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Application of flame spraying coatings of neutron-absorbing boron-polymer composite powder for spent nuclear fuel container

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1. Introduction

With the development of nuclear energy, the demand for different types of radiation shielding materials is increasing [1-3]. Among the traditional shielding materials, boron element has a better performance owing to huge thermal neutron absorbing cross sections; therefore, it can be used as a neutron absorber in the nuclear industry [4]. Boron and its compounds have been used for shielding detectors, transportation baskets, disposal equipment, space probes, military applications, boron neutron capture therapy, and radioactive waste. The traditional shielding method was mostly to use a thicker shielding of lead plates, and cast reinforced concrete, etc., mainly by reducing the neutron speed and preventing the passage of neutrons. However, the problem of making or machining the thick protective layers cannot meet the development needs of the security of the nuclear power industry. Currently, most widely used nuclear protective materials are polyethylene plastic plates adding boron carbide, because of polyethylene containing a relatively high content of hydrogen atoms that is an effective neutron moderator by virtue of its scattering power, and boron carbide that is also a good thermal neutron absorber by means of huge thermal neutron absorbing cross section.

In this regard, in the present work, polymer flame spraying coatings of neutron-absorbing boron containing polymer composite powder is developed for application in the field of spent nuclear fuel. Changes in the microstructure of the coating layer are discussed with respect to the content of boron carbide and the thickness of the coating layer in view of the neutron-absorbing efficiency.

2. Methods and Results

2.1 Experimental methods

The starting materials used were commercially available low density polyethylene (LDPE, Wenzhou Huate Hot-Melts Co. Ltd.) powder with an average diameter of 210μm as a matrix and boron carbide (B_4C) powder (LTS, 99.8% purity) with an average diameter of 40μm as a neutron absorbing phase with different contents from 0 to 40wt.%. Boron-containing polymer feedstock particles were prepared first by mechanical milling and then subsequent turbular mixing processes. At first, mechanical milling of LDPE polymer and B_4C powder mixture was conducted using a planetary ball mill machine under an argon atmosphere. The weight ratio between LDPE polymer and B_4C powder was 1:1, while the weight ratio of the stainless steel balls of 8mm in diameter to the powder mixture was 20:1 at the rotational disk speed of 400rpm for 30min. Mechanical milled powders were then mixed with LDPE polymer as a weight ratio of 1:4 under a speed of 70rpm for 24hrs. Fig.1 shows the SEM images of the surface and cross-section of LDPE polymer containing 20wt.% of B_4C particles.

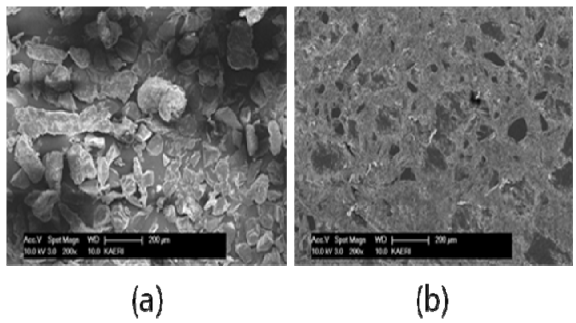

Fig. 1. SEM micrographs of (a) surface and (b) cross-section of 20wt.% B_4C containing LDPE composite powder.

Boron-containing polymer composite powders were coated on an Al substrate using the method of thermal spraying in a torch from a propane-air flame. The microstructure and dispersion of the B_4C particles in the coating layer were observed through optical microscopy, XRD, and SEM. The neutron-absorbing property was measured through the help of four circle diffractometer (FCD) equipped in the HARARO reactor.

2.2 Microstructure of coating layer

Fig. 2 presents the surface morphology of LDPE-B_4C composite powder coating on an Al substrate observed by OM as functions of B_4C content and coating times. With the naked eyes, there is no big difference with different coating conditions from the OM images.

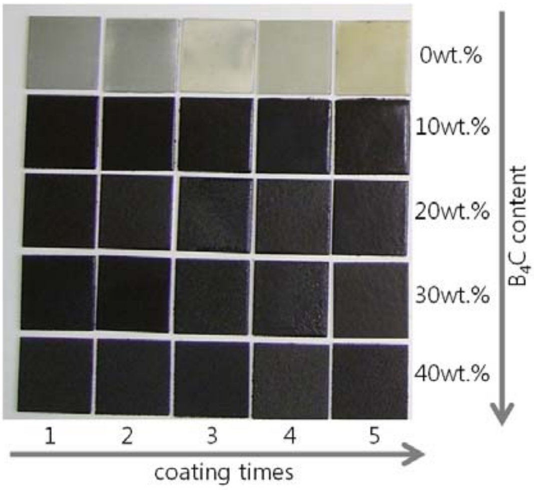

Fig. 2. Optical micrographs of LDPE-B_4C composite powder coating on Al substrate with different B_4C contents and coating times by the help of flame spraying method.

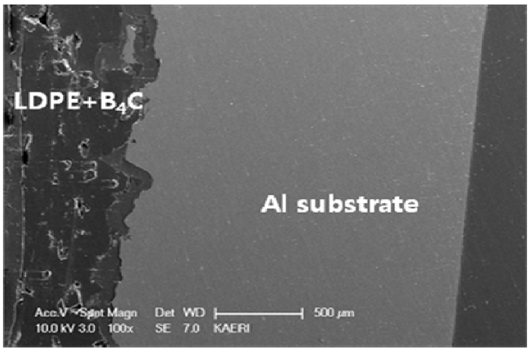

Fig. 3. Cross-sectional SEM image of LDPE-20wt.% B_4C composite powder coating on Al substrate.

Fig. 3 gives cross-sectional SEM image of 20wt.% B_4C containing LDPE composite powder coating on Al substrate. It is readily seen that B_4C particles were distributed uniformly in the polymer matrix. In addition, it is observed that LDPE-B_4C composite coating layer was joined well with the Al substrate without any detachment.

2.3 Thermal neutron absorbing properties

When thermal neutrons pass through an absorbing material, they can be either absorbed, scattered away, or transmitted through. The ability of the neutron absorbing material to capture the neutrons can be estimated by a transmission measurement. For strong thermal neutron absorbers, the thermal neutron incident intensity is reduced mainly by the absorption of the neutrons, and minimally by the scattering effect. Therefore, the thermal neutron absorbing efficiency is measured by the transmission measurement with the help of FCD equipment. Fig. 4 shows the changes in the ratio of the transmission (I) and incident (I_0) thermal neutron intensity of LDPE-20wt.%B_4C composite powder coating on an Al substrate with respect to the coating times. As the coating time increased, the transmission thermal neutron intensity decreased linearly, implying the increase in the thermal neutron absorbing property. When the coating process was repeated five times, the transmission thermal neutron intensity decreased down to 25% compared with the incident one.

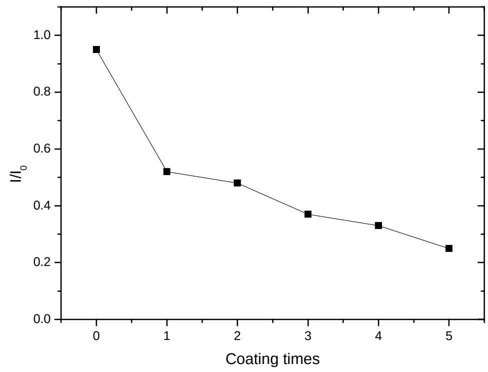

Fig. 4. Change in thermal neutron absorbing efficiency of LDPE-B_4C composite powder coating on Al substrate with respect to the coating times.

3. Conclusions

In this work, polymer flame spraying coatings of neutron-absorbing boron containing polymer composite powder was developed for application in the field of spent nuclear fuel. From the observation of coating layer, B_4C particles were distributed uniformly in the polymer matrix and the LDPE-B_4C composite coating layer was joined well with Al substrate without any detachment. The thermal neutron absorbing property is enhanced with an increase in the coating thickness. A flame spraying coating method of boron-containing polymer composite powder is very effective way for the application in a spent nuclear fuel facility.

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