Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Design and Characterization of Dual Neutron Absorber Reinforced Aluninum Composites for Dry Storage Basket Materials

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1. Introduction

Recently, attention to spent nuclear fuel (SNF) storage has increased greatly due to a capacity limit excess of current storage methods (wet storage methods). All of the wet storage facility will be saturated in Korea until 2024 [1]. In result of this situation, developing of new SNF storage method is urgent.

Dry storage methods are the troubleshooter technology for problems in current SNF storage methods. Dry storage methods are able to solve capacity, disposal, cost, and safety issues because of their superiority in expendability transportability, simplicity, and passive safety[2, 3]. Therefore, there is much active research is on-going all around the world.

Developing basket materials is critical to enhancing performances of dry storage methods because the materials have multiple roles. These materials conduct the only role of neutron absorbing, but also heat removal and structural support [4–6]. Therefore, developing a basket is important for multiple viewpoints.

In this study, a new concept of basket materials containing dual reinforcement, Gd_2O_3 and B_4C, is designed and verified. The neutron absorbing capability was tested by MCNP simulation in the geometry of standard dry storage cask (GBC-32). Mechanical properties were characterized by tensile test and analyzed by scanning electron microscopy. Heat removal capability was simulated by ANSYS simulation program. The proposed material showed improved properties in all every aspect of this work.

2. Methods and Results

2.1 Material Design by MCNP Simulation

Composite materials are designed with various fraction combination of reinforcement; B_4C, Gd_2O_3. The fraction of each reinforcement is in the range from 0 vol.% to 10 vol.% with an interval of 0.1 vol.%. Total 10,000 sets of fraction combination were generated. Performances of the generated set of materials are verified by MCNP6 code. The code calculated neutron absorbing capability by calculating k-value of a dry cask geometry. The geometry of a cask followed the design specification of GBC-32 cask [6]. K-code was used to get k-value. The total numbers of the cycle of simulation were 800 and first 200 cycles were skipped. 1000 histories per cycles were used to ensure error lower than 0.1%

The result of the simulation is shown in Fig.1 as 3D scatter plot. Fig.1 indicated that using the only Gd_2O_3 is worse than only using B_4C only, which does not consensus with common sense. The lowest contents of dual reinforcement are 4 vol.% that has neutron absorbing power comparable to 10 vol.% B_4C reinforced the material. The material consists of 0.5 vol.% Gd_2O_3 and 3.5 vol.% of B_4C. In the result of the simulation, 0.5 vol.% Gd_2O_3 and 3.5 vol.% of B_4C were proposed as optimum reinforcement contents combination..

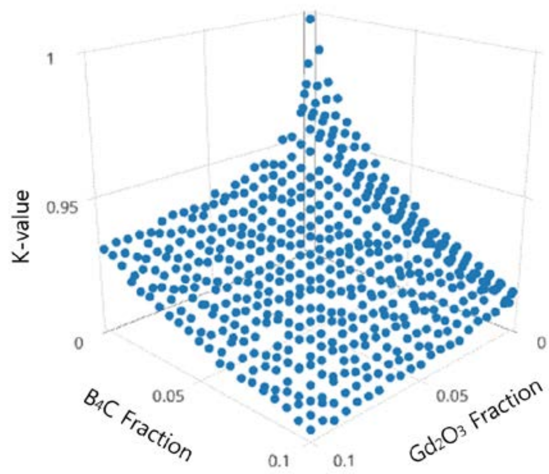

Fig. 1. K-value plot of generated 100 by 100 reinforcement fraction combination.

2.2 Materials Fabrication and Characterization

The proposed neutron absorbing material is fabricated using 3.5 vol.% B_4C powder, 0.5 vol.% Gd_2O_3 powder, and aluminum powder. The powders were mixed using a 3D mixer with 40 RPM motor speed. The mixed powder was pressed was sintered at 40 MPa pressure and 450ºC using a spark plasma sintering (SPS) method. The sintered samples were hot forged by SPS machine.

Cross-sectional images of the samples were taken by SEM. The fraction of reinforcement was calculated by counting the pixel of reinforcement region. The obtained volume fraction was used to calculate the theoretical density. Bulk densities were measured by pycnometer.

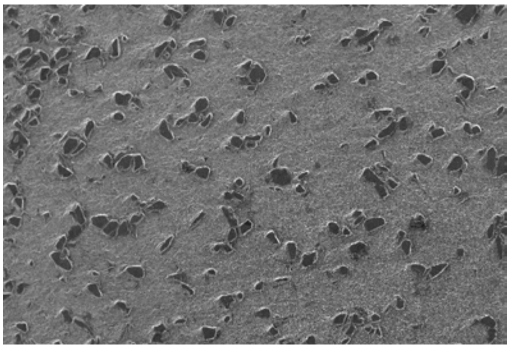

Fig. 2. Cross-section SEM image of fabricated composites.

A thermal conductivity was predicted by simulation. ANSYS program was used to calculate the thermal conductivity of the proposed material. Fig. 2 is the geometry of simulation. The obtained thermal conductivity is compared to result of other calculation models. Furthermore, the interface cavity effect on thermal conductivity was investigated.

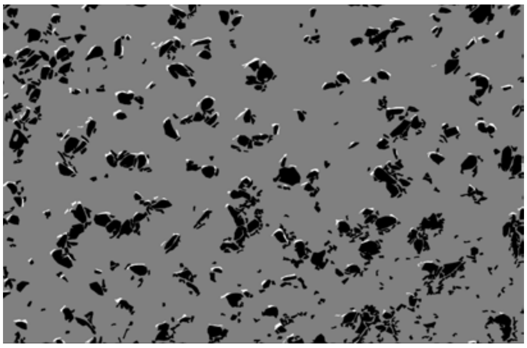

Fig. 3. The geometry of thermal conductivity simulation.

3. Conclusions

Dual reinforcement (B_4C, Gd_2O_3) aluminum composite is designed and characterized in this work. The optimization of reinforcement contents is done by MCNP simulation. The simulation result showed that 3.5 vol.% B_4C and 0.5 vol.% Gd_2O_3 is the optimum in a viewpoint of criticality. The criticality of proposed material was 0.813 that is comparable to 10 vol.% B_4C reinforced composite. The proposed material show superiority in mechanical properties compared to 10 vol.% B_4C reinforced composite. The materials show improved ductility and heat conductivity while maintaining its strength. Improvement of ductility implies the increase of productivity, which is a critical disadvantage of common composite materials.

The result of this work will contribute to a change of the neutron absorbing materials field, which is dominated by B_4C single reinforcement composited.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF, No. 2014M3C1A9060721) grant funded by the Korea government

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