

THERMAL HYSTERESIS OF THE MODULUS OF ELASTICITY IN GLASSY MATRIXES WITH QUARTZ

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1. INTRODUCTION

The study and knowledge of the mechanical properties of ceramic materials are necessary for the optimisation of the formulation and processing of these products in both advanced and traditional ceramics.

The modulus of elasticity is a material property that does not only depend on the composition¹, but also varies with temperature² and the presence of microstructural defects (microcracks³ and porosity⁴). In certain cases, therefore, monitoring the modulus of elasticity with temperature can provide information on microcracks in the pieces. In porcelain tile compositions, cracks originate as a result of the difference between the coefficient of thermal expansion (CTE) of the glassy matrix and that of the quartz particles⁵.

2. EXPERIMENTAL

Test pieces were prepared from sodium feldspar powder (*Mario Pilato*). The powder was milled for 30 minutes in water, dried, and then moistened to 8% with an aqueous solution of 5% PVA. This was then pressed at 350 kgf/cm².

Four compositions were prepared, adding 18.5% by volume of quartz particles. The average size, D_{50} , of the quartzes used is detailed in Table 1. The test pieces were sintered in a *Pirometrol* furnace at a heating rate of 210 °C/min to 500 °C, followed by a rise in temperature to 1205 °C at a rate of 25 °C/min, and a dwell at peak temperature of 6 min. Cooling took place inside the furnace.

Quartz (Sibelco)	Average particle size D_{50} (μm)
SE-500	3.4 ± 0.5
SE-100	13.4 ± 0.6
SE-12	20.4 ± 1.1
SE-8	31 ± 4

Table 1. Average quartz particle size.

To determine the modulus of elasticity up to 700 °C, an apparatus that measures the natural vibration frequency (*Grindosonic*, *J.W. Lemmens*) was used.

3. RESULTS

Figure 1.a shows that, at ambient temperature, the modulus of elasticity decreased with the rise in quartz particle size. Above the quartz $\alpha \rightarrow \beta$ allotropic transition temperature⁶ (573 °C) all materials displayed the same modulus of elasticity. The hysteresis, measured as the difference in the modulus of elasticity between heating and cooling, is shown in Figure 1.b. It may be observed that the hysteresis was greater when the quartz particles were larger.

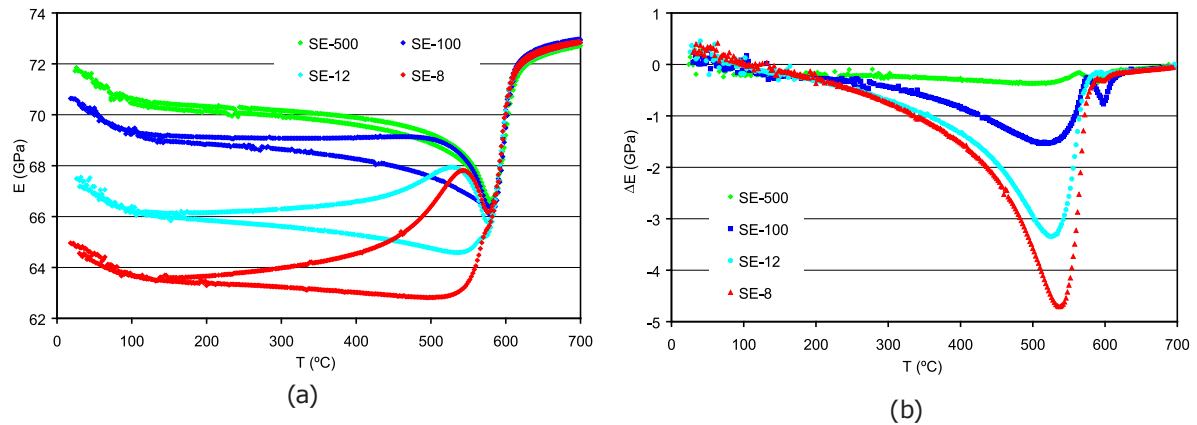


Figure 1. Results of the modulus of elasticity (a) and hysteresis (b) of the test pieces.

Figure 2 shows the microstructure of the test pieces that contained fine (a) and coarse (b) quartz particles. It may be observed that the quartz particles with a larger D_{50} gave rise to bigger defects. This would explain the results shown in Figure 1: at ambient temperature, the test pieces with coarse quartz had more cracks so that their modulus of elasticity was lower. At high temperature, the greater cumulative expansion of the quartz (owing partly to its allotropic transition) caused the cracks to close and all test pieces displayed the same modulus of elasticity.

This phenomenon also affected hysteresis (Figure 1.b). During heating, the cracks were open and the modulus of elasticity was relatively low. During cooling, the initial situation was such that the cracks were closed, making it necessary to overcome a certain adhesion force to open them, so that the modulus of elasticity was greater.

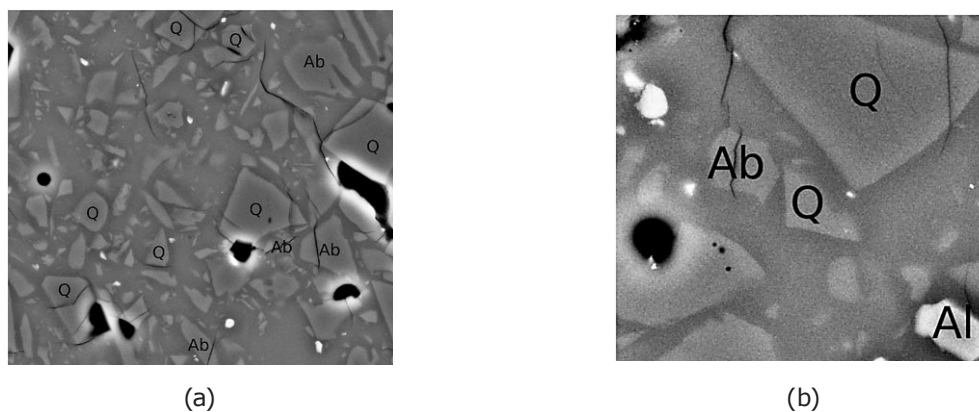


Figure 2. Microstructure of test pieces with fine quartz particles (a)(SE-500) and coarse quartz particles (b)(SE-8).

ACKNOWLEDGEMENTS

The authors gratefully thank the Ministry of Science and Innovation for the co-financing received in the National Programme for Basic Research Projects (BIA2009-10692) and the CAPES-DGU project (Brazil: BEX 6505/10-4).

REFERENCES

- [1] SCHILLING, F.R.; HAUSER, M.; SINOGEIKIN, S.V.; BASS, J.D. Compositional dependence of elastic properties and density of glasses in the system anorthite-diopside-forsterite *Contrib. Mineral. Petrol.* 141(3), 297-306, 2001.
- [2] ROUXEL, T. Elastic properties and short-to medium-range order in glasses. *J. Am. Ceram. Soc.*, 90(10), 3019-3039, 2007.
- [3] BUDIANSKY, B.; O'CONNELL, R.J. Elastic moduli of a cracked solid. *Int. J. Solids Structures*, 12, 81-97, 1976.
- [4] BOCCACCINI, A.R.; FAN, Z. A new approach for the Young's modulus-porosity correlation of ceramic materials. *Ceramics International*, 23(3), 239-245, 1997.
- [5] NONI, A. DE JR; HOTZA, D.; CANTAVELLA, V.; SÁNCHEZ, E. Analysis of the development of microscopic residual stresses on quartz particles in porcelain tile. *J. Eur. Ceram. Soc.*, 28(14), 2629-2637, 2008.
- [6] OHNO, I.; HARADA, K.; YOSHITOMI, C. Temperature variation of elastic constants of quartz across the alpha-beta transition *Phys. Chem. Minerals*, 33(1), 1-9, 2006.