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Methods of lighting of concrete structures for high-speed camera measurement

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Abstract. In extensive research, damage to concrete panels by explosion is investigated. For detailed monitoring of particular phases of explosion, exploitation of a high-speed camera is intended. The paper presents testing of possibilities of lighting of the scene at detonation with explosive agents. Four alternatives of agents were tested – three varying amounts of aluminium powder and argon. Paper presents results of the tests – intensity of lighting for tested variants, delay between ignition of lighting agent and the main detonation, and evaluates convenience of tested explosive agents for illuminating of the scene captured by high-speed camera.

1. Introduction

Current high-speed cameras are used to record high-speed phenomena or to capture very short periods of time which cannot be seen with the naked eye or ordinary camera. High-speed camera was used in previous research, but without the primary light source [1,2]. Common frame rate is in the order of tens of thousands of frames per second, for special applications the frame rate exceeds one million frames per second. The subsequent slow-motion playback enables analysing of areas around exploded charge, as deformations of structures exposed to shock wave or propagation of the shock wave itself.

Before the actual start of the recording, the observed phenomena must be known to prepare the scene, lens, camera settings and select suitable lighting. Often a compromise between image resolution, frame rate and image luminance must be chosen. Varying conditions of the scene during recording must be considered, too. In explosion of the blasting agent, the scene is excessively lighted, what has to be taken into account in setting of lens and camera, to capture the desired action correctly and in the best possible quality.

1.1. Problem description

Blast resistance of concrete panels with dimensions 1000 x 1000 mm and thicknesses 100 mm, 150 mm and 200 mm was tested. The explosive was set on the upper surface of concrete panel and above the panel in various heights (figure 1). Cracking is an important feature followed in investigation of blast resistance. The principal cracks arise on the side opposite to the explosive. To prevent damage of the camera by flying concrete pieces impact and to enable observing the cracking, an inclined mirror serves to reflect the image. The record of cracking is used for comparison with the numerical model.





Figure 1. Picture of the scene.

The record was captured by a pair of high-speed cameras situated 25m from the monitored concrete panel. One camera recorded the overall scene and explosion (see figure 1), the other camera aimed at the mirror to (see figure 2) to monitor cracking. The development of blast cracks is a very fast process, which has to be monitored with higher frame rate than common image records. However, the higher frame rate requires better lighting conditions. A drawback is also a shadow on the mirror given by the concrete panel.

The explosion causes partial lighting which, however, proved to be insufficient (see figure 2). The shooting was performed under full sunlight. Lighting from primary source (see figure 3).

To improve the lighting conditions, an alternative was proposed where the set of mirrors should have been turned to illuminate the scene with sunlight. This way of lighting the scene proved to be inadequate and insufficient too. Due to the rotation of the Earth around its axis and around the Sun, the turning of the mirrors had to be constantly adjusted.



Figure 2. Figure of cracking after explosion with insufficient lighting.



Figure 3. Figure of cracking after explosion with primary source of lighting (aluminium powder).

Therefore, another primary light source was tried - aluminium powder (see figure 4). At a distance 1.6 meters from the concrete panel, 150g of aluminium powder and 150g of Semtex were placed to ignite the aluminium. All tests were lighted like this. The objective was to provide maximum possible illumination on the monitored side of the panel during development of cracks. Correct timing of the delay between ignition of the illuminating agent and the main detonation is very complicated and needs to be addressed in detail. With regard to this findings, an experiment was conducted, which explores the possibilities of illumination of the detonation, intensity and time course of the lighting for various types of lighting substances.

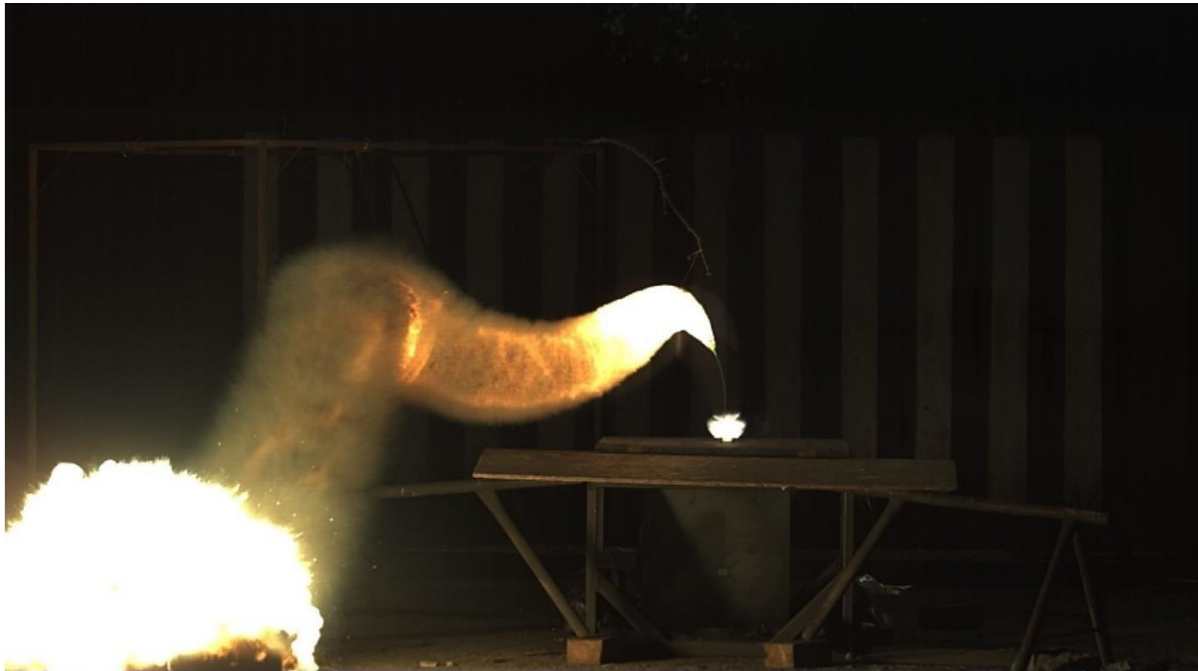


Figure 4. Shot of the explosion. On the left is the primary source of lighting – aluminium powder.

2. Experiment

2.1. Agents used for illumination

2.1.1. Aluminium powder. Burning of aluminium powder emits high light output. The burning rate is affected by the fineness of grinding of the used aluminium. The particle size analysis of the aluminium used in tests is shown in table 1 and the properties of the aluminium used are shown in table 2.

Table 1. Particle size distribution of the aluminium powder.

Retained on sieve	Percentage
0.1 μm	0.81 %
0.063 μm	25.14 %
0.045 μm	48.67 %
Passing 0.045 μm	51.33 %

Table 2. Properties of aluminium powder.

Specification	Value
Fe content	max. 0.14 %
Si content	max. 0.07 %
Cu content	max. 0.001 %
Humidity	max. 0.2 %
Melting point	661 °C
Ignition point of the powder	250 °C
Burning temperature	2500 °C

2.1.2. Argon. Argon under permanent pressure is a gas. A 1.5 litre bottle was filled with 1 bar overpressure.

2.1.3. Petrol. Bottle filled with 0.5 l of petrol was used in the test. The results of the test are not presented, as the full ignition of petrol came 60 ms after detonation of explosive. The increase of illumination intensity is much slower than start-up time of illumination of aluminium and argon. Inflammation of petrol is conditioned by dispersion of petrol in the air and reaching of a suitable compression ratio. Petrol was classified an improper illumination method and it has been eliminated from the experiment.

2.2. Description of the experiment

The camera was 10 m away from the light source, using 85 mm lens with a f/1.4 aperture diameter. The framerate was set to 10,000 fps, an image resolution of 1600 x 1200 px, and an electronic shutter of 33,339 ns. The electronic shutter speed was intentionally reduced (threefold) in order to observe the ignition of fumes, not the illumination as such. The same camera and lens settings were used for all records.

In the experiment, aluminium powder weighing 75 g, 150 g, 300 g and argon, which was filled into the bottle with 1 bar overpressure, were tested as a light source. Ignition of all light agents was provided by the same explosive (Trinitrotoluene) of 75 g weight. In contrary to original method of illumination described in the first chapter, the weight of the explosive was reduced by half, to reduce the shock wave magnitude.

2.3. Description of the testing

Representative images were selected to describe the monitored process. The first image captures the time just prior to the explosion (see figure 5, figure 9, figure 13 and figure 17). The second image captures a moment 1 ms (millisecond) after the explosion. At this moment, a fireball is formed what is accompanied by creation of explosion products. The third figure depicts moment 3 ms after explosion. At this moment the explosion products ignite and a shape of fireball is evaluated. The time of the last figure is different. The presented figures show moment, when a fireball is formed, all products have been ignited and a full lighting is provided. At this moment the fireball does not necessarily have the biggest volume; in all cases, the fireball has grown but the light intensity has not increased much.

3. Results

3.1. Lighting source – Aluminium powder 75 g



Figure 5. Just prior to explosion.



Figure 6. Time 1 ms after explosion.



Figure 7. Time 3 ms after explosion.



Figure 8. Time 9.5 ms after explosion - full illumination.

Initially, a big amount of explosive products is created (figure 6), which flash in the next phase (figure 7). Fireball is compact and emits light with high intensity for a long time (figure 8).

3.2. Lighting source – Aluminium powder 150 g



Figure 9. Just prior to explosion.



Figure 10. Time 1 ms after explosion.



Figure 11. Time 3 ms after explosion.



Figure 12. Time 8.5 ms after explosion - full illumination.

A time 1 ms after explosion, a horizontal strip of explosive products is formed (figure 10 and figure 11), which fully lights at time 8.5 ms (figure 12). The dose 75 g of activation explosive is sufficient to ignite all aluminium and the illumination intensity is higher than illumination given by 75 g of aluminium powder. The fireball is compact and during decrease of the light intensity, the source is divided in two parts.

3.3. Lighting source – Aluminium powder 300 g



Figure 13. Just prior to explosion.



Figure 14. Time 1 ms after explosion.



Figure 15. Time 3 ms after explosion.



Figure 16. Time 7 ms after explosion - full illumination.

The results show that the 4:1 ratio between the aluminium powder and the explosive is too high (figure 14). A great deal of the aluminium is dispersed around without ignition (figure 15). Intensity of lighting is higher than for 75 g of aluminium powder, but lower than for dose 150 g of aluminium powder (figure 16).

3.4. Lighting source – Argon



Figure 17. Just prior to explosion.



Figure 18. Time 1 ms after explosion.



Figure 19. Time 3 ms after explosion.



Figure 20. Time 10 ms after explosion - full illumination.

During detonation, horizontal expansion occurs first, and a cloud of explosion products is formed (figure 18 and figure 19). The explosion products ignite at time 10ms (figure 20). The resultant fireball shape is not a sphere and the intensity of lighting is lower than intensity of 75 g of aluminium powder.

The summary information and evaluation of test shows table 3. It describes the time course of lighting for each method, respectively each explosive agent.

Table 3. Time course of illumination.

Source of lighting	Creating of compact fireball	Full luminosity	Marked decrease of luminosity
Aluminium powder – 75 g	9.5 ms	20 ms	26 ms
Aluminium powder – 150 g	8 ms	13 ms	22 ms
Aluminium powder – 300 g	7 ms	11 ms	16 ms
Argon – 1 l	10 ms	12 ms	14 ms

Figures 21 – 24 show image characteristics using histograms, which depict number of pixels (vertical axes) related to luminance intensity (horizontal axes). The horizontal axis shows characteristics of pixels in grey scale from 0 (black) to 255 (white) for variant methods of lighting at the moment of maximum

lighting of the fireball. Results show that the highest intensity of lighting was reached for aluminium powder of weight 150 g, followed by aluminium powder of weight 300 g. Aluminium powder with weight 75 g embodies similar intensity of lighting as bottle with argon.

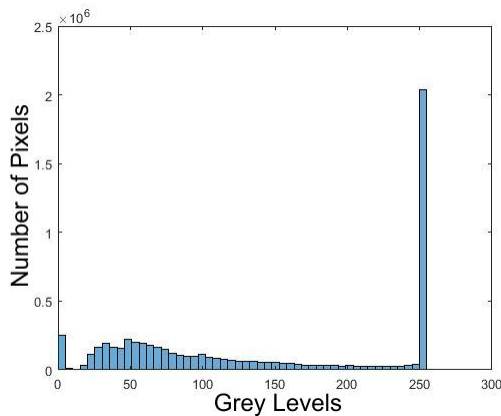


Figure 21. Pixel histogram of figure 8 which depicts explosion of aluminium powder of weight 75 g at time 9.5 ms after detonation.

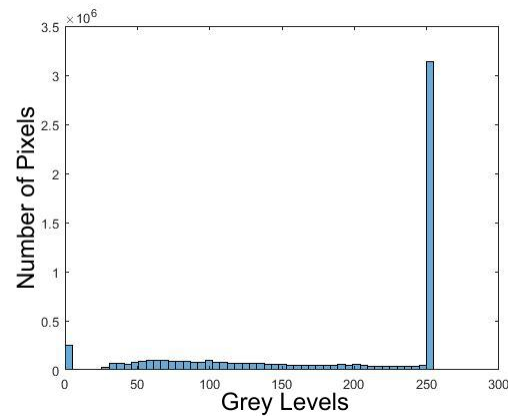


Figure 22. Pixel histogram of figure 12 which depicts explosion of aluminium powder of weight 150 g at time 8 ms after detonation.

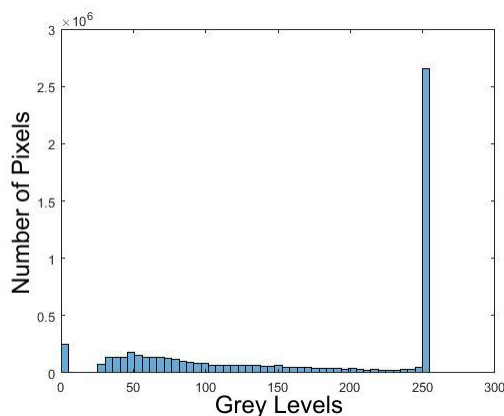


Figure 23. Pixel histogram of figure 16 which depicts explosion of aluminium powder of weight 300 g at time 7 ms after detonation.

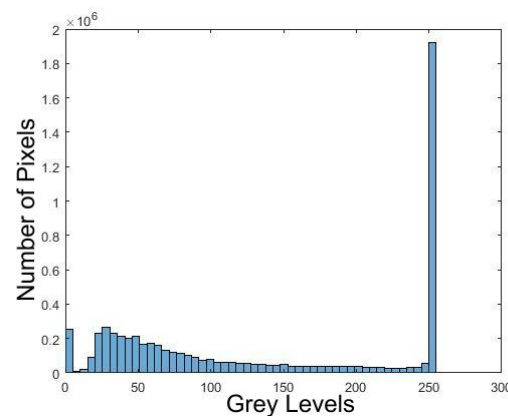


Figure 24. Pixel histogram of figure 20 which depicts explosion of bottle with argon at time 10 ms after detonation.

4. Conclusions

The experiment proved that aluminium powder is a stable light source which, in contrary to argon, can be accurately dosed. The optimal delay time between ignition of the illumination agent and the main detonation can be set to 8 ms. The time optimal for capturing the process by high-speed camera can be estimated at 6 ms. The most convenient illumination was achieved for combination of aluminium powder and 75 g of trinitrotoluene, when a compact fireball formed with intensity sufficient for lighting the scene throughout the duration of the monitored phenomenon. Luminosity of 1.5-liter argon bottle is comparable to 75 g of aluminium powder, but the lighting time is three times shorter. The results show that increasing of the aluminium powder dose does not enhance lighting of the scene.

Acknowledgments

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5. References

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