-2.53
Al_2O_3	**3.3** ± 0.3	**6** ± 1	**0.47** ± 0.06	<1	**0.11** ± 0.01	0.01
Si_3N_4	**2.8** ± 0.3	**4** ± 1	**4.5** ± 0.6	<1	**0.42** ± 0.05	-0.046
E1	**0.32** ± 0.08	**16** ± 2	**5.4** ± 0.9	44	**90.2** ± 0.9	-2.79

Table 1. Average values and typical deviations in the mechanical characterisation of the tested materials.

The results obtained show that, as toughness increases and the brittleness index of the material decreases, the specific wear rate decreases. With relation to the quantity of glassy phase present, it may be inferred that, in these materials, an increase in the quantity of glassy phase in the material entails a lower wear resistance, the presence of crystals in the glass having a positive effect on this phenomenon, though bulk crystallisations in some matt glazes lead to adverse effects. Roughness does not noticeably affect the overall wear resistance of the material, though it causes greater mass loss in the initial phases of the test.

The micrographs of different abraded areas enabled various wear mechanisms to be observed. The classification below (figure 3) was established, based on the nature of the wear: a micrograph of the abraded surface is shown, and the type of mechanism, materials that display this, and characteristics of the arising wear track are described.

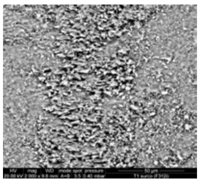
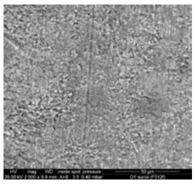
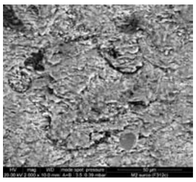
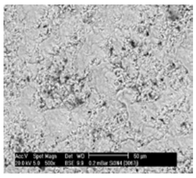
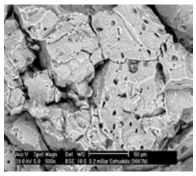
Micrograph					
Type	**Type I**	**Type II**	**Type III**	**Type IV**	**Type V**
Materials	Glasses and transparent glazes	Opaque glazes	Matt glazes and porcelain tile	Advanced ceramics (Al_2O_3 and Si_3N_4)	Extruded stoneware
Fracture pattern	Brittle fracture, appearance of sharp edges	Homogeneous wear, without cohesive failure	Laminar spalling	Spalling of little importance	Severe cohesive failure

Figure 3. Classification of wear mechanism.

4. CONCLUSIONS

The determination of the resistance to deep abrasion by means of a pin-on-disk tribometer was established as an appropriate technique for distinguishing between the behaviour of ceramic materials of different nature. The ceramic glazes on the extruded material displayed greater wear resistance than the underlying ceramic bodies. However, the tested advanced ceramics displayed a lower specific wear rate than the other tested samples, owing to their more ordered microstructure and high density.

In the ceramic glazes, there was a strong correlation of the microstructure and mechanical properties of the material with its specific wear rate. The greater the glassy phase content present in the matrix, the higher was the material's specific wear rate. This is because the crystalline phase content increases the toughness and hardness of the material, enhancing its wear resistance.

A certain influence was also observed of the surface roughness of the samples with the initially abraded volume percentage, calculated from the ordinate at the origin of the wear straight line.

Different wear mechanisms were observed, which depended on the microstructure and composition of the test materials: brittle fracture occurred in glassy materials; important cohesive failures occurred when the crystalline phases were large in size; and small spalling occurred in advanced ceramics.

ACKNOWLEDGEMENTS

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REFERENCES

[1] ASTM G99-05: Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus.

[2] Guía de la baldosa cerámica. 5th ed. Valencia: Instituto Valenciano de la edificación, 2006.