Optical techniques for determining dynamic material properties

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ABSTRACT

Miniature plates are laser-launched with a 10-Joule Nd:YAG for one-dimensional (1-D) impacts on to target materials much like gas gun experiments and explosive plane wave plate launch. By making the experiments small, flyer plates (3 mm diameter x 50 micron thick) and targets (10 mm diameter x 200 micron thick), 1-D impact experiments can be performed in a standard laser-optical laboratory with minimum confinement and collateral damage. The laser-launched plates do not require the traditional sabot on gas guns nor the explosives needed for explosive planewave lenses, and as a result are much more amenable to a wide variety of materials and applications. Because of the small size very high pressure gradients can be generated with relative ease. The high pressure gradients result in very high strains and strain rates that are not easily generated by other experimental methods. The small size and short shock duration (1 - 20 ns) are ideal for dynamically measuring bond strengths of micron-thick coatings. Experimental techniques, equipment, and dynamic material results are reported.

Keywords: dynamic material properties, spall, strain rate, gas gun, explosive plane wave, spall strength, EOS, equation-of-state, electronic streak, stress-strain, bond strength

1. INTRODUCTION

Shockwaves can easily be generated in materials by pulsing a high power short duration laser on the surface of a material or through a transparent window on an absorbing layer. The primary disadvantage of this technique is that the shockwave profile is strongly dependent on the laser beam spatial and temporal profile and the absorption of the material. Laser pulses that are Q-switched and multimode can easily vary temporally pulse-to-pulse and materials vary in absorption and optical coupling with numerous material conditions and laser power variations. All these varying parameters result in a shockwave that is difficult to predict, characterize, and reproduce. By using the same laser to launch a miniature plate much like a gas gun the plate launch method is decoupled from the plate impacting a shockwave into a target material. Experimentally a laser-launched plate performs much like one accelerated by a gas gun or explosive planewave lens.

2. EXPERIMENTAL TECHNIQUE

The method for laser launching miniature plates has been well documented.^{1,2,3} These proceedings). The use of miniature laser launched plates is a miniature version of an explosive planewave lens or gas gun. The launched plate is allowed to reach terminal velocity before impacting a target plate (Fig 1). The target plate may be opaque or transparent of any metal, composite, laminate, or base material with a coating. If the target is a transparent material a flyer plate can be impacted on the target and by recording the impact velocity and the particle velocity of the interface, the equation-of-state of either material can be determined if the other material is known. By replacing the transparent target with an opaque and recording the free surface velocity of the target the dynamic spall

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strength of the target can be determined. This same experimental technique can also be used to determine bond strength of thin coatings on a base material (Ref 4).

Fig. 1. The Nd:YAG laser beam is focused through a sapphire substrate and on the carbon/sapphire interface. The "trapped" plasma expands and accelerates the flyer plate attached to the substrate.

3. EXPERIMENTAL RESULTS

Laser-launched miniature plates have been used to determine the EOS of standard metals and the results compared with traditional experimental methods (Fig 2, Ref 5,6). Miniature laser-launched plates can generate high pressure and stress gradients in a laboratory environment with little or no collateral damage, and recover both the flyer plate and target for post analysis (Fig. 3). These same laser-launched plates can be used to measure bond strength of coating on a base material (Fig.4, Ref 4).

Fig. 2. The EOS of OFHC copper by laser-launched miniature plates are represented by squares and crosses. The other symbols are data by other experimental methods. (fig. from ref. 6)

4. APPLICATIONS

Short duration (1 - 10 ns) shockwaves from miniature flyer plates can be used to study dynamic material properties, bond strengths of interfaces, and EOS with a minimum quantity of material. Laser-launched flyer plates are a compliment to tradition experimental methods for dyanmic material property measurements.

Fig. 4. Comparision of flyer plates recovered after impact at $>1\text{km/s}$. The plate on the left was launched with a pseudo-Gaussian laser beam spatial profile. The plate on the right was launched by a Tophat beam. The results of lateral stresses are obvious in the left image.

5. CONCLUSIONS

Laser-launched flyer plates are a compliment to traditional gas guns and explosive planewave lenses for performing dynamic 1-D impact experiments. When sample size is thin or small may be the only available experimental method. For coatings on base materials, laser launched plates can provide a unique experimental method. The all optical plate-launch and optical diagnostics to determine material EOS and dynamic material properties does not perturb the miniature plate performance and optical diagnostic techniques have the necessary temporal response for sub-nanosecond resolution.

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