Meso-scale strain measurement of heterogeneous materials under dynamic loading

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Abstract. We present an experimental setup to measure the meso-scale strain field in heterogeneous materials under dynamic loading conditions. The experimental setup is based on a high magnification- high speed imaging and digital image correlation technique. Dynamic loading of the samples is performed in a split Hopkinson bar setup and the *insitu* images are captured during loading using the setup developed. The local strain field is calculated using digital image correlation technique based on which the primary failure mechanisms are investigated.

Keywords: Meso-scale, Strain, Digital image correlation, Heterogeneous Material

Introduction

Particulate composites, such as asphalts and polymer bonded explosives (PBX)s are class of highly heterogynous materials. These materials are subjected to dynamic loading of strain rate varying from 10^2-10^3 S-1, during manufacturing, machining and transport. In the case of PBX this can cause severe damage and formation of hot spots that can lead to deflagration of the material, which in turn affects safety and chemical stability [1–3]. It is believed that the grain scale strain localization due to heterogeneity in the microstructure, material property mismatch between binder and explosive crystal, defects such as voids, cracks and inclusions plays a major role in the local failure and formation of hot spots. Quantification of the meso-scale strain field is essential to understand the mechanism in which the failure occur in PBX under dynamic loading. However, the experimental methods that are available today lack spatial resolution in order to quantitatively strain at grain scale level. In this study, we used an experimental setup that has been developed recently that can capture strain within a grain of 200µm at a temporal resolution of 200 ns [4].

Materials and Methods

Polymer bonded sugar, a well-known mechanical simulant of PBX is used. These specimens were prepared by cold pressing the mixture of plasticized hydroxyl terminated polybutadiene (PHTPB) with the sugar crystals. It composed of 95% /wt of sugar crystals with sizes varying from 250-600 µm and 5% /wt of PHTPB. The pressed sample billets were cured at 90^0C for 8 hours. Samples of dimensions 14x14x14 mm were extracted from these completely cured billets. Surface of the samples are polished and area of interest were marked. Microstructural images were acquired before the loading in order to compare strain field with underlying microstructure. In order to facilitate for the strain measurement using DIC, a small speckle pattern of average diameter 15-20µm was applied on the area of interest.

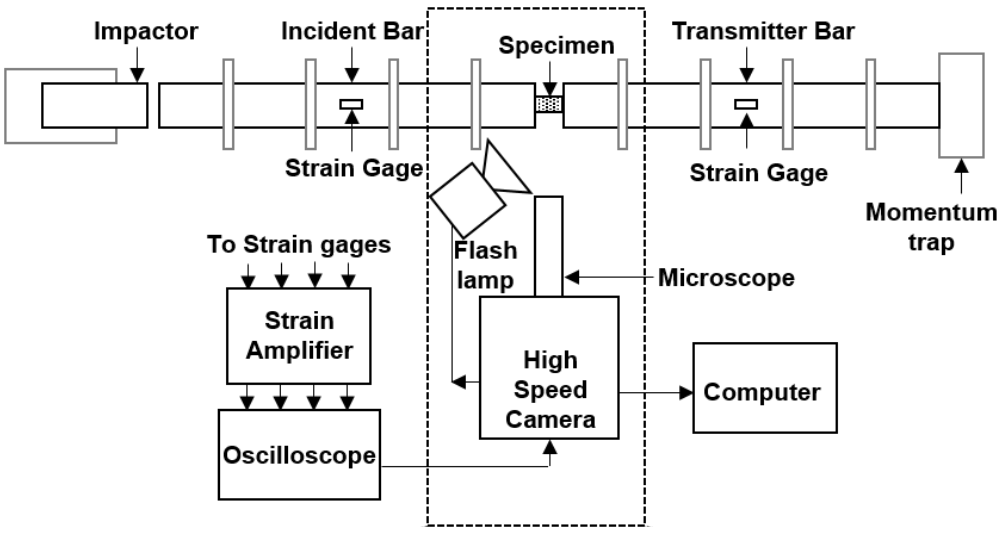

Fig.1 Complete schematic of the experimental setup

A complete schematic of the experimental setup is shown in Fig.1.The loading of the sample was performed in a split Hopkinson pressure bar setup (SHPB). Due to low impendence of the specimen, polycarbonate

incident and transmitter bars are used. Specimen was placed between the incident and transmitter bar as shown in Fig.1. Images of the deforming specimen during loading was obtained with the help of ultrahigh speed-camera equipped with high magnification lens. The ultrahigh speed camera used in this study was HPV-X2, which is capable capturing images at 5million frames/second. For this experiment, 1million frames/second was utilized considering the strain rate of the experiment. High magnification optical system from Navitar was selected carefully considering the depth of field and working distance. The optical system has a capability of obtaining a spatial resolution close to 3µm/pixel. In this study, a spatial resolution of 10.66µm/pixel was used considering depth of field and required field of view of the experiment. A field of view of 4.26×2.66 mm was obtained at the spatial resolution used in this study. Postprocessing of the images are performed in Vic2D, commercial software by correlated solutions. A subset size of 96x96 µm with a step size of 1 was used.

Results and Discussion

The strain rate of the experiment is 620 /s. Fig.2 shows the microstructure and the local axial and transverse strain with the crystal numbering at 70µs (1.83% global Axial strain). High axial and transverse strain close to 6% is observed for a very low macro scale strain of 1.83%. It is clear that the large strain localization occurs around the crystals which is either from crystal to crystal contact or due to presence of a soft polymer. High strain localization cause delamination and crystal fracture in the material even at very small applied strains. Crystal fracture is apparent in Crystal 1, Crystal 4, Crystal 13, Crystal 20 and Crystal 23, which shows up as high local transverse strain in the material, see Fig 2c.

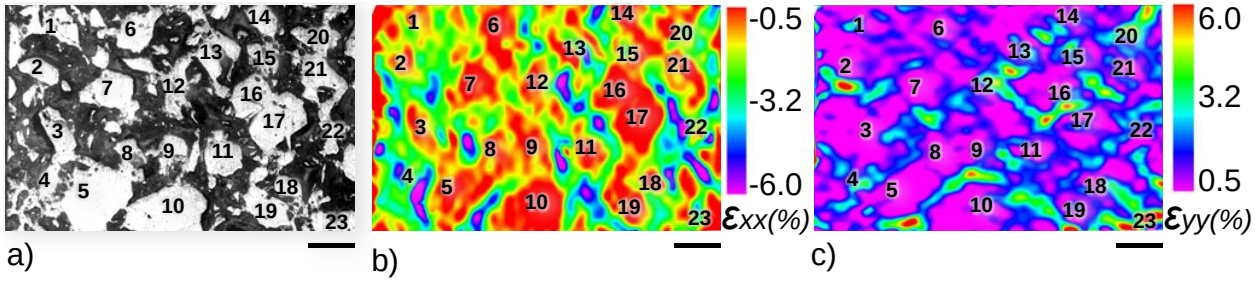

Figure. 2 a) Microstructure of PBX and number of the crystals, b) Local Axial Strain at 70µs (1.83% global Axial strain), c) Local Transverse Strain at 70µs(1.83% global Axial strain)

Conclusion

An experimental setup capable of measuring local strain field in polymer bonded explosives under dynamic loading. High strain localization was observed along the polymer rich interfaces. It was observed that the majority of the deformation is localized in the highly polymer region between crystals. In this case, it is clear that, the crystals are rotating to accommodate the deformation which could have caused heating due to friction.

References

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