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ENHANCED STRESS WAVES IN SOLIDS

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ENHANCED STRESS WAVES IN SOLIDS

ABSTRACT

Bonding transparent materials to the input face of an aluminum target increases the efficiency of laser energy absorption. This produces increased stress and strain in the specimen.

Aluminum targets included a 1 in. thick plate, various foils, 1/2 in. diam rods 1 in. and 4.5 in. long, and a 1/8 in. diam rod 2.8 in. long. The transparent materials included cellophane tape, didymium glass, single MgO crystals, slide glass, quartz plate, x-cut quartz rod, sapphire and epoxy.

A 2 J, Q-switched ruby laser was used as the energy source input to the transparent material specimen configuration. The induced stress pulses were detected with a Li_2SO_4 transducer and recorded on an oscilloscope.

Thin sheets of aluminum were subjected to laser radiation with a variety of transparent materials bonded to the absorbing face. Holes were produced in aluminum as thick as 0.015 in. using a focused laser pulse with a fluence of $\sim 300 \text{ MW/cm}^2$.

INTRODUCTION

Augmented or enhanced stress pulses by laser irradiations have been reported by N. C. Anderholm,¹ Skeen and York,²⁻³ O'Keefe, *et al.*⁴ and Chun and Rose.⁵ The augmented pulses generated in Anderholm's experiment were accomplished using an aluminum film 0.5 μ thick vapor-deposited to the back of a quartz disc. The transparent quartz impeded the expansion of the aluminum film during vaporization, thus generating a large amplitude stress pulse. O'Keefe, Skeen and York proceeded first by coating targets with transparent, thin layers of volatile materials and then in subsequent experiments reverted to the Anderholm method of vapor depositing 1 μ or less of aluminum on a plexiglass substrate and bonding this to a thin metallic target, generally aluminum, with adhesive.

The present report is the result of an effort to increase the amplitudes of stress pulses in cylindrical rods and thick plates. This was done in order to provide additional information in conjunction with a previous report.⁶ Increased energy absorption makes it possible to extend material properties measurements to higher strain levels. It thereby provides a basis for exploring the behavior of materials in the high strain-high strain rate and plastic as well as elastic regimes using the Q-switched ruby laser. The purpose of this report then is to describe the techniques used and experimental results of applying laser energy enhancement to produce relatively high stress pulses in extended solid media.

EXPERIMENTAL ARRANGEMENT AND PROCEDURE

Figure 1a shows the typical experimental arrangement. A nominal 3/8 in. diam aperture was used with the 1/2 in. diam rods to confine the radiation to the face of the specimen. Aperturing was unnecessary with the 1 in. thick aluminum plate. The recording transducer was protected from direct laser radiation in all cases. Figure 1b represents an idealized oscilloscope recording of the high and low frequency components of the stress history.

Specimen preparation consisted of bonding a transparent material to the face of the aluminum target with a fast cure, clear epoxy or adhesive. On the aluminum plate, the various transparent materials were bonded at different locations so that no area was irradiated more than once.

Several different aluminum rods were used. After each exposure the input face was sanded smooth and flat and cleaned with 190 proof alcohol before applying a new transparent material. The prepared specimens were then aligned so that the incident radiation was approximately perpendicular to the input face. A 20 MHz lithium sulfate transducer was wrung on the back of the specimens with vacuum grease to record the stress pulses. The recording oscilloscope had vertical amplifiers capable of 225 MHz and 500 MHz response.

EXPERIMENTAL RESULTS

All of the specimens with the bonded transparent materials showed increases in the induced stress pulses over the normal condition with the exception of the didymium glass. Didymium glass is more absorbing to the ruby frequencies than the other tamper materials. Percival used didymium glass as an absorber in his experimentation.⁷

Figures 2-4 show the oscilloscope records of the resulting stress pulses for the 1 in. thick plate and the 1 and 4-1/2 in. rods. Figures 5-7 show a comparative amplitude plot of the various effects of the transparent materials for these specimens. The higher frequency components of the stress history appear above the abscissa and the lower frequency components appear below. The materials are arranged generally in order of increasing total enhancement.

The 1 in. aluminum plate showed a marked increase in the higher frequency portion of the stress pulse history while exhibiting little change in the lower frequency portion. The 1/2 in. diam 1 in. long aluminum rod produced approximately equal high and low frequency components with low frequency components slightly predominant. The 1/2 in. diam $\times$ 4-1/2 in. long aluminum rod produced comparatively high amplitude, low frequency components while the higher frequency components were generally of low amplitude and relatively the same for all of the transparent materials.

In a separate experiment an 1/8 in. diam aluminum rod 2.8 in. long was made part of a Hopkinson split bar arrangement. An 0.005 in. thick disc of x-cut quartz was

Fig. 1a. Experimental arrangement for measuring stress waves in solid specimen.

Fig. 1b. Idealized oscilloscope recording of the stress pulse.

Fig. 2. Stress pulses resulting from laser irradiation of three different aluminum target shapes with various treatments of the input face: a) bare, b) blackened, and covered with c) cellophane tape, and d) 0.5 in. diam didymium glass 0.125 in. thick.

Fig. 3. Stress pulses resulting from laser irradiation of three different aluminum target shapes; input face covered with: a) MgO single crystal 0.075 in. thick, b) slide glass 0.125 in. thick, c) quartz plate 0.2 in. thick, d) 0.5 in. diam sapphire 0.02 in. thick.

Fig. 4. Stress pulses resulting from laser irradiation of three different aluminum target shapes; input face covered with: a) 0.5 in. diam sapphire 0.2 in. thick, b) 0.5 in. diam quartz rod 0.5 in. thick, c) epoxy about 0.02 in. thick.

Fig. 5. Amplitudes of high and low frequency stress pulse components resulting from laser irradiation with various transparent materials covering the input face of a 1 in. aluminum plate.

Fig. 6. Amplitudes of high and low frequency stress pulse components resulting from laser irradiation with various transparent materials covering the input face of a 0.5 in. diam aluminum rod 1 in. long.

Fig. 7. Amplitudes of high and low frequency stress pulse components resulting from laser irradiation with various transparent materials covering the input face of a 0.5 in. diam aluminum rod 4.5 in. long.

sandwiched between the 2.8 in. long piece of aluminum rod and a 3 in. long backup aluminum rod. Semiconductor strain gages mounted on the 2.8 in. aluminum rod were calibrated by a "ball-drop" technique. Then we determined the sensitivity of the x-cut quartz by comparing with the strain gage output.

The split Hopkinson bar arrangement was then subjected to the 2 J Q-switched, unfocused ruby laser beam. A strain of $\sim 50 \mu\epsilon$ was produced in the aluminum rod when the laser energy was incident on the bare face of the rod. Then we modified the same bar arrangement by bonding a single crystal 0.075 in. thick of MgO on the face of the aluminum rod. The strain resulting from irradiating this specimen with the same energy as before was measured at $1053 \mu\epsilon$. Applying the transparent MgO crystal increased the strain over a factor of 20. Figure 8 shows the relative stress pulses from the 1/8 in. diam aluminum bar due to varying face input conditions.

Various thicknesses of aluminum foil were subjected to a focused beam from the Q-switched ruby laser. Fluences as low as 300 MW/cm^2 , with a 50 nsec pulse width, produced holes in aluminum as thick as 0.015 in. when a transparent material was bonded to the input face of the specimen. Figure 9 shows a $1.5 \times 1.5 \times 0.005$ in. piece of aluminum which was subjected to a focused laser pulse of $\sim 300 \text{ MW/cm}^2$. An 0.020 in. layer of transparent epoxy was adhered to the face of the aluminum. The three different effects were produced by varying the spot size of the focused laser beam. The maximum spot size causing a hole through the aluminum was measured to calculate a total fluence of 300 MW/cm^2 .

CONCLUSIONS

Thin Aluminum Specimens

The plastic deformation and holes through the thin aluminum are due to confining the reaction at the surface of the specimen. Two possible mechanisms for this phenomenon have been previously described.³⁻⁴ In this particular experiment the resulting plastic deformation and holes were produced by a combination of gas pressure produced from the interaction of the focused laser beam with the semi-volatile epoxy coating on the aluminum, and by the vapor pressure produced by the laser beam interaction with the aluminum surface in a confined configuration. These holes were produced with much less energy than was used in previously reported experiments.⁴ Whereas O'Keefe *et al.* employed a fluence of 1.4 to 1.7 GW/cm^2 to produce plastic deformation and holes in thin aluminum specimens, the maximum fluence used in this experiment was $\sim 300 \text{ MW/cm}^2$. This is an increase in "efficiency" of a factor of almost 6 where efficiency is defined as incident laser energy compared to absorbed laser energy.

Aluminum Plate, 1 in. Thick

The response of the aluminum plate, as shown in the oscilloscope recordings and the comparative graphs, indicates that at least two distinct mechanisms contribute to

Fig.8. Stress pulses from the 1/8 in. diam aluminum Hopkinson split bar under varying input face conditions.

Fig. 9. Plastic deformation and damage to thin (0.005 in.) aluminum specimen covered on the input side with a layer of epoxy 0.02 in. thick.

the total stress history. The transit time of the higher frequency components, or precursors, corresponds to that of a longitudinal stress pulse traveling through 1 in. of aluminum at dilatational velocity. We believe a "thermophysical" mechanism causes this component of the stress history. Since the laser energy penetrates to a depth of only a few microns and the deposition time is on the order of 25 nsec the material responds by propagating a thermally generated stress wave with a dilatational velocity characteristic of aluminum.

We believe evaporation of material on the surface of the aluminum causes the lower frequency components of the stress history. The rapidly heated material vaporizes, producing a pressure pulse. Confining this reaction significantly increases the amplitude of generated stress pulses. A second reaction, the recoil of the ejected plasma against the specimen surface and confining material, also adds to the lower frequency stress pulse amplitude.

Aluminum Rod, 0.5 in. Diam, 1 in. Long

This specimen was designed to show the effects of preventing lateral diffusion of the shock front. In the experiment with the 1 in. thick aluminum plate, there was no lateral boundary imposed, i.e. the plate appeared as a semi-infinite solid to the incident laser energy. Imposing boundary conditions severely modifies the shape of the laser-generated stress pulse. Figure 6 shows the relative amplitudes of the high and low frequency components of the stress history in the aluminum rod. Generally the lower frequency components of the stress pulse history are of greater amplitude than the higher frequency components. Again, the cause of the high and low frequency components appears to be the result of two separate mechanisms.

The relative amplitudes of the high frequency components of the rod and plate are extremely similar. This would be expected since both the plate and the rod are 1 in. thick.

The lower frequency components in the rod, however, are up to 16 times as high as those from the plate. This increase is a direct result of the restriction imposed by the 1/2 in. diam of the rod.

Aluminum Rod, 0.5 in. Diam, 4.5 in. Long

This specimen is the same as the 1 in. rod except for the increased length. In this experiment the higher frequencies were attenuated while the lower frequencies generally increased compared to the shorter specimen.

Laser Energy Enhancement

Enhancement of laser energy into an extended solid medium has been experimentally verified. The application of this enhanced energy to produce high amplitude stress pulses in a variety of test specimens has been accomplished and at relatively low initial

energy levels. Further experiments are being conducted to determine the maximum efficiency possible for absorbed to incident laser energy in a solid. Application of this enhanced energy in the area of high strain and high strain rate phenomena are presently being pursued.

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