Article

Pulse laser ignition of a small amount of secondary explosive powder

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Laser induced ignition of secondary high explosive charge will be one of the promising method of safe and reliable way of ignition of high explosives. The present method is based on the energy conversion from the pulsed laser energy to high pressure high temperature plasma generation by pulse laser ablation of thin metal layer adjacent to explosive. Method is also based on our findings that very efficient energy conversion process from optical to mechanical takes place by intentional roughening of the surface of a transparent medium through which laser beam propagates.

Some of the unique feature of this study are as follows : (i) a very small amount of PETN of 3 to 15 mg is used, (ii) explosive thin layer is sandwitched in between the PMMA plates, whose thickness is almost 500 μm, and (iii) the laser focused surface is intentionally roughened. Nd:YAG laser beam was focused through a PMMA plate of roughened surface, which simulates experimentally the use of plastic optical fiber. Initiation process was observed by the streak photography of the self-luminous wave front in PETN as well as the pulse laser shadowgraphy of the high-amplitude stress wave in PMMA medium induced by the detonation.

1. Introduction

Instantaneous high tenperature high pressure state can be achieved on the solid surface by focusing very intense laser beam on it. This results in an explosive burst of plasma and particles from the surface, and the phenomena is called laser ablation. This is one of the processes that the laser pulse energy can be converted to other form of energy very effieicently. Ultra high pressure states attained by this process is considered promising as a scientific tool to study these high energy density states and its applications. Physical processes subject to the laser irradiation is considered to be quite different by varying the thickness of the layer on the surface of which laser beam is focused.

Several authors have published works on the laser induced ignition of various kinds of explosives and in various ways.[1-5] Since most of the energetic materials are almost transparent for wide range of light wavelength, very intense laser intensity is necessary for the direct initiation of the explosive by laser focus. In this sense, some kind of energy conversion method for the explosive to absorb an appreciable amount of energy to the explosive is necessary. In the case of a thick metallic layer, high-velocity foil can be realized by the laser focus, which may be used to initiate explosives.[1]

In case of thinner metal layer of the thickness of less than 1 μm, ablation takes place. In this case, high temperature plasma instead of foil flyer

Received : May 17, 2002
Accepted : December 11, 2002
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is generated. We are studying the feasibility of applying the same phenomena to the initiation of high explosive charge without danger of accidental explosion by electrical noise. Accurate timing of initiation can be expected by the proper choice of energy deposition method. In this application, infrared and ns duration laser is preferable. Furthermore, particle size dependence on the laser initiation sensitivity has been reported.[1, 2] Coarser explosive particles are found to be less sensitive to the laser initiation.

In this study, we propose a new energy deposition method on explosive through the generation of high-temperature metal plasma due to the pulse laser ablation of vacuum deposited thin metal layer on a roughened polymer surface. During the course of this work, we have found an enhanced absorption of pulse laser energy by a roughened surface.[6, 7] As a result, high-pressure shock wave generation was evidenced in an ambient medium by using the laser shadowgraphy technique. Strength of shock wave produced in these conditions is further enhanced, if a thin metal layer is deposited on the roughened surface. In such cases, laser energy transfer to the desired position might be made through use of plastic or glass optical fiber. End surface of the optical fiber is intentionally roughened and then metallized.

In this report, we have presented streak photographs of luminous reaction front, and several shadowgraphs to show the generation of high pressure shock wave in the container material of explosive. Acceleration of detonation wave front with propagation is also discussed.

2. Experiments and discussions

2.1. Laser shadowgraphy of the detonation induced stress waves in PMMA

Although previous reports on the laser ignition stated that finer explosive particle is preferable for the low energy threshold of laser initiation, PETN powder we have used was about 100 μm in grain size, which are provided by Asahi chemical industry, LTD. Quantity of the explosive, and confinement geometry as well as the initial density of the explosive is supposed to be important parameters. We have used an extremely small amount of explosive of 3-15 mg of PETN. Due to this small quantity of specimen, estimated initial density may have rather large error of 10-20 %. Quantity of PETN powder used in an experiment is chosen to be limited to less than 10-15 mg. Typical value of the initial density of PETN powder in this experiment is 0.6 to 0.9 g/cm^3 ± 0.1 g/cm^3.

We expected that very close confinement of the explosive might be effective to lessen the threshold energy to initiation, since small amount of explosive seems to increase the threshold value of initiation energy due to the less chance of generating hot spots. In this study, thin explosive layer is sandwitched by two PMMA plates, through one of which laser beam focuses. As explained, the laser focus plane was intentionally roughened and aluminized.

Interaction of the high-energy density plasma with high explosive is the key of the initiation process. We have tested the initiation test of PETN powder charged into very thin layer of 0.5 mm to

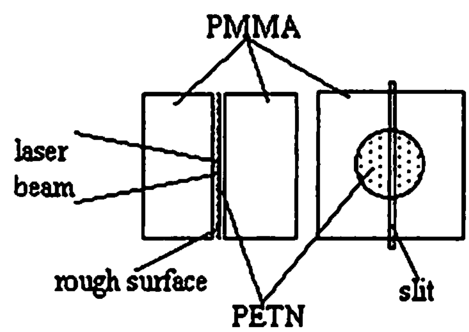

Fig. 1 Experimental setup for laser shadowgraphy of detonation induced stress wave in PMMA. Two thick PMMA plates of both sides are used to observe the induced high pressure stress wave in PMMA by explosion as well as to confine the explosive layer

1 mm. Figure 1 shows the experimental setup for the present study especially for the laser shadowgraphy of the stress wave propagation in PMMA. PETN powder is filled into 0.5 mm space. Pulse laser beam is focused on the rear surface of the aluminized layer to ablate the layer. Explosive sensitivity was tested with varying the focussed

diameter and laser energy. Although thickness of the explosive layer is very thin and the particle size is relatively large, explosion is observed for the laser focus onto less than 2 mm diameter. Explosion is determined by the streak record of self luminous front propagation, sound, smell, and broken assemblies. In some cases, incomplete detonation, half detonation was observed. It is found that the results cannot be described by the laser fluence.

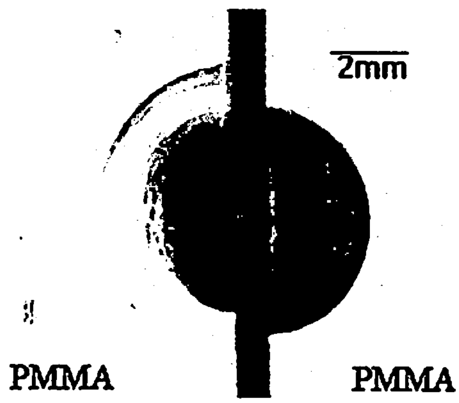

Fig. 2 Typical shadowgraph of the stress wave pattern induced by the phenomena. Three wave fronts can be recognized. Laser beam comes from left side. Delay time after laser irradiation is 1168 ns.

Figure 2 shows the typical shadowgraph of the induced high pressure stress waves in PMMA. SHG of Nd:YAG laser of 12 ns was used as a light source, which was triggered synchronized with the ablation laser irradiation with a definite delay time. Ablation laser beam comes from lhs of the figure. Three wave fronts are seen, two in lhs PMMA plate, one in rhs PMMA plate. As easily recognized by the figure, these three wave front position is shifted slightly with each other. The most thin fastest front is created by the laser ablation, while the other two are caused by the detonation of PETN powder. Since we have used a small aperture inside the optics of shadowgraph record, dark region behind the wave front suggests that high amplitude stress field is induced by the detonation. The first stress wave was induced by the ablation of metal layer at the pulse laser input, and this wave propagates only through the PMMA plate of the laser focused side. Corresponding stress wave to the laser beam direction could not be observed. This result may be attributed to the fact that high-temperature high-pressure plasma generated by laser ablation may act as a piston to press the low density PETN powder strongly to the PMMA wall of the opposite side. This may take time to induce another stress wave in PMMA plate.

By a series of experiments of shadowgraphy of stress waves in PMMA as in Fig. 2, one may plot the x-t diagrams of three kinds of wave trajectories in PMMA. Figure 3 shows the x-t diagram of this

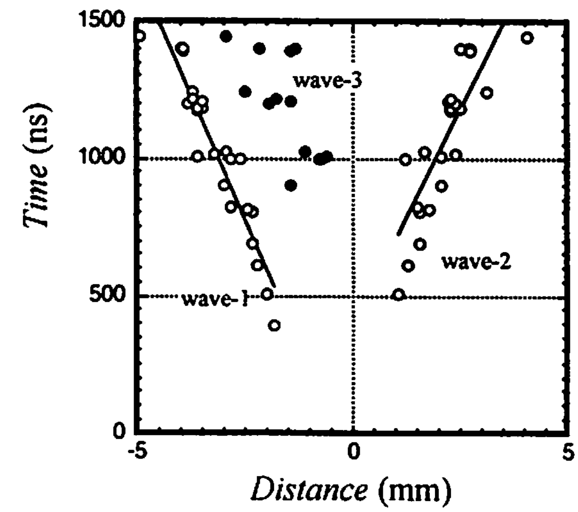

Fig. 3 The x-t diagram of the three wave fronts seen as in Fig. 2. Explosive thickness in all the data is about 0.5 mm.

three kinds of wave fronts in PMMA. One may note that the time origin of these three waves are all shifted with each other. Time shift between the first and the second wave is the time delay of the onset of initiation after laser irradiation. We noticed that the detonation front can be seen only the left hand side in the early stage of initiation. This time shift might be caused by the PETN powder compaction process by the high temperature high pressure metal plasma, and onset of appreciable reaction takes place in a region adjacent to the PMMA wall of far side from the laser beam. The slope of the x-t diagram suggest the stress generated by this process amounts to several GPa.

2.2. High-speed streak photography of the detonation front propagation in thin

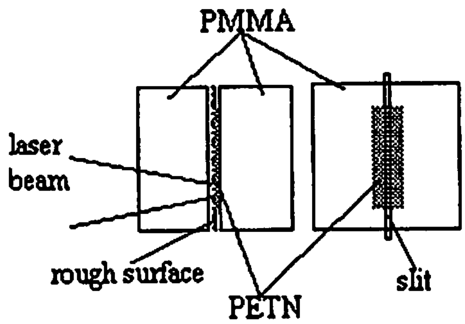

Fig. 4 Experimental setup for the streak shadowgraphy to observe the wave propagation along the thin explosive layer.

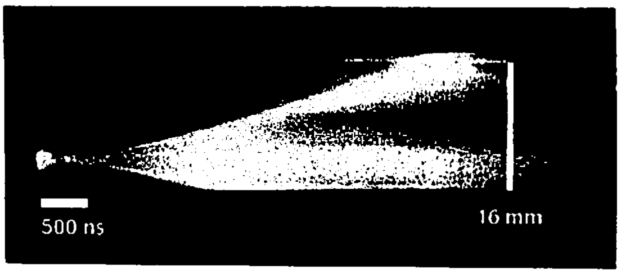

Fig. 5 Streak photograph of delayed and accelerated detonation front propagation in PETN powder of 10 mg. Nd:YAG laser pulse of 180 mJ is focused to about 1.5mm diameter.

explosive layer

Figure 4 shows the schematic drawing of one of the typical assembly to observe the propagation of radiant reaction front along the thin explosive layer. In this assembly, laser beam ignites the bottom region of the explosive to see the proceedings of the wave upward.

Figure 5 shows a typical example of streak photograph of self emission due to laser induced reaction of PETN thin layer. As seen in Figs. 2 and 3, detonation reaction is found to be delayed 200-300 ns after laser ablation. In the photographs, intense flash due to laser ablation is recorded in the streak photograph, since the light intensity of ablation is brighter than the self emission of detonation. Clear evidence of the front velocity acceleration with propagation is obtained in this photograph of Fig. 5. It is found that the detonation velocity estimated by the slope of the streak photography approaches to the value of the detonation velocity of the bulk charge, although the value of this experiment is still somewaht smaller.

3. Conclusion

A new energy conversion mechanism has been studied from the laser pulse energy to shock wave energy by intentional roughening of energy deposition surface with thin metal coating. Combination of surface roughness and thin metal layer is very effective for the enhanced absorption of laser energy and produces a very strong shock wave in ambient media. We have succeeded in the detonation of very thin PETN powder layer of 100 mm grain. Detonation velocity is found to be accelerated with propagation approaching the published bulk detonation velocity.

Acknowledgements

Authors wish to thank Ms. S. Hatano, and Mr. Y. Mori for their help of experiments. They also wish to thank Asahi Chemical Industry for providing PETN explosives.

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