129 High-Speed Infrared investigations of local heating in a Graphite-Fiber-PDMS Composite material Under dynamic loading

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Abstract. We investigated potential hot-spot formation in polymer bonded explosives made of graphite cylindrical rods embedded in a polydimethylsiloxane (PDMS) of using the Telops FAST M3k combined with a microscope lens on Split Hopkinson pressure bar experiments. The Telops FAST M3k was used with frame rates of 20 KHz and 19 KHz with a spatial resolution of the order of the pixel pitch (30 µm). We observed the temperature near the rods inclusion to be is nearly 22 times higher than in the regions away from the binder. However, further investigation is required to confirm the deformation mechanism that causes the temperature rise.

Introduction

The enormous progress made in the three last decades in high-speed thermal imaging have given rise to a wide variety of applications, of which material testing is maybe one of the most prominent. Split-Hopkinson bar experiments can especially benefit from the development of high-speed and high-resolution thermal infrared imaging. When materials are subjected to mechanical stress, rapid changes in the structure can occur. Being able to monitor hot spots prior to the breaking can help in the characterization of new material. Elsmore, experimental temperature measurement is essential to understand the physics of many mechanic's problems. For example, the physics of accidental explosions of polymer bonded explosives are not very well understood. However, it is believed that the highly localized temperature regions called hot spots are the causes of such material behaviour. However, the understanding of its formation and the dynamics of hotspot evolution are very limited. This requires high spatial resolution and high temporal resolution temperature measurements. Latest high-speed IR cameras provide high temporal and spatial resolution, which helps in understanding the challenging problems. The idea of using thermography for the characterization of material properties started in 1853 when Lord Kelvin found that elastically deformed bodies generate temperature changes when loading is applied. Tension causes cooling, while compression causes heating [1]. Later, in 1967, Belgen demonstrated that the thermoelastic effect could be used for stress analysis by applying infrared radiometry [2]. Infrared field temperature measurement techniques have therefore been used as a non-contact and real-time method for capturing the thermal energy being radiated from a surface in an inelastic deformation [3-5]. Jordan and Sandor, for example, have used differential temperature measurement for monitoring the elastic-plastic behaviour of metals in 1978 [6]. Following recent developments in thermographic techniques [7], quantitative stress measurements became possible by measuring the change in infrared photon emission produced by mechanical deformation.

Experimental mechanics testing could more than ever benefit from the improved performances of infrared cameras. Latest high-speed IR cameras provide high temporal and spatial resolution, which aid in the characterization of challenging targets. When a solid is submitted to dynamic loading, the energy conversion process leads to a concentration and conversion of diffuse mechanical energy in spatially confined regions, resulting in intense localized heating called hot spots. They are believed to be about 0.1 - 10 µm in diameter and may initiate chemical reactions in the material. Some of the hot spot's theories have predicted relaxation times of 0.01 - 1 ms and temperatures of hundreds of Kelvin degrees [8]. A classic example of mechanochemical processes in solid materials related to the formation of hot spots is the mechanical initiation (by impact or shock) of explosions.

Experiments and Results.

In the present work, we used the Telops FAST M3k combined with a microscope lens to investigate potential hot-spot formation in polymer bonded explosives. Split Hopkinson pressure bar was used to load the sample at higher strain rate. The Telops FAST M3k was used with sub-portions of 64 × 64 and 128 × 40 pixels at frame rates of 20 KHz and 19 KHz respectively. A microscopic lens with 1x magnification, designed by Telops, was used for the experiments, leading to a spatial resolution of the order of the pixel pitch (30 µm). The striker bar of the Split-Hopkinson bar set-up was fired from a gas gun at a pressure of 5 psi. The samples in this experiment were made of graphite cylindrical rods embedded in a polydimethylsiloxane (PDMS). The sample dimensions are measured to be about 8 mm × 8 mm × 8 mm. The graphite rods were about 500 µm in diameter, aligned parallel to the PDMS cube edges or at a 45° angle. All samples were treated with a black coat layer before the test to minimize the temperature variations induced by emissivity difference between graphite and epoxy. For our experiments, we selected a camera field of view covering only the region of the sample containing the fibers inclusions.

Figure 1 depicts the experimental results for the PDMS sample with an inclusion of three graphite rod aligned parallel to the loading direction. A sub-portion of the FPA detector of 64 × 64-pixel with a frame rate of 20 KHz was used for the test. Selected infrared images recorded before and after the stress wave enters the sample are shown. The deformation of the sample due to the stress wave loading induced temperature increase is therefore shown in Fig.1. The images recorded before were used as a reference for image subtraction. Subtracting the reference image from the subsequent images gives the net temperature increase in the sample.

When the sample is deforming due to the stress wave, the temperature plot shows a negligible temperature increase in the binder. Net temperature increased in the binder away from the inclusion is than 2°C. Interestingly, significantly higher temperature was observed near the inclusions indicating the rigid inclusions have significant effect on the temperature evolution in composites. Figure shows the dynamics of the inclusions in the binder. Such movement of the crystal causes significant relative movement of inclusions and the binder which could cause high friction between the binder and inclusion. The temperature near the inclusion is nearly 22 times the temperature in the regions away from the binder. However, further investigation is required to confirm the deformation mechanism that causes the temperature rise.

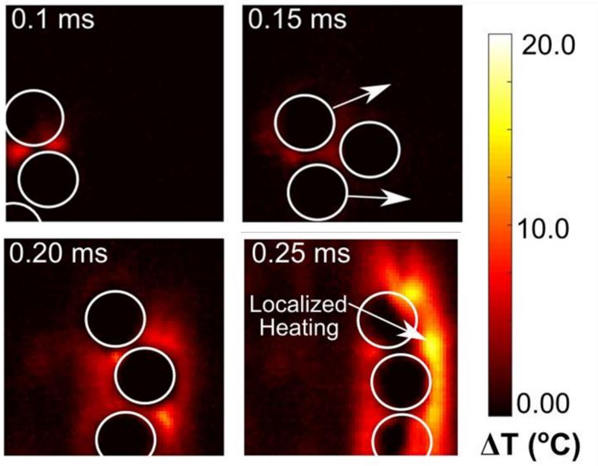

Figure 1 Selected infrared images of the split-Hopkinson experiment carried out on the sample with multiple cylindrical inclusions

Conclusion

We have investigated heat generation dynamics in a graphite cylindrical rods embedded in a polydimethylsiloxane (PDMS) composite material. With the Telops' FAST M3k camera and the G1 1X microscope lens, we were able to reach a temporal resolution of 50 μs and a spatial resolution of a few tens of μm, which was ideal to investigate crack initiation and hot-spot formation within the materials.

We were able to observe the effect of both tensile and shear stress on the fibers. The breaking was mostly due to shear stress. Some moderate tensile-stress-induced hot spots were measured with temperature nearly 22 times higher. However, further investigation is required to confirm the deformation mechanism that causes the temperature rise. Further research may also be conducted to clear the influence of the thermodynamic properties of the material in the formation of hot spots. However, we observed a clear influence of the fiber alignment and density in the epoxy matrix on heat generation and the breaking dynamics of the fibers.

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