Melt Growth Composites for Ultra High Efficiency Gas Turbine Components

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Yoshiharu Waku, Narihito Nakagawa*, Kenji Kobayashi**, Kazumi Hirano*** and Shinya Yokoi

HPGT Research Association
*Ube Research Laboratory, Ube Industries, LTD.
**Advanced Technology Department, IHI.
***National Institute of Advanced Industrial Science and Technology
Background & Motivation

- **Single Crystal Eutectic Composites**
  
  ex. $\text{Al}_2\text{O}_3/\text{Y}_3\text{Al}_5\text{O}_{12}$ (YAG), $\text{Al}_2\text{O}_3/\text{GdAlO}_3$ (GAP), $\text{Al}_2\text{O}_3/\text{Er}_3\text{Al}_5\text{O}_{12}$ (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

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*New eutectic composites* → *Improving design methodology*

Ultra-high temperature structural components for gas turbine

*Combustor liner, Turbine nozzle & Blade*
MGC Fabrication Process

【Merits】
- Microstructure control
- Production of complex near net shaped components

Mo crucible
Heat-insulating materials
Melt
Solidified body
High frequency induction coil
Graphite susceptor
Bridgman furnace at JUTEM

Molybdenum divided mold
Al₂O₃/YAG plate
Al₂O₃/GAP 53 mm rod
Microstructure and Three-Dimensional Network of MGCs

Microstructure of MGCs

Three-dimensional connected porous structure of irregular shape

A 3D image showing the network structure of the Al$_2$O$_3$/YAG system MGC obtained from X-ray computerized tomography (micro X-ray CT).
Temperature Dependence of Strength

CMSX®-4:
- Tensile strength
- Compressive strength
- Flexural strength

Al₂O₃/YAG/ZrO₂ (MPD):
- Al₂O₃/YAG binary MGC
- Al₂O₃/YAG/ZrO₂ ternary MGC manufactured by MPD**
- CMSX®-4
- S₃N₄*

YAG
- A axis sapphire

** Professor T. Fukuda of Tohoku University
Thermal Stability of the microstructures

- The grain growth was slightly observed after 1000 hours. However, the present MGC were shown to be comparatively stable without void formation during lengthy exposure at 1973 K in an air.
- The MGC components have excellent oxidation resistance with no change in dimensions, weight and surface roughness after 1000 hour at 1973 K in an air.

SEM images of the microstructures of cross-section perpendicular to the solidification direction of the Al₂O₃/GAP binary MGCs after 1000 hours of heat treatment at 1973 K in an air.

| Table.1 Difference of the MGC nozzle vane after 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           |
| Rouphness (Ra/μm) | 0.46           | 0.78           | 0.75            | 0.29            |
Organization of NEDO Project

Project term
FY2001-2005

Ministry of Economy, Trade and Industry (METI)

Total budget
(5 years)
3,000 million yen

New Energy and Industrial Technology Development Organization (NEDO)

Engineering Research Association for High Performance Gas Turbine (HPGT)

Ube Industries, LTD.
Ishikawajima-Harima Heavy Industries, LTD.
Kawasaki Heavy Industries, LTD.
A NEDO project on MGC application technology to ultra high efficiency gas turbine system (FY2001-05)

**Materials & Process Technology: UBE**
R&D on Innovative Process & Manufacturing Technology

- Near-Net Shape Casting of Complex Shape Components
- Improvements of Materials Reliability & Long-term Durability under Severe Environments (highly water vapor pressurized at ultra-high temperatures)

**System Integration Technology: IHI & KHI**
R&D on Gas-Turbine System Integration Technology

- MGC Gas Turbine System & Cycle Analysis
- MGC Turbine Nozzle & Vane

![MGC Bowed Stacking Nozzle](image1)

![Low NOx Combustor with MGC panels](image2)
Cycle Analysis - Efficiency Improvements -

Performance estimation of MGC gas turbine

Output Power : 5000kW

Cooled metal turbine nozzle

Non-cooled MGC turbine nozzle

Current GT

MGC GT

OPR : Overall pressure ratio
TIT : Turbine inlet temperature

Efficiency [%]

Specific power [kW / (kg/s)]
MGC Components of High Efficiency Gas Turbine

*The bowed stacking nozzle, the outer band and the inner band were manufactured from the Al$_2$O$_3$/GAP binary MGC that has high temperature strength superior to that of Al2O3/YAG binary MGC.

*The combustion panel was manufactured from the Al$_2$O$_3$/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.
Steady State Temperature and Thermal Stress Distribution at TIT of 1973 K

Temperature distribution

Temperature / K

Leading edge

Trailing edge

Thermal stress distribution

Tensile stress / MPa

Leading edge

Trailing edge

Maximum stress 117 MPa
High Temperature Test Rig at 1973 K

* The high temperature test rig (maximum temperature ~1973 K) have been improved to measure continuous temperature distribution on the nozzle surface by using an infrared camera.
* We are now planning the test rig at an inlet gas temperature level of 1973 K in order to ensure the structural integrity of the MGC bowed stacking nozzle and heat shield panel under the steady-state and thermal cycle conditions.
Concluding Remarks

• MGCs have the unique microstructure consisting of three-dimensionally continuous and complexly entangled single-crystal Al₂O₃ and single-crystal compounds.

• MGCs (melt growth composites) have many advantages over other ultra-high temperature structural materials.

• The NEDO project on MGCs Gas Turbine System was briefly introduced.

• The structural integrity of MGC turbine nozzles and heat shield panels was verified under the steady-state and trip conditions at 1773K.