Silicon nitride composites containing graphene nanostructures

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Abstract

Ceramic composites containing graphene nanostructures have not raised as much expectation as polymer composites, although the inclusion of graphene in ceramics has shown important effects on several properties of these new composites, and with the added benefit of multi-functionality. In particular, an increase in toughness (K_{IC}) from 2.8 to 6.6 MPa.m$^{1/2}$ for Si_3N_4/graphene[1] composites has been reported and electrical conductivities of 5709 S.m^{-1} were observed in Al_2O_3/graphene[2] composites.

Ceramic-graphene composites are mainly fabricated by mixing fine ceramic powders (normally under 1 μm) and graphene flakes. The graphene flakes in the composites show a range of thickness from few nm to100nm for the so-called graphene nanoplatelets (GNP), and much thinner flakes when graphene oxide (GO) is used as starting nanostructure.[3] The more common densification sintering method is the spark plasma sintering that allows very fast sintering rates and consolidation at lower temperatures than more conventional methods. The characteristics of the technique – application of load and pulsed direct current on the graphite die containing the compound- induce orientation of the flakes in the composite microstructure, as evidenced in the fracture surface image of Fig.1. This arrangement of the graphene flakes produces a certain degree of anisotropy in the properties.[4,5]

We will show that high electrical conductivity and exceptional mechanical properties are achieved for Si_3N_4/graphene composites by an appropriate selection of the graphene source. Electrical conductivities of 4000 S.m^{-1} -13 orders of magnitude higher than the monolithic material- and a percolation threshold of 0.07[5] are observed for Si_3N_4/GNP composites, but electric percolation is accomplished for much lower GO volume contents (0.04). The electrical conductivity attained gives an important attribute to the material, such as the possibility of being shaped using electrical discharge machining (EDM).[6] Si_3N_4 ceramics are hard materials, which are costly and difficult to machine and require the use of diamond tools; therefore, the possibility of using EDM is one interesting utility provided by the graphene network.

The influence of the graphene source is also evidenced in the K_{IC} of these composites. In fact, K_{IC} of 10 MPa.m$^{1/2}$ has been measured for composites fabricated from reduced GO, which is the highest reported to date for Si_3N_4-graphene composites, whereas a more modest toughening effect was measured in alike composites containing GNPs (4.1 MPa.m$^{1/2}$).

Graphene flakes also have an interesting influence on the composite tribology. Decreases in the friction coefficient and the wear volume (~56 %) for high contact loads are observed when compared to the plain material. This effect is mostly related to the lubricant effect caused by the buildup of graphene layers –detached from the composite- on the wear track (Fig. 2). The improved wear behavior of the composites may find application in gasoline direct injection engines.[7]

Summarizing, graphene-Si_3N_4 composites show excellent mechanical, tribological and electrical properties, in conjunction with an outstanding wear behavior, all these characteristics make possible their application in many fields, such as automotive industry, MEMS, turbines, etc.

References

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Figures

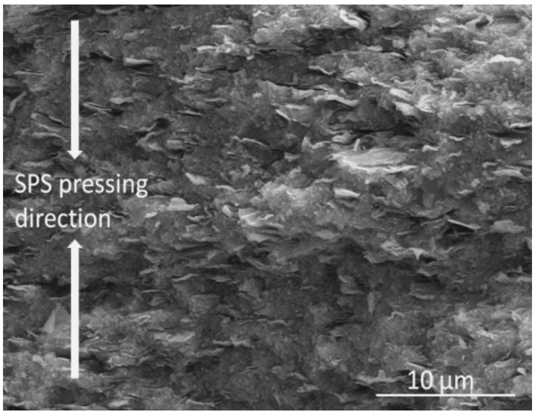

Figure 1: Field emission scanning electron micrograph of a Si_3N_4-GNP composite showing GNP orientation

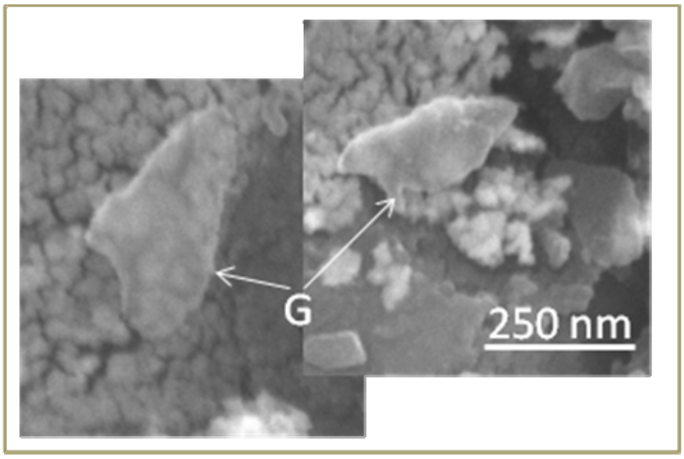

Figure 2: Presence of graphene flakes in the composite wear track