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The cohesive law for the particle/matrix interfaces in high explosives

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Abstract

The debonding of particle/matrix interfaces has an important effect on the macroscopic behavior of composite materials. There are extensive analytical and numerical studies on interface debonding in composite materials based on cohesive zone models which assume a phenomenological relation between the normal (and shear) traction(s) and opening (and sliding) displacement(s) across the particle/matrix interface. However, there are little or no experiments to determine the cohesive law for particle/matrix interfaces in composite materials. In this paper, we develop a method to determine the cohesive law for particle/matrix interfaces in the high explosive PBX 9501. We use the digital image correlation technique to obtain the stress and displacement around a macroscopic crack tip in the modified compact tension experiment of PBX 9501. We use the extended Mori–Tanaka method (which accounts for the effect of interface debonding) and the equivalence of cohesive energy on the macroscale and microscale to link the macroscale compact tension experiment to the microscale cohesive law for particle/matrix interfaces. Such an approach enables us to quantitatively determine key parameters in the microscale cohesive law, namely the linear modulus, cohesive strength, and softening modulus of particle/matrix interfaces in the high explosive PBX 9501. The present study shows that Ferrante et al.'s [1982 Universal binding energy relations in metallic

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adhesion. In: J.M. Georges (Ed.), Microscopic Aspects of Adhesion and Lubrication, Elsevier, Amsterdam, pp. 19–30.] cohesive law, which is established primarily for bimetallic interfaces, is not suitable to the high explosive PBX 9501.

Keywords: Mechanical testing; Microstructure; Fracture; Microcracking; Inhomogeneous materials

1. Introduction

High explosives (e.g., PBX 9501) consist of very high volume fraction (~93%) of energetic particles in polymeric binder matrix (e.g., Skidmore et al., 1997; Bennett et al., 1998), and therefore have very high specific surface (the interface area per unit volume of the material). The behavior of particle/matrix interfaces significantly influences the macroscopic behavior of high explosives. The localized sudden interface debonding can cause the formation of hotspot, thus trigger detonation of high explosives under low-level loading. Interfacial debonding between the polymeric binder matrix and energetic particles may also significantly reduce macroscopic moduli of high explosives. The bulk modulus of PBX 9501 is more than 40% lower than that of the same material with perfect interfaces without any debonding (Tan et al., 2005). Interfacial debonding also governs fracture of high explosives. Experiments have repeatedly shown that crack propagation in the high explosive PBX 9501 is always along the particle/matrix interfaces (e.g., Wiegand and Pinto, 1996; Rae et al., 2002a,b). This is because the particle volume fraction is very high (~93%), and the energetic particles are hardly fractured. Fig. 1 shows the optical micrograph of the post failure route (i.e., path of crack propagation) in the high explosive PBX 9501 (Rae et al., 2002a). A single crack propagating along particle/matrix interfaces is clearly observed in Fig. 1. Except for interface debonding, the energetic particles remain intact. This path of crack propagation is called the "path of interface debonding" (Fig. 1).

There are extensive numerical studies of particle/matrix interface debonding based on the cohesive zone models (e.g., Needleman, 1987; Tvergaard and Hutchinson,

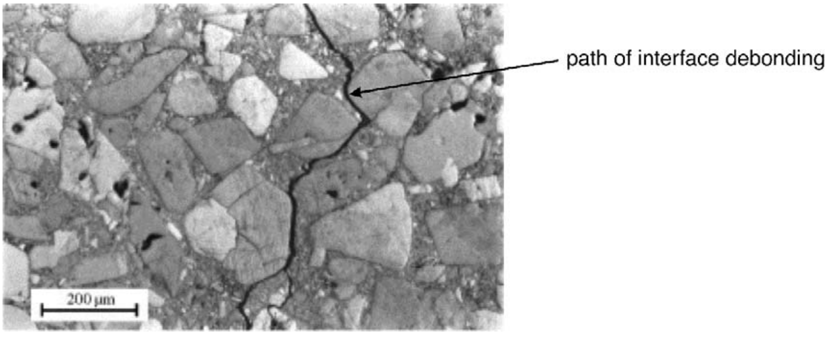

Fig. 1. Optical micrograph of the post failure route in the high explosive PBX 9501 (Rae et al., 2000a).