Development of High-Temperature LiPb-SiC Blanket

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Li-Pb blanket studies at Kyoto Univ.

Topics include in this talk

• SiC-LiPb blanket concept development
• Li-Pb loop and its operation
• Compatibility tests
• Deuterium permeability evaluation of SiC materials at high temperature
1) LiPb-RAFM blanket with SiC insert
   • compatibility issue
   • thermal insulation
   • MHD pressure drop
   • tritium solubility

2) SiC Heat Exchanger program
   • Dual coolant for high temperature heat
     → heat extraction with He from LiPb using SiC components.
     → high temperature He as secondary heat transfer medium.
SiC-LiPb Blanket Concept

- Module box temperature made of the RAFS must keep under 500 °C.
- Li-Pb outlet temperature target 900 °C.
- We propose the new model of active cooling in Li-Pb blanket.
- This concept is equipped He coolant channels in SiC/SiC composite and provides more efficient isolation between the RAFS and high temperature Li-Pb.
- We evaluate the feasibility of high temperature blanket in this model.
Model of Calculation (ANISN) reported last WS

One Dimensional Neutron Transport Code (ANISN)

- TBR
- Neutron Shield
- Nuclear Heating

### Neutron Flux

- Neutron Flux: 1MW/m²
- Plasma Region: 100 [cm]
- Li₁₇-Pb₈₃: 1.5 [cm]
- SiC/SiC: 1.5 [cm]
- 0.5x0.5cm He Channel
- FW(F82H): 1.5 [cm]
- 0.5x0.5 He Channel (8MPa)

### Neutron Shield Thickness

<table>
<thead>
<tr>
<th>Li-Pb [cm] (Net thickness [cm])</th>
<th>40.5<del>55 (45</del>59.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6Li [%]</td>
<td>7.4 ~ 90</td>
</tr>
</tbody>
</table>
Last year’s result: Tritium Breeding

- Contribution to $^7$Li for TBR is less than 5% of all.
- $^6$Li concentration is needed.
Neutron Multiplier

Type I: front of breeder

- Neutron Fluence
- Plasma: 100 cm
- Be: 5~3 cm
- F82H: 1.5 cm (with He coolant)
- SiC: 1.5 cm
- Li-Pb: 40.5 cm ~ 42.5 cm

Type II: front & back of breeder

- Neutron Fluence
- Plasma: 100 cm
- Be: 4~6 cm
- F82H: 1.5 cm (with He coolant)
- SiC: 1.5 cm (with He coolant)
- Li-Pb: 40.5 cm ~ 42.5 cm
Tritium breeding ratio with multiplier

Type I

Highest values of TBR are obtained at 5.5 cm Be length.
Local TBR > 1.4 can be obtained at a certain condition with total length of blanket of 52.5cm.

Type II: length of LiPb = 42.5cm

Neutron reflection by back Be layer increases TBRs.
Total length of Be layer can be made shorter than Type I, and including additional SiC layer the blanket length is same in case of 4 cm Be layer
Comparison of TBR and Neutron shielding for different configurations with same total length of blanket (52.5cm)

<table>
<thead>
<tr>
<th></th>
<th>LiPb:48cm</th>
<th>Be:5.5cm -LiPb:42.5cm</th>
<th>Be:3.5cm -LiPb:42.5cm -Be:0.5cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBR</td>
<td>1.25</td>
<td>1.41</td>
<td>1.41</td>
</tr>
<tr>
<td>14MeV flux</td>
<td>2.74x10^{11}</td>
<td>1.53x10^{11}</td>
<td>1.31x10^{11}</td>
</tr>
<tr>
<td>0.1MeV flux</td>
<td>8.21x10^{13}</td>
<td>2.15x10^{13}</td>
<td>2.19x10^{13}</td>
</tr>
<tr>
<td>Total</td>
<td>9.54x10^{13}</td>
<td>2.65x10^{13}</td>
<td>2.90x10^{13}</td>
</tr>
</tbody>
</table>
Distributions of Nuclear Heating

Type I

- Be: 5.0cm – LiPb:42.5cm
- LiPb: 47.5cm

Higher heat generation is calculated at front part of LiPb layer due to increase of slow neutron in Be multiplier layer.

Type II

- Be: 3.5cm – LiPb:42.5cm – Be 0.5cm
- Be: 4.0cm – LiPb: 42.5cm

Compared with Type I, heat generation at front part of LiPb layer decreases and spreads over the layer.
Conspectus of Li-Pb Loop at Kyoto Univ.

- Fluid: Li$_{17}$Pb$_{83}$
- Main Piping: 3/4inch, SUS316
- 2 EM pumps
- Flow rate: 3L/min
- Temperature at Test Section > 700°C
- " at pipe ~450°C
- 3-test sections → simultaneous tests
- 1week (~100h) continuous operation
Overview of Li-Pb Loop at Kyoto Univ.

- TS2
- TS1
- Expansion Tank
- Main Heater
- EM Pump
- Extension
- Original
Compatibility tests

• Sample: SiC/SiC composite pipe with outer diameter of 12mm, thickness of 1mm, and length of 35cm.

• Enclosed in a SUS pipe.

• Heated by an Infrared Image Furnace (maximum temperature on the outer surface of the SUS pipe > 1000°C).

• Measure real fluid temperature by inserting thermo-couple into the pipe.
Test Section 1  Before install
Test Section 1

With an Infrared Image Furnace (4.8kW)
Achieve the temperature on the heat section > 1000°C and the fluid temperature > 860°C. Due to temperature limits of main piping and valves, corrosion experiments have carried out with fluid temperature of 700°C for 2 weeks.
Test Section 1
after experiments

Pre-heater and thermo-couples need to replace
No reactive product is observed in interfacial layer between SiC/SiC composite and LiPb.
Observation of SiC/SiC composite pipe after high temperature experiments

Observe samples after 700°C, 2week(~200hour) Operation

Outlook: there are silver attachments on the surface (Pb was completely removed by acetic acid)

No significant corrosion is observed
Observations of SiC surface after compatibility test

- No corrosion is observed after 200-hour experiment with maximum temperature of 900°C, for SiC/SiC composite, but there are some attachments on the surface.
- They attach on the fiber.
- Through element analysis, the element are identified as Cr and Fe.
- Adhesion of Pb, removal of SiC, reactive layer are not observed.
Observation of SiC/SiC composite after compatibility test with LiPb

• SiC fiber

Fe and Cr are attached on the fiber surface

• SiC matrix

Compared with the fiber, amount of adhesion is smaller. Nothing is attached on YAG(Y₃Al₅O₁₂)
Corrosions of Stainless Pipe

- During LiPb-loop extension in 2006, some part of original piping were replaced, and we made corrosion observation.
- Material: Stainless steel, operation time <1000 hr
- Attached Pb is removed using acetic acid, before observation

Weld bead
Lower    Upper

Corrosion is clearly observed at bottom of the weld bead.

Bottom part is corroded where LiPb is more contacted by gravity.

Line wound → physical corrosion
Corrosions of Stainless Pipe

Observation by SEM, and Elementary Analysis

By etching, Pb is almost completely removed. First Ni and Cr are solved and corrosion of Stainless steel starts.
The device consists of two lines with high and low pressure divided with disk sample. Permeation of deuterium was measured by using quadrupole mass spectrometer.
Outlook of the measurement device
Typical data from measurement

Diffusivity $D$:

$$D = \frac{d^2}{4t} \quad [m^2/sec]$$

* $D$ does not depend on $P_h$

Solubility $S$

$$S = \frac{K}{D} \quad [mol/Pa^n \cdot m^3]$$

- $d$: thickness of sample
- $A$: cross-section of sample
- $t$: delay time
- $K$: permeability
- $P_h$: the pressure of high pressure line
- $n$: permeation flow rate

Sample: Nickel 1mm-thick
Temperature: 400 degree
Gas: $D_2$
Pressure: $9.9 \times 10^3$Pa

Deuterium Pressure in secondary line [Pa]

Sample: Nickel 1mm-thick
Temperature: 400 degree
Gas: $D_2$
Pressure: $9.9 \times 10^3$Pa
The permeation flow rate is

- a few order larger than those of monolithic SiCs,
- proportional to the pressure of the high pressure line.

$\rightarrow$ permeation without dissociation?

$$K_2 = n \cdot d / A \cdot P_h$$

$[\text{mol Pa}^{-1} \text{ sec}^{-1} \text{ m}^{-1}]$
Gas Permeation of
NITE-SiC/SiC composite (2)

Same order of permeation flow is observed for helium gas

Flow rate shows linearly dependence on the pressure of primary gas line

Permeation route?
- crack
- Include some materials in which helium can permeate
Dependency of permeability of NITE SiC/SiC composite on temperature and gas species

Dependency on the temperature is almost same for different gas species, the absolute values show small difference.
Permeation route?

Temperature dependency of Helium permeation

\[ K_2 = \frac{n \cdot d}{A \cdot P_h} \quad [\text{mol/Pa} \cdot \text{sec} \cdot \text{m}] \]

There is temperature dependency ↓

Helium may permeate through material contained in the sample.

The NITE-SiC/SiC composite contains quartz (SiO_2) as sintering additive

activation energy calculated from Arrhenius plot

\[
\begin{align*}
\text{SiO}_2 & : \quad 2.53 \times 10^4 \ [\text{J/mol}] \\
\text{NITE} & : \quad 2.88 \times 10^4 \ [\text{J/mol}] \\
\end{align*}
\]

SiO_2 contained in the composite contributes to the permeation.

→ as the cross-section, it is ~0.1% of total surface

*2 シリカガラスの科学 粟津浩一
Conclusion

- LiPb-SiC blanket concept is now actively studied in Japan at Kyoto University.
- Compatibility test of SiC/SiC composite and Ferritic steel with Li-Pb flow is undergoing using extended Li-Pb loop with temperature up to 900°C.
- Deuterium permeability experiments of monolithic SiC and SiC/SiC composite are carried out. The results show a few order different from those of previous experiments.