

## Chapter 53

# Meso-scale Deformation Mechanisms of Polymer Bonded Energetic Materials Under Dynamic Loading

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**Abstract** To understand the plastic deformation mechanism of polymer bonded energetic materials, a meso-scale experiment is conducted under dynamic loading. Energetic simulant material with polymer plasticizer are cold pressed using a mold made of stainless steel. An experimental setup is developed to obtain the local strain field at the meso-scale under dynamic loading conditions. The setup consists of a high speed camera with extension tube and microscope objective lens to obtain magnifications ranging from  $1\times$  to  $50\times$ . A high intensity halogen light source is used for illumination. The field of view for the experiment is  $1700 \times 690 \mu\text{m}$ , with a spatial resolution of  $4.427 \mu\text{m}/\text{pixel}$  at 100,000 frames/s. Dynamic loading is performed using a split Hopkinson pressure apparatus to obtain a range of strain rates. The strain fields are obtained using digital image correlation technique. To facilitate for the digital image correlation technique, the specimens are speckled using air brush with average speckle size ranging from 12 to  $18 \mu\text{m}$ . Results are presented for the measured strain fields and the associated deformation mechanisms as a function of loading rate.

**Keywords** Polymer bonded explosive • Dynamic • DIC • Meso-scale • Strain localization

### 53.1 Introduction

Polymer bonded explosives (PBX) are highly solid filled class of particulate composites that have a wide variety of applications. Though there are different formulations and variety of polymer binder materials, most of the PBX material contains 70–95 % explosive solid particles and 5–30 % binder materials [1, 2]. The main function of the binder is to hold the particles together which also enables for easy machining and casting into required shape and size. Most of these materials are shock sensitive and the sensitivity is a function of material properties. Weak shock initiation of the polymer bonded explosives is not very well understood because of the difficulty in obtaining the deformation fields in the polymer bonded explosive under dynamic loading conditions, its complexity in composition, microstructure and limitations in the experimental techniques.

Characterization of these materials under shock loading conditions is difficult due to safety issues. Therefore most of research work conducted is with the help of mock materials [3]. One of the main mock materials used is sugar. In this study we have used sugar crystals as the mock simulant and hydroxyl terminated polybutadiene (HTPB) as binder.

Most of the shock based experimental research work on PBX was done with the help of Split Hopkinson bar apparatus and Taylor experiments. Some researchers used digital image correlation to get the full field deformation field [4]. However, according to our knowledge, the local deformation occurred in these materials under dynamic loading conditions are not investigated yet. In this study we have developed an experimental setup to study the local deformation behavior of these materials at meso scale under dynamic loading conditions. The experimental technique, specimen preparation and results from the experiments are presented.

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**Table 53.1** Specimen constituents and final density of the material

Specimen	Sugar (%)	HTPB (%)	DOS (%)	TDI (%)	Density of specimen (g/cm <sup>3</sup> )
PBS	85	10.8	2.89	1.31	1.45

## 53.2 Materials and Experimental Procedure

### 53.2.1 Preparation of the Material

In this study polymer bonded sugar contains plasticized hydroxyl terminated polybutadiene (HTPB) as binder and sugar crystals of size vary from 100 to 500  $\mu\text{m}$  is used. HTPB is mixed with plasticizer dioctyl sebacate (DOS) and curing agent toluene diisocyanate (TDI). Steps involved in making raw material for the preparation of simulant specimens involves following steps,

- 1) Mixing of the plasticized HTPB with sugar crystals,  
First HTPB is mixed with the plasticizer (DOS) with the help of a mechanical mixer for 20 min. Subsequently, curing agent (TDI) is added and stirred for 10 min. The blended material is mixed thoroughly with the sugar crystals. The mixture is then cured at 60 °C for 24 h.
- 2) Pressing into billets  
The partially cured mixture is then cold-pressed in a steel mold at a pressure of 90 MPa to produce billets of size 25 mm in diameter and 25 mm in height. The density of the specimen along with the constituents is shown in the Table 53.1.
- 3) Curing of the specimen,  
For complete curing of the specimen, the pressed billets are kept at 60 °C for 90 h in a vacuum oven. The proportions of the constituents and names of each specimen are given in Table 53.1.

### 53.2.2 Experimental Methods

Cubic specimens of dimension 12 × 12 × 12 mm were extracted from 25 × 25 mm cylinders. The specimen is polished using silicon carbide papers of grit size from 300 to 1200 and then dry polished with the help of diamond particles of size 3  $\mu\text{m}$  to give the final dimension of 10 × 10 × 10 mm. Due to insufficient contrast between the polymer binder and the sugar crystals, capturing the micrograph of the specimen is difficult. Therefore, graphite was deposited on the specimen. A final polishing step was introduced to remove the graphite from the sugar crystal component. The polishing process resulted in a specimen surface with sufficient contrast difference between the sugar crystals and the polymer binder so that micrographs of the specimen could be obtained before loading.

The complete experimental setup for the meso-dynamic experiments is shown in Fig. 53.1. The setup is comprised of an extension tube (Navitar) for high magnification imaging, high speed camera (Photron SA-X2), high intensity halogen lamps (EKKKA), oscilloscope (Not shown), strain amplifier (not shown) and a data acquisition system (not shown). To obtain the images of the deforming specimen, the triggering of the camera is done from the output of the oscilloscope. The magnification of the extension tube is set to be 2X, resulting in a field of view of 1700 × 690  $\mu\text{m}^2$  at an image capturing speed of 100,000 frames/s. Spatial resolution for the experiment is 4.427  $\mu\text{m}/\text{pixel}$ . The distance of the extension tube from the specimen is 86 mm and the depth of field of the system is 550  $\mu\text{m}$ . Loading of the specimen is conducted with the help of a split Hopkinson bar setup. In this experiment the material to be tested is soft due to the presence of polymer in the composition. Therefore, obtaining sufficient transmitted signal is difficult. We have used a low impedance polycarbonate bar to overcome this issue [5, 6]. The split Hopkinson bar setup in this experiment includes an input and output bar of 1830 mm in length and 25.4 mm in diameter. The striker is made of the same material as the incident and output bars. Strain gages are placed at the center of the input and out bar.

The digital image correlation technique [7] was used to obtain the local strain field in this experiment. To facilitate taking high contrast images, the specimens are speckled using spray paint and boron nitride black powder with particle sizes 12–18  $\mu\text{m}$ . A thin coat of white paint was first applied on the specimen, and then just before it dried, boron nitride powder was distributed on the paint, which results in a high contrast and random speckle pattern as shown in the Fig. 53.2c. During testing, the specimen is placed between the incident and transmission bars of the Hopkinson bar setup. Lubricant is applied

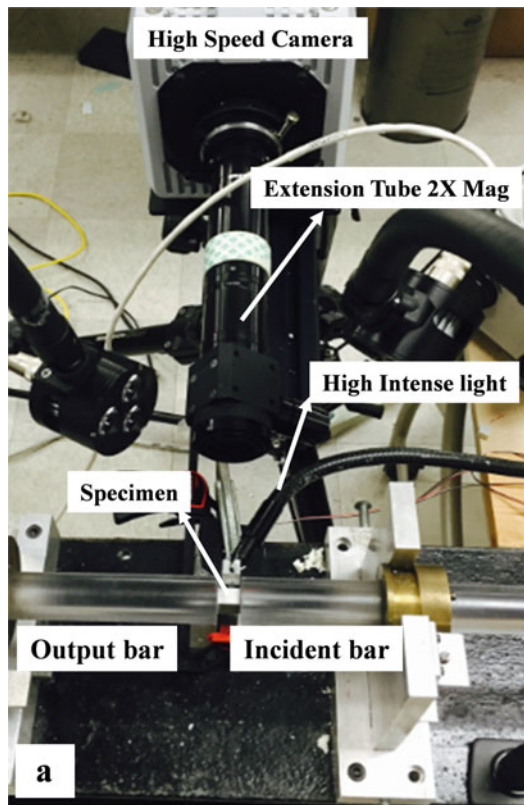


Fig. 53.1 Experiment setup and speckle pattern

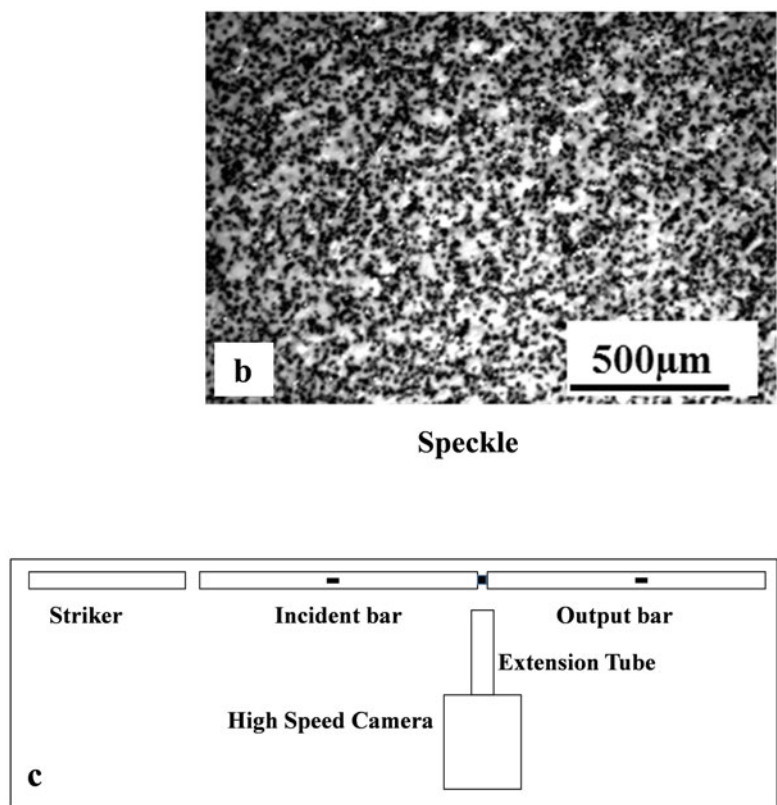
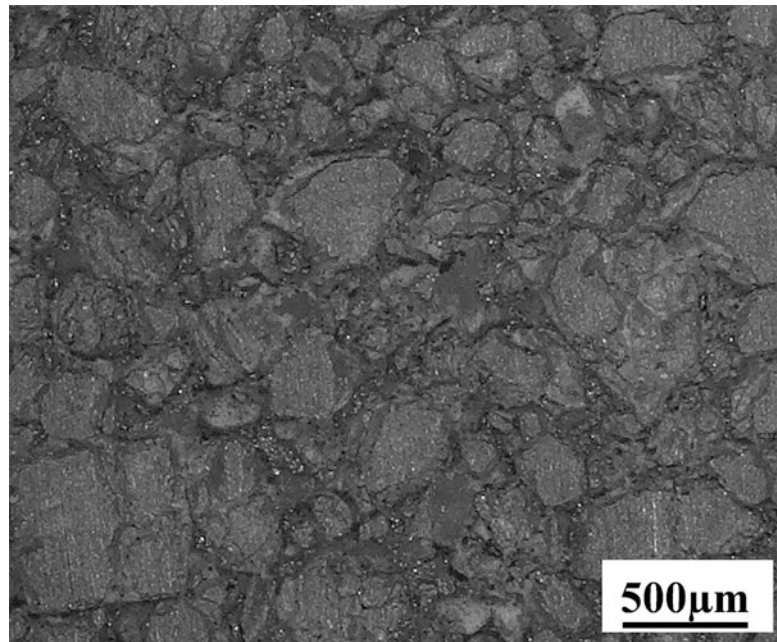


Fig. 53.2 Micro-graph of the specimen



on the specimen surface to reduce friction at the contact surface of the specimen and the bars. The camera is arranged in such a way that the camera lens is perpendicular to the front face of the specimen. For post processing of the images, commercial digital image correlation software Vic2D was used. In post processing a subset size of  $21 \times 21$  pixels ( $89 \times 89 \mu\text{m}^2$ ) and step size of 3 pixels.

### 53.3 Results and Discussion

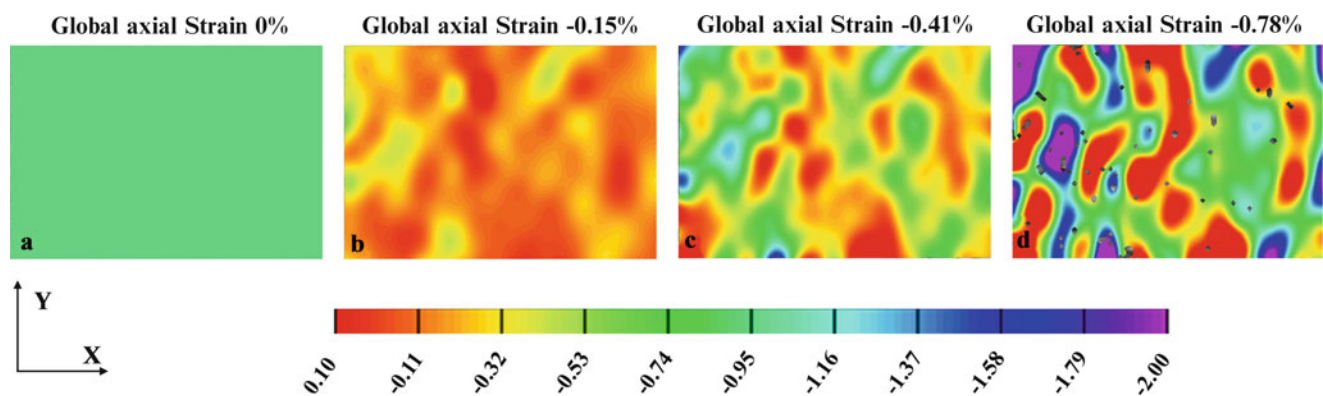
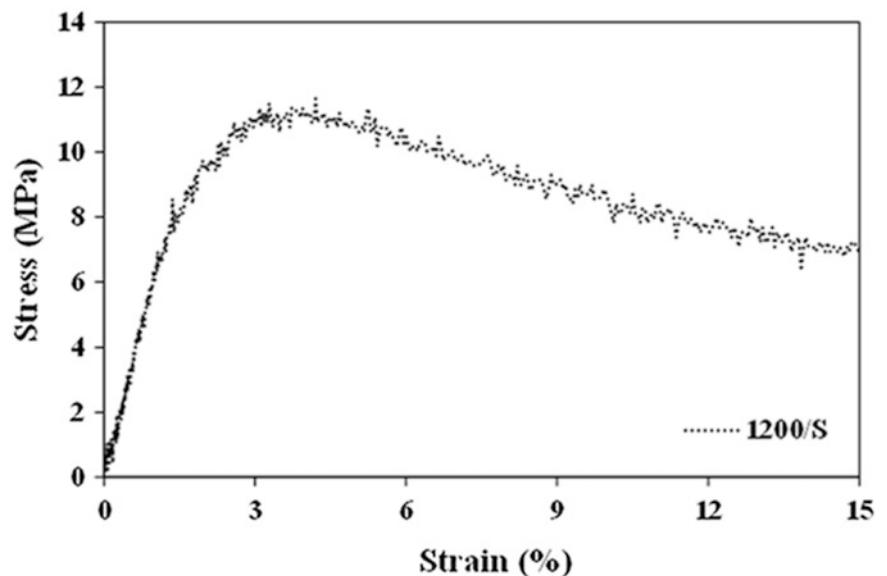
The microstructure of the polymer bonded sugar simulant is shown in Fig. 53.2, indicating an average size of the crystals is about 400  $\mu\text{m}$ . Thus, approximately 15 subsets are analyzed within a single sugar crystal.

Figure 53.3 presents a typical stress-strain curve for of PBS specimen under dynamic loading at a strain rate of  $1200\text{ s}^{-1}$ . It shows that the yielding starts at about 11.2 MPa and at a strain  $\sim 2.7\%$ .

Local axial strain distributions developed in the PBS specimen under dynamic loading for three different global strains are shown in the Fig. 53.4. It clearly shows that the local strain varies from small tensile strain to compressive strain of 2%. It is expected that the low strain corresponds to the solid particles in the materials and the higher compressive strain occurs in the polymer bond between the crystals (Fig. 53.4).

Local transverse strain in specimen loaded under compression is tensile in nature which would result in debonding of the crystals from the binder material in the material (Fig. 53.5). It can be seen that localization is along the diagonal close to  $45^\circ$  with the loading axis. Further loading resulted in crack initiation, with failure occurring along the line shown in Fig. 53.6a. It is noted that the crack is curved at the right bottom of the specimen and the strain along both sides of the localized cracks are reduced, suggesting that fracture occurred along the interface of the crystals.

**Fig. 53.3** Stress-strain curve for quasistatic and dynamic loading conditions



**Fig. 53.4** Local axial strain field

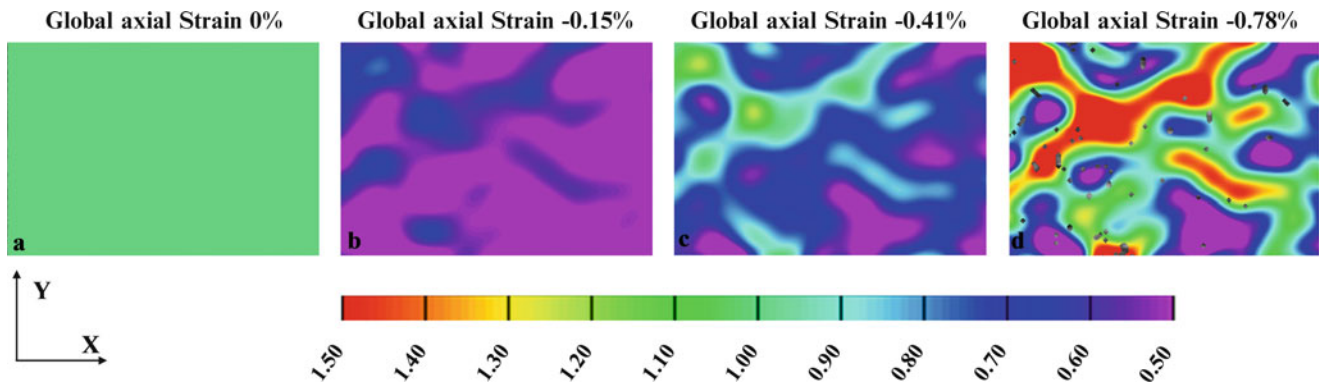


Fig. 53.5 Local transverse strain field

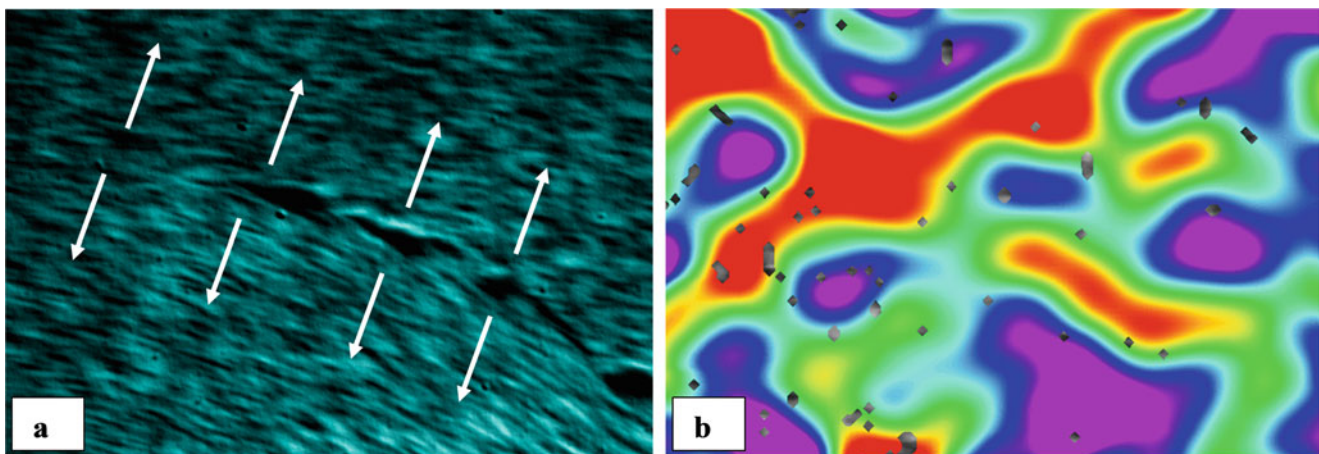


Fig. 53.6 (a) Crack formation in the PBS sample, (b) Strain field just before crack formation from DIC

## 53.4 Summary

A DIC based experimental system is developed for meso-scale dynamic characterization of materials. Strain localization is captured up to 0.78 % of the applied compressive strain. In the PBS specimen considered in this work, failure occurred along the weak binder boundary due to debonding caused by transverse tensile strain.

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