Technologies for reliable titanium alloy forgings focusing on ultrasonic inspection in aerospace industry

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Kobe Steel, Ltd.
Kobe Steel has integrated production line for titanium alloy products which allows us consistent quality design and quality control.
Long Supply History for Aerospace – 55 years

- No. 1 titanium supplier on the aerospace market in Japan.
- First delivery for aerospace application was in 1959.

Supply Record for V2500 Jet Engine

- Fan Cases: More than 10,000 pcs Delivery with Internal Ingots since 1985
- Compressor Disks and Shafts: More than 6,000 pcs Delivery with Internal Ingots since 1986

(Courtesy IHI)
New production facilities

• Recently, we have installed new production facilities which allowed us provide large titanium forgings meeting specifications in aircraft industry.
• 50,000 metric ton forging press, Heat Treatment Plant, Inspection Plant, et al.

Japan Aeroforge: 50,000 metric ton forging press  
Started-up in 2013
Technology platform for process design

- Process design is key technology to provide high quality titanium forgings.
- Establishment of forging simulation technique and processing window is essential.

![Diagram of process design]

- **Process design**
  - **Initial condition**
    - Forging method
    - Forging condition
    - Dies shape
    - Preform shape et al.
  - **Forging simulation using FEM**
    - Temperature, Strain
    - Strain rate
    - Shape, Load et al.
  - **Processing window**
    - Based on microstructure, properties et al.
  - **Mechanical tests**
  - **Inspections**
    - Tensile properties
    - Fatigue properties
    - Toughness
    - Ultrasonic inspection
    - Metallograph et al.
Forging simulation using FEM analysis

Stress-strain curves (Compression test)

Isothermal flow stress curves (Input data in FEM)

- Removed the adiabatic heating effect

Optimized boundary condition

Equivalent strain distribution

Temperature distribution

Kobe Steel, LTD. Proprietary Information
Experimental facilities for process design

- **Thermo-mechanical simulator (Small test piece)**
  - Hot deformed microstructure
  - Forging Temperature/PC
  - Strain

- **Lab-scale forging press**
  - Isothermal forging
  - Billet forging

- **Microstructural analysis, characterization**
  - OM, SEM
  - SEM/EBSD
Technologies of improving ultrasonic detectability

- Our goal
  - Design our forging process (Shapes of dies and preforms, and process conditions et al.) to optimize mechanical properties and ultrasonic detectability.
Necessity of ultrasonic inspection

- Each defects in titanium alloys have the potential to cause catastrophic aircraft engine failures.

- Defects in forgings
  - Inclusions (Hard alpha et al.)
  - Cracks
  - Voids
  (Rarely occurred, but it is crucial.)
Influence on ultrasonic detectability

- Material characteristics
  - Density, Wave speed,
  - Attenuation,
  - Grain size, Grain shape,
  - Texture, et al.
- Inspection characteristics
  - Frequency (Wavelength),
  - Diameter of transducer,
  - Focal length, Focussed or flat, et al.

Beta forged Ti-6246 alloy
- It have good strength and toughness balance so it is used for critical parts (disks et al.) in aircraft engine. But it is well known that beta forged titanium alloys generate high backscattering noise due to microstructure.

- Clarification of the effect of microstructure on ultrasonic noise.
- Establishment of a prediction technique of ultrasonic noise.
Lab-scale experimental results

Microstructures
(Non-deformation)
0% reduction

67% reduction

Ultrasonic signals (Measured)
- Frequency: 5MHz

Surface echo

Bottom echo

F.D.: Forging direction

F..D.: Forging direction

β grain boundary

Elongated β grain

RMS signal level / V

Time/μs

230 235 240 245 250

200μm

200μm

0% 67%

Kobe Steel, LTD. Proprietary Information
Lab-scale experimental results

Incident ultrasonic wave

- Parallel to the F.D.
- Perpendicular to the F.D.

Elongated β grain

F.D. : Forging direction

Graph:

- Red line: Parallel to the F.D.
- Blue line: Perpendicular to the F.D.

Axes:
- X-axis: Time/μs
- Y-axis: RMS signal level / V

Values:
- Time/μs: 230, 235, 240, 245, 250
- RMS signal level / V: 0, 0.005, 0.01, 0.015, 0.02, 0.025
Computer simulation regarding ultrasonic scattering

- Computer simulation based on FEM

**Transducer**

**Homogeneous body**

**Multilayered model (Titanium alloy)**

**Air**

**Grain** (Velocity 1)

**Planar grain boundaries**

**Ultrasonic signals (Simulated)**

- Transmitter pulse
- Bottom echo

- Intensity of signal (a.u.)

- Time/μs

- Backscattering
Computer simulation regarding ultrasonic scattering

Case 1  Case 2  Ultrasonic signals (Simulated)

- These simulation models provide similar profiles to experimental results.
Concept of process design for ultrasonic detectability

- Initial condition
- Forging simulation using FEM
- Ultrasonic simulation using FEM
Practical application to production-scale parts

- Material: Ti-6246 alloy

Heating → Hot die forging → Fan AC followed by STA → Machining

General Appearance of disks
- Diameter: approx. 700mm
- Thickness: approx. 50mm

Disc 1: Not applied
Disc 2: Applied
Practical application to production-scale parts

- It allows us to provide forging parts with lower backscattering noise (Higher reliability).

Disc 1: Not applied
Higher noise (Bad)

Disc 2: Applied
Lower noise (Good)
Conclusions

• Kobe steel is an integrated manufacturer of titanium forgings, from melting process to final products, and we have essential technologies to provide high quality titanium forgings, such as forging simulation, dies design, process design, et al.

• Besides mechanical properties, ultrasonic detectability is required for critical parts (like disks) in aircraft engine. It is well known that ultrasonic testing for titanium alloy forgings is difficult because ultrasonic backscattering noise due to microstructural features can mask reflection from defects.

• This talk introduced the outline of our technologies to improve the ultrasonic detectability of titanium forgings.
Thank you for your attention.