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Melt Growth Composites for Higher Efficiency Gas Turbine Systems

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Background & Motivation

❑ Single Crystal Eutectic Composites

ex. $Al_2O_3/Y_3Al_5O_{12}$(YAG), $Al_2O_3/GdAlO_3$(GAP), $Al_2O_3/Er_3Al_5O_{12}$(EAG)

❑ Advantages

- Three-dimensional network structure
- High strength up to melting point temperature
- High creep and oxidation resistances
- Good machinability and productivity to fabricate complex shape components

❑ Disadvantages

- Low fracture toughness and low thermal shock resistance

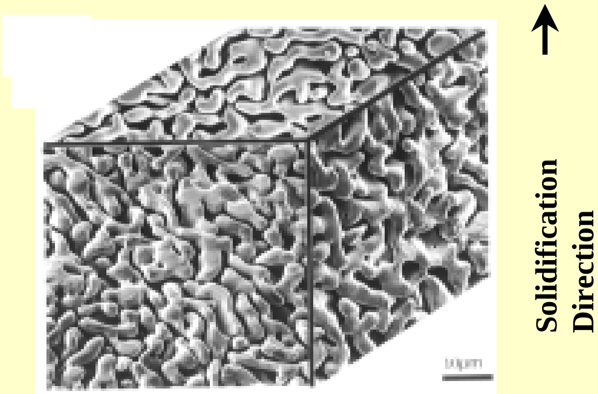
New eutectic composites ↓ *Improving design methodology*

Ultra-high temperature structural components for ultra-high efficient gas turbine

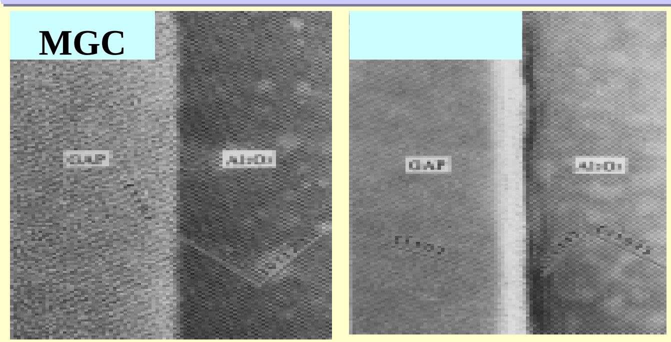
Combustor liner, Turbine nozzle & Blade

Superior Temperature Dependence of Strength of MGC

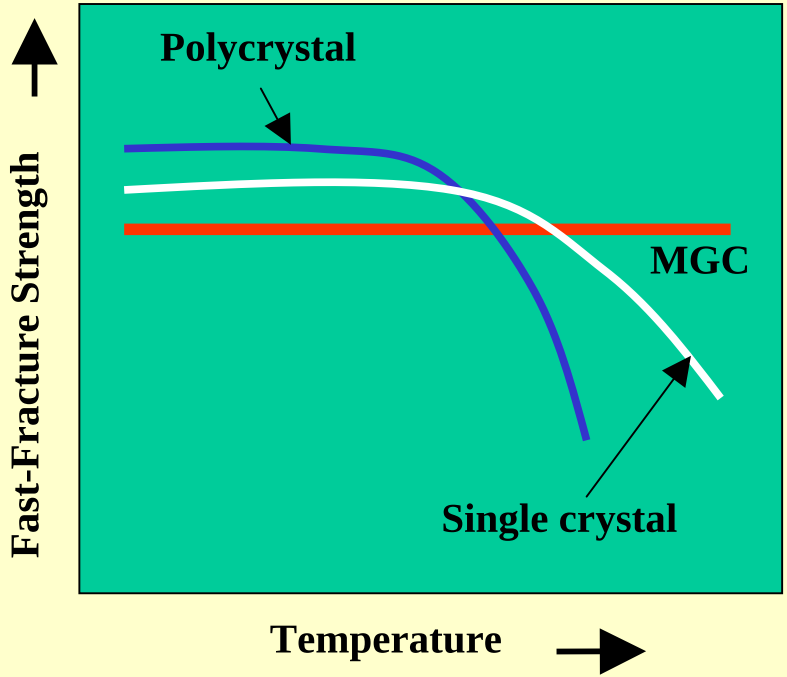
MGCs:<u>M</u>elt <u>G</u>rowth <u>C</u>omposite<u>s</u> (Single Crystal Eutectic Composites)



SEM image of single-crystal GAP configuration



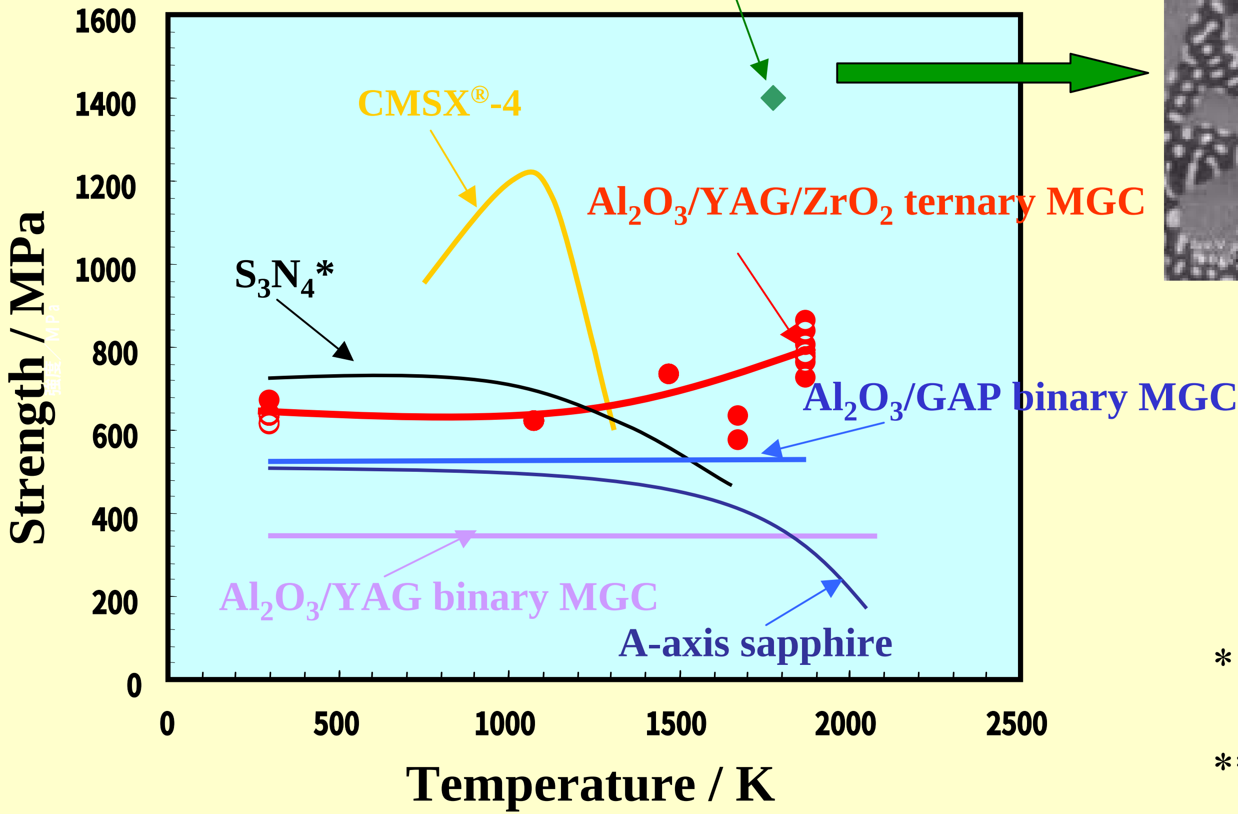
HRTEM image of interface

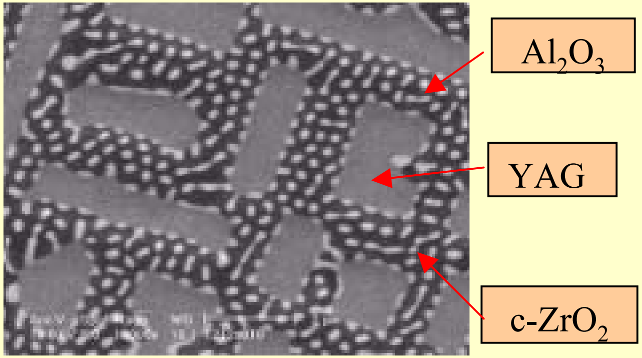


Temperature dependence of flexural strength of MGC compared with the polycrystal and single crystal.

Temperature Dependence of Strength

New type MGC of Al_2O_3/YAG/ZrO_2 ternary system manufactured by the micro-pulling down method**





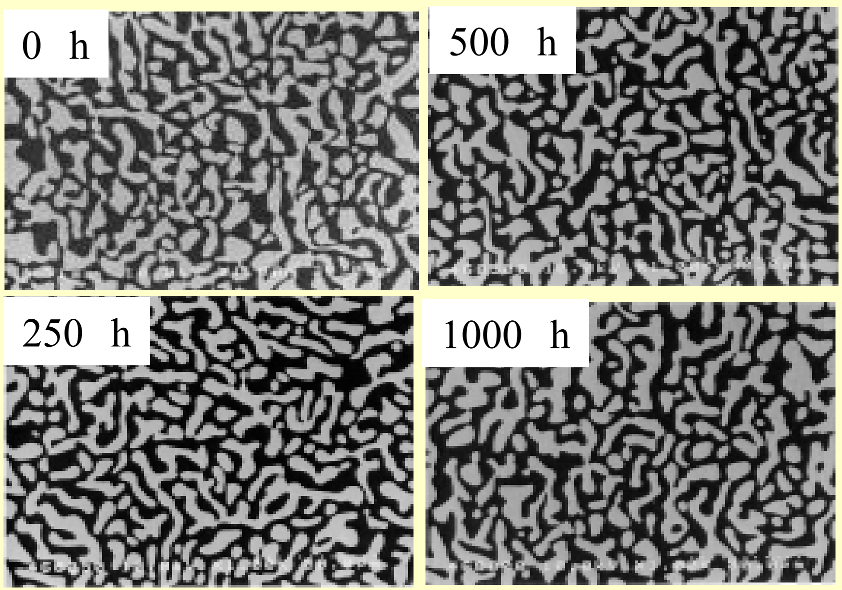
CMSX®-4:
Tensile strength
Al_2O_3/YAG/ZrO_2(MPD):
Compressive strength
Others:
Flexural strength

* Yoshida et al (1998)

** Professor T. Fukuda of Tohoku University

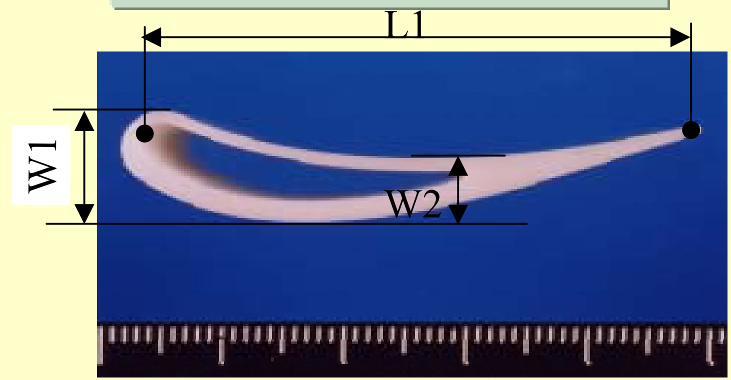
Thermal Stability of microstructures of MGC gas turbine components

The MGC components have excellent oxidation resistance with no change in dimensions ,weight and surface roughness after 1000 hours at 1973 K in an air.



SEM images of the microstructures of cross-section perpendicular to the solidification direction of the Al_2O_3/GAP binary MGCs after 1000 hours of the exposure test at 1973 K in an air.

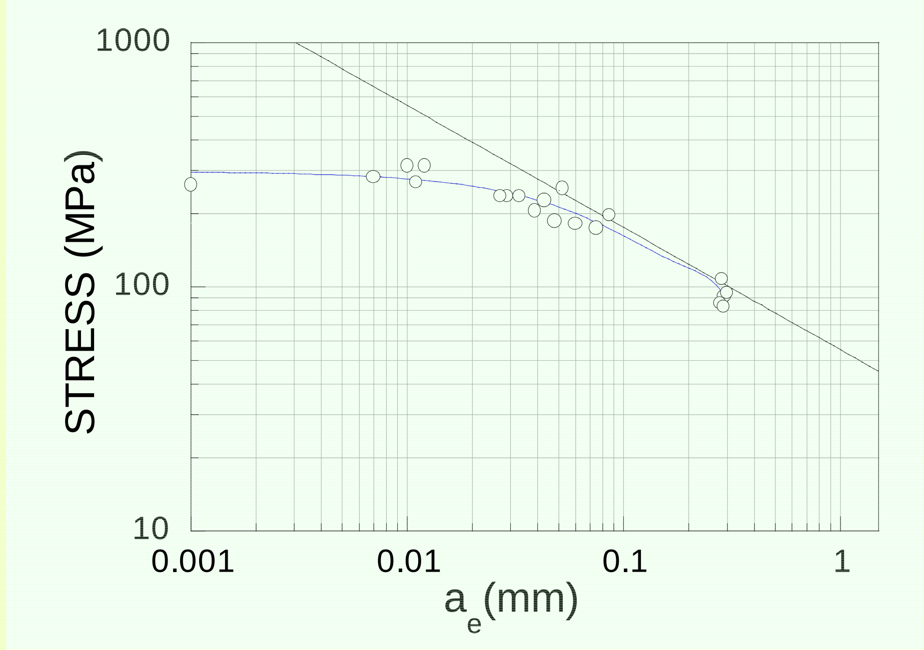
Hollow Turbine Nozzle Vane

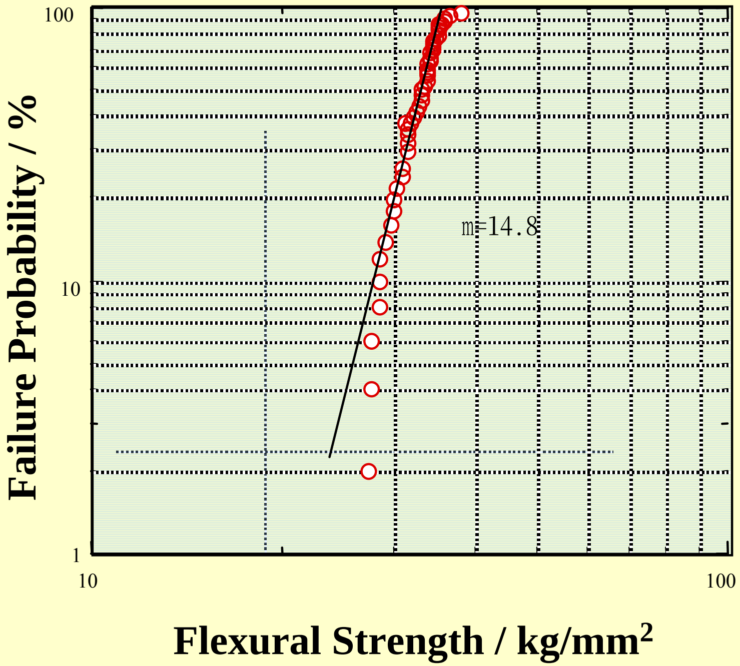


Properties of the MGC nozzle vane after the exposure test for 1000 hours at 1973 K in an air atmosphere.

Length	0 h	500 h	1000 h	Dimensional change
L1 (mm)	43.971	43.977	44.000	0.029
W1 (mm)	10.614	10.614	10.598	−0.022
W2 (mm)	5.389	5.385	5.371	−0.019
Weight (g)	26.194	26.232	26.227	−0.019
Roughness (Ra/μm)	0.46	0.78	0.75	0.29

Reliability for MGC





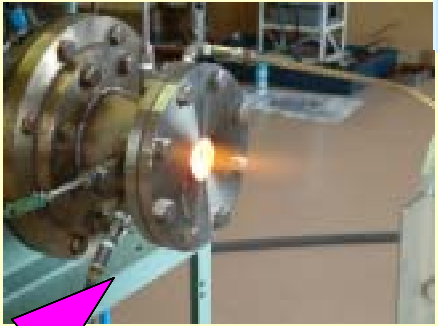
Relationship between equivalent crack length and fracture stress for Al_2O_3/YAG system MGC

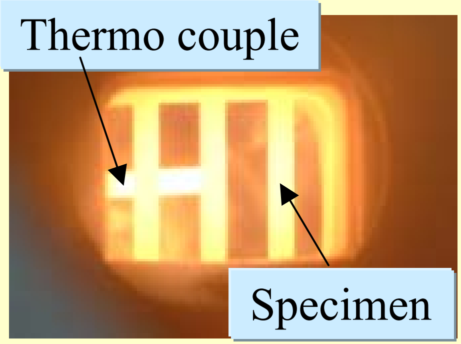
Weibull plot of the four-point flexural strength of Al_2O_3/YAG system MGC

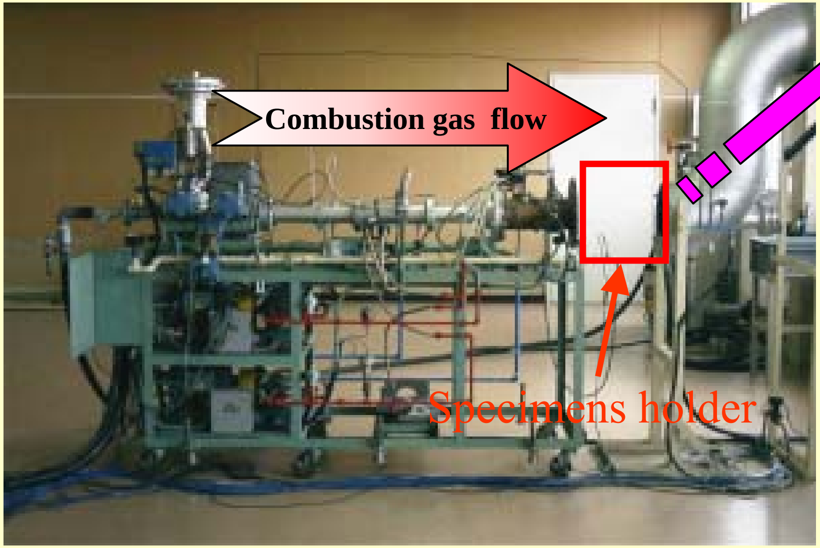
Exposure tests in combustion gas flow environment

Specification

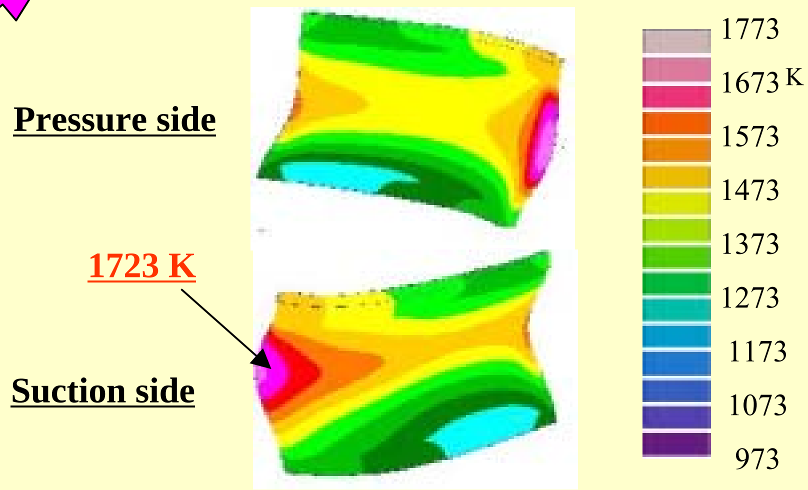
*Fuel : kerosene
*Combustion gas exit temperature : 1723-1773 K
*Combustion gas pressure : 0.3MPa
*Combustion gas speed : 500 m/s
* Vapor partial pressure : 45KPa
*Specimen size : 3x4x50 mm





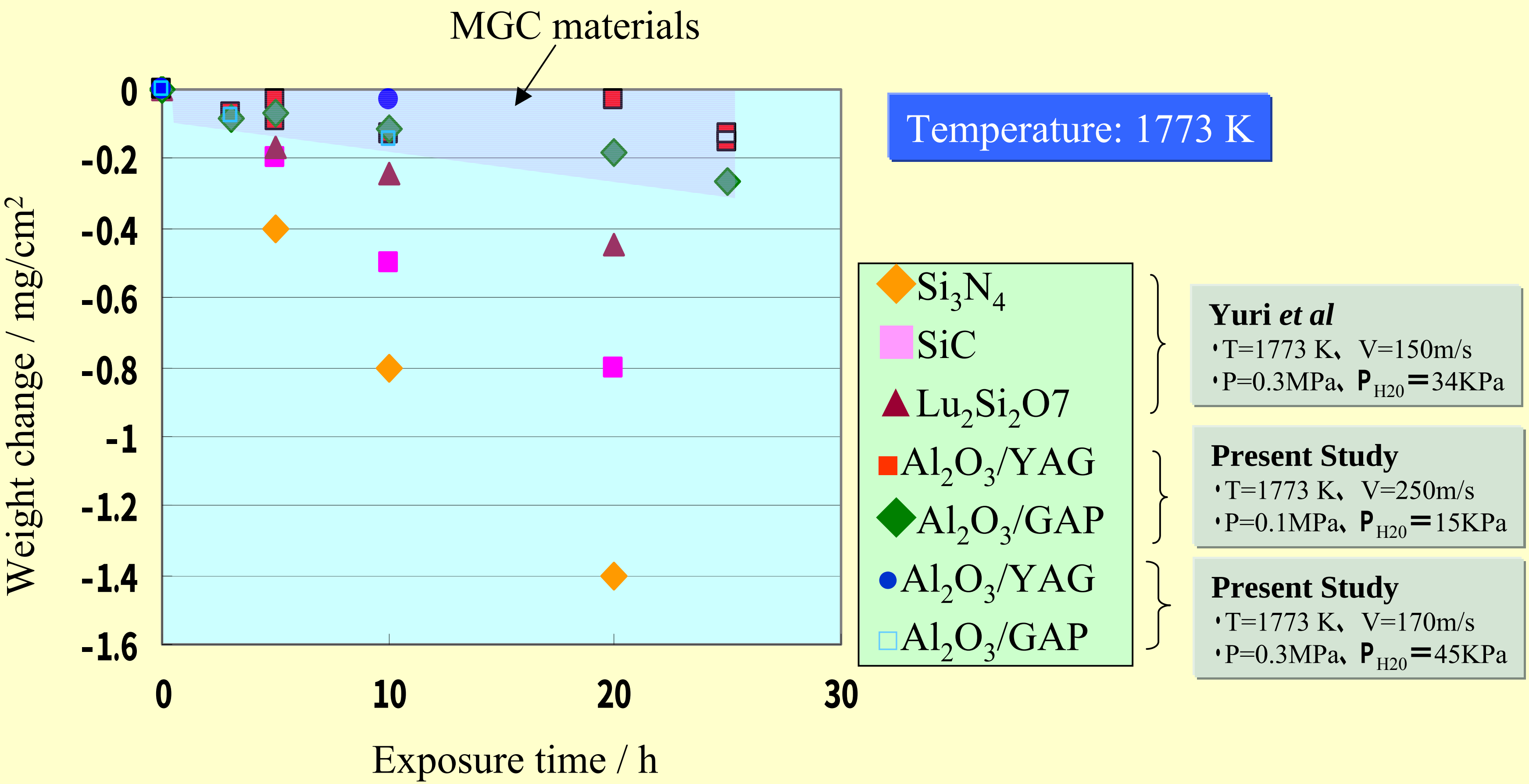


Appearance of combustion gas flow testing apparatus



Temperature distribution on the nozzle surface of the bowed stacking nozzle at a TIT of 1973 K.

Change in Weight Gain in Combustion Gas Flow for MGCs and Other Heat Resistant Materials



MGCs show superior resistance to the combustion gas flow atmosphere at 1773 K.

Prediction of Recession of MGC in Combustion Gas Flow Compared with Other materials

<u>Condition for SiC, Si_3N_4 and Al_2O_3</u>
P=1.52 MPa
V=110 m/s
P_{H2O}=94-155kPa
Time=10000 hr (estimated)

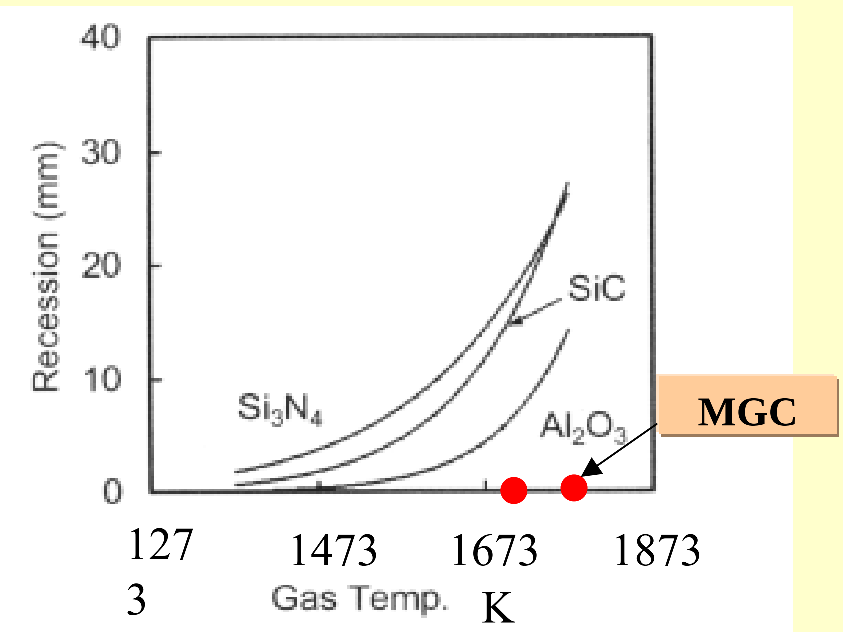
<u>Condition for MGC</u>
P=0.3 MPa
V=170 m/s
P_{H2O}=45 kPa
Time=10000 hr (estimated)

Maximum use temperature for oxide compound at P_{H2O}=1 atm

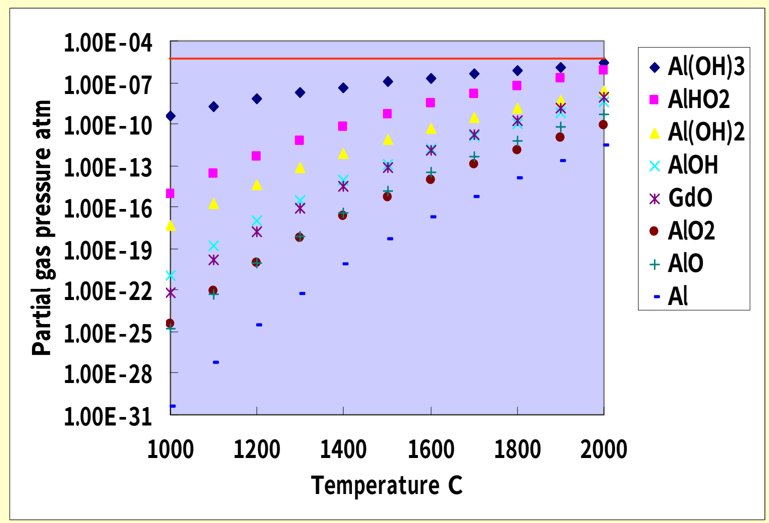
YAG : ~1973 K, GAP : ~1973 K

EAG : ~1973 K, Al_2O_3 : ~1723 K

ZrO_2 : >2273 K



Relationship between combustion gas temperature and predicted recession under a gas turbine condition



Partial gas pressure vs temperature for GAP

National Project in Japan

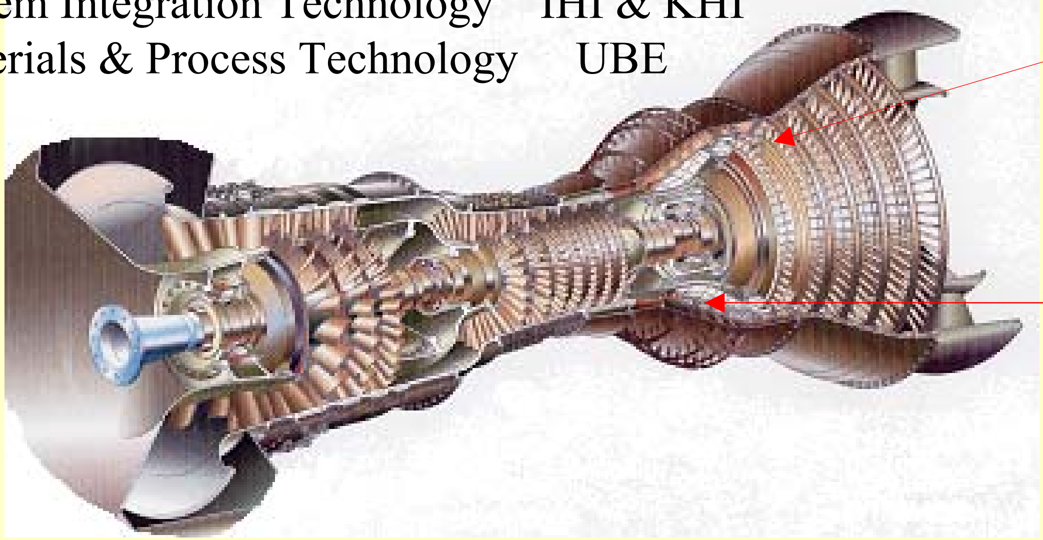
A NEDO national project on MGC run for 5 years from 2001 to 2005.

Objective:

- **MGC application technology to ultra-high efficiency gas turbine system**
- **MGC applied 1973 K class non-cooled, TBC/EBC-free gas turbine system**

The project was pushed forward by IHI, KHI and Ube Industries, LTD.

- System Integration Technology IHI & KHI
- Materials & Process Technology UBE

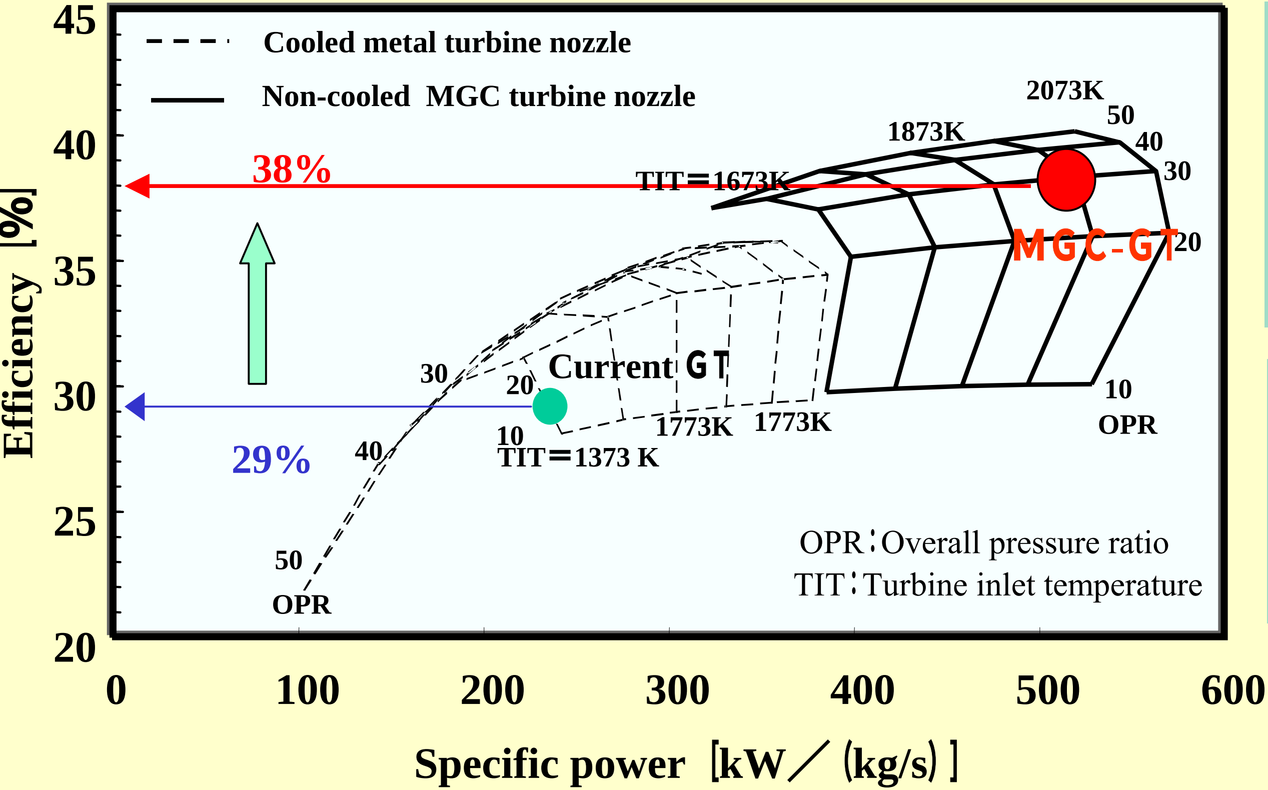


MGC Bowed Stacking Nozzle

MGC Combustor panels

Cycle Analysis - Efficiency Improvements -

Output Power : 5000kW



The dotted lines: the conventional gas turbine with the cooled metal turbine system.

The solid lines: MGC gas turbine with non-cooled turbine nozzle

Performance estimation of MGC gas turbine

The efficiency of the MGC gas turbine is higher than that of conventional gas turbine. For TIT 1973 K, a pressure ratio of 30, the efficiency increases from 29% to 38%.

MGC Components for High Efficiency Gas Turbine

Bowed stacking nozzle

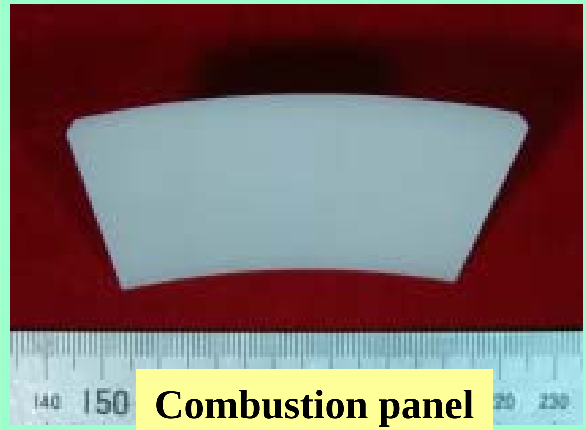
Outer band

Inner band

Nozzle

Assembly

Liner



Combustion panel

*The bowed stacking nozzle, the outer band and the inner band were manufactured from the Al_2O_3/GAP binary MGC that has high temperature strength superior to that of Al_2O_3/YAG binary MGC.

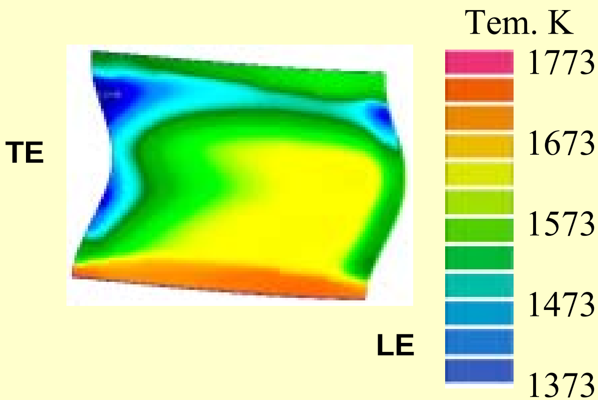
*The combustion panel was manufactured from the Al_2O_3/YAG binary MGC that is relatively easy to fabricate a larger component.

*All components were manufactured from MGC ingots by machining with a diamond wheel.

*We verified the structural integrity of this nozzle under the steady-state at 1973 K using the test rig.

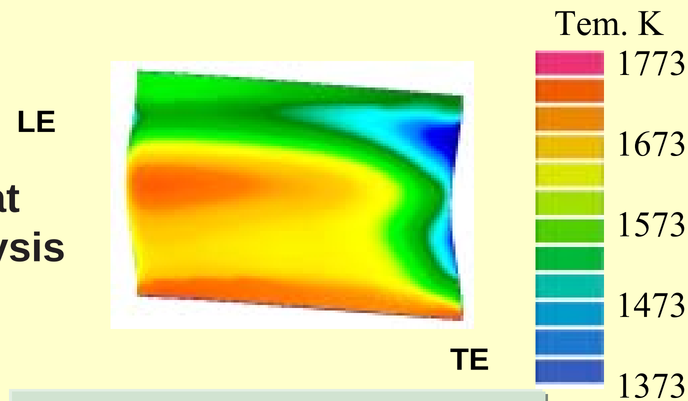
Analyzed transient tensile stresses in the bowed stacking nozzle during turbine shut-down

For selected nozzle under a TRIP condition from 1973 K

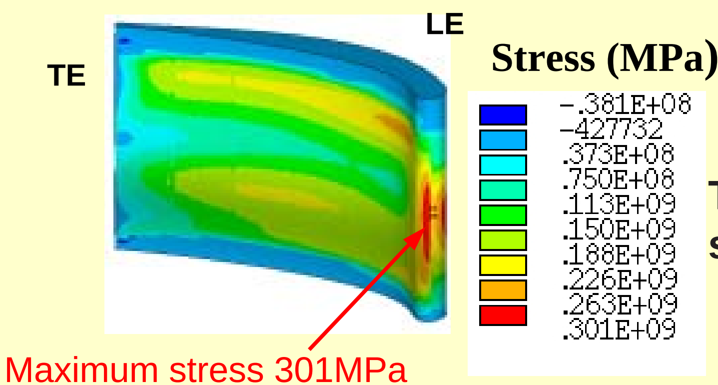


Surface temperature field (pressure side)

Transient heat transfer analysis

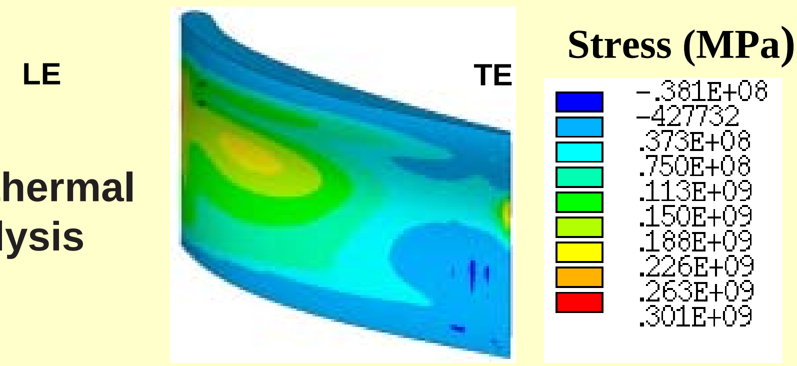


Surface temperature field (suction side)



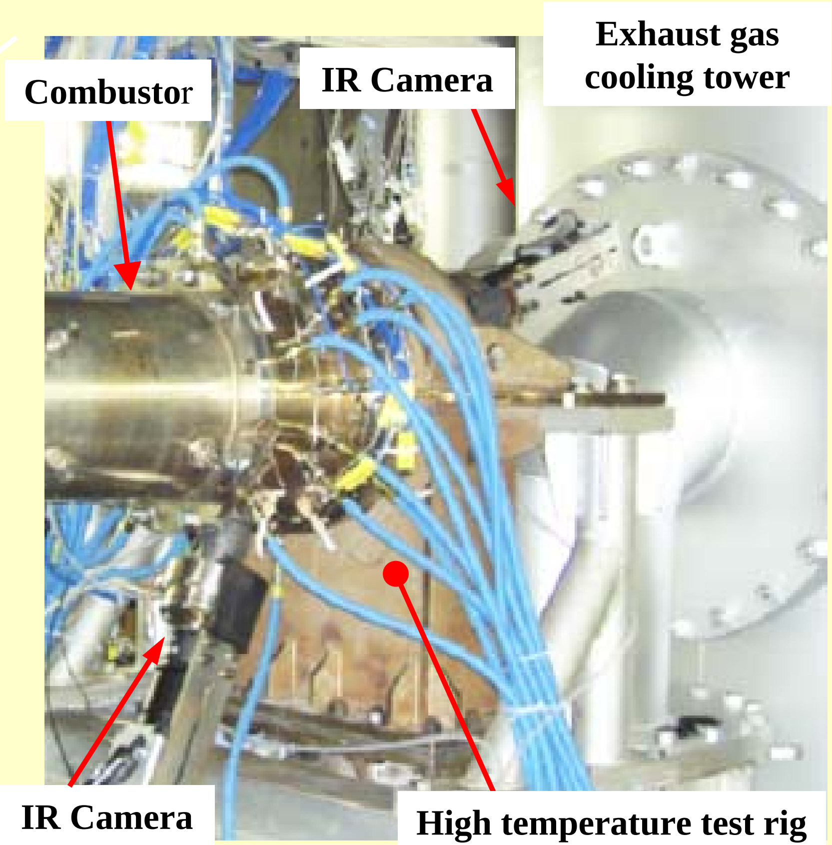
Stress field (pressure side)

Transient thermal stress analysis

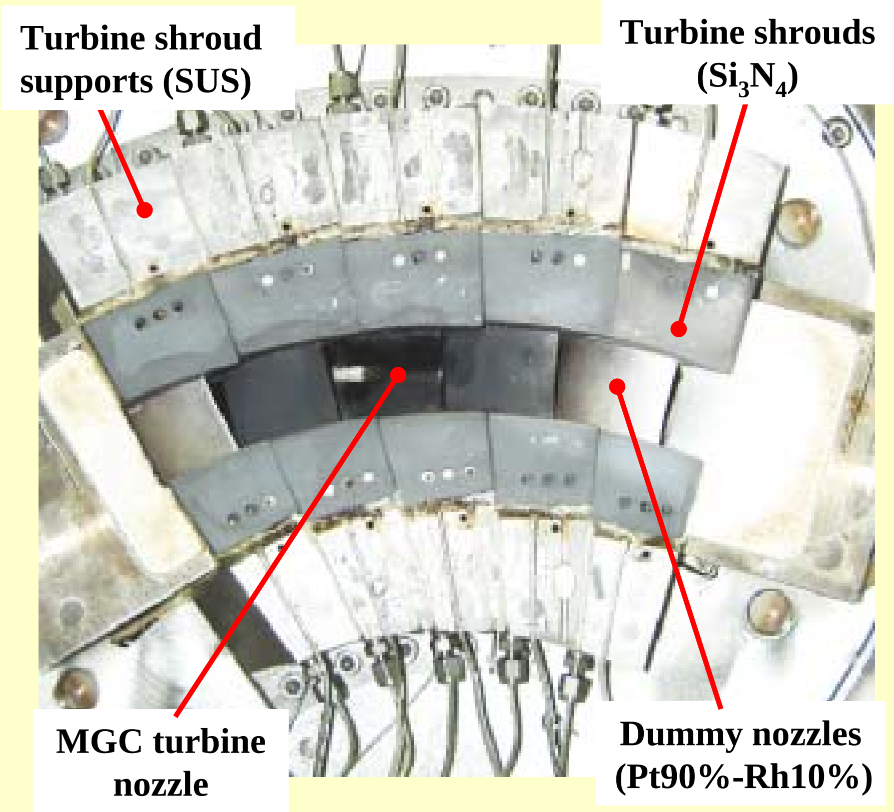


Stress field (suction side)

High temperature cascade test rig



Test rig installed in the high temperature test equipment



Nozzle cascade

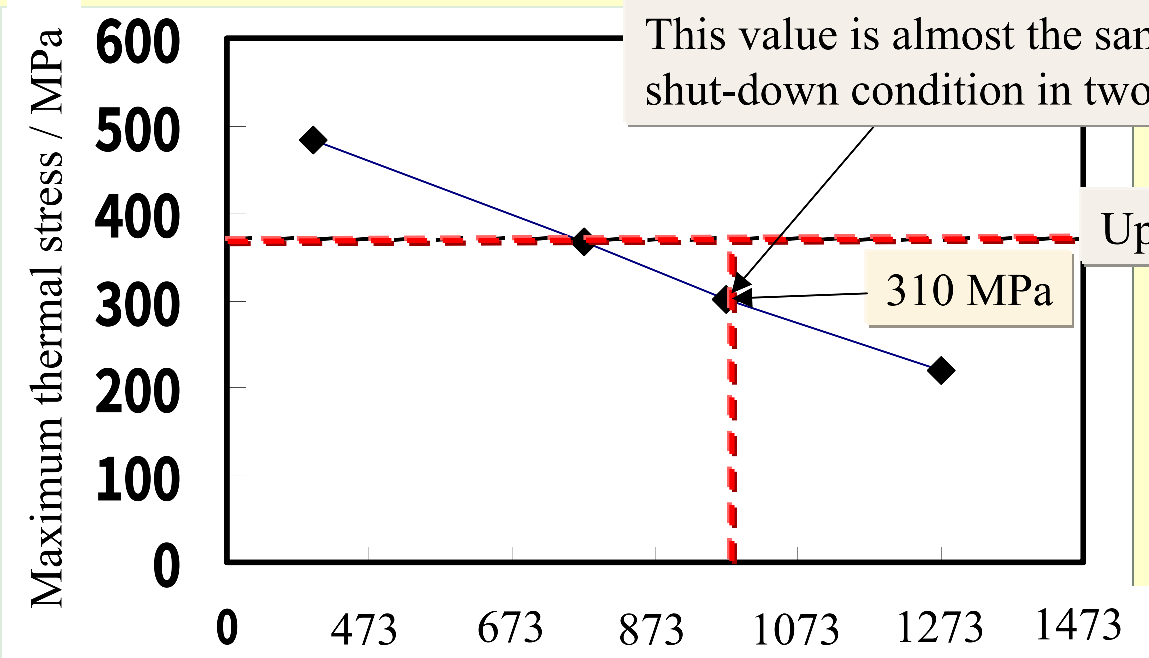
Maximum transient tensile stress and shut-down condition from 1973 K

Maximum transient tensile stress generated on the bowed stacking nozzle is about 310 MPa during shut-down in two seconds from TIT 1973 K to 973 K.

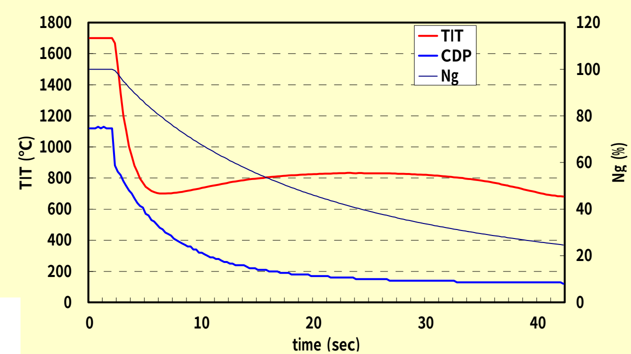
This value is smaller than the ultimate tensile strength of 370 MPa of the Al_2O_3/GAP binary MGC.

This value is almost the same as that analyzed under shut-down condition in two seconds from 1973 K to 773 K.

Upper limit of thermal stress

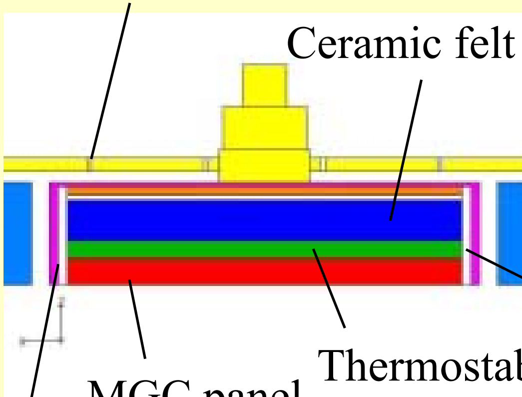


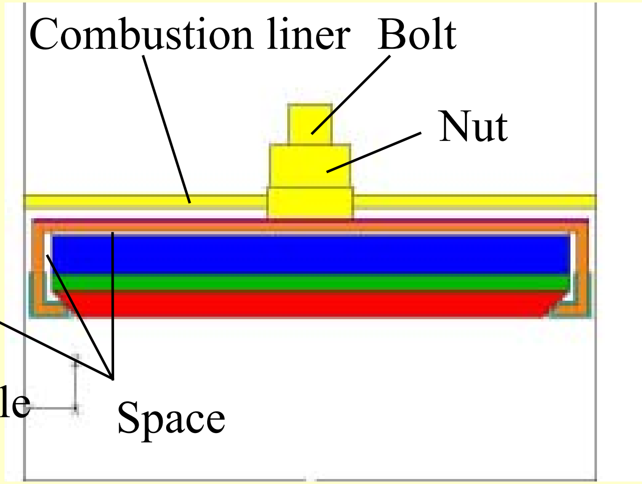
Temperature lowered from 1973 K during shut-down condition

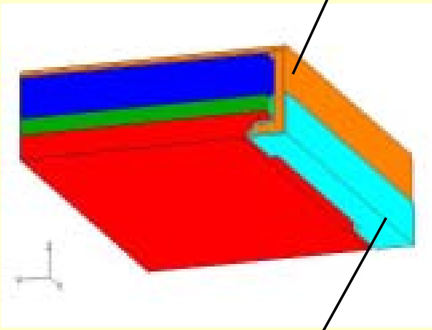


Change in TIT under TRIP condition

Improved MGC panel segment

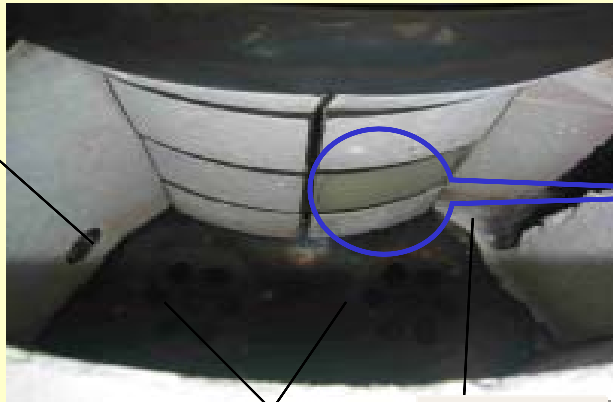




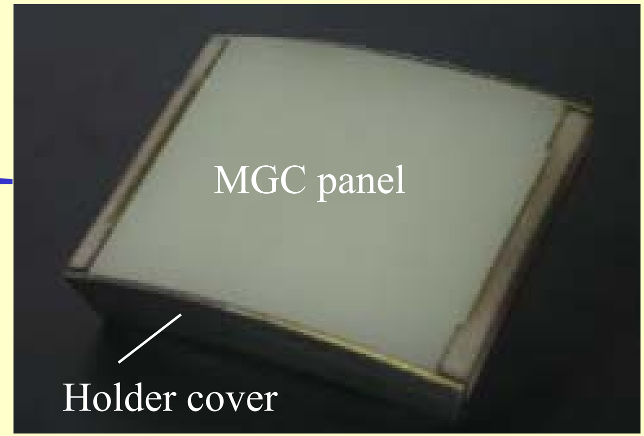


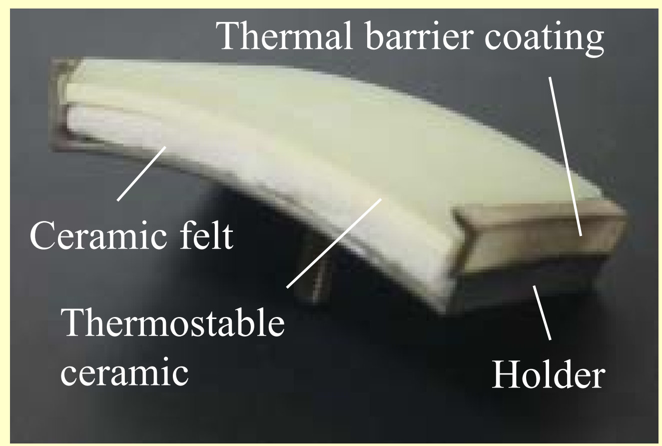
- The panel segment was consisted of MGC panel, thermostable ceramic and ceramic felt.
- The holder had thermal barrier coating.
- The panel segment had spaces to insulate from metal holder and holder cover.

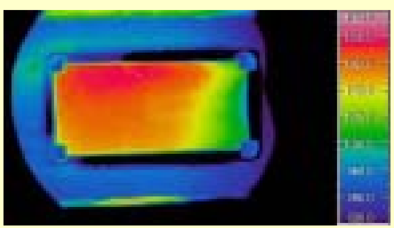
The internal of the model sector combustor



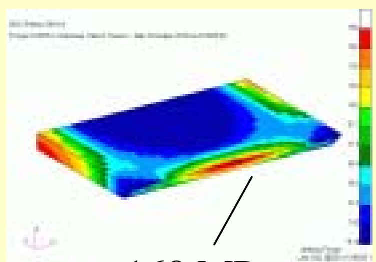
The inside of the 1973 K class model sector combustor







Temperature distribution on the panel (1973 K)



Thermal stress distribution (1973 K)

Concluding Remarks

- MGCs have the unique microstructure consisting of three dimensionally continuous and complexly entangled single-crystal Al_2O_3 and single-crystal compounds.
- MGCs (melt growth composites) , therefore, have many advantages over other ultra-high temperature structural materials.
- Especially, MGC shows superior resistance to the combustion gas flow atmosphere at 1773 K in comparison to SiC, Si_3N_4 and $Lu_2Si_2O_7$.
- Newly designed components for MGC such as the bowed stacking nozzle and the improved combustion panel segment to lead the minimum thermal stress generated during the shut-down were proposed and test rigs were carried out using these new designed components.
- The structural integrity of these components were ensured during the shut-down condition in two seconds from TIT 1973 K to 973 K .