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Title	Development of F82H-based composite materials with a high thermal conductivity [an abstract of dissertation and a summary of dissertation review]
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Degree Grantor	北海道大学
Degree Name	博士(工学)
Dissertation Number	甲第14871号
Issue Date	2022-03-24
Doc URL	https://hdl.handle.net/2115/85277
Rights(URL)	https://creativecommons.org/licenses/by/4.0/
Type	doctoral thesis
File Information	Heo_Jeongwoo_abstract.pdf, 論文内容の要旨



学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Development of F82H-based composite materials with a high thermal conductivity
(高熱伝導率を有する F82H 複合材料の開発)

If a nuclear fusion reactor is successfully developed, The electrical energy would stably be obtained greater than that of existing nuclear power plants even in the face of external shocks such as natural disasters. For this reason, research for the development of structural materials for fusion reactors is currently underway in advanced countries. In particular, the reduced activation ferritic martensitic (RAFM) steel has been mentioned as one of the strong candidates for fusion reactor structural materials due to its low coefficient of thermal expansion, stress corrosion cracking resistance, swelling resistance, and He brittleness resistance. However, there are two main issues to be solved. One is the material hardening/brittleness that occurs under high-energy neutron irradiation, and the other is the low thermal conductivity of RAFM leading to the difficulty of the efficient heat transfer to the cooling pipe.

In this study, thermal properties, mechanical properties, and changes in physical properties after irradiation were analyzed after manufacturing a composite material by adding copper and tungsten to F82H steel, one of the RAFM steels. Each composite material was manufactured by putting Cu or W wire into F82H powder produced by a gas atomizing and sintering by using a spark plasma sintering (SPS) at temperatures of 850 °C and 1000 °C. After the SPS, all specimens were annealed at 800 °C for 180 min. The density measurement was conducted by using Archimedes' method and a laser flash analysis (LFA) was applied for the thermal diffusivity measurement, followed by the thermal conductivity estimation of each specimen. The scanning electron microscopy (SEM) and the energy dispersive spectroscopy (EDS) were conducted for the surface structure observation of SPSed and annealed samples. Mechanical property examinations were performed to the general F82H and the SPSed F82H-based composite materials. With the SPS holding at 850 °C for 10 min to 120 min, the composite materials showed very poor mechanical properties such as tensile properties and Vickers hardness. The reason why the F82H-based composite material showed low mechanical properties seemed that the relative densities were low, and pores were formed inside the material probably due to a low sintering temperature. In order to increase the relative densities, the temperature was increased at the rate of 50 °C/min and the sintering temperature was increased to 1000 °C.

The F82H-based composite material sintered at a temperature of 1000 °C showed a thermal conductivity improvement of up to 3.3 times compared to the existing F82H. However, in the composite material containing W, as the volume fraction of W increased, the ductility of the composite material significantly decreased, resulting in very low toughness. The reason for this result is related to the formation of intermetallic compounds such as Fe_7W_6 , Fe_3W_3C , and Fe_2W phases found at the interface between tungsten and matrix in sintered steels. F82H-W reaction layer surrounding W wire, Fe_7W_6 intermetal-

lic compounds would result in the embrittlement of entire elongation and initiation of fracture during the tensile test. In contrast, F82H-20Cu composite material showed no separation or crack initiation at the interface between F82H and copper wire, resulting in a satisfactory tensile property. From those results, F82H-20Cu composite material SPSed at 1000 °C for 120 min is suggested that the optimized condition to achieve the improvement of the thermal conductivity with a comparable tensile property to that of the general F82H.

The triple ion beam, He and H, irradiated F82H-20W composite material showed a higher irradiation hardening than that of F82H-20Cu composite material. Cu wire in F82H-20Cu showed less irradiation hardening after the irradiation at 500 °C. F82H-W reaction layer tended to become wider with increasing the holding time of SPS. And the wider reaction layer resulted in larger hardening. Few radiation-induced dislocation loop was observed in F82H after ion irradiation at 500 °C. These results suggested that F82H-Cu composite could be a better candidate material than F82H-W composite as the structure material for a fusion reactor divertor, especially at higher temperatures.