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Micromechanical Behavior of TBCs After Isothermal Oxidation

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Abstract

Thermal protection of metallic components by Thermal Barrier Coatings, TBCs, is widely used in rocket engines, aircraft industry and gas turbines for power generation; this technology reduces substrates temperature up to 165°C. Apart from thermal protection they can also protect against abrasion, oxidation and corrosion.

This work reports on the mechanical characterization of APS 6-8 wt.% Yttria Stabilized Zirconia (YSZ) as top layer, bonded by an HVOF NiCoCrAlY layer to a superalloy substrate (Inconel 625), using micro- and nano-indentation techniques on test specimens after heat treatment at 1100°C and different exposure times (0, 200, 400, 600, 800, 1000, and 1700 hours).

The fracture toughness of the ceramic coating was measured trough IF method, in conjunction with failure statistics, proved to be a powerful tool that helps to understand microstructural and mechanical evolution of the coating due to high temperature exposition.

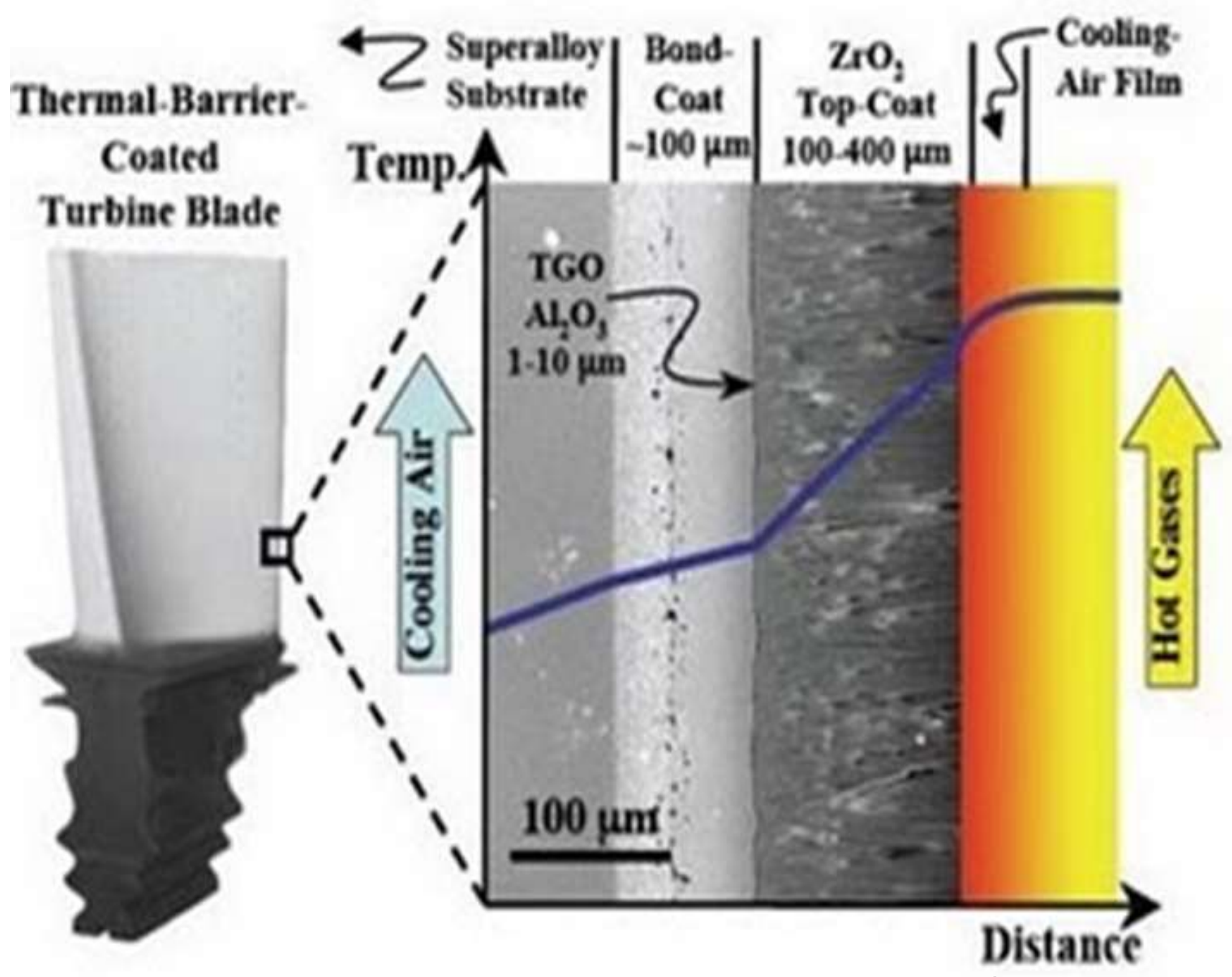

Fig. 1. Schematic of a TBC's general structure [1].

Materials and Methods

Test specimens, with dimensions of 1.7 x 1.7 cm, were heat treated at 1100°C during 0, 200, 400, 600, 800, 1000, and 1700 hours respectively, then they were mounted in phenolic resin, and samples were extracted for metallographic preparation: Grinding with sand paper Nº 400 and 600 (during 15 min); polishing with diamond suspension of 12, 6, 3 µm (during 15 min) and 1 µm (during 60 min), keeping a pressure of 37.5±3.54 KPa.

Nano- and micro-indentation techniques were carried out on the cross-sections to measure elastic modulus, hardness, and fracture toughness. OM and SEM microscopy were used to measure the size and shape of the indentations, the state, evolution, and morphology of the cracks; and the general structural aspects of the ceramic coating. The fracture toughness (K_{1C}) of the TC was evaluated with the James Lankford model.

$$K_{1c} = 0.0363\left(\frac{E}{H}\right)^{\frac{2}{5}}\left(\frac{P}{a^{1.5}}\right)\left(\frac{a}{c}\right)^{1.56}$$

A method employing Weibull statistics was applied to evaluate results from K_{1C} values:

$$P(K_{1c}) = 1 - e^{-\left(\frac{K_{1c}}{K_0}\right)^m}$$

where m, is the Weibull modulus, and K_0 is the characteristic fracture toughness.

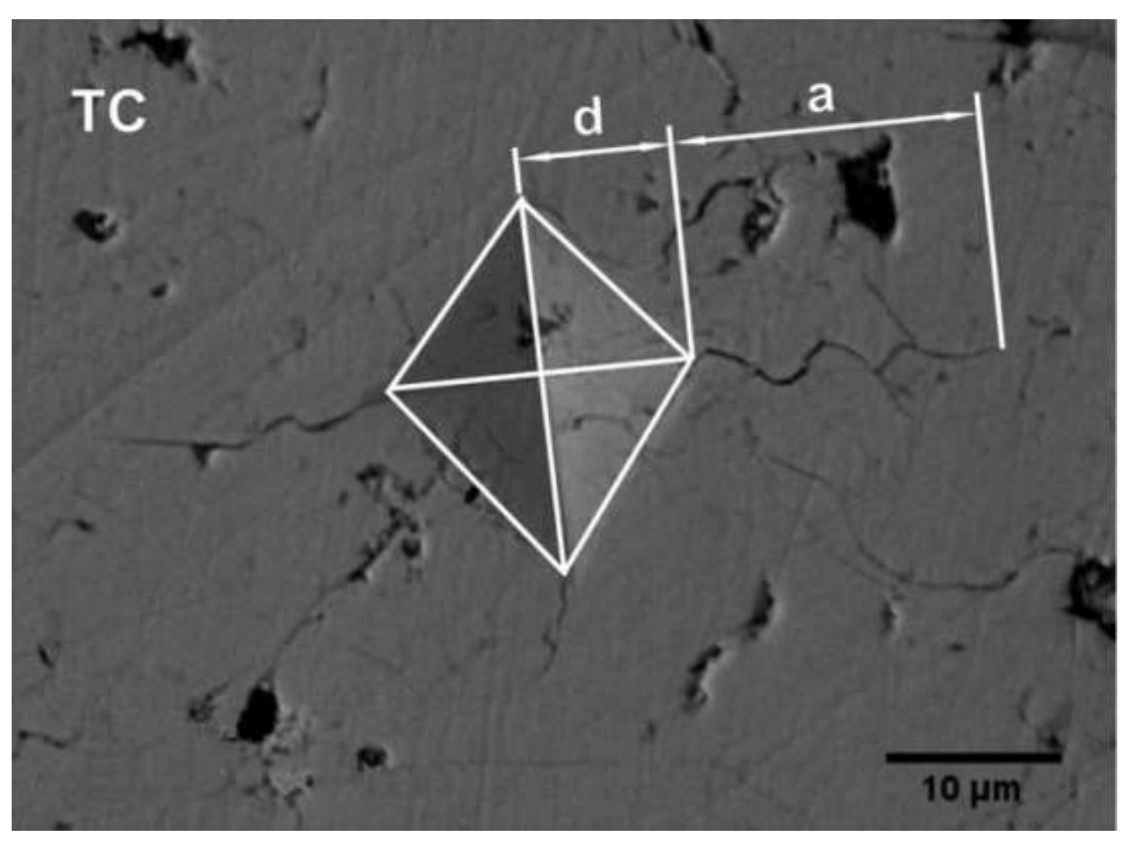

Fig. 2. Vickers indentation of a heat treated sample (1100°C, 1700 h).

Results

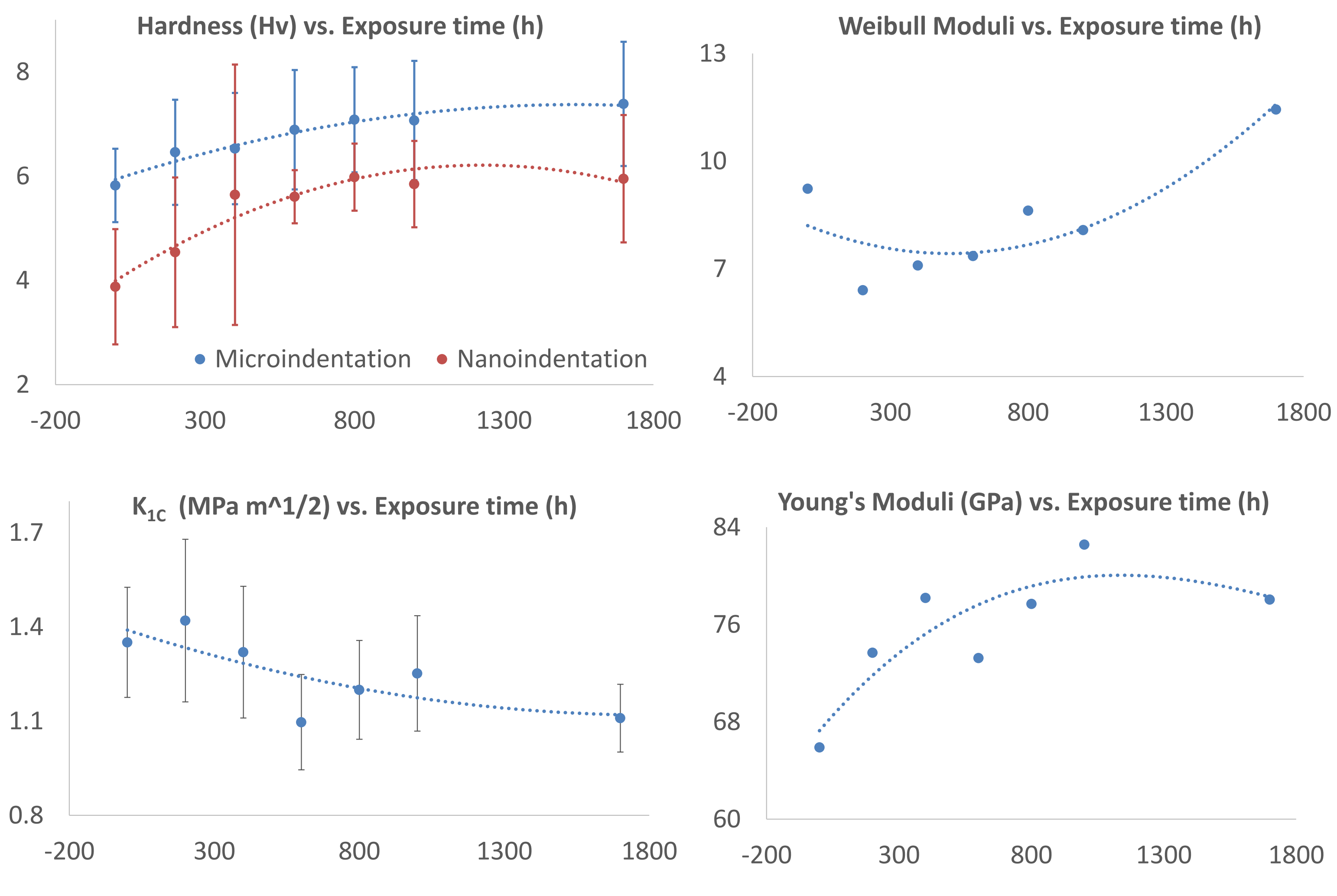

Fig. 3. Hardness, fracture toughness, Weibull and Young's moduli of TBCs, at 1100ºC at different times.

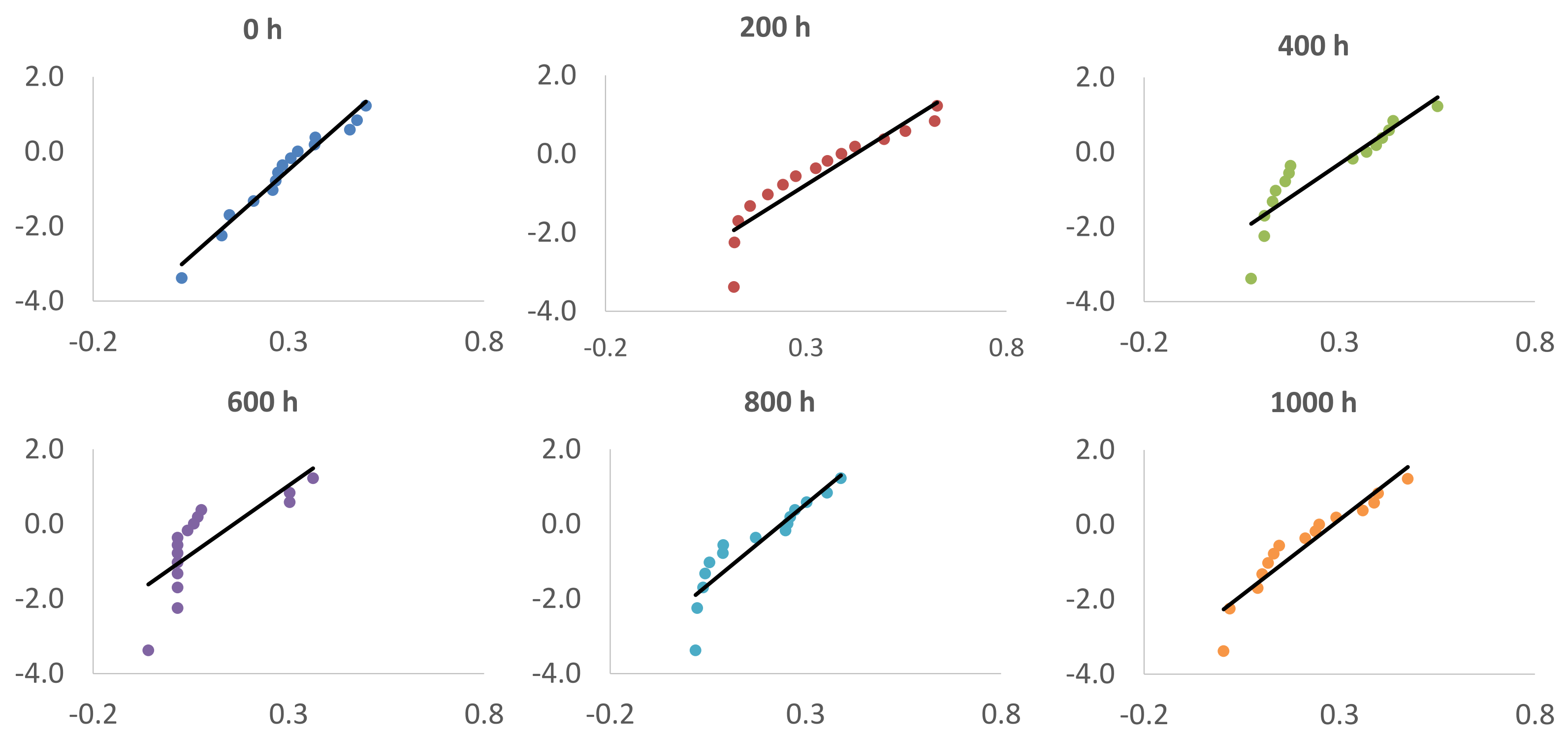

Fig. 4. Weibull plots for fracture toughness - $\ln\ln(1/(1-P(K1c)))$ vs $\ln K_{1c}$.

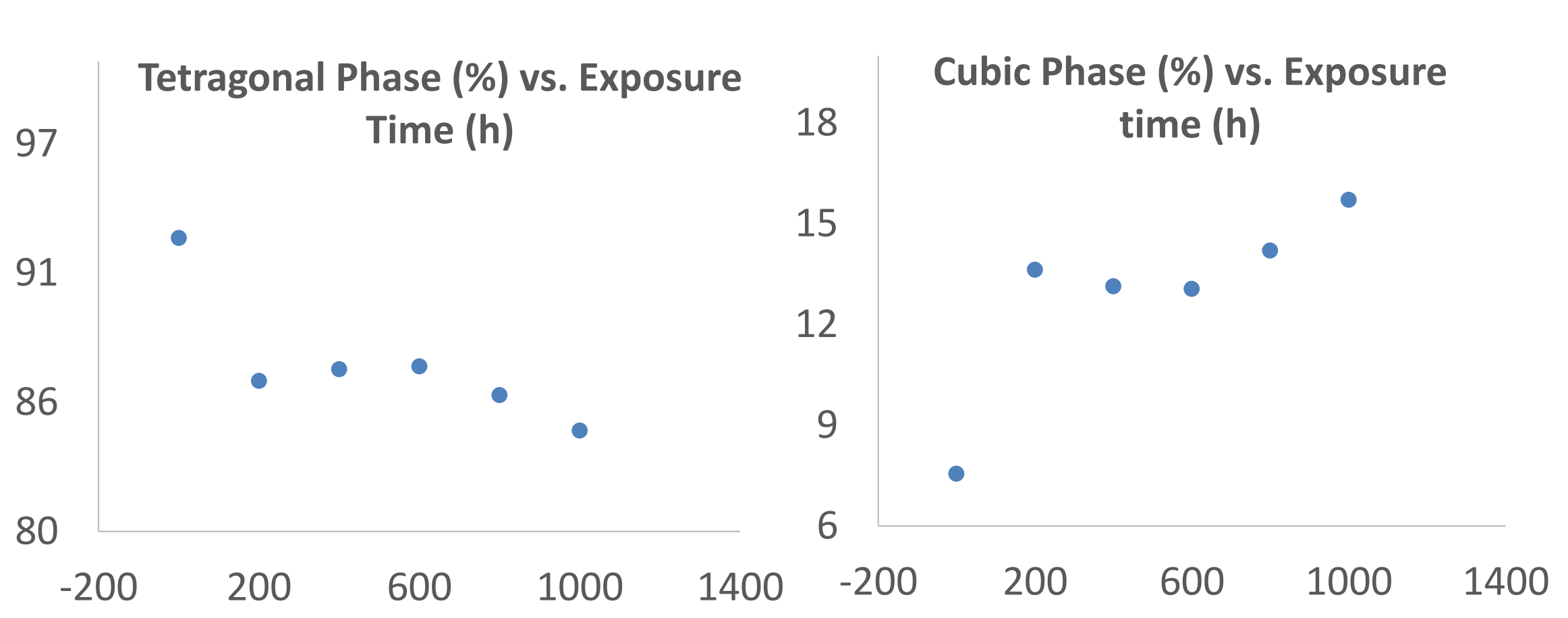

Fig. 5. Quantification of tetragonal and cubic phases by Rietveld method [2].

Time (h)	m	K_0
0	9.2	26.0
200	6.4	15.0
400	7.1	11.5
600	7.4	3.2
800	8.6	12.9
1000	8.1	9.9
1700	11.4	5.5

Table 1. Weibull parameters at different exposure times.

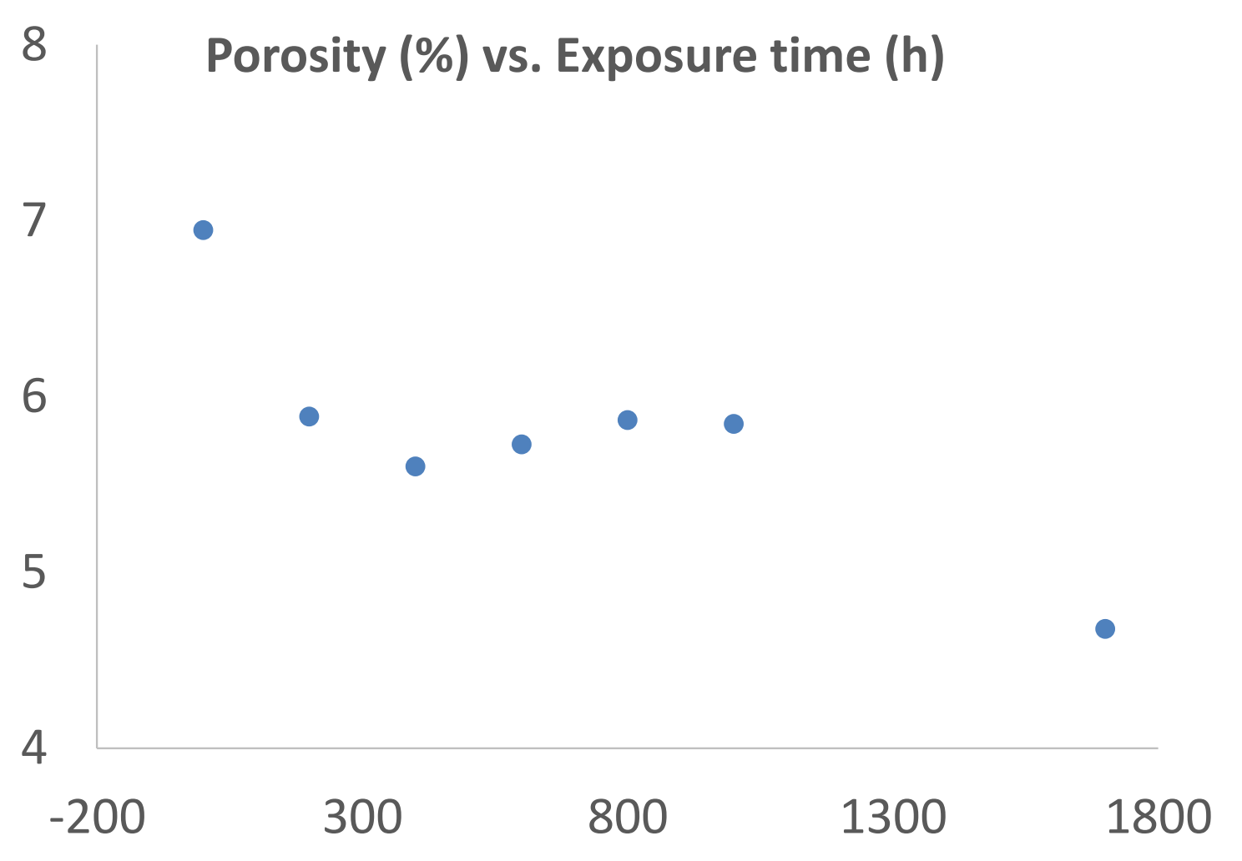

Fig. 6. Porosity content vs. Exposure time [2].

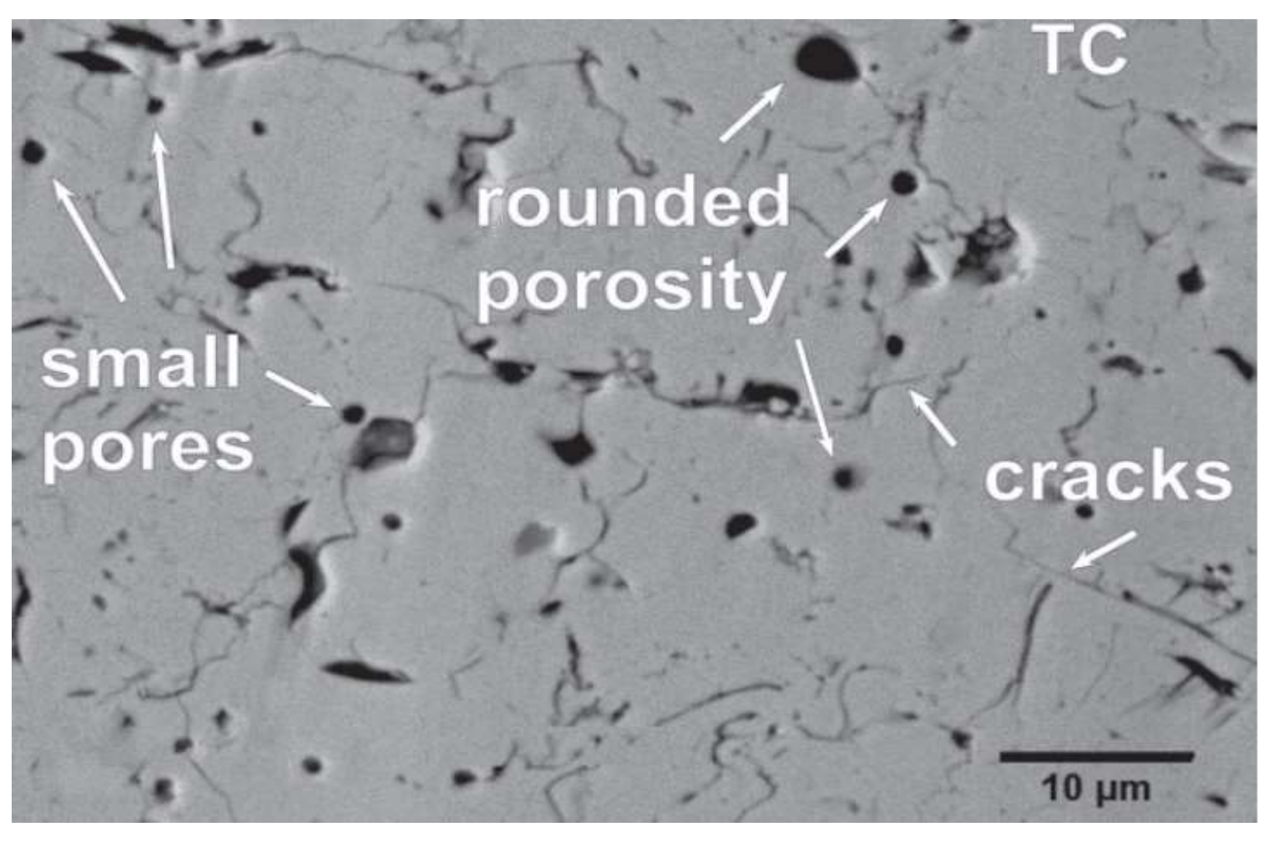

Fig. 7. Cross-section of the TC heat treated sample at 1100°C during 1700 h.

Conclusions

- From 0 up to 600 hours of heat treatment, before the formation of the monoclinic phase, hardness and Young's modulus of the TC rapidly grew up; this is explained by the sintering phenomena. Further from the 600 hours, the hardness continued growing up, but the young's modulus got to a steady state due to competition between sintering mechanism and phase transformations (where sintering tried to augment E and phase transformation tried to reduce it).
- The fracture toughness decreased with exposition time up to 23% showing a detriment of the ceramic layer. The Lankford Model gave results similar to those found in the literature for the 6-8 wt.% YSZ, showing a reliable method.
- After indentations, the direction in which radial cracks spread was ruled by the TC microstructure (parallel to the TC/TGO).
- In general K1c data follows the Weibull's equation. However, between 400 and 600°C, the data do not conform with weibulll´s equation due to their scatteredness; this can be explained by the fact that the material undergoes structural transformation that is caused by phase changes, sintering , and evolution of residual stresses.
- The IF method, in conjunction with failure statistics, has proven to be a powerful tool for the assessment of the microstructural behavior, showing the trend of the densification due to sintering.

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