Dynamic Characterization of Short Duration Stress Pulses Generated by a Magnetic Flyer Plate in Carbon-Fiber/Epoxy Laminates

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OCT 27 1995

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Abstract

There is a great deal of interest in characterizing the dynamic mechanical behavior of laminated carbon-fiber/epoxy composites for military and aerospace applications. Current research efforts have been directed at measuring the strength lost because of accumulated damage. Very little work has been done to determine how this damage is accumulated during dynamic mechanical loading. Of particular interest is the effect of short duration ($< 1 \mu s$) stress pulses on mechanical behavior such as delamination. In this paper, a magnetic flyer plate apparatus is presented for generating a short duration stress pulse in a unidirectional carbon-fiber/epoxy laminated composite. The stress pulse is characterized using a dynamic moiré interferometer.

I. Experimental Procedure

A system was designed for generating short duration mechanical pulses using a magnetic flyer plate (see Figure 1) [1]. The magnetic flyer plate consisted of a 0.254 mm thick, 6.25 mm wide strip of aluminum. A current was passed through the strip in one direction, then passed behind it in the opposite direction to generate the opposing magnetic fields that accelerated the plate. The current was dumped from an 18 μF storage capacitor at 10 kV using a spark gap. To determine the velocity of the flyer plate, shorting pins were placed at several locations along the flight path of the flyer plate and the time to impact was measured at several voltages. From these velocity measurements (Figure 2) it was found that the velocity profiles were consistent between capacitor shots for a given voltage and the plate remained almost flat while in flight.

To image the short duration stress pulse generated by the magnetic flyer plate, a dynamic moiré interferometer was used (see Figure 3) [2]. The interferometer measured the full-field

displacements on the surface of a specimen in the direction that the stress wave propagated. A pulse ruby laser was used in the interferometer capable of generating high-intensity pulses lasting for a hundred nanoseconds. Moiré fringe patterns were captured on high-speed infrared and Polaroid film. Because of the sensitivity of the infrared film and the intensity of the ruby laser, neutral density filters had to be used to prevent saturation.

Gratings were placed on the front and back surfaces of specimens. A special 1200 line/mm dual frequency grating was used on the front of the specimen so that a helium-neon laser could be used to align the interferometer. On the back, a regular 300 line/mm grating was used for a diffraction gage. The diffraction gage consisted of a 2 mm diameter He-Ne laser beam with a fiber optic sensor placed approximately 1 meter from the specimen and aligned along the first diffraction order of the grating. By placing the sensor at an appropriate distance from the specimen, the diffraction gage was able to detect the exact time that a stress wave passed a given location along the length of the specimen from the deflection of the laser beam. These data could then be used to determine the proper trigger time for the ruby laser.

II. Experimental Results

A short duration stress pulse was characterized for a 0° unidirectional carbon-fiber/epoxy specimen (see Figure 4). The specimen was 4.5 mm thick, 11.7 mm wide, and 150 mm long. The end of the specimen was placed 7 mm from the flyer plate, which resulted in an impact velocity of approximately 175 m/sec. The moiré interferometer covered 42 mm of the specimen, starting at a location 35 mm from the impacted end of the specimen. The diffraction gage was positioned at the edge of the grating closest to the impacted specimen end.

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During the course of the experiment, it was determined that extraneous light generated from the current being discharged through the magnetic flyer plate was saturating the optical sensor of the diffraction gage and the film used to capture the moiré images. Consequently, interference filters had to be used to eliminate this problem.

The stress pulse captured in the experiment had a slightly bowed wave front (see Figure 5). This probably indicates that the flyer plate is slightly bowed when it impacts the specimen. The stress pulse was approximately 3 mm in length. To calculate the duration of the stress pulse it was necessary to estimate its wave speed. The longitudinal wave speed, c_L , for the 0° direction in a carbon-fiber/epoxy laminated composite has been measured to be 8 mm/ μ s [3]. For an infinite plate of finite thickness, the effects of dispersion result in a phase velocity of approximately 0.56 c_L for a pulse length of 3 mm and a plate thickness of 4.5 mm [4]. Thus, the corresponding period of the stress pulse can be estimated as 700 ns. In addition, there is a substantial wake behind the stress pulse.

III. Future Work

The short duration stress pulse generated by a magnetic flyer plate has been characterized in a unidirectional carbon-fiber/epoxy composite. Efforts are currently underway to examine the interaction of short duration stress pulses with delaminations in $0/90^\circ$ carbon/fiber epoxy composites. Multiple interferograms will be obtained using a high speed framing camera. From these interferograms, crack tip opening and sliding displacements will be extracted. Specimens will also be subjected to various loading rates and input energies by controlling the flyer plate velocity. The behavior of delaminations can then be characterized as a function of pulse magnitude and duration.

IV. Acknowledgments

This work is supported by the U.S. Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, Dr. O.A. Manley program manager under DOE Contract No. DE-AC07-94ID13223. Specimens were supplied by Hercules Advanced Materials Co. through their internal and development funding. The technical assistance of Mr. Jim Lee is also gratefully acknowledged.

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Figure 1: Magnetic flyer plate apparatus.

Figure 2: Velocity measurement data using shorting pins

Figure 3: Dynamic moiré interferometer setup

Figure 4: Location of dual grating on carbon-fiber/epoxy specimen.

Figure 5: Short duration stress pulse captured in unidirectional 0° carbon-fiber/epoxy laminated composite.

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