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A unified theory of plasticity, progressive damage and failure in graphene-metal nanocomposites

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Abstract

Several experiments have shown that, with a small amount of graphene volume concentration, the maximum strength of graphene-metal nanocomposites could increase notably while its failure strain decrease drastically, but at present no theory seems to exist to explain these opposing trends. In this paper we present a unified theory of plasticity and progressive damage that ultimately leads to the failure of composite. The theory is written in a two-scale framework, with the small scale constituting the ductile matrix and the microvoids generated during progressive damage, and the large scale combining the damaged metal matrix with 3-D randomly oriented graphene. To calculate the overall stress-strain relations the method of field fluctuation and interface effect are both considered, and to assess the evolution of microvoids during progressive damage a new damage potential is suggested. The final outcome is a simple and analytical model for the strength and ductility of the nanocomposite. We highlight the developed theory with a direct application to reduced graphene oxide/copper (rGO/Cu) nanocomposites, and demonstrate how, in line with experiments, the tensile strength can increase by 40% and the failure strain can drop from 0.39 to 0.14 as graphene volume concentration increases from 0 to 2.5 vol.%. The rapid increase of damage effect at high graphene volume concentration was found to be responsible for the sharp drop of ultimate strain.

Keywords: Plasticity, Progressive damage, Failure, Graphene-metal nanocomposites, Imperfect interface effects, Two-scale homogenization

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