Interface Chemistry and Strain Rate Effect on Fracture in Energetic Material Interfaces

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Abstract. The fracture failure behaviour of Hydroxyl-Terminated Polybutadiene (HTPB)- Ammonium Perchlorate (AP) interfaces is investigated as a function of strain rate. A rate dependent power law viscoplastic constitutive model of HTPB, AP and the HTPB/AP interface is characterized using nanoscale impact experiments at strain rates up to 100 s^{-1}. A cohesive finite element method (CFEM) is used to predict the effect of strain rates and the interface chemistry on the interface fracture failure for a HTPB/AP sample with one AP particle. The cohesive parameters were obtained based on an in-situ mechanical Raman spectroscopy framework that measures cohesive strength and fracture energy correlation as a function interface chemistry.

Introduction

The fracture resistance of composite materials can be strongly affected by the toughness of the interface between constituents. The complex mechanical behaviour of these materials is due to the complicated microstructure and physical processes occurring in the body at multiple length scales. Energetic compounds have been potential ingredients for a large number of applications, such as, explosives, propellants, and pyrotechnic formulations. For example, heterogeneous solid propellants, used in rocket industry, are composed of a crystalline oxidizer (ammonium perchlorate-AP) embedded in a polymeric binder (generally HTPB: Hydroxyl-Terminated Polybutadiene). Defects in energetic materials caused by impact or shock may result in unwanted detonation due to hot-spot formation. One of the key factors that can contribute to this type of defect is the failure initiated at the interfaces between matrix and particle. Examples include failure at interfaces such as those be-tween HTPB-AP in an energetic material. Interface properties between HTPB and AP can be altered using binding agents, e.g. Tepanol. Two samples were prepared for analysing the chemistry effect on the interface. One (Sample-1) consist of ammonium perchlorate (AP) particles embedded in hydroxyl-terminated polybutadiene (HTPB). In the second sample (Sample-1), a surface binding agent (Tepanol) was added at a mass ratio of 0.5 to fabricate samples with higher surface adhesion [1].

Results

The dynamic indentations were performed using a high strain rate impact schedule of Micro Materials, UK [2]. A stress-strain curve was obtained (Fig. 1) by fitting the rate dependent power law viscoplastic model [3]. The effect of binding agent is significant on the stress-strain curve for interface and the HTPB. However as expected AP remains unaffected from the addition of binding agent. A tensile fracture experiment combined with In-situ Mechanical Raman Spectroscopy was used to obtain fracture properties. A bilinear cohesive zone model parameters were obtained from the consideration of local stress and the cohesive energy required for delamination. The effect of interface chemistry and strain rate on the failure behaviour of one particle HTPB-AP sample is studied next.

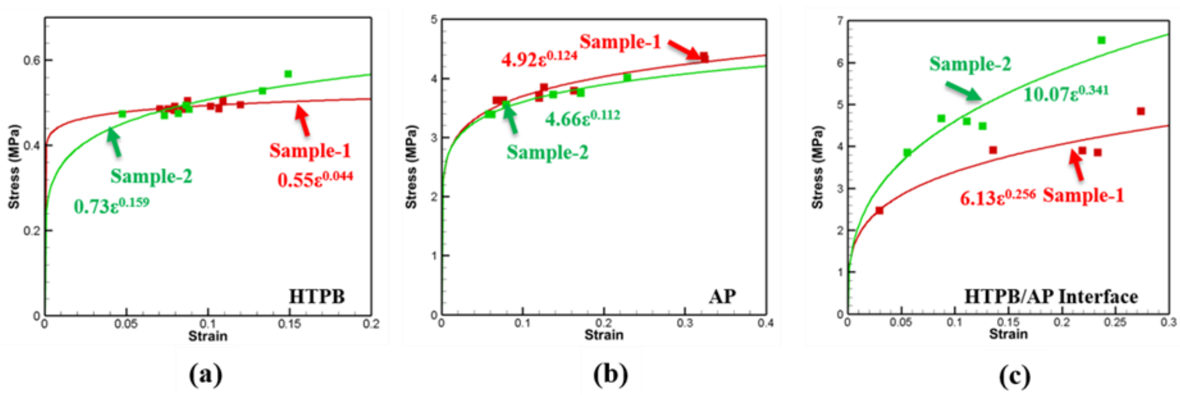

Figure 1. Stress-strain response of (a) HTPB, (b) AP and (c) Interface for sample without binding agent (Sample-1) and with binding agent (Sample-2).

Dynamic failure of one particle sample was simulated using a cohesive finite element method. A two dimensional numerical simulation is carried out for the AP-HTPB specimen with a single AP particle embedded in HTPB binder. A series of single particle HTPB/AP model was simulated by changing the cohesive strength of the interface between particle and matrix. Fig. 2 shows the effect of strain rate as well as interface strength on the cohesive energy in the material.

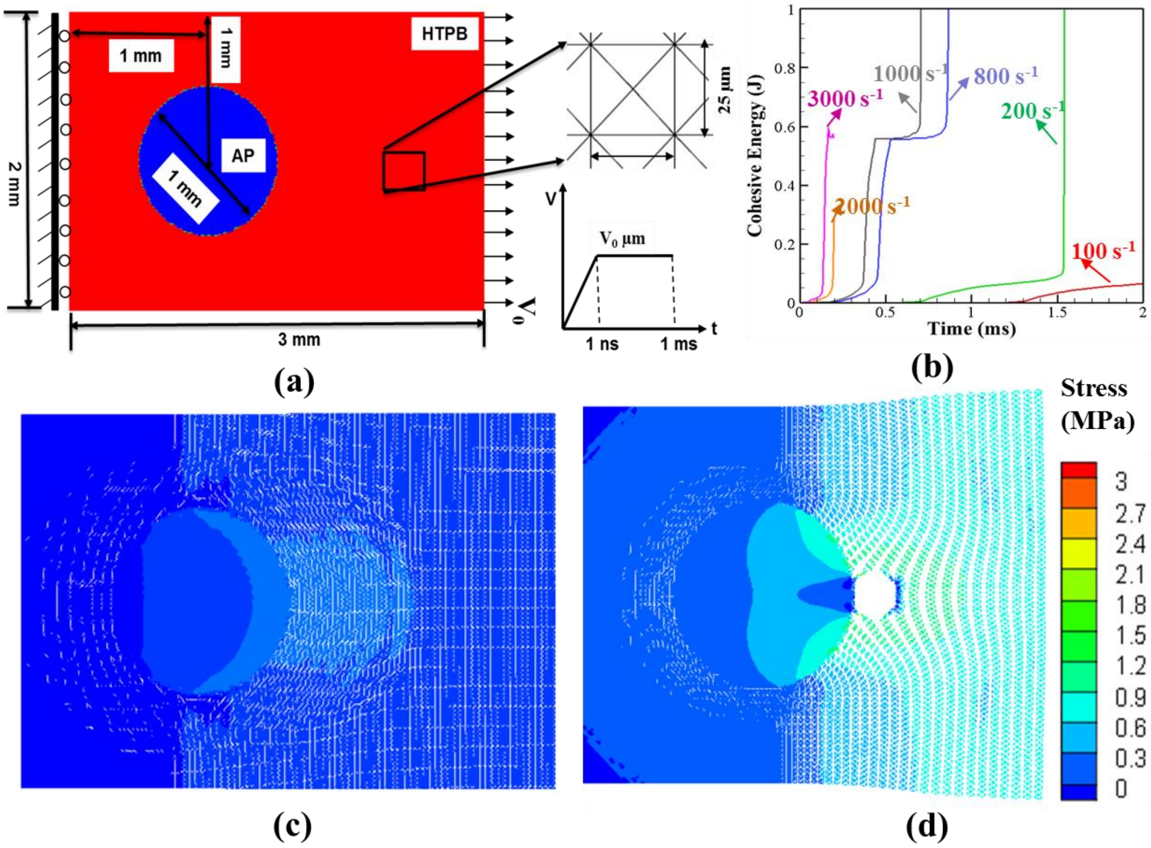

Figure 2. (a) Schematic of Finite Element model (b) Cohesive energy of the system failure with time for different strain rates and Stress distribution at 87.5 µs for (c) 1000 s-1 and (d) 10000 s-1.

Conclusion

A combined computational-experimental study of the fracture behaviour of AP-HTPB energetic material under dynamic loading conditions is presented. The study considered the viscoplastic constitutive models of the composite constituents, which are obtained using nano-impact experiments. Cohesive zone model parameters were obtained using In-situ Mechanical Raman Spectroscopy from the consideration of local stress and the cohesive energy required for delamination. The effect of interface chemistry and strain rate on delamination mode can eventually effect the possible hot-spots in the material.

Acknowledgements

The authors would like to acknowledge the financial support from grant FA9550-15-1-0202 (Program Manager: Dr. Martin Schmidt).

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