CONFERENCE PRE-PRINT

EXPERIMENTAL STUDY ON TRITIUM RELEASE FROM LI_2TIO_3 PEBBLES AS TRITIUM BREEDER THROUGH INTERNATIONAL COLLABORATION BETWEEN KOREA AND CHINA

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Abstract

Lithium metatitanate (Li_2TiO_3) is a primary candidate material for tritium breeder in solid type of breeding blanket concepts such as Helium-Cooled Ceramic Pebble (HCCP), Water-Cooled Ceramic Breeder (WCCB), Helium-Cooled Ceramic Reflector (HCCR), Helium-Cooled Ceramic Breeder (HCCB), and so on [1, 2]. The solid breeder is used as a pebble form in the breeding blanket due to advantages in packing, stress distribution, thermal conduction, purge gas flow, and so on [3]. The critical properties of breeder pebbles include not only physical properties, such as diameter, sphericity, porosity, and strength, but also their tritium release behaviour. The tritium is generated by nuclear reaction between neutrons from fusion plasma and lithium atoms in the breeder pebbles. Therefore, both a neutron source and a tritium handling facility are essential to investigate the tritium release behaviour. Korea Institute of Fusion Energy (KFE) has established source technology for manufacturing of tritium breeder pebble. While the Institute of Nuclear Energy Safety Technology (INEST) operates a neutron source and tritium handling facility. This study presents the preliminary experimental results of Li_2TiO_3 pebble manufacturing, neutron irradiation, and the tritium release testing through Korea-China collaboration.

1. INTRODUCTION

Lithium metatitanate (Li_2TiO_3) has been widely considered a primary candidate material for tritium breeder in solid type of breeding blanket concept, such as Helium-Cooled Ceramic Pebble (HCCP), Water-Cooled Ceramic Breeder (WCCB), Helium-Cooled Ceramic Reflector (HCCR), Helium-Cooled Ceramic Breeder (HCCB), and so on [1, 2]. These concepts employ pebble shaped breeders due to their advantages in packing behaviour, stress distribution, thermal conductivity, purge gas flow, and so on [3]. Key properties of breeder pebbles include not only physical properties, such as diameter, sphericity, porosity, and strength but also tritium release behaviour. As tritium is generated by nuclear reaction between neutrons from fusion plasma and lithium atoms in the breeder pebbles. Therefore, both a neutron source and a tritium handling facility are essential infrastructure in order to investigate the tritium release behaviour of breeder pebbles. Korea Institute of Fusion Energy (KFE) in Korea has established source technology for manufacturing of tritium breeder pebbles. Meanwhile, Institute of Nuclear Energy Safety Technology (INEST) in China is operating a neutron source and a tritium handling facility. Therefore, the international collaboration between Korea and China has been launched to investigate the tritium release behaviour of breeder pebbles. The preliminary experimental results of the Li_2TiO_3 pebble manufacturing, fusion neutron irradiation, and tritium release test from the irradiated pebbles are addressed in this study.

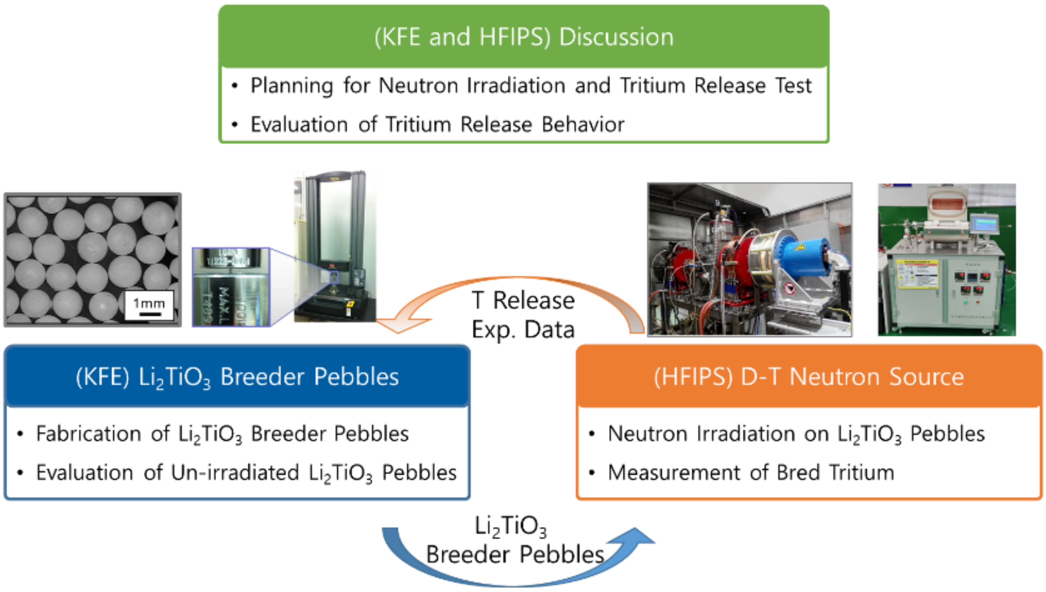

FIG. 1. Structure of International Collaboration between Korea and China

2. EXPERIMENTS

2.1. Preparation of Li_2TiO_3 pebbles

Li_2TiO_3 pebbles with 3.43 mm in diameter were manufactured using the Powder Injection Molding (PIM) process which was first application to pebble production by KFE. Li_2TiO_3 powder and binder material were injected into a PIM mold by high pressure. Green bodies were detached and debinded from the molded product. Finally, the Li_2TiO_3 green bodies were sintered at 1000 ºC for 3 h in an air atmosphere. The specially designed rotating furnace system was utilized to avoid the adhered pebbles during sintering.

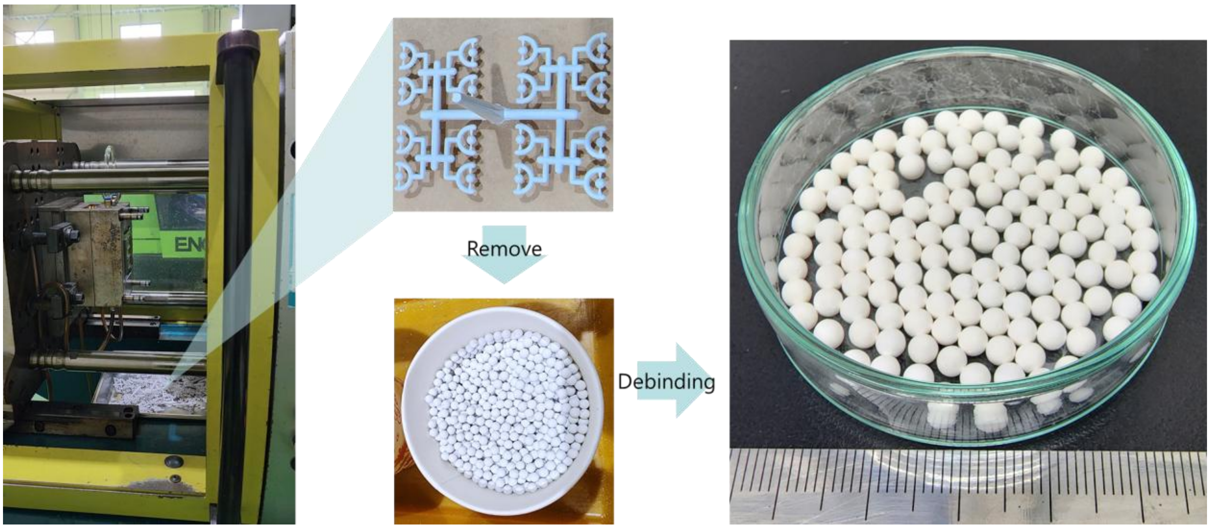

FIG. 2. PIM process for pebble shaping

2.2. Neutron irradiation test

The High-Intensity D-T Fusion Neutron Source (HINEG-CAS) at INEST was utilized for the neutron irradiation experiment on the Li_2TiO_3 pebbles. The average neutron intensity during the irradiation was 5×10^{10} n/s. Total number of neutron with 14 MeV energy on the pebbles was reached to approximately 1.104 x 10^{15} n. The irradiation test was conducted for about 6 h at room temperature [5]. The neutron intensity was measured using the activated Nb foils which was positioned behind the sample assembly after irradiation. The measured value was about 9.96 x 10^{11} n/cm^2.

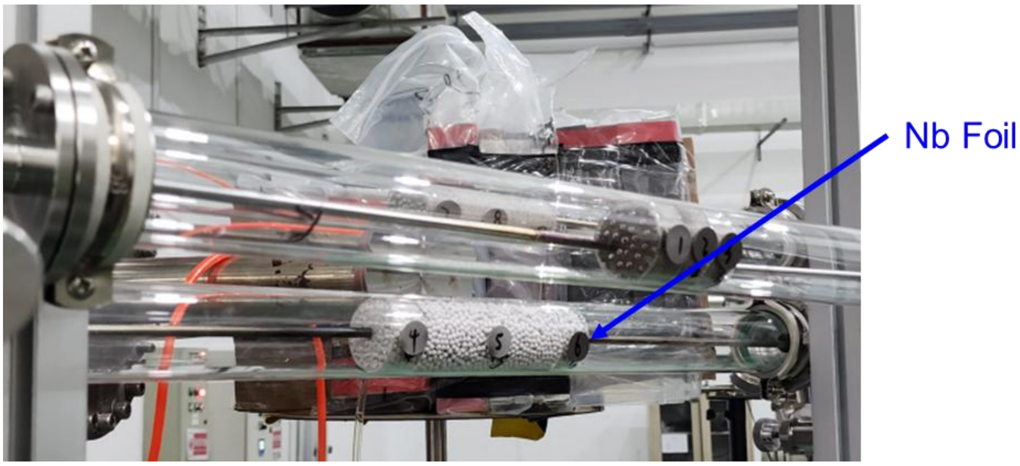

FIG. 3. Installed pebble assembly in front of HINEG target for neutron irradiation test

2.3. Tritium release test

Tritium release test from the irradiated pebbles was conducted at INEST using a dedicated tritium release system [6]. The chemical composition of a purge gas was He + 1 % H_2. The flow rate and humidity of the purge gas were controlled as 100 ml/min and less than 15 ppm, respectively. The temperature of tritium release test was from room temperature to 800 ^oC with 100 ^oC / 1 h of heating rate. The temperature holding and the tritium collection by water bubblers were performed at every 100 ^oC. The collected tritium was measured by ultra-low background liquid scintillation spectrometer [5].

FIG. 4. Furnace and trapping bubblers of tritium release system

3. RESULTS AND DISCUTION

3.1. Properties of Li_2TiO_3 pebbles

During sintering process, the volumetric shrinkage ratio of Li_2TiO_3 pebbles was about 15 %. It can be used as a parameter to design the PIM mold in order to control the diameter of pebbles. In addition, the connected pebbles were not observed due to the pebble moving in the specially designed rotating furnace system. Therefore, the defects, such as crack, bump, flatted surface, and so on, were not formed at the surface of sintered pebbles. Also, the pebbles had a uniform microstructure with same particle size and open pores at the surface and inside of pebbles, and an extremely good sphericity. Average sphericity and grain size of the pebbles were less than 1.01 and 1.00 μm, respectively. The porosity was about 39.7 % which was a relatively high as a breeder pebbles [4].

However, the amount of binder material has to be reduced during PIM process to decrease a porosity of the pebbles to improve the mechanical/thermal properties and increase the lithium density for high-performance of tritium breeder.

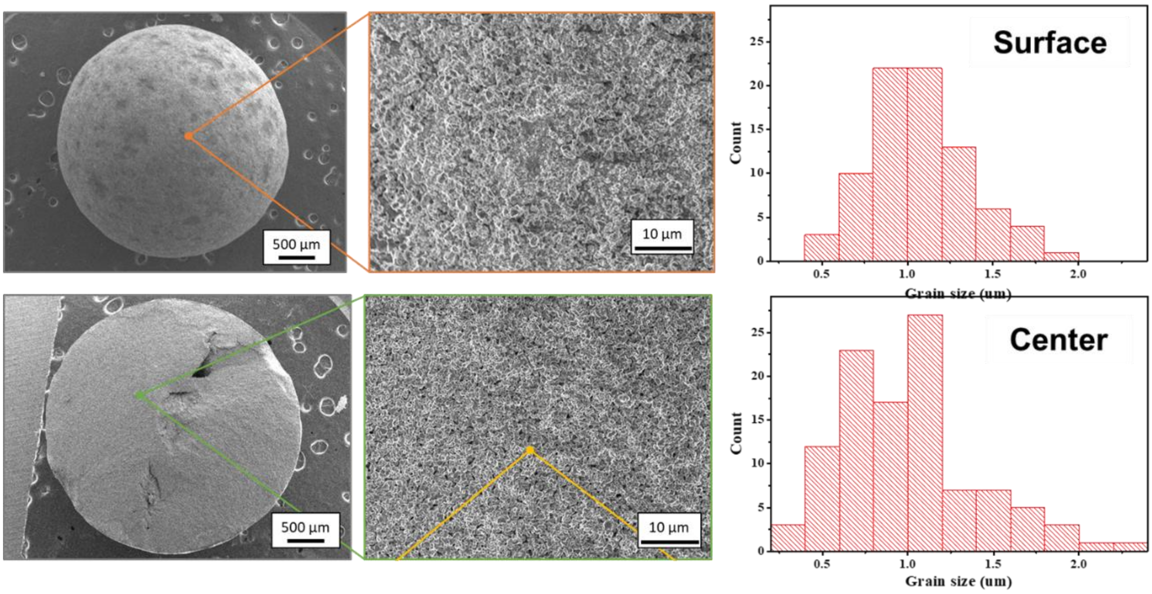

FIG. 4. Microstructure and grain size of sintered Li_2TiO_3 pebble

3.2. Tritium release performance

The total radioactivity of release tritium from the irradiated Li_2TiO_3 pebbles with 274.1 g in weight was about 1866.4 Bq. Tritium release behaviour including the ratio between HTO and HT from water bubblers at elevated temperature was preliminary investigated. Before heating, HTO and HT activities were 54.4 Bq and 23.6 Bq, respectively. It was estimated that the tritium was bred at the surface during irradiation. The released tritium increased gradually up to 400 ºC, and subsequently decreased at higher than 400 ºC. And then, the tritium radioactivity was decreased to background level after 4 h at 800 ºC. The total ratio between HTO and HT at 400 ºC was about 79.3 % to 20.7 %.

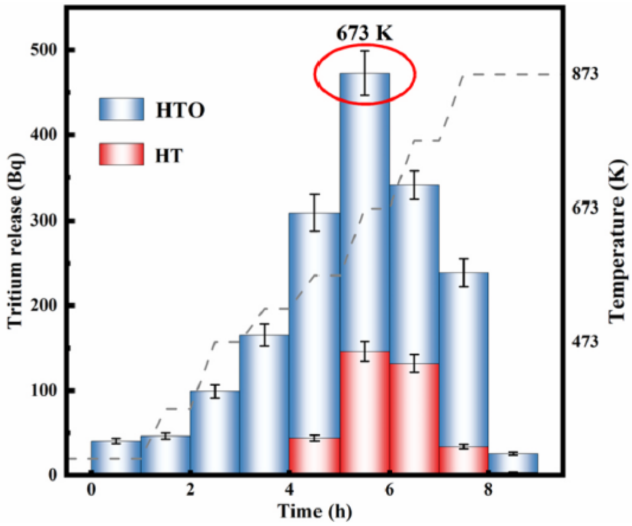

FIG. 5. Amount of released tritium from irradiated Li_2TiO_3 pebble bed at elevated temperature [5]

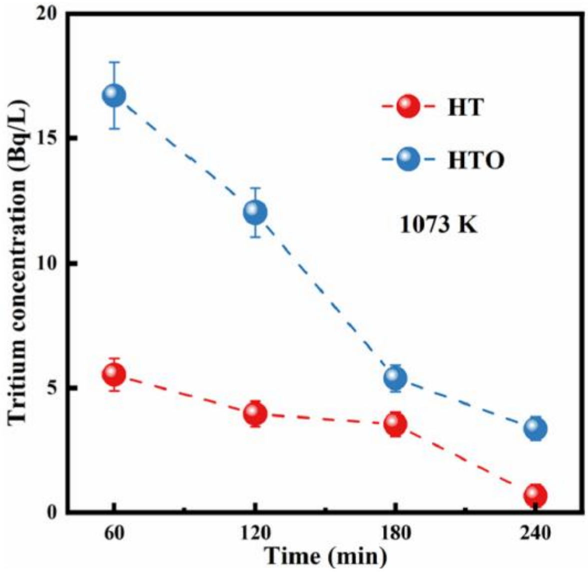

FIG. 5. Amount of released tritium from irradiated Li_2TiO_3 pebble bed at 800 ^oC [5]

4. SUMMARY

Li_2TiO_3 pebbles with 1 μm in grain size and high sphericity for tritium breeder material were successfully manufactured using the PIM process. In the PIMed Li_2TiO_3 pebbles, a uniform microstructure was observed both at the surface and inside, while no defects resulting from sintering between neighbouring pebbles were detected during the sintering process. Tritium production and release experiments were conducted on Li_2TiO_3 pebble bed with 14 MeV fusion neutron source HINEG-CAS and tritium release system. The total radioactivity of tritium released from the irradiated Li_2TiO_3 pebbles with a weight of 274 g was approximately 1,866.4 Bq. The release pattern of HT was similar to that of HTO. Tritium release peaked at 400 ^oC, with the ratio of HTO to HT being approximately 79.3 % to 20.7 %. However, it has different tendencies with the previous reports. Therefore, Future works will focus on validating the performance of oxidizer in the tritium release system, as this remains a key factor in understanding release mechanisms. In addition, the effects of purge gas composition on tritium release behaviour will be systematically investigated to clarify its impact under relevant operating conditions. Furthermore, the influence of breeder pebble properties, such as open porosity and grain size, on tritium release performance will be compared to provide deeper insights into material optimization for fusion blanket applications.

ACKNOWLEDGEMENTS

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REFERENCES

[1] MU-YOUNG. AHN, SEUNGYON CHO, DONG WON LEE, CHEOL WOO LEE, KYU IN SHIN, DUCK YOUNG KU, YI-HYUN PARK, CHANG-SHUK KIM, IN-KEUN YU, YONG OUK LEE, EO HWAK LEE, HYUNG GON JIN SUK-KWON KIM, Design change of Korean HCCR TBM to vertical configuration, Fusion Eng. Des. 88 (2013) 2284-2288.

[2] LUCIANO M. GIANCARLI, MU-YOUNG AHN, SEUNGYON CHO, YOSHINORI KAWAMURA, ARTUR LEAL-PEREIRA, MARIO MEROLA, YVES POITEVIN, ITALO RICAPITO, QIAN SHENG, HIROYASU TANIGAWA, HISASHI TANIGAWA, JAAP G.VAN DER LAAN, XIAOYU WANG, Status of the ITER TBM Program and overview of its technical objectives, Fusion Eng. Des. 203 (2024) 114424.

[3] A. YING, M. AKIBA, L.V.BOCCACCINI, S. CASADIO, G. DELL'ORCO, M. ENOEDA, K. HAYASHI, J.B. HEGEMAN, R. KNITTER, J. VAN DER LAAN, J.D. LULEWICZ, Z.Y.WEN, Status and perspective of the R&D on ceramic breeder materials for testing in ITER, J. Nucl. Mater. 367-370 (2007) 1281-1286.

[4] YOUNG AH PARK, YI-HYUN PARK, MU-YOUNG AHN, YOUNG SOO YOON, Fabrication and characteristics of Li_2TiO_3 pebbles manufactured by using powder injection molding (PIM) process, J. Nucl. Mater. 597 (2024) 155140.

[5] WENHAO WU, HAIXIA WANG, XUEWEI FU, JIAQING WANG, ZHENGKUI ZENG, FENG XU, DAN XIAO, YONG ZHANG, SIWEI ZHANG, SIZE CHEN, TAOSHENG LI, YI-HYUN PARK, Experiment study on tritium release behaviour of Li_2TiO_3 ceramic breeder irradiated by 14 MeV fusion neutron, Int. J. Hydrogen Energy 68 (2024) 1393-1397.

[6] HAIXIA WANG, WENHAO WU, XUEWEI FU, SIWEI ZHANG, ZHENGKUI ZENG, DAN XIAO, YONG ZHANG, SIZE CHEN, TAOSHENG LI, JIE YU, Development of a tritium release system for ceramic tritium breeder pebbles irradiated by high intensity DT fusion neutron generator at INEST, Nucl. Mater. Energy 39 (2024) 101653.