Chapter 6
Differences in Fracture Propagation Response of PBX 9501 Simulant at Low Versus High Strain Rates

Benjamin Solomon and Nathan Spulak

Abstract Polymer-Bonded Explosive (PBX) 9501 is an energetic material of interest to the defense and aerospace industries as a solid fuel and warhead material. In those applications the material can be subjected to dynamic loading conditions that can cause high stress concentrations, leading to localized fractures that will affect the burn response as well as potential temperature increases that can cause premature ignition and detonation. Understanding the high-rate compressive strength and fracture response is vital for designing safe, effective systems that use PBX 9501. An inert PBX simulant is tested under low-rate loading using a hydraulic load frame, and high-rate tests are performed on a Split-Hopkinson pressure bar. Digital Image Correlation is used to compare the local strains at the fracture locations between the different strain rates, and assess changes to how the fracture propagates. It is found that the material exhibits differing strains at fracture, fracture initiation, and fracture progression at different loading rates. The fractures in the low-rate tests propagate primarily parallel to the applied compression load, while in the high rate testing the fractures propagate at an angle to the compression direction. Additionally, the low-rate specimens show significant ductility post-fracture, remaining as a single joined piece in spite of the numerous cracks, while under high-rate loading they exhibit significant fragmentation.

Keywords split-Hopkinson bar · polymer-bonded explosive · simulant · compression · fracture behavior

Introduction

Polymer-Bonded Explosive (PBX) 9501 is an HMX (i.e., cyclotetramethylene-tetranitramine) based energetic material with primary applications in the aerospace and defense industries as an explosive and as a solid fuel. In these applications the material can be subjected to various loading conditions, including dynamic loading due to launches or high-speed aerial maneuvers. These conditions have been known to cause high strain concentrations and localized temperature increases [1, 2], which could result in premature ignition and detonation of energetic materials like PBX. Even if premature ignition does not occur, any localized fracture of the PBX material will adversely affect the burn rate and detonation waves upon eventual ignition [3]. As such, data on the fracture behavior of PBX under dynamic loading conditions is of vital importance for safe and effective implementation of the material. Additional strain information can be recorded using Digital Image Correlation (DIC), which utilizes cameras to track the movement of a speckle pattern applied to the surface of the specimen. These displacements can be analyzed to determine the full-field surface strain data which can be used to examine complex fracture behavior during the tests.

Experimental Methods

As previously stated, testing conditions that induce fracture in the PBX material may cause ignition or detonation. Therefore, to safely test the material an inert simulant of the PBX 9501 is made by substituting sucrose for the energetic HMX particulate

Benjamin Solomon · Nathan Spulak
Department of Mechanical and Aerospace Engineering,
University of Alabama in Huntsville, Huntsville AL 35899
e-mail: benjamin.solomon@uah.edu; nathan.spulak@uah.edu

© The Author(s), under exclusive license to River Publishers 2026

Paul Allison et al. (eds.), *Dynamic Behavior of Materials, Volume 1, 2026*, Conference Proceedings
of the Society for Experimental Mechanics Series, https://doi.org/10.13052/rp-9788743816249

[4]. Both low-rate and high-rate compression testing are performed to investigate the different fracture responses of the PBX simulant.

The quasi-static tests are performed using a hydraulic load frame to control displacement at a nominal strain rate of 10^{-3} s^{-1}. Two 2.3MP Basler acA2440-75um cameras with resolution of 2448 x 2048 pixels are used to capture DIC images of the test at 4 fps for analysis. A thin layer of lubrication is applied to the ends of the specimen before the test to reduce friction effects.

The dynamic tests are performed using a compression split-Hopkinson bar (SHB) setup with 19mm diameter Al6061 bars at a nominal strain rate of 1000 s^{-1}. SHB tests are a method of investigating the behavior of a material under dynamic, high strain-rate conditions [5]. These tests place compression specimens between an incident and a transmitter bar, then accelerate a striker bar into the incident bar to create a wave of stress and strain that travels down the bar and into the specimen. Because the PBX simulant is a soft low impedance material, a pulse shaper is used to increase the rise time of the incident wave so as to aid in achieving dynamic force equilibrium [6]. A copper pulse shaper of thickness 0.56 mm and diameter 6.35 mm is used. A Shimadzu HPV-2 high speed camera is used to capture DIC images of the tests at 250,000 fps for DIC analysis. A thin layer of lubricant is applied to the ends of the specimen before the test starts to reduce friction effects. The camera is triggered by the detection of the incident wave and timed to begin recording right before the stress-strain wave reaches the specimen.

Experimental Methods

A DIC contour plot showing the axial compressive strain just prior to initial fracture during the quasi-static compression test is shown in Figure 1, and the progression of the specimen throughout the test is displayed in Figure 2.

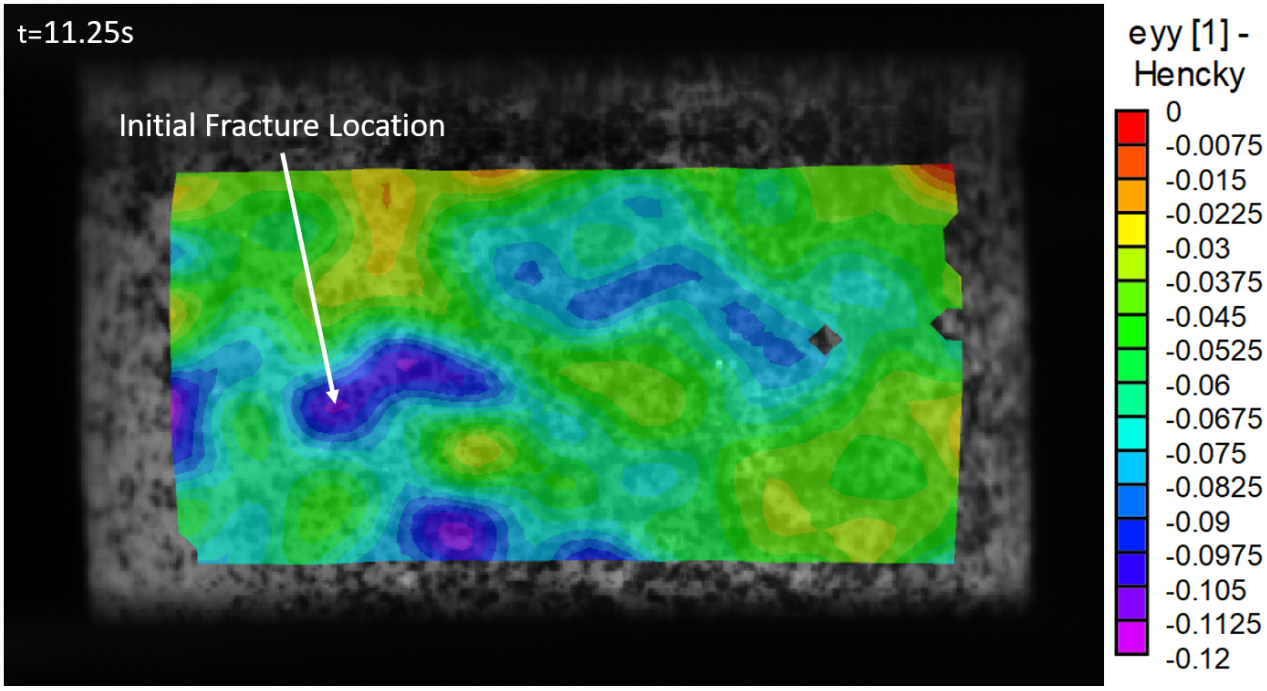

Fig. 1 DIC image showing axial strain just prior to initial fracture of PBX 9501 simulant under quasi-static compression conditions.

The specimen begins to have localized fracture early in the test around engineering extensometer strains of $\varepsilon_{Eng} = -0.0642$. The fractures are primarily vertically oriented (parallel to the direction of compressive loading), which indicates they are predominantly driven by tensile stresses as the specimen radially expands. While numerous cracks initiate and propagate, the specimen material is sufficiently ductile that it remains together as it is compressed, and it is recoved post-test as a single connected piece.

A DIC contour plot showing the axial compressive strain during the dynamic SHB compression test just prior to initial fracture is shown in Figure 3, and the progression of the specimen throughout the test is displayed in Figure 4.

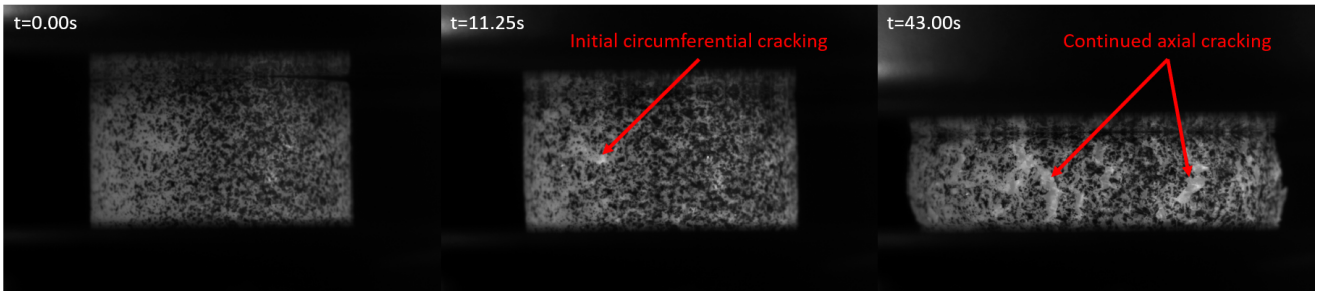

Fig. 2 Specimen deformation and crack propagation during low-rate compression test. Specimen remains as a single piece despite numerous fractures.

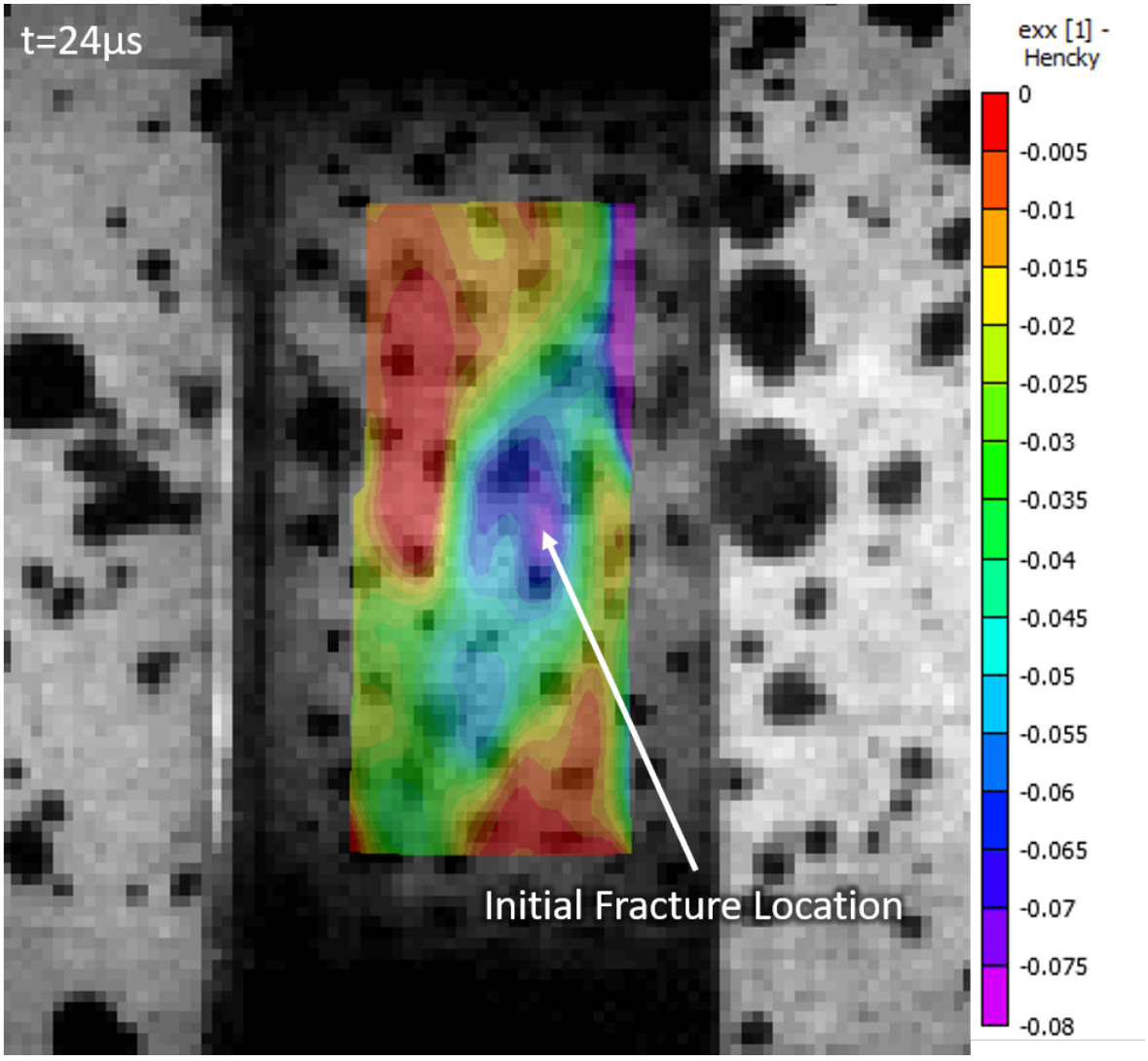

Fig. 3 DIC image showing axial strain just prior to initial fracture of PBX 9501 simulant under dynamic compression conditions.

The specimen begins to have localized fracture at an extensometer engineering strain of $\varepsilon_{Eng} = -0.0350$, almost half the magnitude of the localized strain at fracture for the quasi-static tests which indicates decreased ductility at higher strain rates. In the dynamic tests the specimen does not remain in one single piece, but rather fragments into multiple pieces. This is likely partially due to the dynamic nature of the test and the higher momentum of the specimen material as it deforms

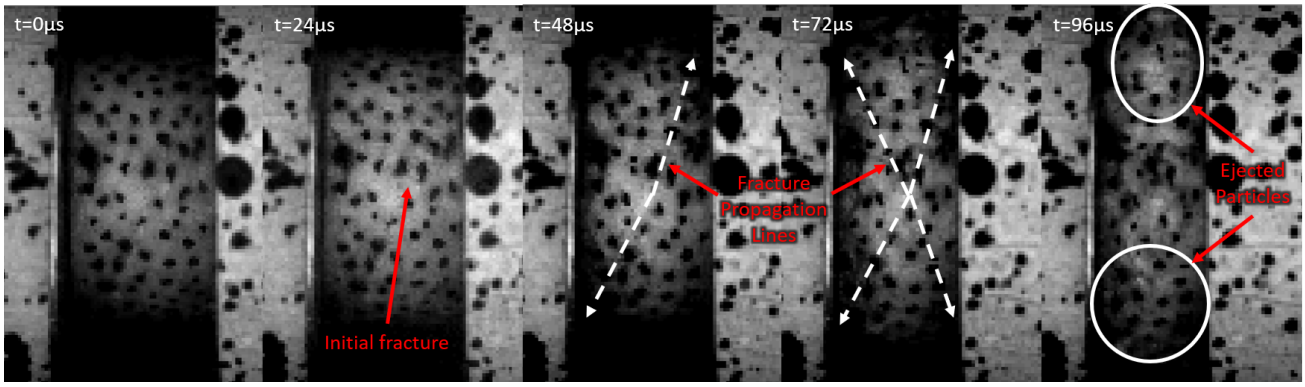

Fig. 4 Specimen deformation and crack propagation during high-rate compression test. Specimen fragments into multiple pieces.

at high velocities. However it may also potentially be indicative of a loss of material ductility at these higher strain rates, which leads to more brittle behavior and a lessening of interfacial cohesive strength on the fractured surfaces after the initial fractures begin and propagate. The crack appears to propagate along the line of increase strain seen in the DIC imagery at an angled offset from the axial compressive loading direction, indicative of a potential shear driven fracture behavior. This differs from the tensile driven fracture responses observed in the low rate tests.

Conclusion and Future Work

Dynamic testing indicates the PBX 9501 simulant fracture response changes from a tensile driven response at low rates to a possible shear driven response at higher rates. Additionally, the material has sufficient ductility even after initial fracture in the low-rate tests that it remains a single interconnected piece even as the cracks propagate. However under high-rate loading, the fractures propagate at an angle and the specimen fragments, potentially indicating a change to a shear driven fracture propagation response coupled with increased brittleness. The material appears to have less elongation at fracture at lower rates compared to higher rates, further suggesting increased brittleness at high strain rates. Future work includes comparing stress-strain data with the DIC imagery which may allow for conclusions on the stress-strain curves of PBX at different rates. Additional tests to determine the fracture response under different loading modes such as shear or tension, as well as investigating the coupled thermo-mechanical response, are also of interest for this material.

References

1. Wu, Y.,Fan, Y., Chen, X., Wen, J., Wang, Q., & Huang, J. (2023). “Low/intermediate speed impact-induced ignition and damage of a novel high-energy propellant”. Propellants Explosives Pyrotechnics, 48(8). https://doi.org/10.1002/prep.202300056
2. Ma, D., Chen, P., Zhou, Q., & Dai, K. (2013). “Ignition criterion and safety prediction of explosives under low velocity impact”. Journal of Applied Physics, 114(11).
3. Zhou, Z., Chen, P., & Huang, F. (2012). “Study on dynamic fracture and mechanical properties of a PBX simulant by using DIC and SHPB method”. In AIP Conference Proceedings (Vol. 1426, No. 1, pp. 665-668). American Institute of Physics.
4. Rae, P. J, Williamson, D.M., & Addiss, J. (2011). “A Comparison of 3 Digital Image Correlation Techniques on Necessarily Suboptimal Random Patterns Recorded By X-Ray.” Experimental mechanics 51.4: 467–477. https://doi.org/10.1007/s11340-010-9444-1
5. Kolsky, H. (1949). “An investigation of the mechanical properties of materials at very high rates of loading”. Proceedings of the physical society. Section B, 62(11), 676.
6. Song, B., & Chen, W. (2004). “Dynamic stress equilibration in split Hopkinson pressure bar tests on soft materials”. Experimental mechanics, 44(3), 300-312.