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Fabrication of beryllide pebble as advanced neutron multiplier

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HIGHLIGHTS

- A new beryllide granulation process that combined process with a plasma sintering method for electrode fabrication and a rotating electrode method (REM) for granulation was suggested.
- The beryllide electrode fabrication process was investigated for mass production.
- As optimized beryllide electrode indicated higher ductility and was sintered at a lower temperature for a shorter time.
- It appears to be more able to not only withstand the thermal shock from arc-discharge during granulation but also produce beryllide pebbles on a large scale.
- These optimization results can reduce the time for electrode fabrication by 40%, they suggest the possibility of great reductions in time and cost for mass production of beryllide pebbles.

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ABSTRACT

Fusion reactors require advanced neutron multipliers with great stability at high temperatures. Beryllium intermetallic compounds, called beryllides such as $Be_{12}Ti$, are the most promising materials for use as advanced neutron multipliers. However, few studies have been conducted on the development of mass production methods for beryllide pebbles. A granulation process for beryllide needs to have both low cost and high efficiency. To fabricate beryllide pebbles, a new granulation process is established in this research by combining a plasma sintering method for beryllide synthesis and a rotating electrode method using a plasma-sintered electrode for granulation. The fabrication process of the beryllide electrode is investigated and optimized for mass production. The optimized beryllide electrode exhibits higher ductility and can be sintered at a lower temperature for a shorter time, indicating that it is more suitable not only for withstanding the thermal shock from arc-discharge during granulation but also for producing the beryllide pebbles on a large scale. Accordingly, because these optimization results can reduce the time required for electrode fabrication by 40%, they suggest the possibility of great reductions in time and cost for mass production of beryllide pebbles.

1. Introduction

Pure Be metal is a candidate material for a neutron multiplier in the blanket of a fusion reactor. However, several problems are anticipated when fusion reactors are operated under high neutron flux and high temperature conditions, such as volumetric swelling and the hydrogen generation from Be. Accordingly, advanced neutron multipliers with lower swelling and greater stability at high temperature are desired in pebble-bed blankets, which would greatly affect the design of fusion reactors, especially of the blanket operating temperature.

Beryllium intermetallic compounds, called beryllides, such as $Be_{12}Ti$ are the most promising materials for use as advanced neutron multipliers [1,2]. However, few studies have reported on the developments of mass production methods for beryllide pebbles. A granulation process for beryllide should have both low cost and high efficiency, owing to the requirement of 200–400 t of neutron multiplier for its breeder blanket.

In this research, a new beryllide granulation process is suggested. It combines a plasma sintering method and a rotating electrode method (REM). A flowchart for the new granulation flow scheme for the Be–Ti beryllide is shown in Fig. 1. The plasma sintering procedure is simple, easy to control, and can reduce the time required for beryllide electrode fabrication by 30% compared to conventional methods such as the hot isostatic pressing method.

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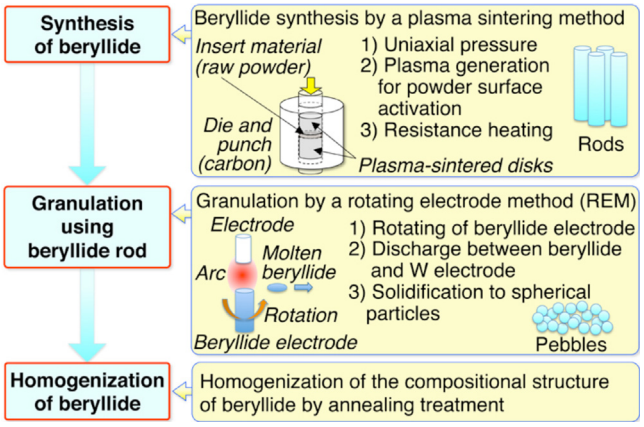

Fig. 1. Flowchart of beryllide granulation process.

To fabricate beryllide pebbles, REM was selected because of the broad experience base of its use in industry, not only for Be pebbles but also for metallic pebbles.

From the plasma-sintered beryllide electrode, prototypic beryllide pebbles of 1 mm average diameter were successfully fabricated, although they were composed of Be, $Be_{17}Ti_2$, and $Be_{12}Ti$ phases owing to a peritectic reaction caused by re-melting [3]. Subsequently, a procedure using annealing treatments to homogenize the pebbles to the $Be_{12}Ti$ phase was evaluated. From the results of annealing treatments on the prototypic pebbles, the pebble phase was homogenized to a single phase of $Be_{12}Ti$ by annealing either at 1473 K for more than 8 h or at 1673 K for 1 h [4].

However, this revealed that an electrode with high beryllide content breaks easily because of thermal shock from arc-discharge in the granulation process of REM owing to the high brittleness of beryllide. The electrode used as a raw material for granulation by REM should thus have a higher ductility. Therefore, for the purposes of mass production of beryllide pebbles, the optimization of the beryllide electrode fabricated by the plasma sintering method is a key issue.

This study describes the effect of plasma sintering conditions on the mechanical properties of the beryllide electrode.

2. Relationship between compositional structures of plasma-sintered electrodes and prototypic pebbles

2.1. Changes in compositional structure of plasma-sintered beryllide electrode under plasma sintering conditions

The effect of the compositional structure of the plasma-sintered beryllide electrodes on that of the prototypic beryllide pebbles granulated via REM was evaluated.

Beryllide disks of a Be–Ti intermetallic compound were synthesized from mixed pure Be and Ti powders. Thirty grams each of beryllium powder (Materion Brush Inc., 99.4 wt.%) and titanium powder (Kojundo Chemical Laboratory Co. Ltd., 99.9 wt.%) were mixed for 60 min with an automatic mortar (RM200, Retsch, Co. Ltd.) made of Al_2O_3. The size of the Be and Ti powders was less than 45 μm. The mixed powder composition was 92.3 at.% Be and 7.7 at.% Ti, which is the stoichiometric composition of $Be_{12}Ti$.

The powder was loaded into a graphite die, and uniaxial pressure was applied for cold compaction. An electric current was applied to create a plasma environment and to activate the particle surfaces (Fig. 1). The compacted powder was resistance-heated while uniaxial pressure was still being applied to the material in the sintering mold. In the present study, a plasma sintering apparatus (KE-PasIII, KAKEN Co. Ltd.) was used. Plasma sintering was conducted at any given sintering temperature and sintering time under a pressure of 50 MPa, while the heating and cooling rates were approximately 100 and 200 K/min, respectively. The plasma-sintered beryllide disks were 20 mm in diameter and 45 mm in thickness.

To fabricate the beryllide electrode for the REM, a joining process to fabricate a beryllide block was performed by using of two plasma-sintered beryllide disks (Fig. 1). For the joining, three grams of powder (i.e., the same raw material used to fabricate the beryllide disks) was inserted between the plasma-sintered disks. The plasma sintering conditions for joining were the same as those for fabrication of the beryllide disk. The joined beryllide block was 20 mm in diameter and 100 mm in length. Using a beryllide electrode 15 mm in diameter and 100 mm in length that was machined by the wire electric discharge method from this plasma-sintered beryllide block, a trial fabrication of prototypic beryllide pebbles was performed via REM.

To evaluate the effects of the plasma sintering conditions on the compositional structure of the pebbles, the plasma sintering was performed at 1073, 1173, and 1273 K for 2.5, 5, and 40 min each.

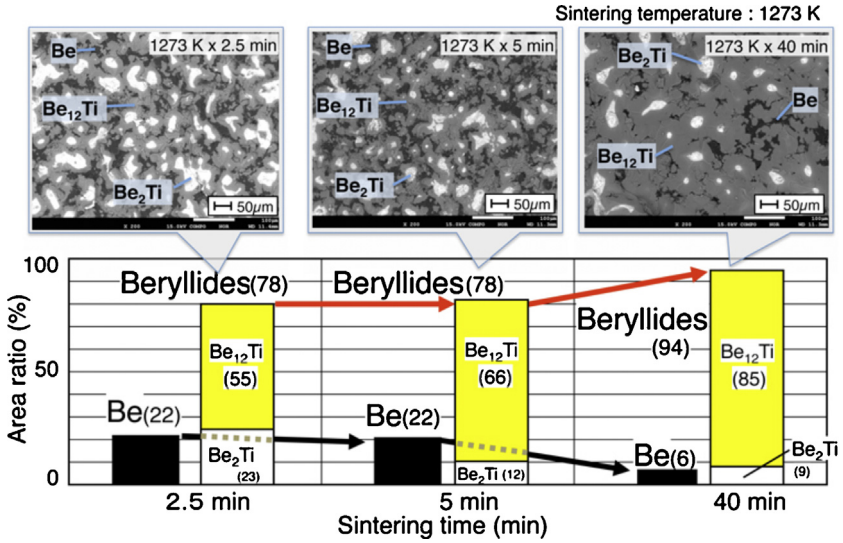

Fig. 2. Changes in compositional structure of plasma-sintered beryllide electrode from plasma sintering at 1273 K for 2.5, 5, and 40 min.