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Study on Stress Relaxation Behavior of Glass-ceramic Coating for its Application as Bond Coat in a Thermal Barrier Coating System

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Background…

Thermal barrier coating (TBC)

- Combination of a ceramic top coat, a metallic bond coat (e.g. NiCoCrAlY or platinum aluminide coating) and a metallic substrate
- Enhance operating efficiency of turbine engines

Thermal exposure of TBC system

- Thermally grown oxide (TGO) scale at the bond coat-top coat interface
- Degradation of the TBC system at critical TGO thickness

Some probable solutions…

- **Pre-oxidation surface treatments of the bond coat**
- **Incorporation of platinum-modified aluminide coating between top coat and bond coat**
- **An intermediate Al_2O_3 diffusion barrier between the bond coat and the top coat**
- **Functionally graded Al_2O_3-ZrO_2 TBC**
- **Use of oxidation resistant bond coat**

Advantages of glass-ceramic bond coat

- Eliminate TGO layer formation
- Accommodate stress within the system
- Protect substrate metal from oxidation
- Lower metal temperature

Our Approach…

- **Feasibility study on glass-ceramic bond coat for TBC system**
- **Study on stress relaxation property of glass-ceramic bond coat**
- **Evaluation of physical, mechanical and thermal properties of the TBC system**

Methodology

- Formulation of different glass compositions and characterization of the glass-ceramic samples
- Application of glass-ceramic bond coat on the metallic substrate using enameling technique and characterization
- Plasma spraying of ZrO_2–8%Y_2O_3 top coat onto the glass-ceramic coated substrate
- Evaluation of physical, mechanical and thermal properties of the TBC system

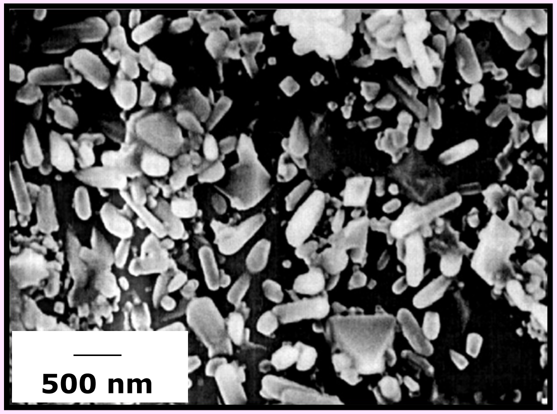
Objectives…

- To develop reliable TBC system using glass-ceramics as bond coat material
- To study the effect of stress relaxation property of bond coat on the mechanical property of the TBC system.

Preliminary Studies…

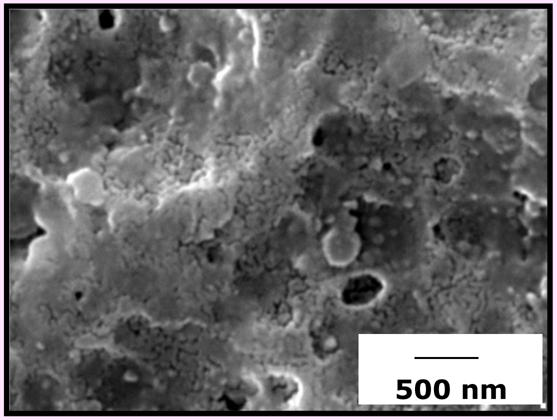
Composition GC1

Oxides	wt. %
SiO_2	32
Na_2O	2
K_2O	5
TiO_2	14
B_2O_3	10
MgO	13
CaO	2
Al_2O_3	22



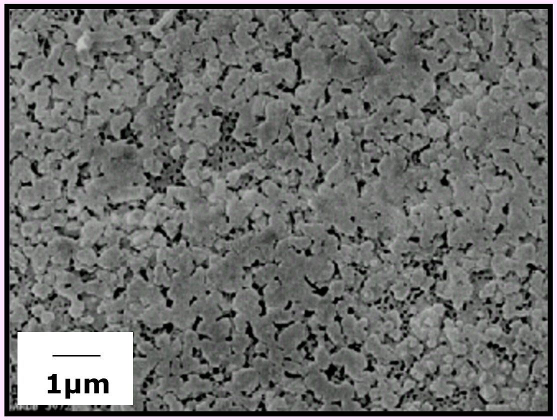
Composition GC2

Oxides	Wt.%
SiO_2	45
BaO	45
CaO	3
MgO	3
ZnO	2
MoO_3	2



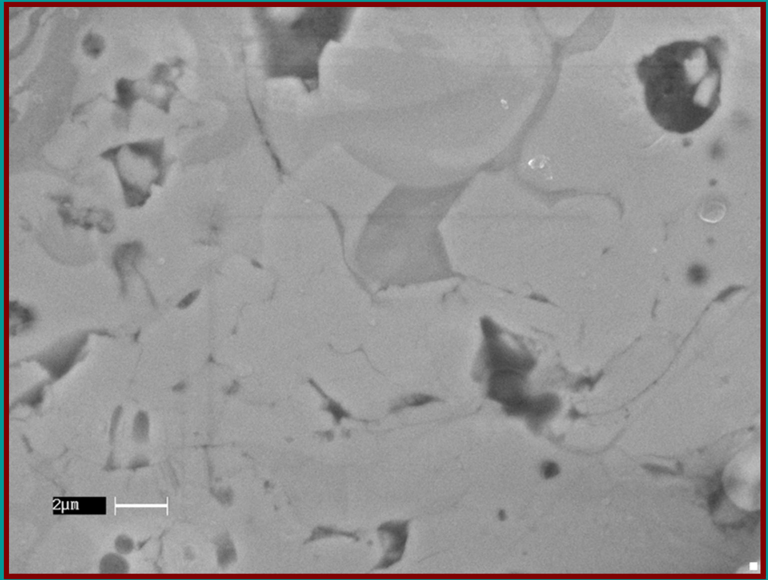
Composition GC3

Oxides	Wt.%
SiO_2	45
MgO	2
ZnO	35
Al_2O_3	15
B_2O_3	1
CoO	1
NiO	1

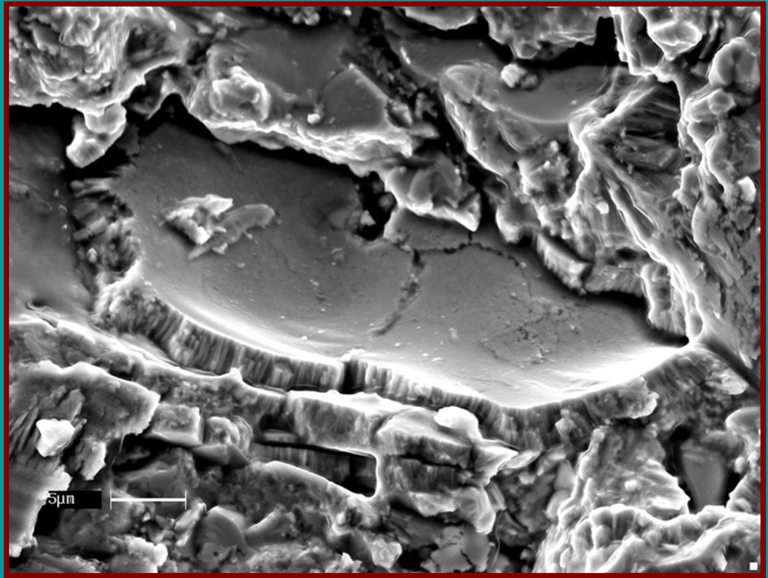


Spraying parameters for YSZ top coat and porosity of YSZ coating

Spraying parameters/Porosity	
Powder injection mm	Outside nozzle 6
Power input (kW)	40
Primary/secondary gas in the plasma (standard l/min)	35 Ar/10 H_2
Carrier gas (Ar) flow in the feeder nozzle (standard l/min)	2.6
Stand-off distance (mm)	120
Porosity (%)	8–12

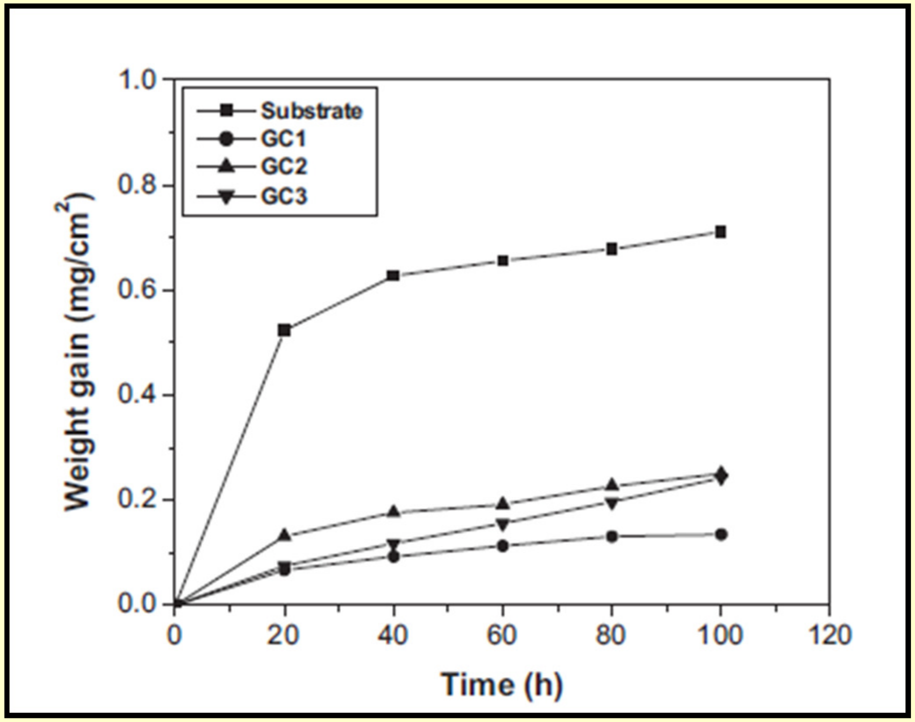


Polished surface of YSZ coating



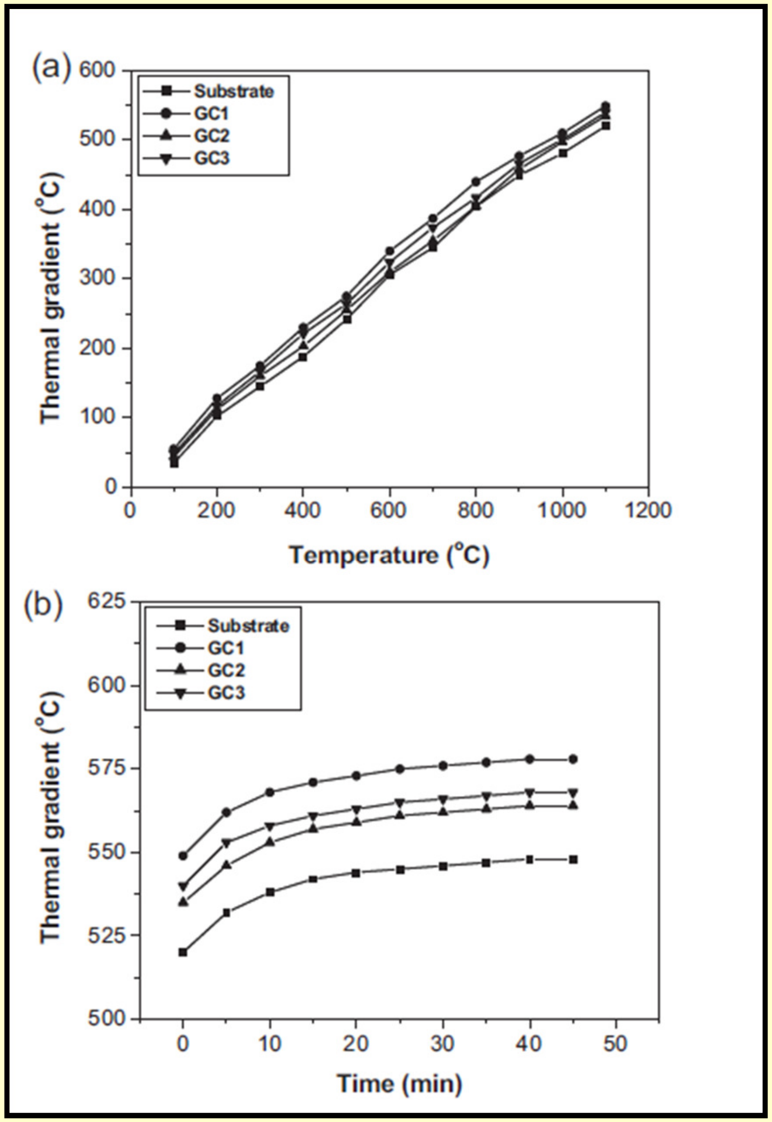
Fracture cross-section of YSZ coating

Oxidation tests…

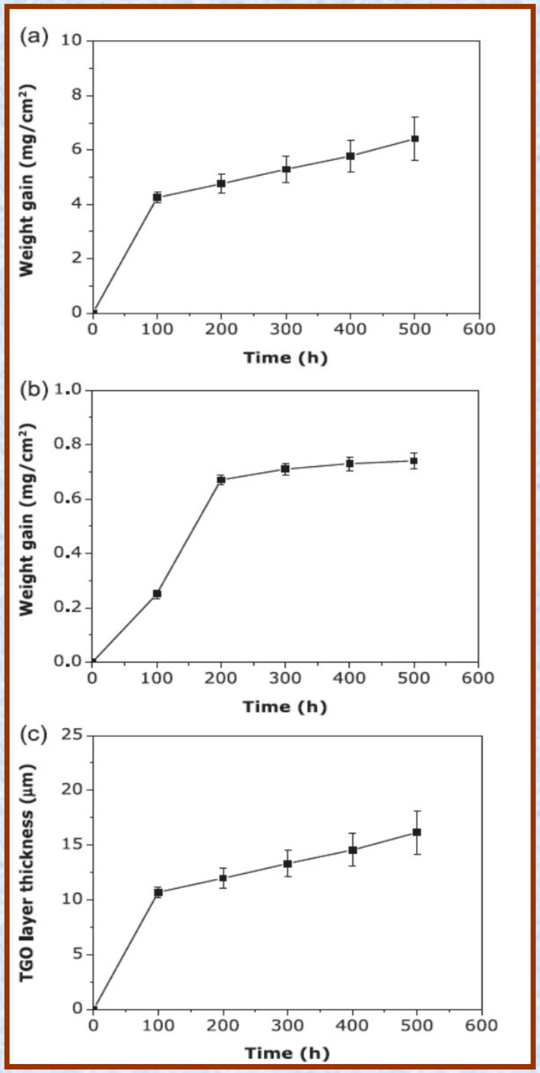


Isothermal oxidation tests at 1000° C for 100 h

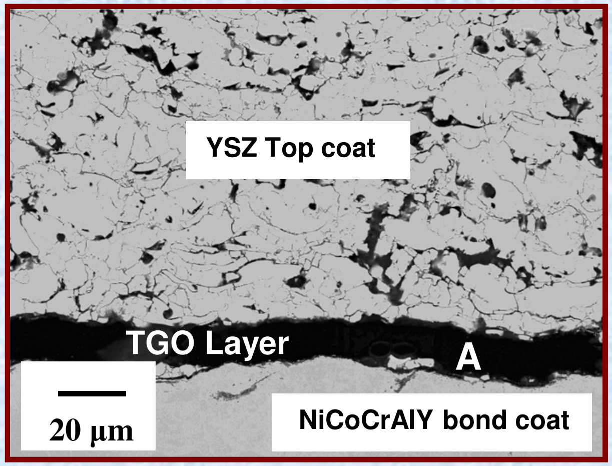
(Substrate- bare substrate; GC1-GC1 coated substrate; GC2-GC2 coated substrate; GC3-GC3 coated substrate)



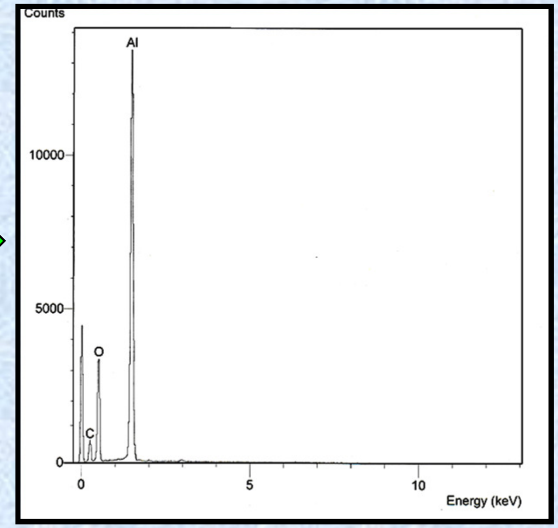
(a) Thermal gradient vs. temperature curve and (b) thermal gradient vs time curve of bare substrate and glass-ceramic coated substrates at 1100 °C.



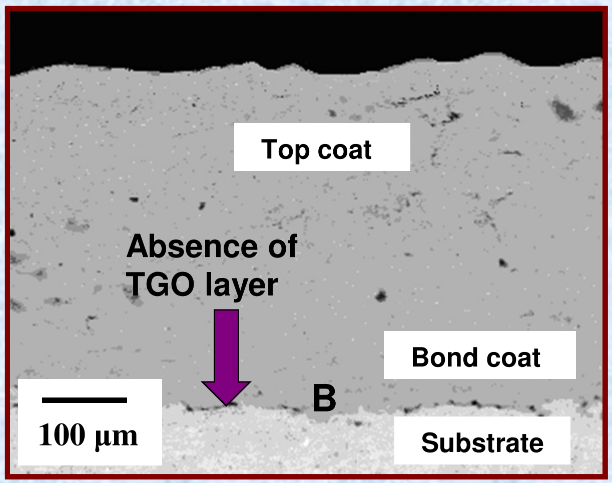
Weight gain of (a) conventional TBC system and (b) glass-ceramic bonded TBC system; (c) TGO layer thickness vs time curve for conventional TBC system during oxidation tests at 1200° C for 500 h.



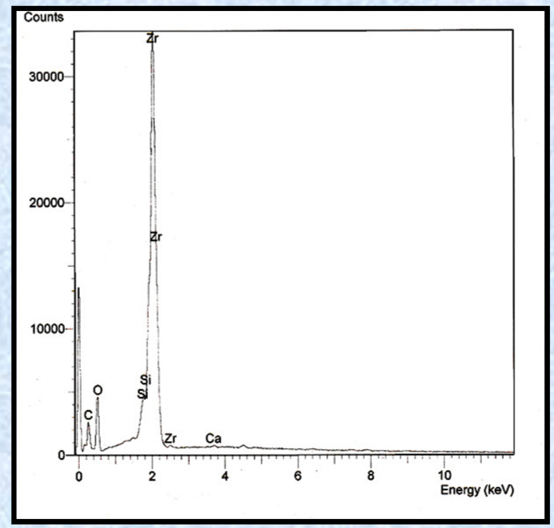
Conventional TBC



EDX Analysis

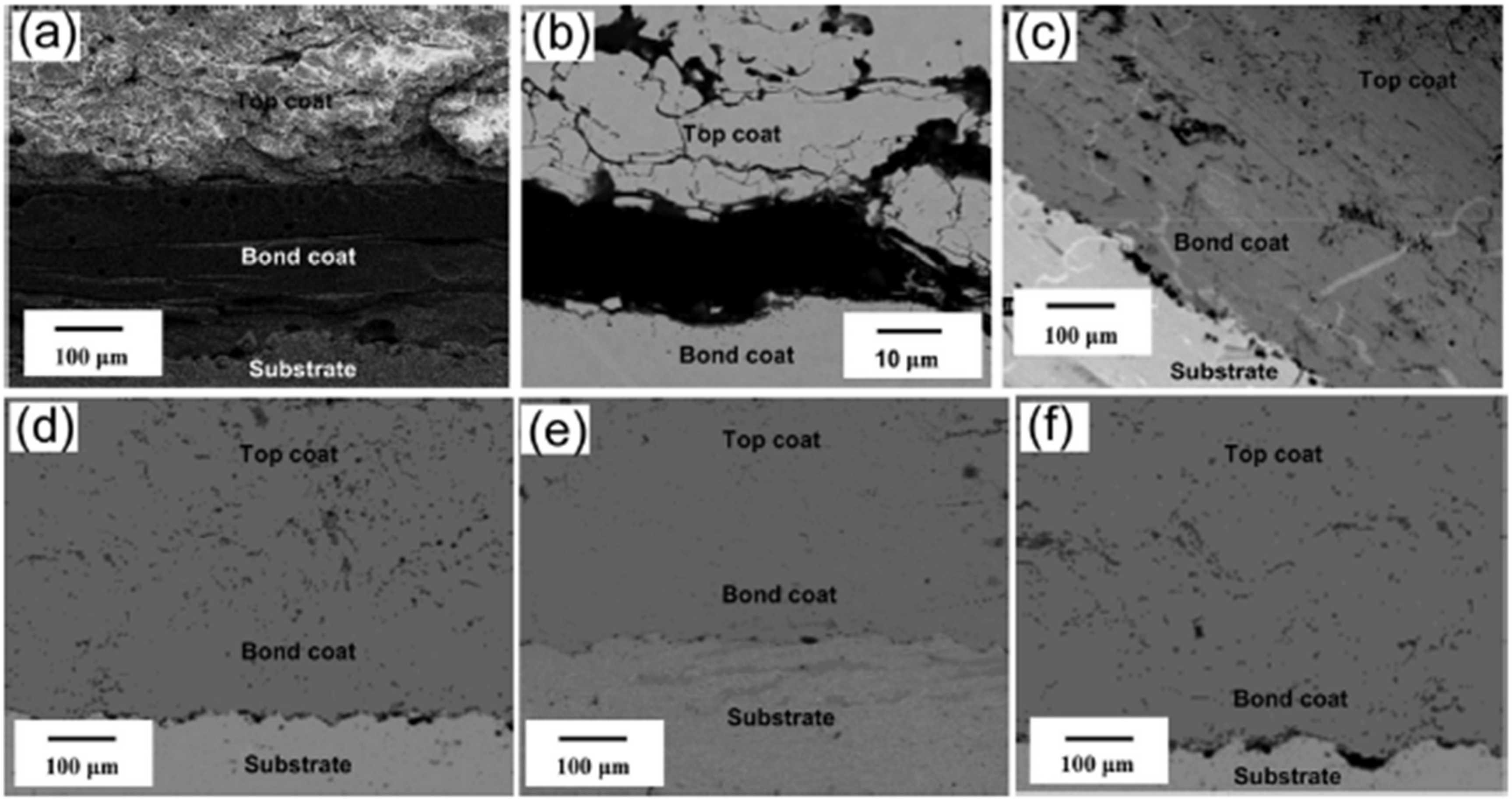


Glass-ceramic bonded TBC



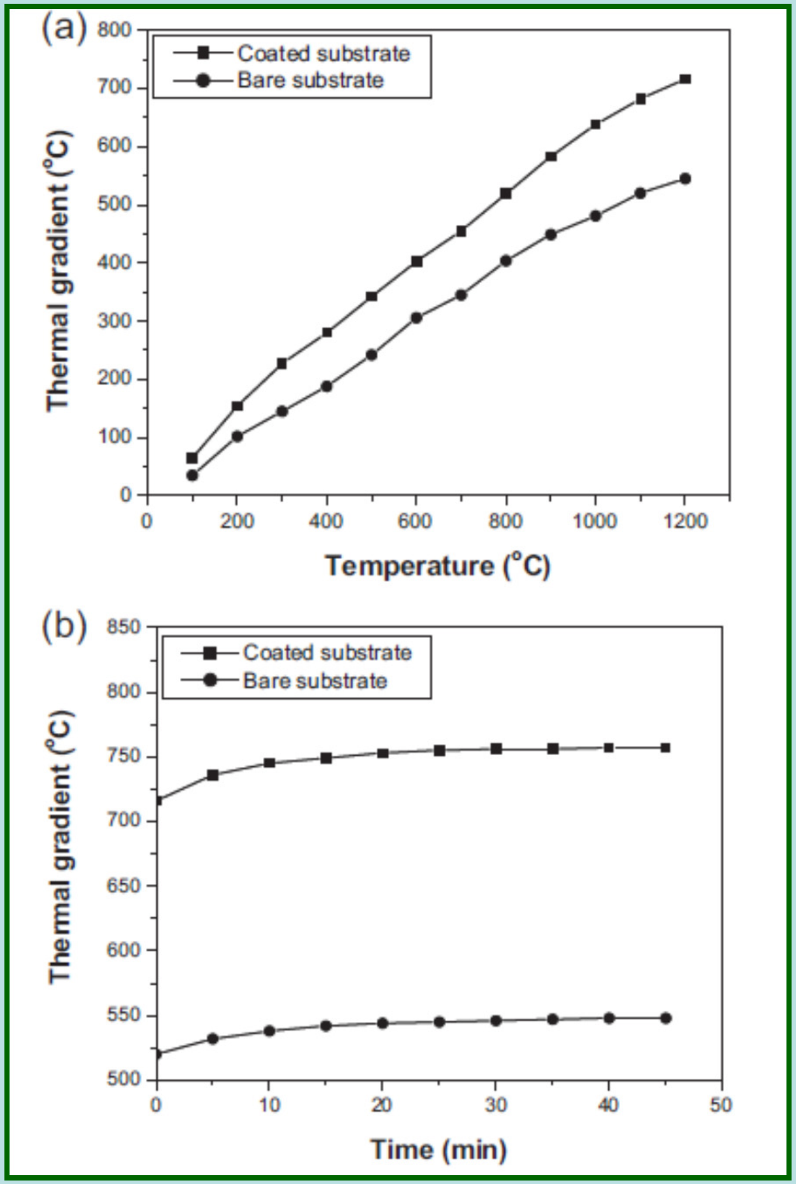
EDX Analysis

Microstructural Observations



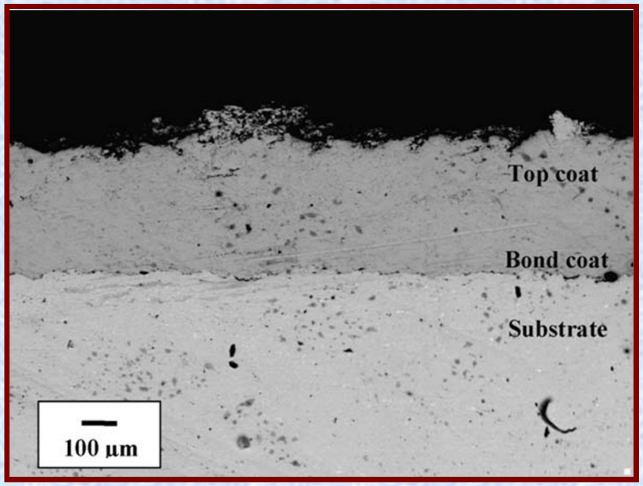
Typical conventional TBC systems (a) before oxidation and (b) after oxidation test at 1200°C for 500 h; (c) typical glass-ceramic bonded TBC system before oxidation; (d) GC1, (e) GC2 and (f) GC3 bonded TBC systems after oxidation tests at 1200° C for 500 h.

Thermal Gradient…

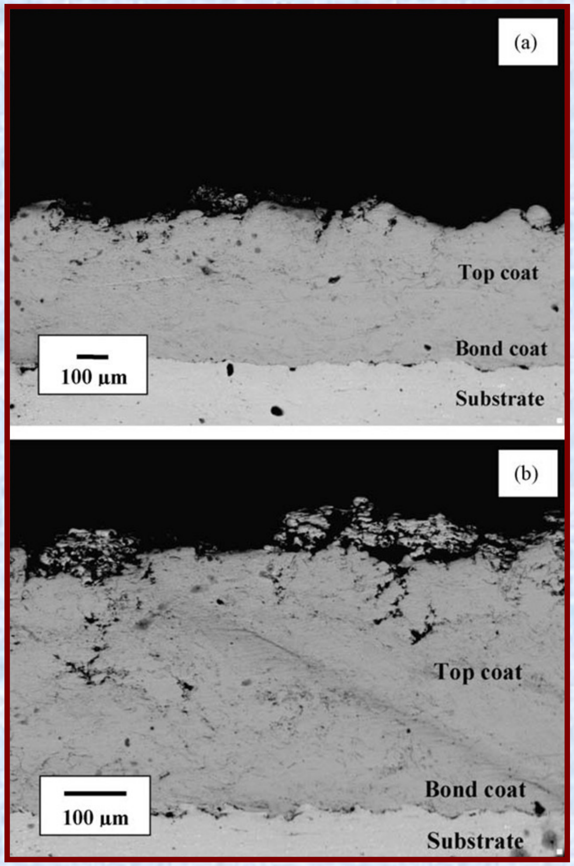


(a) Thermal gradient vs. temperature curves and (b) thermal gradient vs. time curves of bare substrate and a thin TBC system (~700 mm) at 1200 °C.

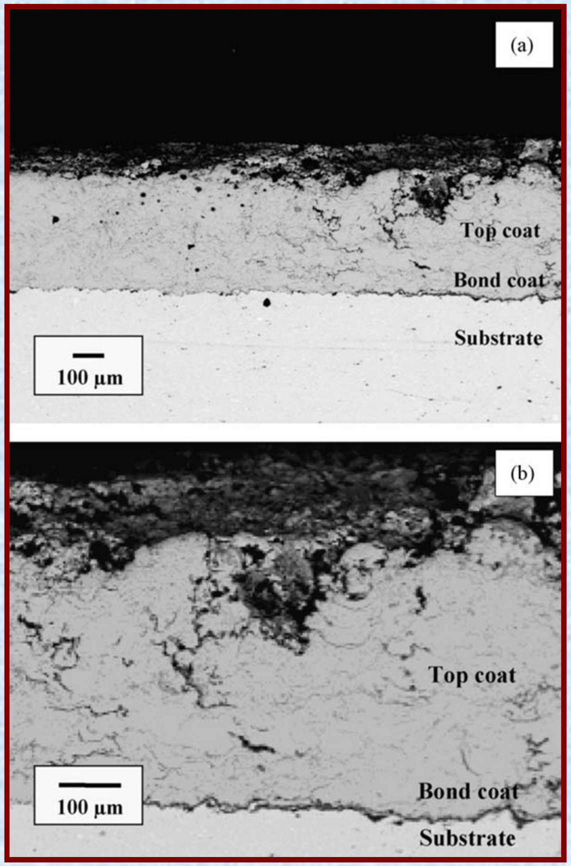
Thermal shock behavior…



As-deposited TBC system

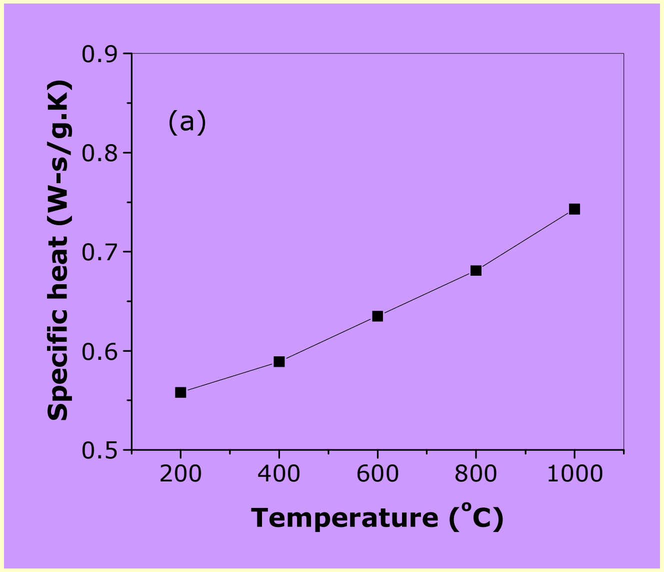


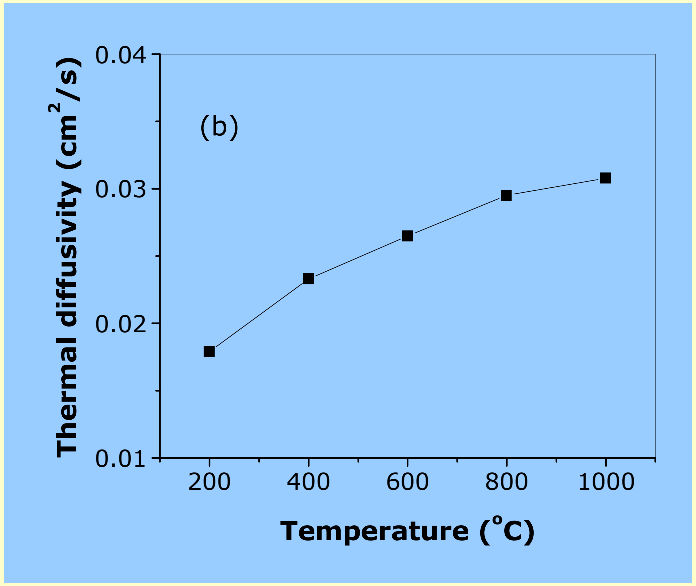
(a) Typical Forced air quenched sample after 100 cycles and (b) magnified view

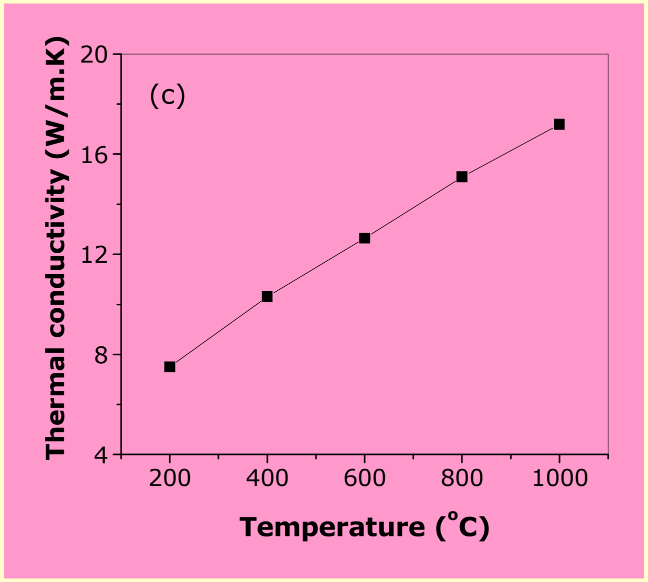


(a) Typical water quenched sample after 100 cycles and (b) magnified view.

Thermal conductivity…

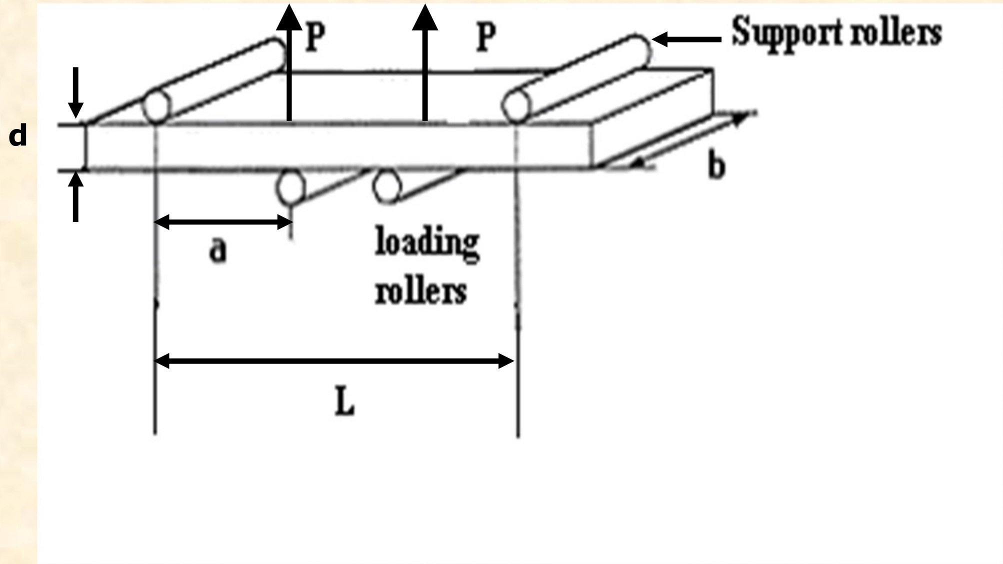






(a) Specific heat vs. temperature curve, (b) thermal diffusivity vs. temperature curve and (c) thermal conductivity vs. temperature curve of TBC (~500 µm) coated substrate.

Four point bend tests…



Four point bend specimen geometry and the loading states

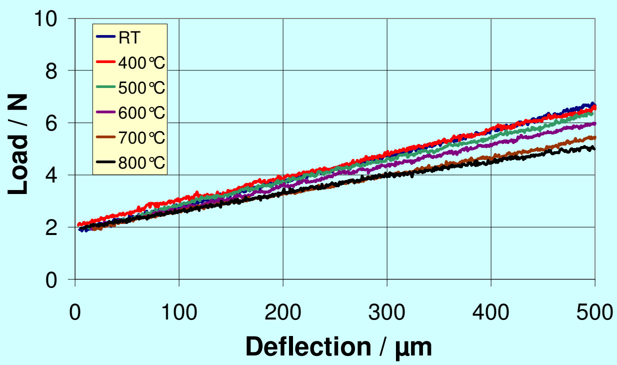
The equivalent modulus of elasticity in bending (E) of the composite material is calculated using the following formulae:

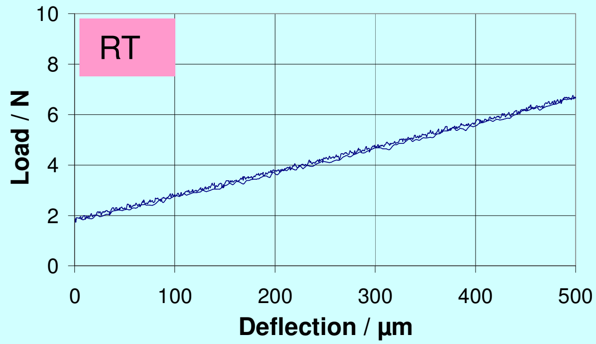
$$E = \frac{a(3L^2 - 4a^2)\Delta P}{4bd^3 \Delta f}$$

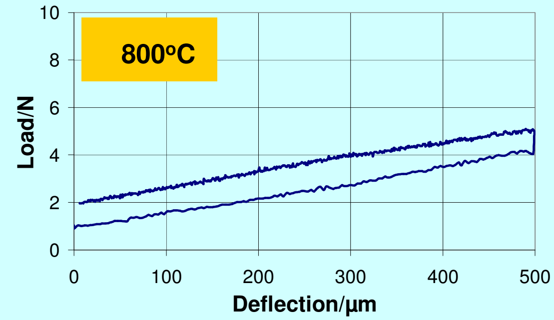
Stress relaxation property…

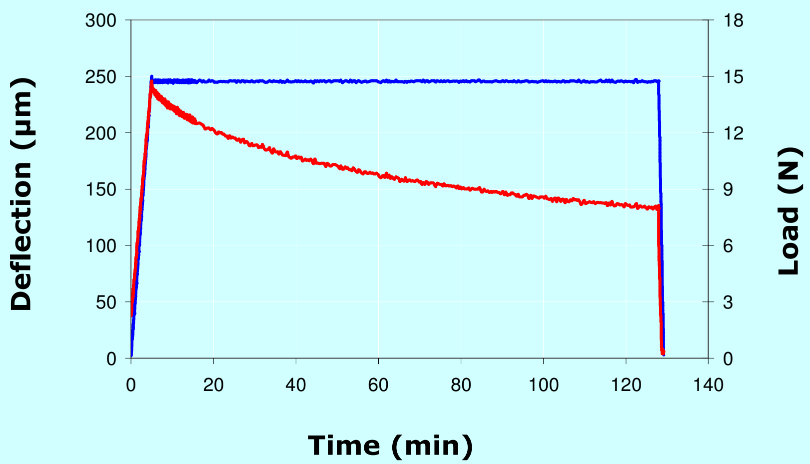
Coating-substrate system	H (mm)	B(mm)	L(mm)
B-01	0.497	4.033	52.16
B-04	0.780	4.024	52.15
B-03	1.483	4.029	52.12

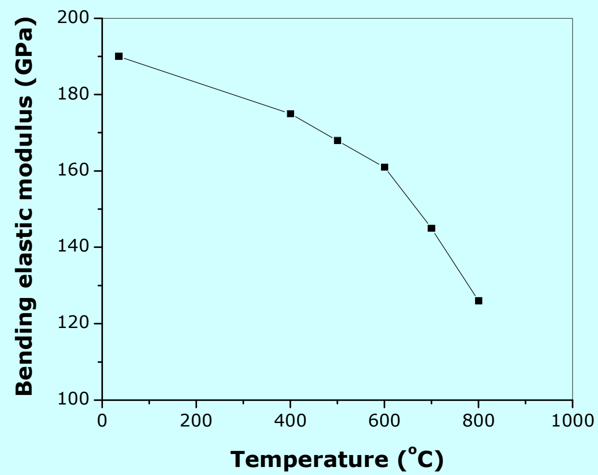
Load vs. Deflection curve of B-01 sample



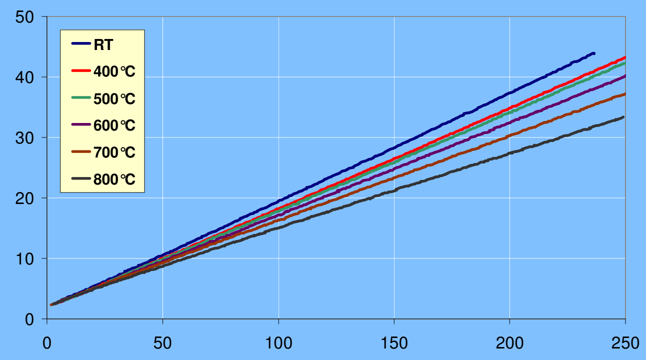


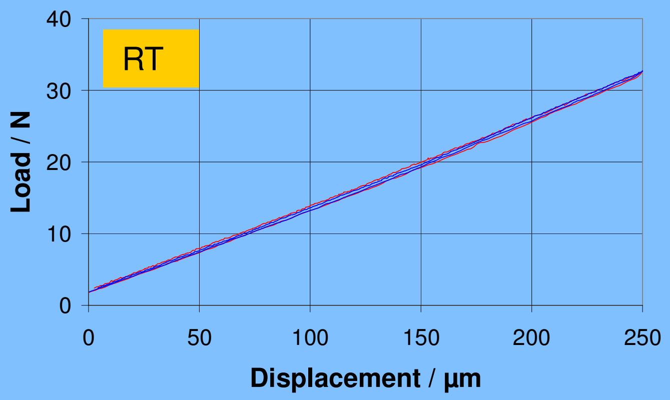


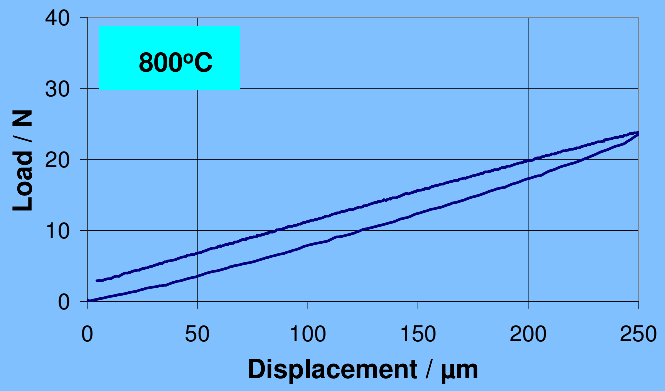


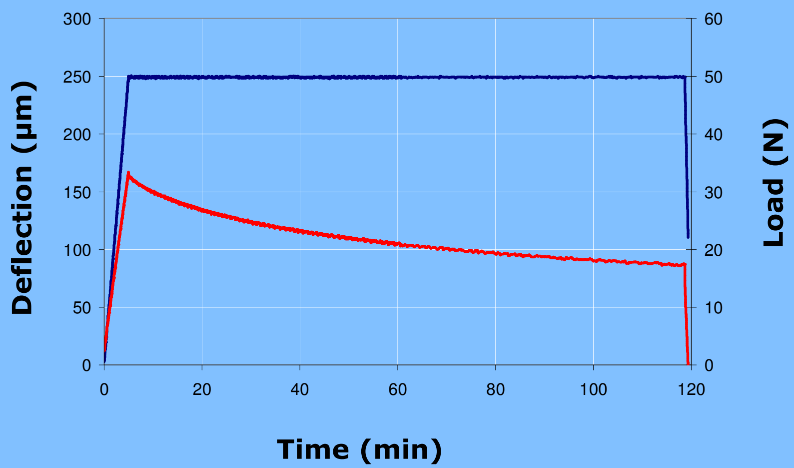


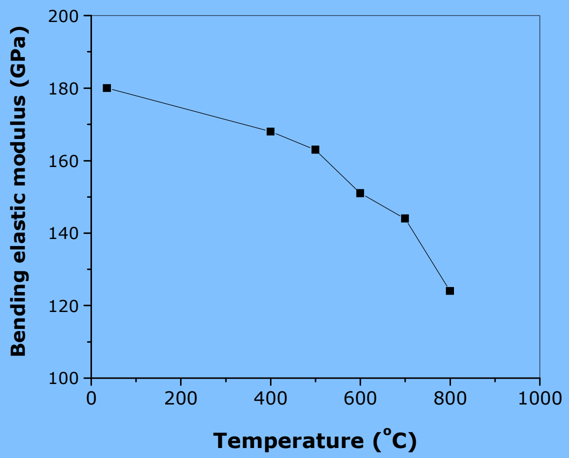
Load vs. Deflection curve of B-02 sample



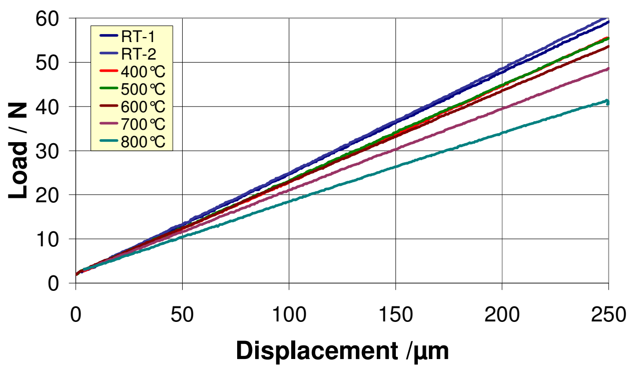


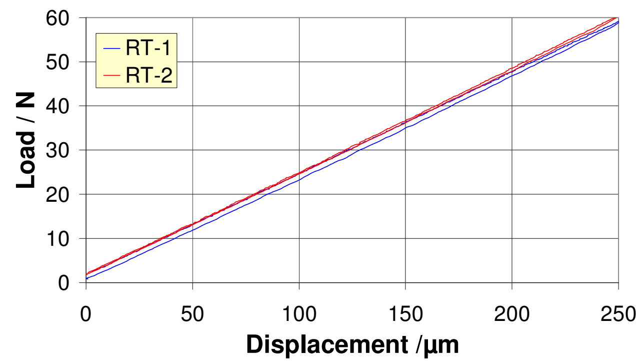


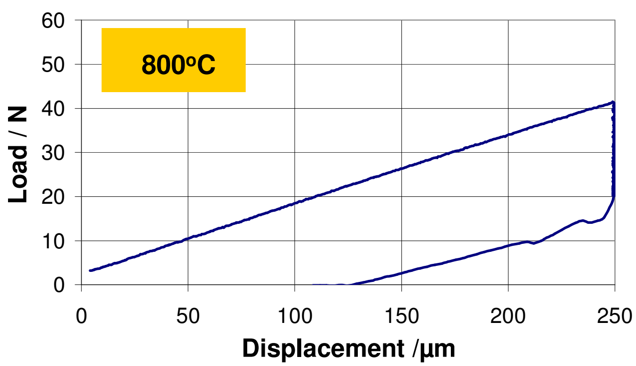


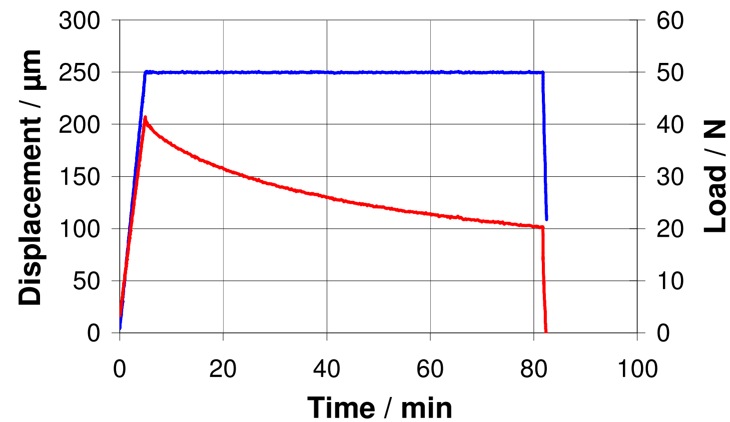


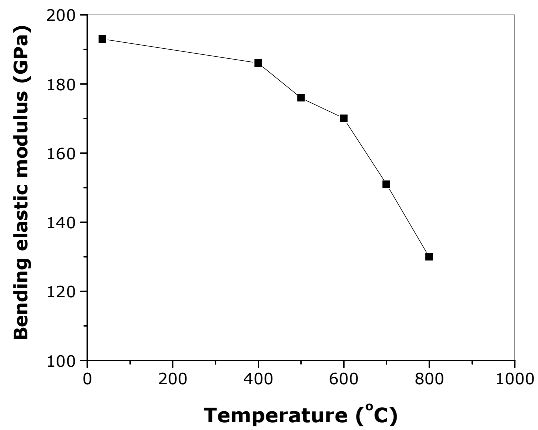
Load vs. Deflection curve of B-03 sample



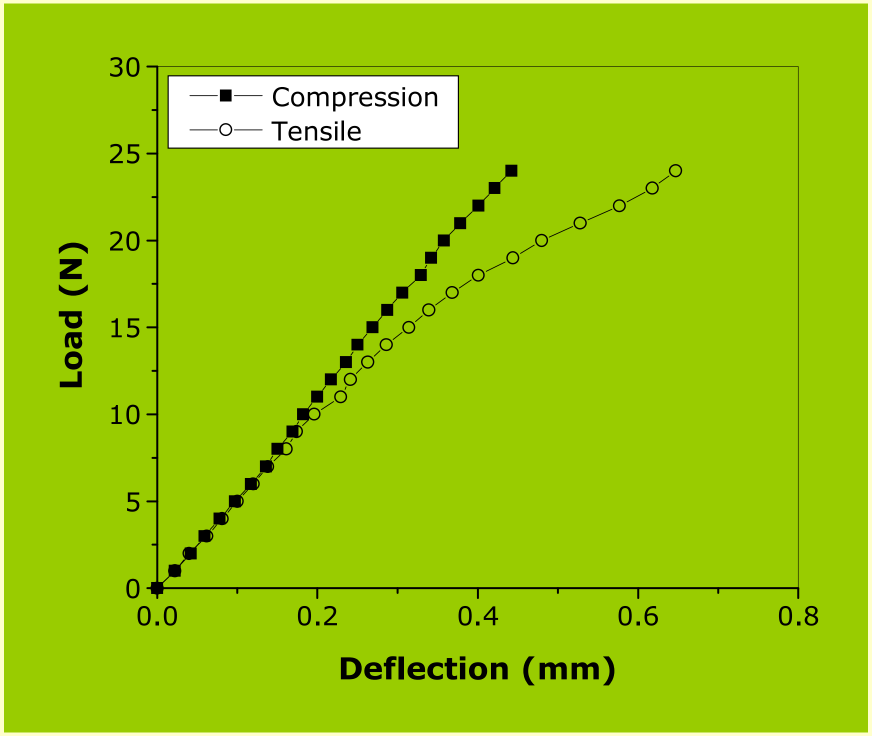


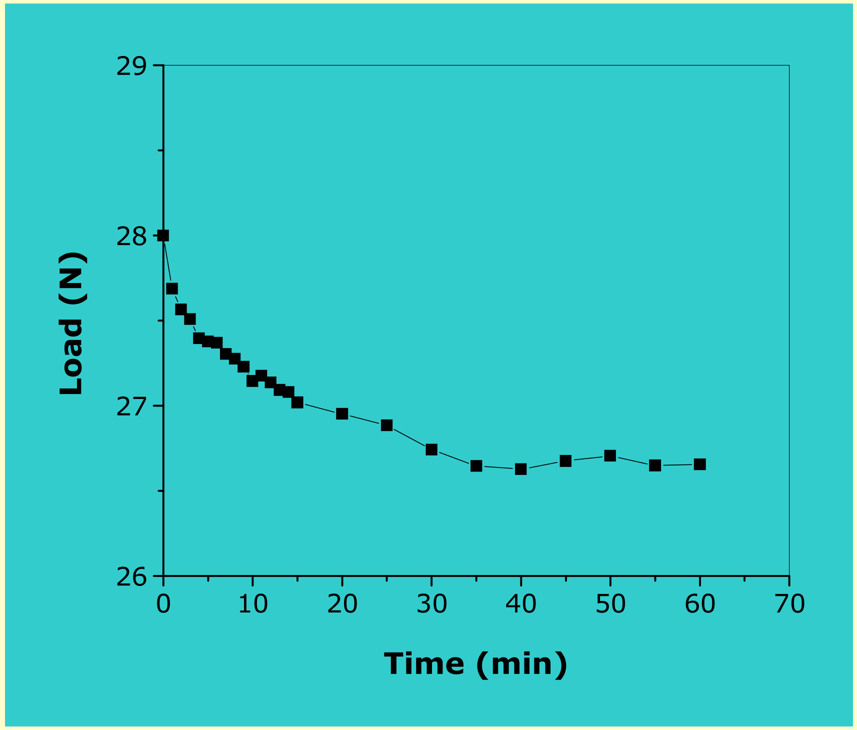






Stress relaxation of TBC system…





Load vs. deflection curves of TBC coated substrates under tensile and compression stress of state of coating.

Stress relaxation effect of TBC coated substrate at room temperature

Conclusions…

- **Isothermal oxidation tests at 1000°C for 100 h showed negligible weight gain (~0.14–0.25 mg/cm^2) of three types of glass-ceramic coated substrate while the bare nimonic alloy substrate had more weight gain (~0.69 mg/cm^2) under identical conditions.**

- **The glass-ceramic bonded TBC system showed high oxidation and thermal shock resistance. The thermal gradient property and thermal conductivity of the present TBC system were satisfactory.**

- **The four point bend tests on three types of glass-ceramic coated substrate showed that the bending elastic modulus values of the coating-substrate systems were in the range of 124–130 GPa at 800°C. These tests also indicated stress relaxation of the glass-ceramic coatings at the higher temperatures up to 800°C.**

Conclusions…

- The four point bend test on the TBC system displayed low stiffness (bending elastic modulus–45–52 GPa at room temperature) that led to low residual stresses in the TBC and consequently relatively high thermo-mechanical stability. Measurement of the TBC stiffness assessed the reliability of the thermal barrier coating system.

- Stress relaxation property of glass-ceramic bonded TBC system was quite satisfactory.

- Based on the present study it can be concluded that glass-ceramic material can be effectively utilized as bond coat in the thermal barrier coating (TBC) system.

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