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LASER CUTTING OF ENERGETIC MATERIALS

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ABSTRACT

We have demonstrated the feasibility of safely and efficiently cutting and drilling metal cases containing a variety of high explosives (HE) using a Nd:YAG laser. Spectral analysis of the optical emission, occurring during the laser-induced ablation process, is used to identify the removed material. By monitoring changes in the optical emission during the cutting process, the metal-HE interface can be observed in real time and the cutting parameters adjusted accordingly. For cutting the HE material itself, we have demonstrated that this can be safely and efficiently accomplished by means of a ultraviolet (UV) laser beam obtained from the same Nd:YAG laser using the third or fourth harmonics. We are currently applying this technology to UXO identification and ordnance demilitarization.

I INTRODUCTION

There are a variety of situations that exist where it is necessary to either cut a high explosive (HE) piece away from metal components, or alternatively, cut away a metal component from a HE piece. Examples include dismantlement of old weapons, remediation of unexploded ordnance, and machining of HE components.

Existing cutting methods, such as sawing, grinding, shearing, or water-jet cutting are usually hazardous and in the case of water-jet cutting, may produce a significant waste stream. We have demonstrated the feasibility of safely and efficiently cutting and drilling metal cases containing a variety of HE by means of a laser. We have also applied the laser cutting tool to dismantlement and recovery of M75 anti-tank mines.

The relative ease of making precise cuts, coupled with the integration of real-time emission spectroscopy to examine the layer being cut, allows for development of a flexible, highly automated cutting tool, suitable for processing a wide variety of ordnance types. By controlling the laser pulse energy, repetition rate, wavelength, cutting speed and assist gas HE and metal layers up to 1/2" thick have been cut using commercially available Nd:YAG lasers.

In this paper we survey our previous work using pulsed and cw lasers to cut bulk HE, demonstrate the utility of the optical emission diagnostic, and show our preliminary results on cutting inert M75 anti-tank mines using a Nd:YAG laser.

II LASER CUTTING OF HIGH EXPLOSIVES

We exposed a variety of HEs including TNT, Comp B, PBX 9404\(^1\), PBX 9502\(^2\), and PETN to a variety of cw and pulsed lasers. All of the experiments were conducted at LANL explosives firing sites. An example of a laser cut explosive is shown in Fig. 1.

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\(^1\) PBX 9404 is a composite containing 94% HMX, 3% NC, and 3% CEF pressed to 1.85 g/cm\(^3\).

\(^2\) PBX 9502 is a composite containing 95% TATB, and 5% Kel F 800 pressed to 1.90 g/cm\(^3\).
The Nd:YAG laser used for our experiments was a Quanta-Ray Model DCR1. The targets for these experiments included TNT, Comp B, and PBX 9404. Some targets were also combined with metal faceplates or backing plates to totally contain the HE. Steel, aluminum, and copper plates, 1.59 mm thick, were utilized. These experiments resulted in cutting the confining metal plates without ignition or significant charring of the HE. Also included for testing was an SE-1 detonator, which has a 1 mm thick brass wall, 1 cm wide PETN containing cylinder. PETN was chosen since it is one of the most sensitive secondary explosives commonly used by DoD. The detonator was slowly rotated and was cut in half in about 10 min., using a repetition rate of 5 Hz, corresponding to a laser average power of 3 W.

We conducted experiments using a Lambda-Physik model EMG-102ES excimer laser. Tests were conducted with bare HE samples 6.35 mm thick and were designed to produce 1 mm diam holes. The pulse repetition rate for the laser was approximately 1 Hz. Examination of the HE samples showed that the entrance and exit faces were only slightly spalled, in contrast to the slag-encrusted holes seen with the CO₂ and to a lesser degree with the Nd:YAG laser. The observation of smooth HE ablated surfaces may be due to photochemically-assisted material removal, proposed for excimer ablation of polymers, or simply a consequence of a smaller heat affected zone, due to the smaller absorption depth of the UV laser. In any case, laser cutting of HE with the excimer gave the best results with respect to kerf quality.

One of the goals of our study was to define the regime where explosives are immune to initiation by laser beams. The excimer laser delivers a very powerful pulse (~7 MW single shot, ~4 MW at 10 Hz) in the UV where explosives are strongly absorbing. Therefore, the excimer laser more or less defines the upper limit of power available to potentially initiate HE samples. All the samples were cleanly cut without incident. The remaining shots were designed to test the response of an HE/metal interface subjected to excimer irradiation. Preliminary testing indicated that this excimer laser was ineffective for metal cutting.

III REAL-TIME SPECTROSCOPIC DIAGNOSTICS

The atomic constituents of the material being cut can be determined by means of spectroscopic observation of the plume. The technique for material identification known as Laser Induced Breakdown Spectroscopy (LIBS) was developed at Los Alamos by Cremers³ and Loree⁴. This technique is a form of atomic emission spectroscopy where

spectral analysis of the light emitted by excited samples can be used to qualitatively identify the sample. With LIBS, laser light is focused to an energy density adequate to ionize the sample. The resulting plasma emissions are relayed optically to a grating spectrometer. The output of the spectrometer is recorded with a photodiode array and the resulting spectrum analyzed to qualitatively identify elements present. This technique has been primarily used for trace analysis with a sensitivity of better than 1 ppm for some elements. The field portability of this technique has been demonstrated with the development of an airborne beryllium detector based on LIBS that is mounted on a cart.

The field scenario for spectrochemical analysis of a device would be to have a pulsed laser source machine through the outer layer of the device simultaneously analyzing the spectra of the actual machining pulse. For example, by maximizing the iron emission by controlling laser pulse energy, cutting speed, assist gas and laser focus, optimum cutting conditions through the metal layer could be maintained. The laser would also be controlled so that it continues pulsing until the spectral signature of the layer contents, i.e., explosives, are first encountered without HE perforation. When the new signature is encountered, the laser could be shut off and a decision made as to what to do next.

IV ORDNANCE CUTTING

An example of a piece of ordnance, namely a M75 anti-tank mine, cut with a laser is shown in Fig.2.

![Figure 2. M75 Anti-tank Mine Cut with Laser](image)

Figure 2 shows the anti-tank mine cut open at the top for removal of the instrument package. This work was done for YUMA Proving Ground, Yuma AZ.

V FIELDABLE PACKAGE

The complete laser-cutting system with LIBS monitoring could be packaged into a fieldable remote system. The Nd:YAG laser fundamental would be used to cut the outer case until the metal/HE interface is detected using LIBS. A tripling crystal would then be introduced allowing the resulting UV beam to continue cutting and spectroscopically observe the HE. If the bomb fill were inert rather than HE, the spectra would probably reveal this immediately. Once the ordnance has been cut open, the HE could be treated using base hydrolysis, super critical water oxidation, or other methods to achieve a safe remediation.

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