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Surface modification of graphene oxide nanoplatelets and its influence on mechanical properties of alumina matrix composites

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ABSTRACT

This paper discusses the effect of modified graphene oxide nanoplatelets (RGO-Al_2O_3) and unmodified graphene oxide nanoplatelets (GO) addition on the microstructure and mechanical properties of alumina matrix composites. The sinters were prepared by powder metallurgy processing using Spark Plasma Sintering to consolidate the powder mixtures. Moreover, the influence of applied reinforcing phase on the fracture mechanism was also investigated. Significant improvement of the fracture toughness (60%) for the composites with 0.5 wt.% RGO-Al_2O_3 compared to the reference sample was observed. Moreover, 20% higher K_{IC} was noticed for RGO-Al_2O_3 reinforced composites than for Al_2O_3-GO.

1. Introduction

It is proven that the addition of graphene nanoplatelets (Gn) or graphene oxide nanoplatelets (GO) to a ceramic matrix, even a small amount, positively affects the mechanical, thermal and electoral properties of the composites [1–5]. Despite this, research is still conducted aimed at improving the properties of the composites. However, preparation of the composites reinforced with Gn still causes many problems, such as: production of high quality graphene, homogeneous dispersion of Gn in a ceramic matrix, degradation of graphene during sintering and proper matrix-reinforcement bonding [4]. While the first three problems can be solved relatively easily through the use of appropriate methods of graphene synthesis, homogenization and consolidation of the powders mixture [6–8], the matrix-reinforcement bonding still poses a lot of problems. It is well known that the provision of an appropriate interface is essential to ensuring high strength properties of the composites. Crack propagation in Gn/GO-reinforced composites can be compared to fibre-reinforced ceramic composites where three occurrences may take place, i.e. a singly deflected crack, a doubly deflected crack, and a penetrating crack across the reinforcing platelets. However, some differences in crack propagation behavior in Gn/GO ceramic composites can be observed. This is due to the high strength and large surface area of Gn. Assuming a strong ceramic-graphene bonding, graphene does not allow a crack to propagate through the flake and the cracking path is more tortuous and greater in length. Additionally, due to the anchoring of the graphene around ceramic grains, a higher force is required to pull out flakes from the matrix compared to fibre reinforced composites [9]. On the other hand, in the case of a lack of bonding between graphene and the matrix, there can be a presence of voids and consequently a decrease of the composites mechanical properties [10].

In the literature, there is relatively little work devoted to the improvement of bonding between graphene/graphene oxides nanoplatelets and ceramic matrix. There are some suggestions that the application of graphene with carbides e.g. SiC and graphene oxide with oxides matrix e.g. Al_2O_3 may provide a better interface bonding and improve the mechanical properties of composites [11]. However, it has not been proved yet. Attempts to improve the graphene nanoplatelets –Al_2O_3 interface has been taken in our previous works [12,13]. The Gn surface was modified by coating Ni or Ni-P layers. The research shows that correctly applied coating parameters allow achievement of uniform coatings. The use of modified graphene nanoplatelets to reinforce Al_2O_3 led to a significant improvement in the fracture toughness (up to 45%), compared to the composites with unmodified Gn. This demonstrates that it is possible to improve the properties of the Gn/GO reinforced composites by providing a good interface bonding of the phases.

In this investigation, alumina matrix composites reinforced with different weight fractions of RGO-Al_2O_3 have been produced and compared with the composites reinforced with unmodified

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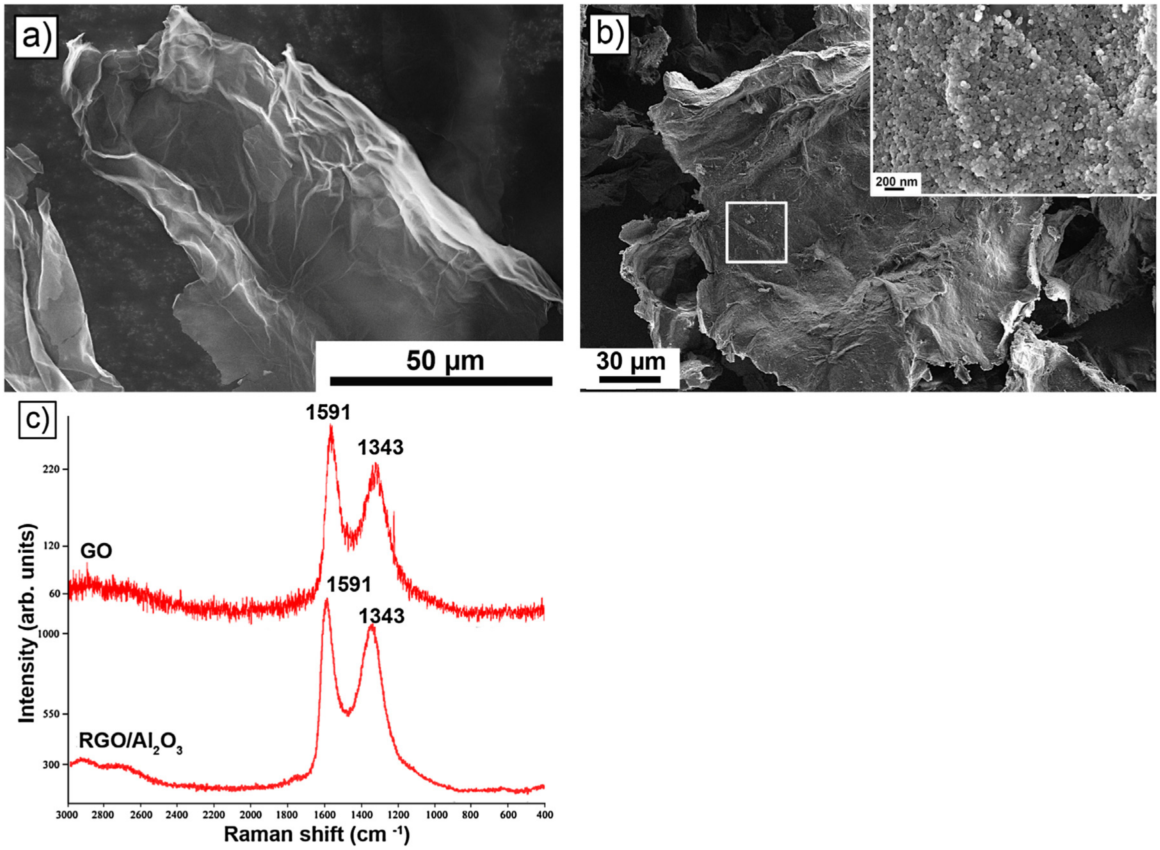

Fig. 1. Morphology of a) unmodified GO, b) RGO-Al_2O_3 and c) the Raman spectrum of GO and RGO-Al_2O_3.

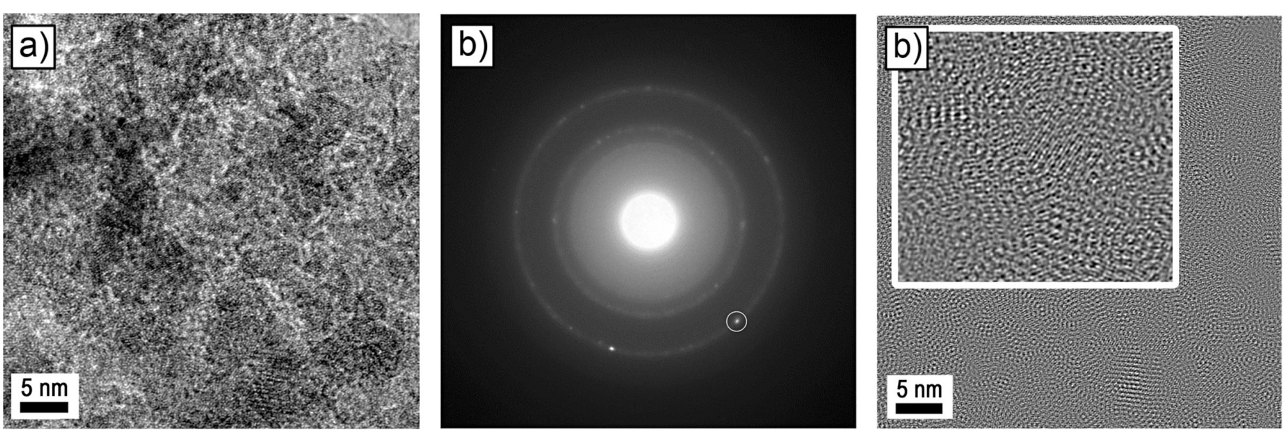

Fig. 2. TEM image taken from the surface of single RGO/Al_2O_3 nanocomposite flake a) and the corresponding electron diffraction (FFT) b) The microstructure (IFFT) presented in c) was prepared for (440) reflection related to the γ-Al_2O_3 phase.

graphene oxide nanoplatelets. Final consolidation of the powder mixtures was carried out with the use of the SPS (Spark Plasma Sintering) method. The changes in the microstructure and mechanical properties were studied and compared with pure Al_2O_3.

2. Materials and methods

In the current work, the Al_2O_3-x of GO/RGO-Al_2O_3, (x – 0.5; 1 and 2 wt.%) composites were fabricated by a powder metallurgy route. For the substrates, commercially available α-Al_2O_3 powder (Taimei Chemicals CO.,LTD., 99.99% chemical purity) and graphene oxide nanoplatelets produced in the Institute of Electronic Materials Technology (99.99% chemical purity) were used. To obtain RGO-Al_2O_3 (20 wt.%) powder, the GO was introduced to the dry isopropanol (Sigma-Aldrich, Gillingham, Dorset, UK) and homogenized for 2 min in a periodical working mode (1 s work/1 s brake) with power of 300 W. Subsequently, the aluminium triisopropoxide (Sigma-Aldrich, Gillingham, Dorset, UK) was introduced to the reaction mixture to obtain the final concentration of 20 wt.% of Al_2O_3 organic precursor on the surface of RGO flakes. The reaction mixture was then stirred, ethyl alcohol (95% v/v, Sigma-Aldrich, Gillingham, Dorset, UK) was introduced and the solvent spontaneously evaporated into the air. Detailed information on the process and the related reactions is given elsewhere [14].

The homogenization of the powder mixtures was realized in two steps: ultrasonically for 1 h and with a planetary mill for 6 h. In