Development of Cold Forging Technology for Beta-Titanium

October 2006

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Various bolts and parts made with titanium

(Reference: Japan Titanium Association)
Titanium materials for bolts and parts

<table>
<thead>
<tr>
<th>Kind of material</th>
<th>Tensile strength</th>
<th>Young’s Modulus</th>
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</thead>
<tbody>
<tr>
<td>Unalloyed titanium</td>
<td>300 ~ 500 MPa</td>
<td>105 GPa</td>
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<tr>
<td>Ti-6Al-4V (annealed) (ST-A)</td>
<td>900 MPa</td>
<td>115 GPa</td>
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<tr>
<td></td>
<td>1200 MPa</td>
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</tbody>
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- Ti-6-4 is generally used for high strength bolts.
Ti-6Al-4V bolts

(1) Hot forging

(2) Machining only

Thread rolling or machining

Manufacturing costs are higher than cold forging.
Feature of Ti-15V-3Cr-3Sn-3Al (1)

- Good cold workability
  - No cracks are generated even if Ti-15-3-3-3 is deformed to 80%.
  - Ti-15-3-3-3 can be cold forged.

- High tensile strength due to aging
  - Tensile strength: 750~800MPa (annealed)
  - Aging: 1000~1200MPa

Ti-15-3-3-3 is a good material for high strength bolts.
- Since Ti-15-3-3-3 does not start creep at room temperature, it is suitable for high strength bolts.
Why is cold forging difficult for Ti-15-3-3-3?

- The Young’s modulus is low. (~80GPa / less than half that of steel)
  - It is easy to gall with the die when the reduction and hollowing process are performed.

- Thermal conductivity is low. (8.1W/m K / one tenth that of steel)
  - The temperature of the contact surface between material and die is increased locally by friction heat, so it is easy to gall.
Ti-15V-3Cr-3Sn-3Al bolts

POINTS

- **galling prevention coating for the material**
  By coating materials with the appropriate oxide layer and lubricant, galling can be prevented.

- **cooling the material and the die effectively**

→ **Trial production**
The cold forging process of the bolts:

Stage 1: Chamfer the edge of the shaft
Stage 2: Reduce the shaft (forward extrusion)
Stage 3: Upset the head part
Stage 4: Reduce the head part and form the head shape
Stage 5: Hollow the head part (backward extrusion) and expand the flange
Production equipment

Parts former
(Reference: SAKAMURA MACHINE CO., LTD)
A bolt made from Ti-15-3-3-3

- Trial production was successful.
  10,000 bolts were made by this cold forging process.
Relationship between the tensile properties of Ti-15-3-3-3 bolts and aging condition.

- **Tensile strength without aging** is about 900 MPa.
- **Though maximum tensile strength exceeds 1200 MPa,** the elongation declines about 1%.
- **Tensile strength of 1000~1100MPa** is appropriate for Ti-15-3-3-3 bolts.
Microstructures of the cross section of screw part
(a) 800 degree C solution treatment and 570 degree C aging
(b) 570 degree C aging

- The microstructure of (a) is coarse, so the elongation is low.
- The microstructure of (a) is fine, so the elongation is not declined.
Relationship between aging temperature and tensile properties of Ti-15-3-3-3 smooth and notch specimens

- When the tensile strength of smooth specimen exceeds 1200MPa, the tensile strength of notch specimen declines from the peak. Then the bolts cannot be used by the tensile strength over 1200MPa.
The relation between temperature and tensile properties of Ti-15-3-3-3 bolts

- A tensile strength of 1000~1100MPa is appropriate for Ti-15-3-3-3 bolts considering the balance between tensile strength and elongation.
Summary

- Cold forging of Ti-15-3-3-3 bolts is enabled by improvements of galling prevention coating, that is the appropriate oxide layer and lubricant.

- The trial production of 10,000 bolts by cold forging was successful. So, it is expected that the cost of high strength titanium bolts become lower than that of Ti-6-4.

- Ti-15-3-3-3 bolt has a strength of 1000~1100MPa and it is expected to contributes to weight reduction of the parts.