JP0450770

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Investigation of Heat Treatment Conditions of Structural Material for Blanket Fabrication Process

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This paper presents recent results of thermal hysteresis effects on ceramic breeder blanket structural material. Reduced activation ferritic/martensitic (RAF) steel is the leading candidates for the first wall structural materials of breeding blankets. RAF steel demonstrates superior resistance to high dose neutron irradiation, because the steel has tempered martensite structure which contains the number of sink site for radiation defects. This microstructure obtained by two-step heat treatment, first is normalizing at temperature above 1200 K and the second is tempering at temperature below 1100 K. Recent study revealed the thermal hysteresis has significant impacts on the post-irradiation mechanical properties.

The breeding blanket has complicated structure, which consists of tungsten armor and thin first wall with cooling pipe. The blanket fabrication requires some high temperature joining processes. Especially hot isostatic pressing (HIP) is examined as a near-net-shape fabrication process for this structure. The process consists of heating above 1300 K and isostatic pressing at the pressure above 150 MPa followed by tempering. Moreover ceramics pebbles are packed into blanket module and the module is to be seamed by welding followed by post weld heat treatment in the final assemble process. Therefore the final microstructural features of RAFs strongly depend on the blanket fabrication process. The objective of this work is to evaluate the effects of thermal hysteresis corresponding to blanket fabrication process on RAFs microstructure in order to establish appropriate blanket fabrication process.

Japanese RAFs F82H (Fe-0.1C-8Cr-2W-0.2V-0.05Ta) was investigated by metallurgical method after isochronal heat treatment up to 1473 K simulating high temperature bonding process. Although F82H showed significant grain growth after conventional solid HIP conditions (1313 K x 2 hr.), this coarse grained microstructure was refined by the post HIP normalizing at temperature below 1313 K. This result implies the thermal hysteresis effects could be canceled by the appropriate heat treatment. Therefore the heating conditions corresponding to fabrication should be combined with refinement heat treatment.

Recent progress in the investigation of mechanical properties of RAFs which experienced several thermal history and the joining properties of solid state bonding of RAFs/RAFs and RAFs/high-heat-flux-materials are also discussed.

Eleventh International Workshop on CERAMIC BREEDER BLANKET INTERACTIONS
15-17, December 2003
Tokyo International Exchange Center

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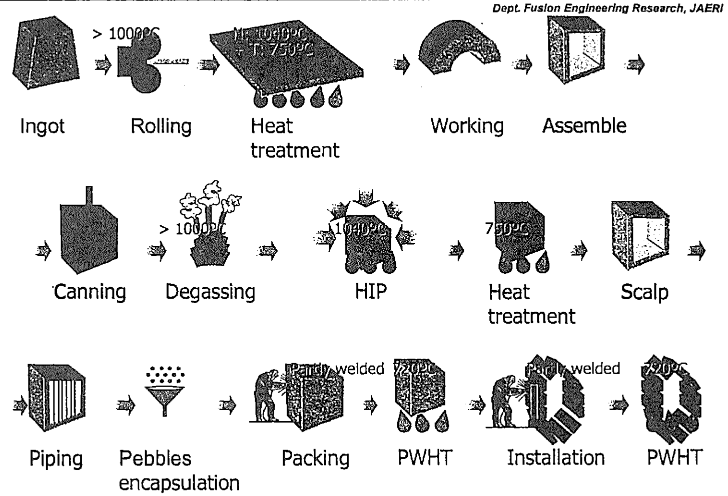
Backgrounds

- Fabrication process for in-vessel component in DEMO
  - Structural material is Reduced Activation Ferritic/Martensitic steel (RAFM).
  - Breeding blanket will be fabricated by near-net-shape process with Hot Isostatic Pressing, HIP.
  - Dissimilar joint technology for armor / structural bonding will be needed for plasma facing component, first wall and diverter.
- Heating process of structural material
  - Some heating is needed for a component fabrication process.
  - The mechanical properties of RAFM strongly depend on heating conditions.
- Joining technology
  - Joining technology with less damage on the materials is needed.
  - Thermal expansion of RAFM is three times larger than that of W.

Conventional blanket fabrication process



Reduced activation ferritic martensitic steel, RAFM

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- Modified 9Cr-1Mo heat resisting steel.
- Harmful (long-term radioactive) elements, such as Mo, Nb, and N were removed and/or replaced by low activation elements.
  - F82H: Fe-0.1C-8Cr-2W-0.2V-0.05Ta
- Tempered martensite structure
  - Good resistance to neutron irradiation.
    - High density dislocation, lath boundaries, fine precipitates work as sink sites for radiation defects.
  - Heat treatment is needed.
    - Two step heat treatment is needed to obtain the structure.

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Heat treatments of RAFM

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- Two step heat treatment…
- Normalizing (HIP, Welding, Brazing etc.)
  Heating to obtain martensite structure is performed at higher than 900°C.
  - Normalizing heat treatment is performed at above the α->γ transformation temperature.
  - As normalized RAFM is strong and brittle due to excess solute carbon.
  - The grain size depends on normalizing condition.
- Tempering (PWHT, PHHT)
  Heating to obtain tempered-martensite structure is performed at lower than 800°C.
  - Tempering makes some carbides, tempered RAFM is tough and strong steel.
  - Precipitation morphology depends on tempering condition.
- The relationship between normalizing condition and grain size are discussed in this work.

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Ductile brittle transition temperature, DBTT

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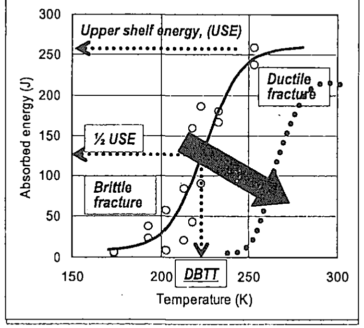
- Materials with B.C.C structure show ductile to brittle transition behavior.
- The transition temperature, DBTT is the lower limit of materials usage.
- The initial DBTT should be low, because the neutron irradiation raises the DBTT.

Ductile-brittle transition behavior of F82H



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Grain size

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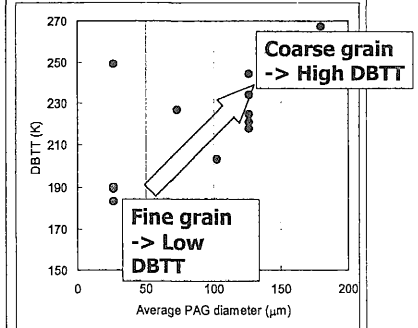
- DBTT depends on the prior-austenite grain (PAG) size.
- To obtain a fine grained steel is useful to long lifetime blanket structure.
- Grain boundaries play as sink site for radiation defects, therefore fine grained steel has good resistance to irradiation.

Grain size dependence of DBTT. F82H steel



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Microstructure of F82H after the fabrication process

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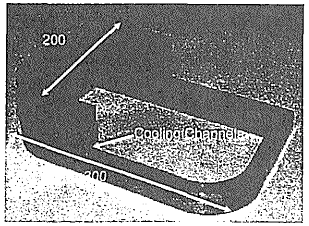
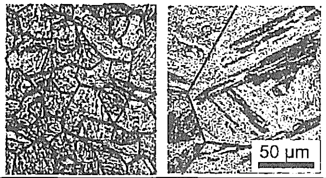
- The bonding, HIP (Hot Isostatic Pressing), brazing should be performed at high temperature.
- The higher temperature heating causes microstructural changes in the steel.

Breeding blanket structure, mock up



Microstructure of F82H before HIP | F82H after HIP



- HIP: 1040°C x 2hr
- The heating during HIP caused PAG coarsening.

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Objectives

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- To clarify the heat treatment response of F82H.
- To establish heating process to fabricate blanket structure with fine grained RAFM.
- *To investigate joint conditions.*
  - Structural material / High heat flux material. (F82H / W)

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Experimental procedure

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HIP simulating heat treatment test.

- Materials used: F82H IEA (D_{PAG}:120μm)
  F82H TMCP* (D_{PAG}:26μm)
  F82H+0.1%Ta (D_{PAG}:20μm)
  Thermo Mechanically Controlled Process
- Temperature: 970, 1000, 1040, 1100°C
- Heating/cooling rate: 400 °C / hr. (Simulating HIP furnace)
- Holding time: 2 hr.

Chemical composition (wt.%)

	C	Si	Mn	S	Cr	W	V	Ta	Ti	N
F82H-IEA	0.1	0.1	0.1	0.001	7.8	2.0	0.2	0.04	0.004	0.007
F82H-TMCP	0.1	0.1	0.1	0.001	8.0	2.0	0.2	0.05	0.004	0.007
F82H +0.1%Ta	0.1	0.1	0.1	0.001	8.2	1.9	0.2	0.09	<0.001	0.002

The composition of IEA and TMCP was almost same.
The D_{PAG} of TMCP and 0.1%Ta was almost same.

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Grain size change by HIP simulating heating

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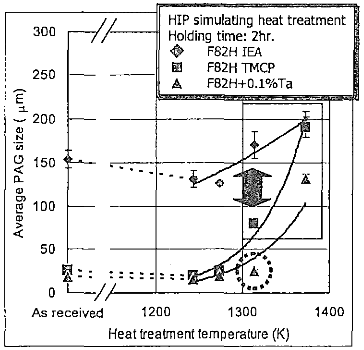

- 0.1%Ta steel kept fine grain at 1040°C.
- Conventional composition steels, IEA and TMCP with 0.05%Ta, showed grain coarsening at 1040°C.
- The conventional steels showed different grain sizes below 1040°C, although they had almost the same composition. They were heated at the same temperature.

- Thermal and/or mechanical hysteresis were not dissolved by the heating at conventional normalizing temperature (1040°C).
- The grain sizes were affected by its original grain size, grain size before heating.
- Heating above 1100°C is needed to homogenize the grain size.

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Grain coarsening and tantalum

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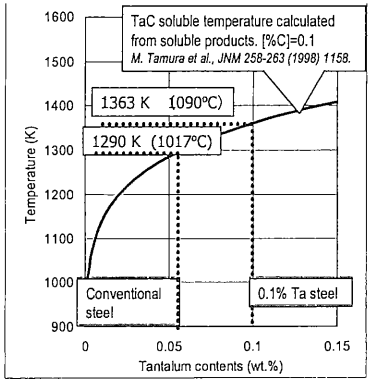

- TaC is the precipitate along with grain boundaries, and it immobilize the grain boundaries.
- The grain coarsening occurred above TaC soluble temperature of each steels.
- The grain coarsening was caused by dissolution of TaC.

- Although low temperature HIP suppress the grain coarsening, it could degrade bonding properties.
- High temperature HIP followed by refining heat treatment could be a solution to obtain fine grained RAFM.

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HIP condition to obtain fine PAG

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- Low temperature HIP below TaC soluble temperature.
  - -> *This process requires severe preparation for HIP, such as surface finish conditions, to keep bonding properties.*
  - -> *Effects of thermal and mechanical histories corresponding to fabrication.*

- High temperature HIP with homogenizing followed by a refining normalization.
  - -> *High temperature HIP requires easy surface finish conditions.*
  - -> *HIP dissolves any thermal and mechanical hysteresis.*

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Homogenizing and refining the PAG

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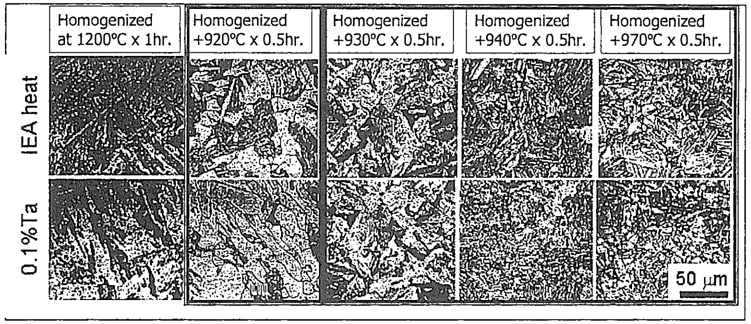
Effects of high temperature HIP treatment
: HIP at homogenizing temperature followed by low temperature normalizing



- The ferrite/martensite dual phase structure was observed after 920°C heating. It is known that the dual phase steel shows significant DBTT shift by neutron irradiation.
- Fine PAG, average diameter: 30μm, was obtained by normalizing at 930~970°C.

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Impact properties of heat treated F82H

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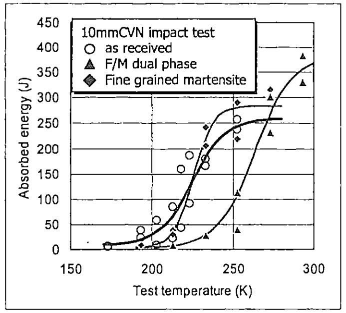

- The fine grained F82H demonstrated the almost same properties with as received ones.
- F82H with ferrite phase showed the highest DBTT.

- The homogenizing and refining process could be useful to fabricate tough HIP joint.
- It also improve the toughness of base metal.

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Summary

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- The conventional normalizing (1040°C x 0.5hr.) was not enough to dissolve the mechanical and thermal hysteresis.
- HIP treatment at higher than 1100°C can homogenize the grain size of F82H. The post HIP low-temperature-normalizing (930~970°C) made the PAG fine.
- This high temperature HIP and PHHT could improve the joining properties and the toughness of F82H HIP joint.
- The mechanical tests on HIP joint processed at 1100°C followed by normalizing at 960°C are in progress.