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Analysis of pyrotechnic devices by laser-illuminated high speed photography

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1. INTRODUCTION

Several types of pyrotechnic igniters have been evaluated using the technique of laser-illuminated high speed photography with a copper vapor laser. The accompanying video tape shows the results of high speed films recorded for two types of igniters (Type X1 and Type X2) fired in confinement in a lucite block and four types of igniters (Type X1, Type X2, Type X3, and Type X4) igniters fired at ambient. The films of the Type X1 and Type X2 igniters were recorded for both a coarse particle titanium potassium perchlorate (TiKP) output charge and a fine particle TiKP output charge. The results of these films are most informative, and the technique is shown to be useful as a design tool for studying the performance of igniters.

2. EXPERIMENTAL

The copper vapor laser used in these experiments has several unique properties. The laser is capable of operating at 10,000 Hz, but is operated at 6,000 Hz for filming the battery igniters. At this pulse repetition rate, the laser has an average power of 30 watts. The 30 nanosecond pulse width of the laser essentially freezes all motion of the functioning igniter, and it provides detailed images of the igniter flame that were never before possible. The peak power of each laser pulse is approximately 170,000 watts which provides ample illumination for the photography.

The optical arrangement used to film the igniters is shown in Figure 1. The laser beam is formed into a thin sheet using a spherical-cylindrical lens combination to illuminate the space above the center of the component. In an orientation perpendicular to the laser sheet, the camera records the component and a field of view of approximately 25 cm above it. The light scattering (Mie scattering) from the smoke and particulates illuminated by the laser sheet provides a unique view of the internal structure (a cross-sectional view) of the igniter output. When the igniters are fired in confinement in a lucite block, the same type of sheet lighting is employed as it illuminates the hole in the block very well.

During an experiment, the camera drives the laser with an

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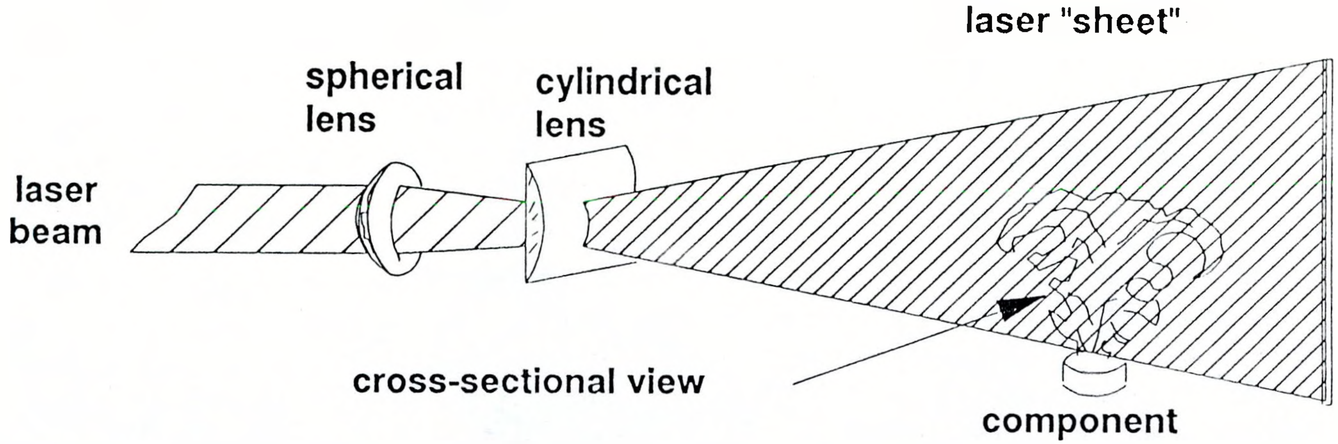

The igniters were filmed using sheet lighting from the copper vapor laser.

Figure 1

appropriate delay that is set to a predetermined value depending on the camera speed. This ensures that when the laser pulse is at the experimental point, the camera shutter is open and the laser illuminated image is recorded. The shutter is open only for a few microseconds, requiring that the timing be quite precise. This precision is achieved using a timing circuit which senses the camera speed. When the desired speed is attained, the timing circuit allows the camera to drive the laser. The camera is a rotating prism type that provides one trigger pulse to the laser per frame of high speed film. When an eight sided prism is used in the camera, full frame images are recorded. For this work a 16-sided prism was used, and two images were recorded per frame. Since only one trigger pulse is provided per frame, one image per frame is laser-illuminated, the other is not. In the accompanying video tape the top image is laser-illuminated. A direct comparison between the laser- and nonlaser-illuminated images can readily be made from the video tape. Such comparisons are useful in distinguishing between hot and cold particles and for observing condensed phases versus gaseous species.

3. RESULTS

The properties of the igniters that were filmed are summarized in Table I. The accompanying video tape contains records of 10 high speed film runs. The first 4 are from igniters fired in confinement in a lucite block. The igniters are Type X1A with a coarse particle TiKP output charge, Type X1B with a fine particle TiKP output charge, Type X2A with a coarse particle TiKP output charge, and Type X2B with a fine particle TiKP output charge. Each of these igniters has a barium styphnate ignition charge. There are two things of major importance to be learned from these films. First, the fine particle TiKP igniters burned about 3 times faster than the igniters with the coarse particle TiKP. This is shown graphically in Figure 2. The burn time for the fine particle igniters was approximately 1.2 msec, and the burn time for the coarse particle igniters was approximately 3.3 msec. Secondly, many hot particles were observed from both the igniters that contained the coarse TiKP, but no hot particles were observed form those igniters that contained the fine TiKP. If hot particles and the length of the igniter burn are important for the ignition of the next component, then the coarse particle TiKP igniters are clearly the choice.

The remaining 6 film records are from igniters fired at ambient. The igniters are fired open to the atmosphere in a vertical orientation. Comparisons between the film records show the effect of both igniter closure disc and the TiKP particle size. Igniter X1 has a glass-ceramic closure disc and igniter X2 has a metal closure disc. Igniter X1A produces no self-illumination in the film record. The light scattering from the laser is probably from unburned pyrotechnic material. However, igniter X2A has the metal closure disc, and there is considerable self-illumination and numerous hot particles are produced. There is also a cloud that appears green in the laser-illuminated images which is laser light scattering (Mie scattering) from TiO_2 produced in the combustion. There was no

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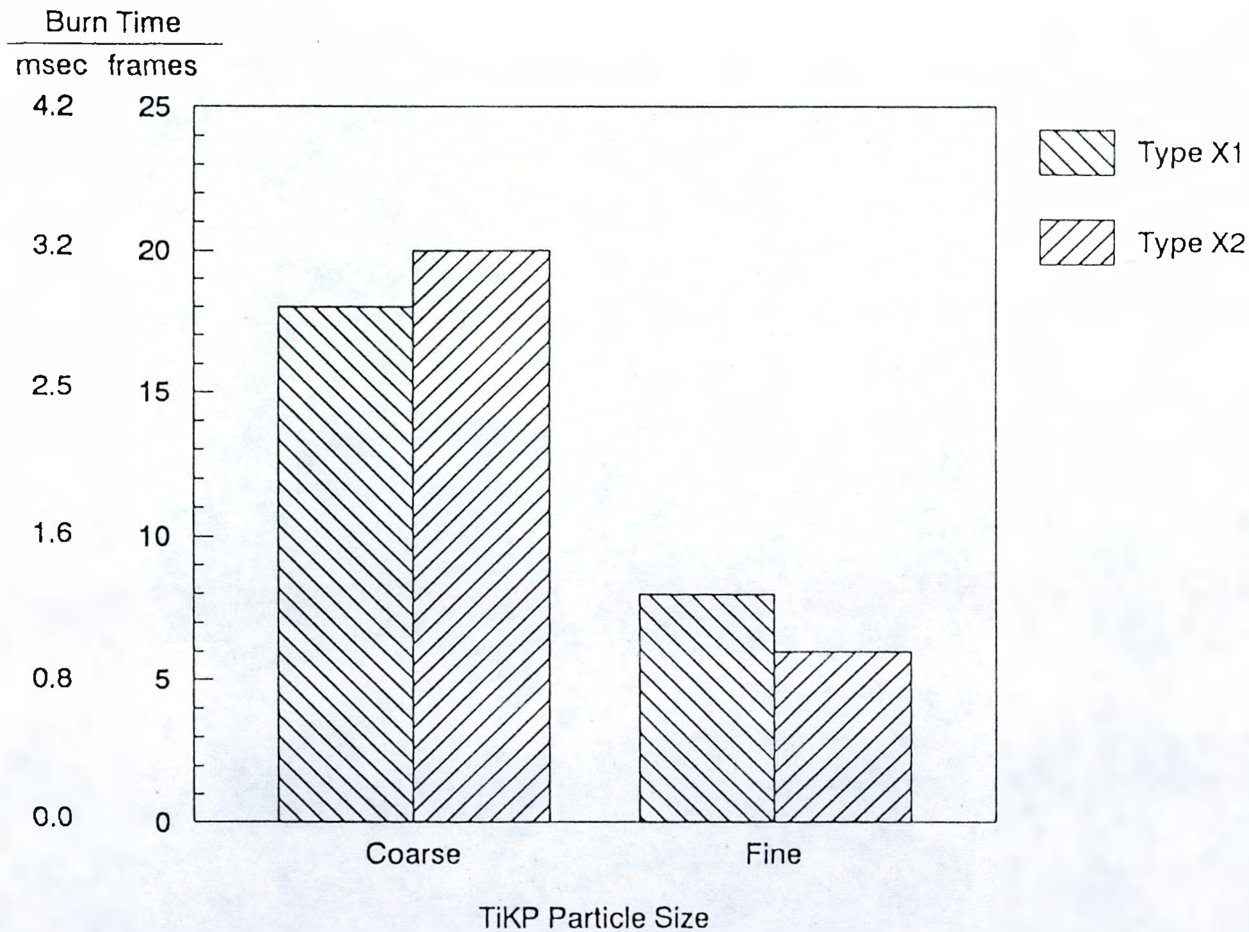
Igniter	R	I	Wt. of Ba Styphnate	Wt. of $TiKClO_4$	Fuel/ Oxidizer	Particle Size
X1A	4.5	0.6	5.0/6.0 mg	7.0/8.5 mg	41/59	coarse (8-10 u)
X1B	4.5	0.6	5.0/6.0	7.0/8.5	33/67	fine (2-3 u)
X2A	4.5	0.6	5.0/6.0	6.5/8.5	41/59	coarse
X2B	4.5	0.6	5.0/6.0	6.5/8.5	33/67	fine
X3	1.0	3.5	-----	9.5/10.5	33/67	fine
X4	1.0	3.5	-----	9.5/10.5	33/67	fine

A Comparison of Pyrotechnic Igniters

Table 1



TiKP particle size has a considerable effect on igniter burn time.

Figure 2

such cloud in the Type X2A igniter. It is informative to compare the formation of this green cloud in the different film records. For both the Type X1B and X2B (fine particle) igniters this cloud has considerable structure and is very predominant. This is probably because there is more TiO_2 produced prior to closure disc rupture in those igniters containing the fine particle TiKP. The fine material burns very rapidly producing TiO_2 and there are no long burning hot particles. Further evidence can be seen in the Type X2B igniter particle where rapidly burning particles can be observed to leave a trail of TiO_2 behind them as indicated by the green streaks in the laser-illuminated image that are out in front of the main illumination. The effect of the closure disc assembly between the Type 1B and Type 2B (fine particle) igniters can also be seen. There are more hot particles coming from the Type X1B at the beginning of the burn. However, this effect is not nearly as important as the effect of TiKP particle size. The Type X3 igniter is an all TiKP igniter and was filmed for comparison. There are hot particles produced at the beginning of the burn, and a predominant green cloud as expected from the laser light scattering from TiO_2. The Type X4 igniter was also filmed since it has been used extensively. The film clearly shows a considerable amount of hot particle formation, and a not so predominant green cloud of TiO_2. This igniter output is very similar to that of the Type X2A (coarse particle) igniter.

4. CONCLUSIONS

The output from several pyrotechnic igniters has been filmed by the technique of laser-illuminated high speed photography with a copper vapor laser and a considerable amount of information has been obtained from the films. Timing information is readily obtainable, and the effect of closure disc assembly and TiKP particle size can clearly be seen. The degree of TiO_2 formation can be determined by the extent of the light scattering of the laser from this material. When TiO_2 is rapidly produced, the laser shows up a distinct green cloud with a stable shape. When TiO_2 is not produced as rapidly and hot particles are produced, this green cloud is not as pronounced, and its shape is not as stable.

Much of the discussion above compares the igniters on the basis of the TiKP particle size. However, it should be pointed out that although the particle size differs, so does the stoichiometry. Igniters with coarse and fine particle size TiKP with the same stoichiometry need to be prepared in order to determine the actual effect of particle size on igniter output.

Most of the data on the igniters comes from only one film run on each type. It would be advisable to take several film runs on at least one of the igniters, and preferably more, to test the reproducibility of the devices.

This type of information could not be obtained by any other technique. As new igniters are designed, their performance should be recorded by laser-illuminated high speed photography and added to the film library that is being maintained on these components. The technique can also be readily applied to investigate the performance of other components as well.