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# Fabrication of BN Nanosheet Reinforced $ZrO_2$ Composite Pellets for Inert Matrix Fuel

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## 1. Introduction

Nowadays, many countries are using the nuclear energy for electricity production using enriched uranium fuel, where Plutonium is produced in substantial amounts during fuel burn up as it is considered as an unavoidable by-product. Plutonium also can be resulted from the dismantlement of nuclear weapons. This will result in the increase of the stockpile of plutonium. For that purpose many organizations are focusing their R&D work on the concept of *Inert Matrix Fuel* IMF, where a U-free matrix is used to eliminate the U-Pu conversion. [1]

R&D work was standardized around Zirconia-based IMF as a result of many screening and ranking studies performed on various candidates. [2] Regardless of its outstanding radiation resistance, chemical stability and its high melting point, it has a very low thermal conductivity, which could be detrimental for the fuel matrix especially in case of accidents. A reinforcement phase could be used for the enhancement of the thermo-mechanical properties. Among many possible reinforcements, 2D structured nanosheets have emerged as an excellent candidate to enhance the thermal properties and mechanical properties simultaneously. In this approach *Boron Nitride Nanosheets* BNNS are used for that purpose.

BNNS have a very low density, very high thermal conductivity, very high mechanical properties and high neutron absorption cross-section for Boron which is used frequently as a burnable poison. They have properties similar to graphene but they exhibit superior thermal stability in the oxide structure. Despite all the studies on other reinforcements, BNNS reinforced $ZrO_2$ has not yet been reported. In this study, pure $ZrO_2$ and partially stabilized Zirconia PSZ (using Yttria) ceramics are mixed with different volume fractions of BNNS.

## 2. Experimental procedure

### *2.1. Preparation of BNNS-$ZrO_2$-based IMF*

BNNS were prepared using a planetary ball milling (Fritsch Pulverisette 5) by means of exfoliation of the nano-sheets by the subjected shear forces on the mixture of hexagonal-BN powder, PSS (Polystyrene Sulfonate) and IPA (Isopropyl alcohol). Then it was followed by centrifuging of the extracted sheets and subsequent filtrations. [3] Four kinds of composite powders (0, 1.0, 3.0, and 5.0 vol.% BNNS) were prepared. Pellets were fabricated using two techniques; spark plasma sintering SPS and microwave sintering techniques. For SPS, where the composite powder was placed into a 13 mm diameter cylindrical graphite die and an electric current of ~1000 A was applied under a pressure of ~50 MPa. The ramping rate was 100°C/min and the sintering was performed at 1500°C for 10 minutes. For microwave sintering, powder was initially compacted in a mold then sintered at 1500°C for 10 minutes under a Nitrogen atmosphere.

### *2.2. Characterization*

The apparent density of the sintered pellets was measured using the Archimedes method. Regarding the microstructural observation Scanning electron microscope (SEM) was used for this purpose, while X-ray diffraction (XRD) was used for the determination of phases inside the microstructure as the matrix phase and the reinforcement. Finally, the chemical interaction between the reinforcements and the oxide matrix will be analyzed using the Energy dispersive X-ray spectroscopy (EDS).

### *2.3. Thermal and mechanical testing*

Laser flash method was used in order to measure the thermal diffusivity, where it has been recognized as a useful method for high-temperature thermal properties measurements of nuclear ceramic materials. [4] Diffraction scanning calorimetry (DSC) was used for the specific heat measurements, and the thermal expansion coefficient was measured by a dilatometer. A three point flexural test was used for the measurements of the flexural stress. The hardness was measured using Vickers indentation on polished surfaces under a 3 kg load with a dwell time of 15 s, and fracture tough-ness was estimated from crack length measurement after 20 kg loading for 15 s.

## 3. Results & Discussion

### *3.1. Characterization of BNNS-$ZrO_2$-based IMF*

The first batch of samples was fabricated using pure $ZrO_2$ mixed with BNNS. The SEM micrograph of the fracture morphology of sintered composite powder indicated that nearly full densification was achieved using SPS, BNNS were relatively well-dispersed in the intragranular sites (Fig. 1). Some agglomerations of BNNS were observed in the fractured surface as well (Fig. 2).

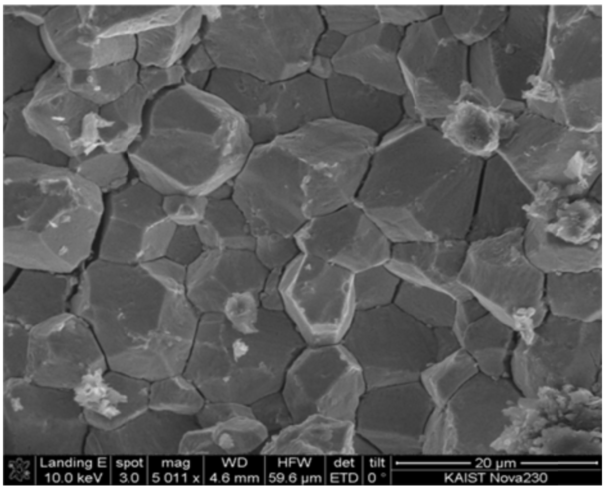

Fig. 1 SEM micrograph of fractured morphology for 5vol% BNNS-$ZrO_2$ sintered by SPS.

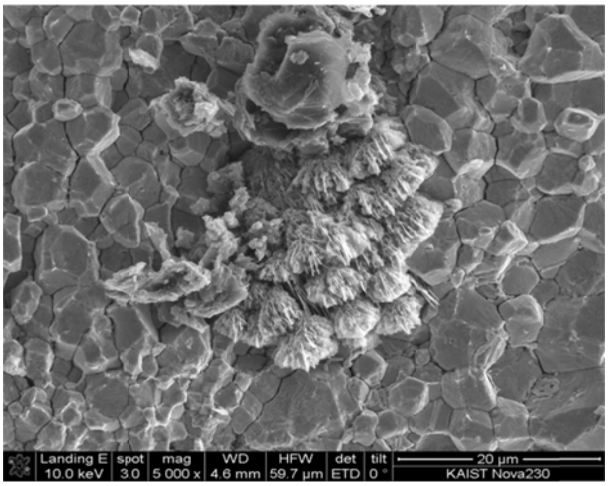

Fig. 2 SEM micrograph of BNNS Agglomerations in the fractured morphology for 5vol% BNNS-$ZrO_2$ sintered by SPS.

## 4. Conclusions

BNNS are expected to increase the thermal conductivity of the fuel matrix as well as the mechanical properties, which will enhance the overall performance of the fuel during operation under normal and off-normal conditions.

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