"A Newly Developed Press-Formable High-Strength Titanium Alloy."

The quantity of cp titanium sheet products shipment has been increasing over the last 10 years. Now a day, plate type heat exchanger (PHE) has become major application. At present, though the highest press-formability of cp titanium (that is the softest: ASTM Gr.1) is required in manufacturing "plates" parts, PHE users request higher working pressure for higher performance in some cases. In other words, titanium sheet itself must have higher strength without deterioration of press-formability. In this paper, in order to satisfy this demand, we have proposed a newly Ti-1.5Fe alpha-beta alloy, which has superior combination of high tensile strength over 500MPa and excellent press-formability, comparing ASTM Gr.2 sheet. These characteristics have been achieved by adding appropriate Iron content to obtain higher strength and maintaining alpha-beta dual phase microstructure, consequently refining microstructure and suppressing Oxygen content in order to maintain higher ductility / press-formability.
A newly developed press-formable high-strength titanium alloy

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Contents

- PHE and Titanium market for PHE
- Requirements to titanium for PHE
- Characteristics of a newly developed alloy
- Simulation technique for press-forming
- Conclusion
What is PHE?

PHE = Plate Heat Exchanger

An example of corrugated pattern

Working principle of PHE

PHE product

Courtesy of Alfa Laval
Applications of PHE using titanium plates

<Conventional application>
- Central cooling system
- Power / Chemical / Desalination, etc

<Near future application>
- Thermal Energy Conversion Plant
  - DTEC: Discharged Thermal Energy Conversion
  - OTEC: Ocean Thermal Energy Conversion

Concept of OTEC
From Institute of Ocean Energy, Saga University
Titanium shipment for PHE

Forecast for construction of DTEC/OTEC* plant

<table>
<thead>
<tr>
<th></th>
<th>2013</th>
<th>2018</th>
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</thead>
<tbody>
<tr>
<td>Power generation output (MW)</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>Quantity of titanium plate (MT)</td>
<td>1,800</td>
<td>18,000</td>
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</tbody>
</table>
Requirements to titanium for PHE

PHE needs

- Low cost & Stable mass supply
- Higher performance
  > Higher pressure
  > Higher temperature
  > Higher heat transfer rate

Solution

- New extracting/refining methods
  > Permissible impurities
- Higher strength with good press-formability
- Simulation technique for plate forming considering forming properties of the material
Requirements to titanium for PHE

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A new refining method in Japan
"JTS method"
under development

TiO₂ + C + 2Cl₂ → TiCl₄ + CO₂

Chlorination

Cl₂

Diaphragm

Ca/CaCl₂

Ca Reduction

Recovering

TiCl₄ + 2Ca → Ti + 2CaCl₂

Electrolysis

Plasma

Melting

Separation

Raw Material

by Osaka Titanium Technologies & Toho Titanium
Requirements to titanium for PHE

**PHE needs**

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**Solution**

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High pressure operation in DTEC

- **Conventional PHE**
  - 2.5MPa (Ex.)

- **DTEC/OTEC PHE**
  - 15MPa
Alloy Design of Ti-1.5Fe

<Elements>
- Fe: 1.0-2.5 wt% → Solution hardening and β phase

<Process>
- Rapid heating anneal → fine and uniform grains
  *Annealing Pickling Line

Good balance of strength and formability
Good balance of strength and stretch-type formability
An evaluation method of formability for PHE

Herringbone type test die

Pressed sample

Die Size 100mm X 100mm

Scoring at each circled point

2 : No crack
1 : Necking
0 : Crack

Formability(%) = \[ \frac{\text{Summed marks}}{\text{Full Marks (No crack)}} \times 100 \]
Formability of Ti-1.5Fe, if well lubricated, is as good as Gr.1’s.
Requirements to titanium for PHE

PHE needs

- Low cost &
  Stable mass supply

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Solution

- New extracting/refining methods
  > Permissible impurities

- Higher strength with good press-formability

- Simulation technique for plate forming considering forming properties of the material
More accurate forming simulation

- Precise data at omni direction
- Stress-strain curves (Left Fig.)
- r-value-strain curves
- Yield surface data
- Constitutive equation from measured yield surface data
- Friction condition

FEM calculation for sheet forming

Tensile strength data at various direction
Simulation during square deep drawing

Good agreement with calculated and experimental data
Simulation of Herringbone type forming

Thinnest part is correspondent with the crack area

<Ti-1.5Fe>
thickness: 0.30mm
Conclusion

- A newly developed alloy shows good balance of strength and formability for high performance PHE.

- FEM simulation considering the omni-directional mechanical properties of titanium and new alloy shows good agreement with experimental results.
# Kobe Steel's original alloys

## Automobiles
- Exhaust system: KSTI-1.2ASNEX, KSTI-1.5AL
- Connecting Rod: KS8-1-1C, KS EL-F, KS EL-FII
- Engine valves: KS72SiC, KS6-4-4-1TA
- Suspension Spring: KS8-8-2-4-3

## Aerospace
- Structural materials:
  - Plate/Sheets: KS TI-9
  - Bars/Forgings: KS EL-F, KS EL-FII

## Industries
- Chemical Plants: KSAKOT, KS50TA
- PHE: KS1.5FE

## Others
- Medical Implants: KS6-2-1, KS15-5-3
- Golf Club: KSTI-9, KS EL-F, KSTI15-0-3,....
- Watches, Cutleries: KS100, KS120SI

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Thank you for your kind attention!