A high performance titanium sheet for plate type heat exchanger

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Contents

- The small thermal energy conversion, such as OTEC
- Requirements to material for PHE
- Press formability development with Pre-coated titanium
- The technology to improve the thermal efficiency of vapor heat exchanger
What’s the OTEC?

- Ocean Thermal Energy Conversion (OTEC) is the power generation system with an extremely low emission of carbon dioxide.
Principles of OTEC Technology

- There is a temperature difference of over 20 degrees Celsius in the ocean.
One major characteristic of OTEC is the use of a working fluid such as ammonia with low boiling point.
Heat exchanger of Evaporator and Condenser

- Titanium Plate Heat Exchanger is the best.

PHE can improve heat transfer efficiency.
### OTEC Roadmap

<table>
<thead>
<tr>
<th>C.Y.</th>
<th>Power Generation Output [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2015</td>
</tr>
<tr>
<td>Hawaii (U.S.A.)</td>
<td>35</td>
</tr>
<tr>
<td>France</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td></td>
</tr>
</tbody>
</table>

1) The Hawaii Clean Energy Initiative  
2) IFREMER  
3) New Energy and Industrial Technology Development Organization

- Demand of titanium is estimated to be 18,000 MT/1000MW
Requirements to material for PHE

Thermal resource is **Seawater**.

A working fluid is **Ammonia**.

Vapor pressure in plate channels is about **15MPa**.

Plates are manufactured by **Press forming**.

**Temperature Difference** is small.

- **Requirements**
  - High corrosion resistance
  - Higher Strength
  - Good formability
  - High heat transfer rate

**Solution**

- **Titanium**
- **Pre-coated Gr.2 titanium**
- **Design optimization of material & PHE**
Press formability development with Pre-coated titanium
## Lubricant for Press forming

### Lubricant and press formability of Titanium Sheet

<table>
<thead>
<tr>
<th>Material</th>
<th>Grade</th>
<th>ASTM G1</th>
<th>Thickness</th>
<th>0.8mm</th>
<th>Finish</th>
<th>2B</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Comparison of usual lubricant method</th>
<th>Pre-coated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press formability</td>
<td>oil</td>
</tr>
<tr>
<td></td>
<td>film</td>
</tr>
<tr>
<td>Press formability</td>
<td>Not good</td>
</tr>
<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Dimensional accuracy of products</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Not good</td>
</tr>
<tr>
<td>Productivity</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Not good</td>
</tr>
</tbody>
</table>

- **Pre-coated**
  - Good

### Erichsen value (mm)

<table>
<thead>
<tr>
<th>Erichsen value (mm)</th>
<th>without lubricant</th>
<th>oil</th>
<th>film (P.E.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lubrication and press formability of Titanium Sheet
Design concept of coating

- Hard to break after severe forming
- Enough thin for forming accuracy
- Easily removed after forming
## Contents of pre-coat layer

<table>
<thead>
<tr>
<th>Contents</th>
<th>mass %</th>
<th>Roll</th>
</tr>
</thead>
</table>
| Acrylic Resin     | 80     | 1) holds sufficient adhesive strength.  
2) maintains enough flexibility to severe deformed surface.  
3) Dissolves easily into alkaline solution. |
| Silica            | ~10    | 1) gives moderate hardness                                          |
| Polyolefin wax    | ~10    | 1) leads to low static/dynamic friction.                             |

- Pre-coat layer contains no harmful metal and organic chemicals.
Pre-coated titanium shows excellent formability compared to one with polyethylene film as lubricant.
Evaluation method of formability

In practical size die

How to Score (Index for Press-formability)

1. Evaluation Points and their number
   - Apex: 18 (Concave) 18 (Convex)
   - Ends of beams: 56

2. Scoring at each point (E)
   - 4: No Crack
   - 3: Necking
   - 2: Severe Necking
   - 1: Small Crack
   - 0: Large Crack

Score (%): \[
\frac{\sum E_{1,2} \times 100}{(18 \times 4 \times 2 + 56 \times 4)}
\]

Dimensions:
- Forming Height: 4.5mm
- Radius of beams: 3.4mm
- Pitch between beams: 14.9mm
- Thickness: 0.5mm
20% stronger pre-coated titanium has same excellent press formability as a conventional CP titanium for PHE using press oil as a lubricant.
Removable coating layer by alkali cleaner

- Only 60 sec. dipping in alkali cleaner can remove pre-coating layer perfectly.
Technology to improve the thermal efficiency of vapor heat exchanger
Improvement process

1. Elucidating and characterizing the behavior of ammonia on a compact plate evaporator, a type of PHE

Because the boiling heat transfer performance of ammonia has not yet been elucidated.

2. Design optimization of material & PHE
Experimental apparatus

Test plate

Thermocouple sheath
Comparisons of local heat transfer coefficient on quality at different mass flux
Visualization

- Liquid phase
- Plate
- Vapor phase
- Flame
- Sight glass

Digital Camera

- Flow direction
- Z=1.0
- Z=0.9

Quality 0.26
Quality 0.28
Quality 0.63
Quality 0.66

- $G = 10 \text{kg/m}^2\text{s}$
- $q_{av} = 20 \text{kW/m}^2$
- $P_{abs} = 0.7 \text{MPa}$
Conclusions

- KOBE STEEL has been developing the high performance titanium for PHE of small thermal energy conversion.
  - Pre-coated titanium for good formability
  - Titanium with high heat transfer coefficient
    (under development)

- There is a possibility to apply these technologies to the conventional heat exchanger.
Thank you for your kind attention!