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Multiwalled carbon nanotube-reinforced ceramic matrix composites as a promising structural material

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ABSTRACT

In this paper, we introduce fully dense, multiwalled carbon nanotube (MWCNT)-reinforced ceramic matrix composites recently processed by a novel powder technology in our laboratory to be considered as a promising potential structural materials for employment in severe working conditions. A strategy is also offered to investigate the effect of working condition on the mechanical properties of MWCNTs embedded in the ceramic matrix for a reliable material selection for the working conditions needed.

1. Introduction

Ceramics with their extraordinary strength, hardness and thermal–chemical stability are promising and reliable structural materials resistant to the corrosive environments; however, their brittleness can strongly reduce their lifetime, and prevent their applications in a variety of industries demanding tough structural materials. Multiwalled carbon nanotubes (MWCNTs) with their exceptional characteristics, and considered as a unique toughening–strengthening agent for conventional materials can be employed to reinforce the ceramics to obtain tough and strong structural materials resistant to the strong mechanical impacts and corrosive environments [1–3]. Theoretically, these expectations can be achieved if the individually dispersed MWCNTs can be entirely wetted by the ceramic phase, which results in the full density of the processed composite.

However, poor interfacial compatibility and wetting between MWCNT and the ceramic matrix, and strong MWCNT entangling caused by attractive Van der Waals forces are important obstacles to achieve this goal [2,3]. The interfacial compatibility issue is greatly pronounced for ceramic materials due to their outstanding chemical stability preventing their homogeneous and atomic-level blending with the chemically-stable MWCNTs. Recently, Estili and Kawasaki established a colloidal powder processing technology to prepare homogeneous MWCNT-ceramic matrix composite powders with a broad range of MWCNT concentration (2.4–15 vol.%). α-Al_2O_3 ceramic was used in their study [2]. By this technology, they resolved three challenging issues encountered in the processing of these composites: (1) aggregation of MWCNTs especially in high concentrations; (2) poor interfacial compatibility between MWCNT and the ceramic matrix, and (3) inability to mass-producing the homogeneous composite powders [2].

This powder approach [2] allowed fabrication of fully dense MWCNT–ceramic matrix composite bulks (Fig. 1) by spark plasma sintering (SPS) even for 15 vol.% MWCNT concentration [4,5] (the highest concentration ever achieved). We achieved a 70% increase in the fracture toughness of the α-Al_2O_3 ceramic matrix due to addition of 3.5 vol.% MWCNT [3].

After the important success in processing of fully dense MWCNT-ceramic matrix composite bulks, Estili et al. [4,5] fabricated MWCNT-based functionally graded ceramics (α-Al_2O_3) by gradual and homogeneous incorporation of MWCNTs to the ceramic matrix. In this newly processed composite, variant properties have been engineered through-the-thickness without premature failure; i.e. they bridged a conventional ceramic to an advanced CNT-concentrated ceramic matrix composite.

Theoretically, these fully dense, MWCNT-reinforced ceramic matrix composites, and newly engineered, CNT-based functionally graded ceramics can find promising applications as structural materials resistant to the severe working conditions such as high loads, high temperatures, and corrosive environments. To prove this, extensive experimental characterizations are required in the future for which a variety of industries can cooperate.

2. Objectives

The most important objective of this letter is introducing the recently processed, fully dense MWCNT-reinforced ceramic matrix composites to be considered as a promising potential structural

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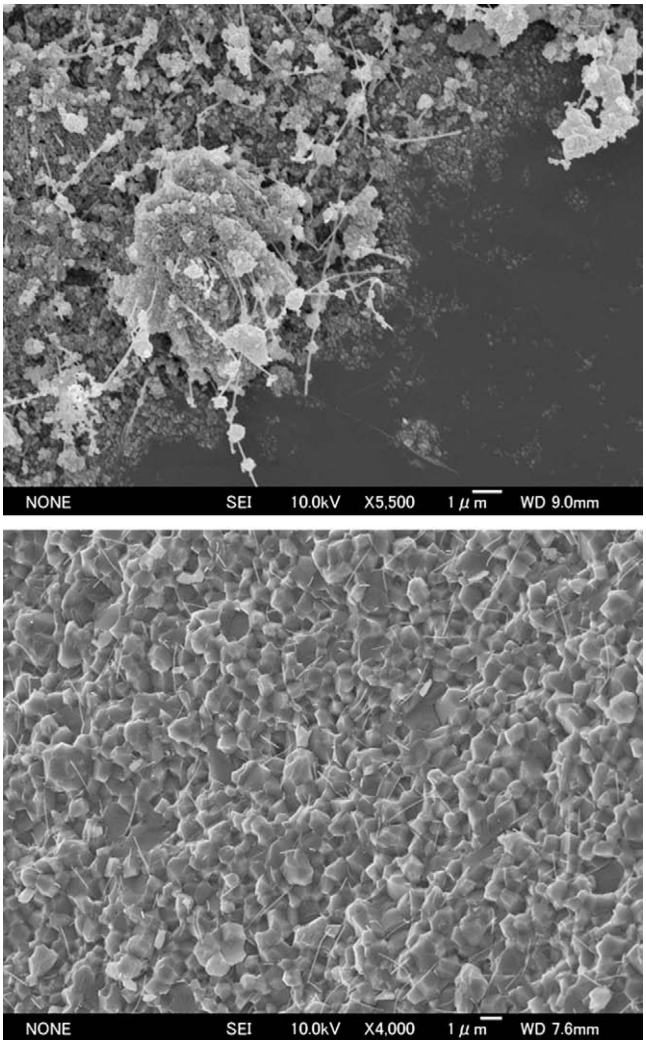

Fig. 1. Field-emission SEM images of the composite powder (top), and fracture surface of the fully dense, SPS-consolidated composite bulk (bottom).

material for employment in the severe working conditions, according to the previous achievements [1–5]. Next, as the working condition may affect the mechanical property of MWCNTs in the matrix, which mostly determines the mechanical performance of the composite, a strategy will be briefly introduced to be employed prior to the material selection step to directly investigate the changes in the mechanical response of MWCNTs (embedded in the ceramic matrix) after the composite experiences a specific working condition. This leads to a more reliable material selection for the working conditions needed.

3. Strategy to investigate the effect of working condition on the mechanical performance of the CNTs of the composite

As mentioned earlier, the working condition of the composite may affect the mechanical property MWCNTs inside, which mostly determines the mechanical performance of the entire composite. Therefore, to properly select the structural composites for a specific working condition, prior investigation of the mechanical performance of MWCNTs (while embedded in the matrix) after the composite experiences a specific working condition is absolutely helpful. First, fully dense and homogeneous MWCNT-α-Al_2O_3 cera-

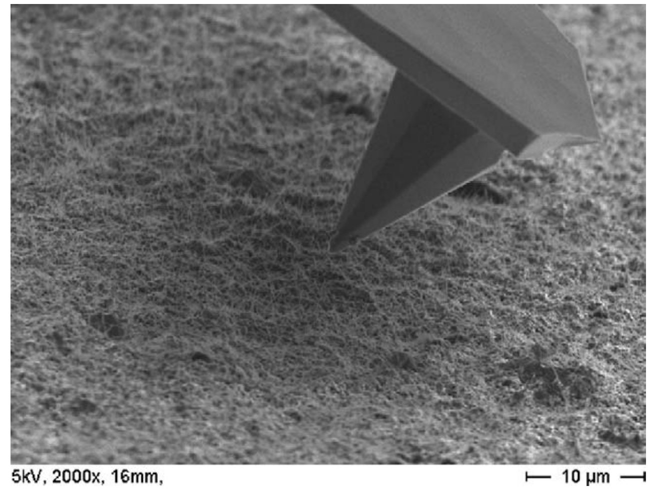

Fig. 2. SEM image of the tip of a cantilever force sensor approaching the CNTs observed on the fracture surface of a fully dense, ceramic matrix composite.

mic matrix composite bulk was fabricated by the recently established powder approach [2,3]. To quantitatively investigate the mechanical property of individual MWCNTs in the composite in a certain working condition, a three-dimensional piezoelectric nano-positioner (SmarAct GmbH, Germany) was employed to approach the CNTs, touch them and finally apply the load. To measure the applied load, a cantilever force sensor (NanoWorld, Swiss) was used which is shown in Fig. 2. Fig. 2 shows the tip of a force sensor attached to the nano-positioner which is approaching the CNTs observed on the fracture surface of the composite. These tests were conducted inside a scanning electron microscope (SEM) (ZEISS, DSM 962, Germany). This experiment was carried out in collaboration with Swiss Federal Institute for Materials Research and Testing, EMPA, Thun. A series of these experiments were successfully conducted for the as-processed composites [1]. Employing this strategy, changes in the mechanical response of MWCNTs after the composite experiences a specific working condition can be investigated, and the results can be helpful in a variety of industries which are looking for reliable ceramic-based structural materials.

4. Summary

Fully dense, MWCNT-reinforced ceramic matrix composites recently processed by a novel powder technology in our laboratory is introduced to be considered as a promising potential structural material for employment in severe working conditions. A more reliable material selection process for the working conditions needed becomes possible employing our proposed strategy enabling us to directly investigate the changes in the mechanical response of CNTs (embedded in the ceramic matrix) after the composite experiences a specific working condition. The results can be helpful in a variety of industries which are looking for the reliable ceramic-based structural materials.

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