Development of new gamma TiAl for turbocharger application

Gamma TiAl has a great potential for use in aircraft engine and automobile engine components. Since we demonstrated the potential of gamma TiAl as a turbocharger turbine wheel in 1987, a great effort has been paid in order to put the gamma TiAl turbine wheel to practical use. Through successful development of gamma TiAl alloy and of processes of casting and joining between the turbine wheel and an alloy steel shaft, we got into mass production of TiAl turbine rotors of turbocharger for passenger car application in 2003. Currently, heat resistance required for turbine wheels has become severe, because of the rise of exhaust gas along with development of fuel saving technologies to reduce CO₂ emission. Therefore, the new gamma TiAl was developed based on a conventional gamma TiAl under mass production. The new gamma TiAl showed high creep and oxidation resistant than the conventional gamma TiAl. In addition, it was confirmed that the new gamma TiAl has equal manufacturability to the conventional gamma TiAl.
Development of new gamma TiAl for turbocharger application

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Daido’s titanium alloys

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<th>Sports</th>
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<td>DAT54 (6Al-4Sn-4Zr-3Mo-1Nb-0.4Si-0.06C)</td>
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* PPC furnace
* GFM forging machine
* LEVICAST*
* LEVI atomization

*: Levitation melting and casting

Automobile

| DAT52F (3Al-2V-REM-S) |                            |
| DAT5M (6Al-4V-Fe)     |                            |
| DAT62M (6Al-2Sn-4Zr-2Mo-0.1Si) |    |
| DAT54                 |                            |
| DAT57M (VLTi, 6Al-1Fe) |                            |
| DAT-TA1 (TiAl)        |                            |
History of development of TiAl T/W in Daido

Export alloy or technology of Daido

Production total: 120,000 P

- Alloy:
  - Ti-36Al
  - Ti-33.5Al
  - RNT004*
  - DAT-TA1
  - DAT-TA2
  *: Ti-33.5Al-1.0Nb-0.5Cr-0.5Si

- Casting:
  - CLV** in CaO crucible
  - LEVICAST
  **: Counter gravity Low pressure Vacuum melt

- Joining:
  - Vacuum Brazing (Silver braze)
  - Pressured induction brazing (PIB)

- Manufacturing:
  - Experimental production
  - Mass production
  - 1998: Auto racing
  - 1999~: Passenger car


- The first publication concerning TiAl turbochargers: 1987
- Practical use of TiAl T/W: 1998
- Year

The first publication concerning TiAl turbochargers
Practical use of TiAl T/W
Feature of turbocharger

- **Feature of turbocharger**

1. **Power up**
   - output increase
2. **Compactification**
   - downsizing
   - weight saving
3. **Fuel saving**
   - combustion efficiency optimization
   - reduction of CO2 emission
4. **Exhaust gas purification**
   - clean making exhaust gas
     by fuel-air ratio optimization

- Good technology for the environment
- Increasing of total number of turbochargers

Fig. Illustration of turbocharger.
Materials for turbine wheel

Estimated Service Exhaust Gas Temperature (deg. C)

- DAT-TA1: Ti-33.5Al-4.8Nb-1.0Cr-0.2Si (Under Production)
- DAT-TA2: Ti-31.5Al-7.5Nb-1.0Cr-Si-C
- Mar-M247: Ni-0.15C-5.5Al-1Ti-10Co-8.3Cr-0.7Mo-3Ta-10W-1.5Hf-0.05Zr-0.015B
- Inconel713C: Ni-0.12C-6Al-0.7Ti-12.5Cr-4Mo-1.8Nb-0.1Zr-0.012B
- GMR235: Ni-0.15C-3.5Al-2Ti-10Fe-15.5Cr-5Mo-0.05B
Alloy design

TiAl under production

DAT-TA1(Ti-33.5Al-4.8Nb-1.0Cr-0.2Si)

High temperature strength

- Al and Nb optimization
- C addition

Lamellar phase stabilization

- Si increase
- C addition

Creep property

Oxidation resistance

- Nb and Si increase

Manufacturability

- Nb and C limitation

Developed TiAl

DAT-TA2(Ti-31.5Al-7.5Nb-1.0Cr-Si-C)
Density

Down by 50%
Tensile & creep rupture properties

**Strength (Tension)**

![Graph showing tensile strength vs. temperature for different materials.](image)

- **DAT-TA2** (Under Production)
- **DAT-TA1** (Under Production)
- **Inconel713C**(as-cast)*
- **Mar-M247**(as-cast)

Open: 0.2% Proof Stress
Solid: Tensile Strength

**Creep Rupture Strength**

![Graph showing creep rupture strength vs. Larson-Miller parameter.](image)

- **DAT-TA2**
- **DAT-TA1** (Under Production)
- **Inconel713C**(as-cast)*
- **Mar-M247**(as-cast)

Test Temp. : 750-1050 deg. C

Larson-Miller Parameter

\[
(273+T) \times \log |\tau t| + 20 \]/1000
Specific tensile & creep rupture properties

**Specific Strength (Tension)**

- DAT-TA2
- DAT-TA1 (Under Production)
- Inconel713C (as-cast)*
- Mar-M247 (as-cast)

**Specific Creep Rupture Strength**

- DAT-TA1
- DAT-TA2

- Larson-Miller Parameter: \((273+T) \times (\log|\Delta t|+20)/1000\)

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TITANIUM 2008

Daido Steel Co., Ltd.
Rotating bending fatigue strength

Rotation speed: 3,500rpm

DAT-TA2

DAT-TA1

Temperature (deg. C)

10^7 Cycles Endurance Limit (MPa)

DAT-TA2
DAT-TA1 (Under Production)
Inconel713C (as-cast)
Mar-M247 (as-cast)
Cyclic oxidation resistance

Test Condition

Atmosphere: air
Dew point: 30deg. C

Test Temp. x30min

RT. x30min

Diagram: Weight Gain (mg/cm²) vs. Temperature (deg. C)

- DAT-TA1 (Under Production)
- DAT-TA2
- Inconel713C (as-cast)*
- Mar-M247 (as-cast)
- Binary TiAl alloy

After 200 cycles
Various specific properties

- **Tensile Strength (900deg. C)**
  - DAT-TA2 (4.01 [g/cm³])
  - DAT-TA1 (3.94 [g/cm³]) (Under production)

- **Creep Rupture Strength**
  - 1000deg. C / 100hr

- **Rotating Bending Fatigue Strength**
  - 700deg. C / 10⁷ cycles
  - Inconel713C (7.91 [g/cm³])
  - Mar-M247 (8.59 [g/cm³])

- **Unit Axis**: MPa/(g/cm³)

The data of Mar-M247 is calculated from the data of 600deg.C and the data of 800deg. C.
<Advantage of LEVICAST>

1. Contamination free melting and casting
   - Oxygen content of TiAl cast is around 500ppm

2. Thin-wall castings
   - Minimum blade tip thickness of TiAl turbine wheel is 0.50mm

3. High productivity as compared with conventional processes
   - Short cycle of melting and casting
Experiment production of TiAl T/W

- **Alloy**: DAT-TA2
- **Condition**: as-cast
- **process**: LEVICAST

Photo. DAT-TA2 turbine wheels manufactured by LEVICAST

Photo. Macrostructure of DAT-TA2 turbine wheel by LEVICAST
In order to provide the excellent performance at higher exhaust gas temperatures, new gamma TiAl alloy DAT-TA2 was developed based on DAT-TA1 which is in production.

- DAT-TA2 has excellent mechanical properties for turbine wheels as compared with conventional turbine wheel materials.
- DAT-TA2 is available for turbine wheels of turbochargers for gasoline engine at high exhaust gas temperatures.
Thank you for your attention