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R&D activities on helium cooled solid breeder TBM in Korea

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ABSTRACT

R&D activities currently being undertaken for HCSB TBM include joining technologies of structural material, breeder and reflector pebble material development, the effect of TBM ferritic–martensitic steel on the ripple of toroidal magnetic field, and ceramic coating on graphite pebble. The HIP joining performance of FM steel is evaluated. Lithium ceramic breeder and graphite reflector pebble fabrication methods are under development using special fabrication process, and the initial characteristics of the pebbles are assessed. Silicon carbide coating on graphite pebble is also investigated and its preliminary results are mentioned. Finally, an accurate evaluation of the effect of TBM and ferromagnetic inserts on magnetic field are implemented. The current results of these R&D issues are addressed in this paper.

1. Introduction

Korean Helium Cooled Solid Breeder (HCSB) Test Blanket Module (TBM) has been designed accounting for the performance of DEMO-relevant blanket. The HCSB TBM uses helium as coolant and purge gas, and reduced activation ferritic–martensitic (FM) steel as a structural material [1,2]. Lithium ceramic breeder material, beryllium neutron multiplier, and graphite neutron reflector are used in pebble-bed forms. One of the unique features of the HCSB TBM is that a reflector is used to reduce the amount of beryllium, while tritium breeding ratio remains almost unchanged with relatively low ^{6}Li enrichment of 40%.

Since joining technologies would be key factors for successful TBM fabrication, the development of various joining methods, such as Electron Beam Welding (EBW), laser welding, Tungsten Inert Gas (TIG), Hot Isostatic Pressing (HIP), is on-going. Especially, the HIP joining characteristics of FM steel have been evaluated [3]. The effect of degassing temperature on the HIP joining surface is investigated. Several pebble fabrication methods of lithium ceramic breeders and graphite reflector are under development considering mass production. The characteristics of the pebbles fabricated by various methods are assessed.

A silicon carbide coating on graphite pebble is important to prohibit the reaction of graphite with steam or air. Protective SiC coatings have been widely used in steel and microelectronic industries because of their intrinsic properties such as good wear resistance, high hardness, high thermal conductivity and very high thermal stability [4,5]. For improving the defects at high temperature, a coating using RF sputtering widely used in industries appears to be very attractive because of its relative simplicity, low deposition temperature and high attainable deposition rates [6]. As a preliminary step to develop SiC coating method on graphite pebbles, a SiC coating on the graphite sheet by RF sputtering has been performed.

Since TBM structures are made of ferromagnetic steel, they are magnetized during normal ITER plasma operation, generating parasitic non-axisymmetric magnetic field perturbations. Recently, concerns have been raised regarding the possibility of the increase of L-H transition power and the degradation of energetic particle confinement due to toroidal field (TF) ripple in the vicinity of TBM-allocated ports. In addition to the TF ripple, non-axisymmetric error fields are likely to be produced by TBMs, potentially leading to the reduction of plasma performance and/or locked mode disruptions. An accurate evaluation of TBM-produced non-axisymmetric field perturbations and their impact on the plasma performance are necessary to be investigated. The current results of all these R&D activities are described in this paper.

2. Joining technology of FM steels

As a joining technology of FM steels, a HIP is selected and the test results are described in this section. The material used in this study was F82H low activation FM steels (8Cr–2W–0.2V–0.03Ta) made by JFE Co. and its chemical composition is shown in Table 1.

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Table 1
Composition of F82H manufactured by JFE Techno-Research Corporation (wt%).

C	Si	Mn	S	Cr	W	V	Ta	Ti	N
0.09	0.09	0.08	0.004	7.93	1.81	0.19	0.03	<0.001	0.001

This material was normalized at 960 °C for 30 min followed by air cooling and tempered at 750 °C for 90 min followed by air cooling.

The joining surface was mechanically polished to be less than 1 μm roughness (Ra) to make sure of high quality joining [7]. In order to observe the effect of degassing temperature, test specimens were degassed in the vacuum condition of 10^{-3} Torr at temperatures of 500, 600 and 700 °C for 2 h. And then, these specimens were HIPped at 1100 °C, 100 MPa for 2 h. After HIP process, to control the grain size and to reduce the residual stress, they are normalized and tempered at 960 °C for 0.5 h and 760 °C for 1.5 h, respectively.

As a result of microstructure observation, the ASTM grain size number of the specimens after HIP joining is about 6 while that of as-received F82H is about 8–9. It is thought that the coarsening of prior austenite grain (PAG) size is caused by tantalum carbide dissolving during HIP process [8,9]. In the HIP interface, second phase particles such as small islands were observed by SEM-BSE (Back Scattered Electron) mode as shown in Fig. 1. These second phase particles seem oxides generated from residual oxygen or segregated carbide during HIP process. The distribution of these particles is independent of degassing temperature as shown in this figure. It may need more detailed analysis in order to find the reason for the formation of these particles.

Compared with as-received F82H, the tensile properties (tensile strength, yield stress and total elongation) of HIP bonded specimens were reduced by 5% due to the increase of PAG size and there was a slight dependency on degassing temperature. Also, it was found based on the Charpy impact test that the impact energy was decreased with increasing degassing temperature as shown in Fig. 2. It shows the importance of degassing temperature in the HIP process of FM steels.

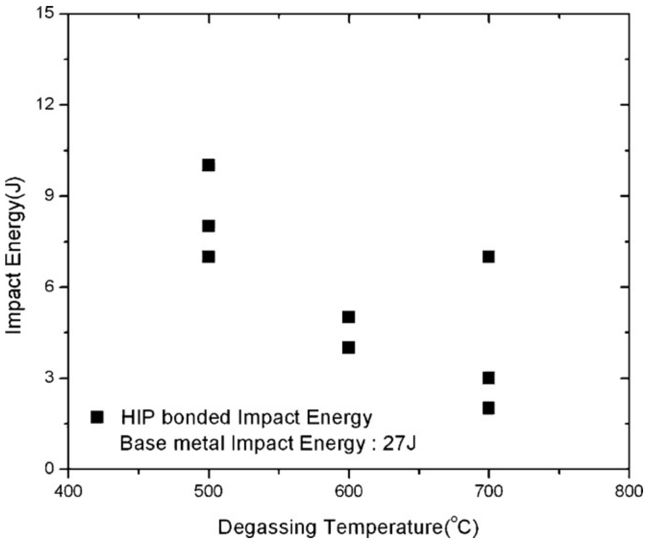

Fig. 2. Charpy impact energy of HIP bonded specimens.

3. Pebble fabrication technology

Pure and fine Li_2TiO_3 powder was synthesized by a polymer solution method. The synthesized powder, which has an average particle size of 0.5 μm and specific surface area of 25 m^2/g, was mixed with D.I. water and ball milled for several hours. The dried Li_2TiO_3 slurry was significantly agglomerated because of the ultra-fine particles. The agglomerates were enough strong to handle for further process. The agglomerates were sieved by #10 and #14 screen mesh and mechanical polished for good sphericity. The mechanical polishing was conducted with a #220 SiC paper. The granulized powders were put between two SiC papers and rubbed by upper SiC paper handled by polishing machine. The pressure and speed on the rubbing process were important for optimum condition. The polished powders showed a good sphericity. However, the strength was not enough for the application. The polished Li_2TiO_3 pebbles were sintered at 900 °C for desirable strength. The pre-sintered pebbles were polished again for more improvement of sphericity. In the 2nd polishing, the rub pressure and speed were more increased. After the 2nd polishing, the pebbles showed excellent sphericity, and were sintered at 1250 °C for 1 h. The sintered pebbles showed almost pure Li_2TiO_3 phase in the XRD analysis and the measured compressive load for fracture was about 143 N. Fig. 3 represents the photographs of the synthesized Li_2TiO_3 powder, granular-type Li_2TiO_3 powder and Li_2TiO_3 pebbles after 1st and 2nd polishing process. The XRD pattern of Li_2TiO_3 pebbles is shown in Fig. 4.

In the case of graphite pebbles, rod-type graphite was used for mass production. The long-rod graphite with the diameter of 2 mm was cut to 2 mm length. The cut rods were mechanical polished through two-step process. In the first step, #80 SiC paper was used for polishing. In the polishing process, more increased pressure and lower speed were applied than the Li_2TiO_3 pebble process for grinding the angle of the graphite rods. In the second step, #220 SiC paper was used for the surface polishing of graphite pebbles. In this process, the pressure was decreased and the speed increased in comparison with the first step. The fabricated pebbles showed almost pure graphite phase in the XRD analysis and the measured compressive load for fracture was about 52 N. In Fig. 5, the photographs of the graphite rods after cutting, and graphite pebbles polished by #80 SiC paper and #220 SiC paper are represented. The XRD pattern of graphite pebbles is shown in Fig. 6.

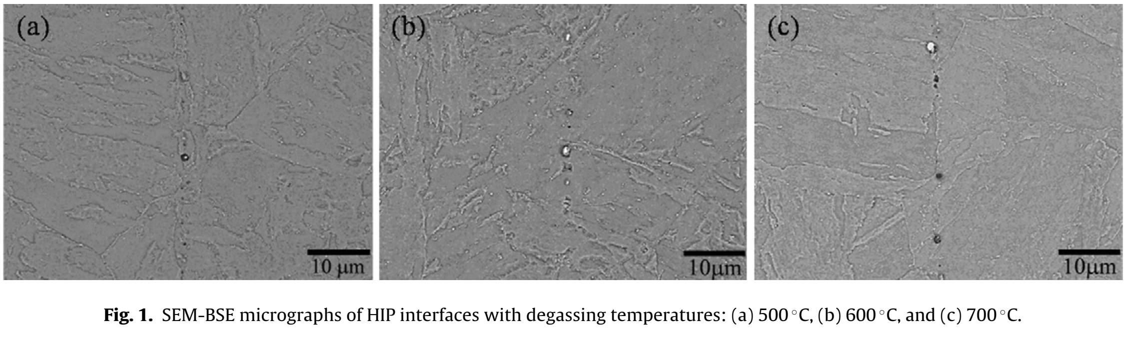

Fig. 1. SEM-BSE micrographs of HIP interfaces with degassing temperatures: (a) 500 °C, (b) 600 °C, and (c) 700 °C.