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EXPERIMENTAL DECOMPRESSION TESTING OF AN ACETYLENE CONTAINING CYLINDER

Abstract. The paper presents the possibilities of using a high-speed measuring camera in experimental tests of decompression of acetylene cylinders in a fire environment. Optical measuring technique was used in the tests. One of the main goals of the experiment was to calculate the energy that the fragments of an exploding cylinder would have during a fire that led to the explosion. In addition, the proposed solution was used to present the advantages and difficulties resulting from the use of measuring equipment in the planned experiment. On this basis, the research methodology was developed and verified. Specifications of the safety zone for the research team were determined, the manner and the rules of fracturing of this type of steel cylinders were determined.

Keywords: industrial gases, acetylene, fire, explosion, fracturing, high-speed camera, fire safety.

1. INTRODUCTION

One of the widely used industrial gases is acetylene, usually stored in a steel cylinder of special design. The mixture of acetylene with oxygen and air is the most dangerous in terms of explosiveness in relation to all other hydrocarbons. Temperature and pressure increases are an important factor in the process of acetylene decomposition. The decomposition process depends mainly on the thermal balance: if heat accumulation inside the cylinder is greater than heat loss, then the decomposition reaction takes place. Decomposition may also occur as a result of a shock. During rescue operations, special care and attention should be exercised, especially when the cylinder has been heated to a high temperature. The explosion of an acetylene cylinder also entails thermal radiation (ball of fire), creation of a shockwave and the flinging of the cylinder. Particularly dangerous are the large fragments of the cylinder, which at the moment of hurling them at a high speed by the force resulting from the explosion, create dangerous elements capable of destroying other objects and posing a very big threat to people.

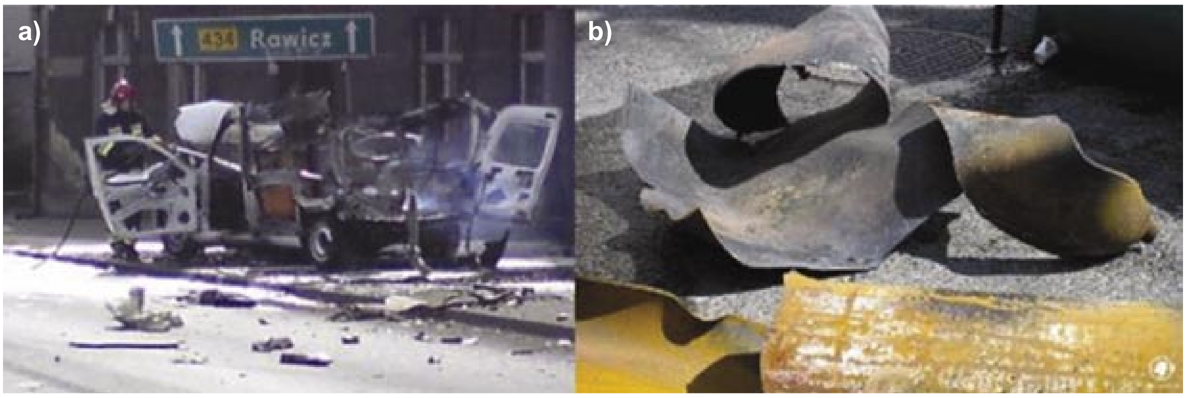

Fig. 1. Explosion of an acetylene cylinder

a) View of a vehicle destroyed by an explosion of an acetylene cylinder (photo by TVN24.pl)

b) Cylinder fragments after the explosion (photo by PSP Opole)

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2 EXPERIMENTAL SETUP AND PROCEDURE

2.1. Subject of the tests

The acetylene cylinder used in the tests was a cylinder of a seamless steel structure, with an external diameter of 0.229 m and a length of 1.21 m, with a shell thickness of 4 to 13 mm (depending on the manufacturer) – Fig. 2.

Fig. 2. Acetylene cylinder used in the tests
(photo by J. Ejsmont, A. Kołacki)

2.2. Test stand

The tests were carried out by a team from the Gdańsk University of Technology on an abandoned naval training ground in Strzepcz. During the tests, the behaviour of the C_2H_2 cylinder subjected to high temperature (simulation of fire), shown in Fig. 2, was studied. The C_2H_2 cylinder was placed in a vertical position on a rack shown in Fig. 4. Combustible material was taken in such amount as to ensure decompression bursting of the cylinder.
Physical parameters were recorded using an ultra-fast optical camera Phantom Miro 310 shown in Fig 3. The camera records at up to 3,200 frames-per-second (fps) at a 1280x800 monochrome image resolution. At reduced resolutions the frame rates can go up to 650,000 fps. TEMA software was used to analyze the physical parameters of the fragments.

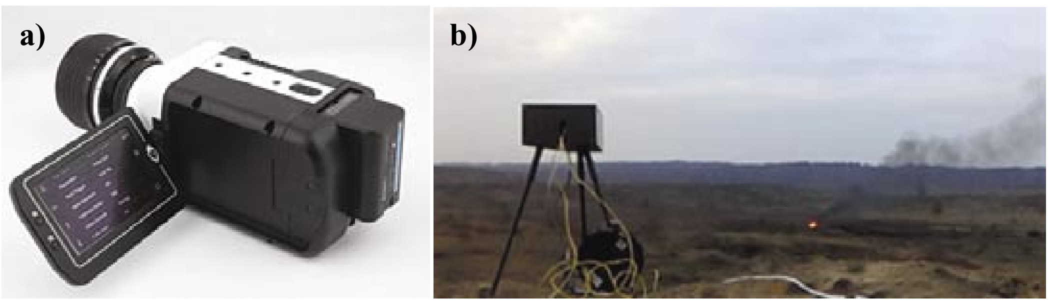

Fig. 3. The optical camera
a) View of the camera **b) Camera in a housing on the measuring stand**
(photo by EC Test Systems Sp. z o.o., Grzegorz Motrycz)

The main difficulties with this type of measurements include the inability to:
- predict the flight direction of cylinder fragments;
- predict the size of fragments;
- install sensors directly next to the burning cylinder due to the pressure propagating during the explosion;
- use standard sensors due to the high temperature near the fire.

In this method, use was made of the possibility of measuring the movement of the cylinder fragments and their angular changes. In order to protect the Phantom Miro 310 camera against damage caused by the flying fragments, it was placed in a protective housing of special design shown in Fig 3b.

3. RESULTS

The field tests were conducted under the following weather conditions: pressure 1002 hPa, ambient temperature 14°C, humidity 80%, wind speed ca. 0.5 m/s. The acetylene containing cylinder was placed freely in a vertical position on a prepared metal rack (Fig. 4a) and covered with combustible material soaked with a mixture of 50% diesel oil and gasoline (Fig. 4b). The fire was initiated remotely by means of an electrical fuse (Fig. 4c).

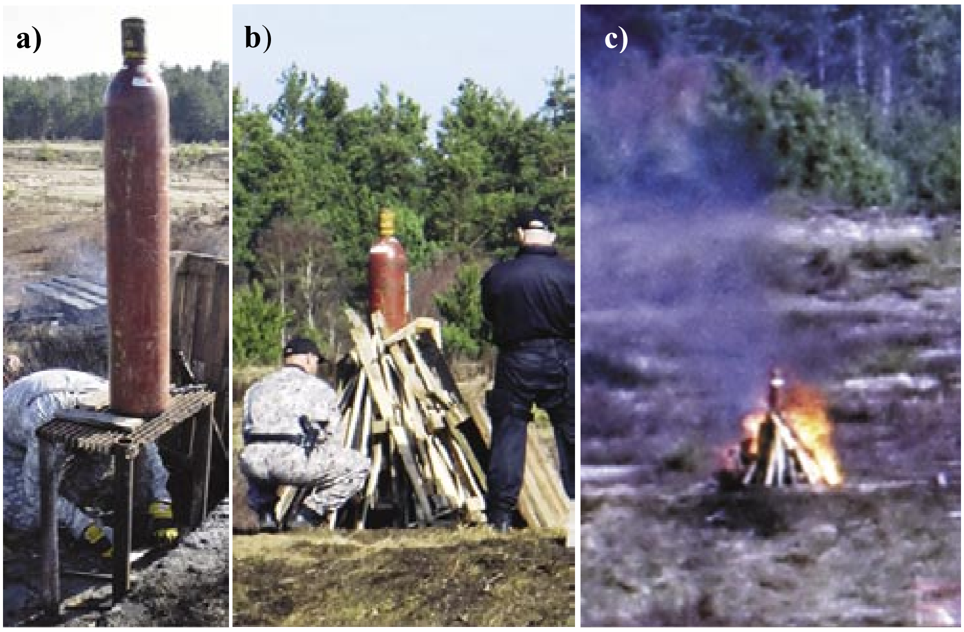

Fig. 4. Test stand
a) fastening the cylinder b) preparing the fireplace c) fire initiation

(photo by J. Ejsmont, A. Kołacki)

After starting the fire, the acetylene cylinder was constantly covered by flames (Fig. 5a). The temperature of the burning wood flame was estimated at about 900 - 1000°C. After 495 seconds, cylinder decompression occurred, as shown in Fig. 5d. It is known that above 400°C, acetylene decomposition can commence without an initiator. As a result of acetylene decomposition, heat is released, which causes the reaction to become self-propelling, accompanied by a rapid increase in pressure, which may lead to the bursting of the cylinder. This is due to the high reactivity of acetylene resulting from the instability of the triple bond between carbon atoms. The equation of the reaction occurring during the process is presented below.

$$C_2H_2 \rightarrow 2C + H_2 + 8.7\ MJ/kg_{C2H2}$$

As a result of the cylinder bursting, due to the presence of oxygen in the air, the reaction transforms into deflagration or detonation combustion of hydrogen and acetylene molecules that have not decomposed. The heat of combustion of hydrogen is in the range of 120-142 MJ/kg, which is more than twice as high as that of acetylene [3]. Figures 5 a - f below demonstrate the process of disintegration of the acetylene cylinder in a fire environment during the test.

Fig. 5a - <u>0 s</u> - decompression

Fig. 5b - <u>0 - 0.014 s</u> – H_2 release from the cylinder

After **0,0195 s** from the moment of decompression the released H_2 was ignited.

Fig. 5c - <u>0 - 0.0195</u> s – H_2 ignition

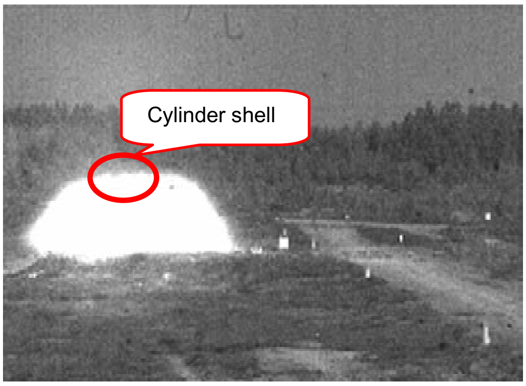

Fig. 5d - <u>0.2695 s</u> after decompression - flying cylinder fragment spotted

After 0.25 s from H_2 ignition a thermal wave (fireball) was observed. The maximum width of the fireball was estimated at about 13 m, and the height of the fireball at 4.7 m.

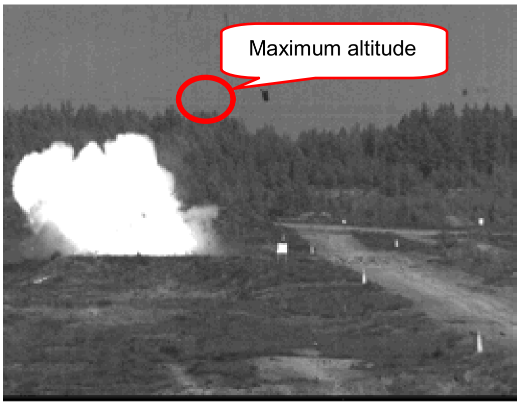

Fig. 5e - 1.075 s after decompression – the cylinder shell reaches its max. altitude

Fig. 5f - 2.686 s after decompression - place where the cylinder shell landed

Fig. 6b shows the place where the cylinder shell landed after the explosion. The cylinder shell was thrown away at a distance of about 138 m; then it bounced off the surface and tumbled over a distance of 145 m - Fig. 6b.

Fig. 6. Place of cylinder shell landing
a) place where the acetylene cylinder shell hit the ground, b) location of the cylinder after the explosion
(photo by G. Motrycz)

A sketch was drawn of the place where the experiment was carried out based on the position of the cylinder fragments. Based on the data from the time analysis of the film recorded with the Phantom Miro 310 camera, the time parameters of the individual phases of the acetylene cylinder detonation were determined.

Upon making some simplifying assumptions, including the neglection of air resistance, and assuming that the motion is at constant gravitational acceleration g [0, -g], the physical quantities characterizing the course of the experiment were determined on the basis of kinematic and trigonometric relations. Fig. 8 shows the parameter of the oblique launching, which reflects the flight of the cylinder shell during the experiment. The motion of the cylinder shell can be treated as a combination of uniform horizontal motion and uniformly retarded vertical motion.

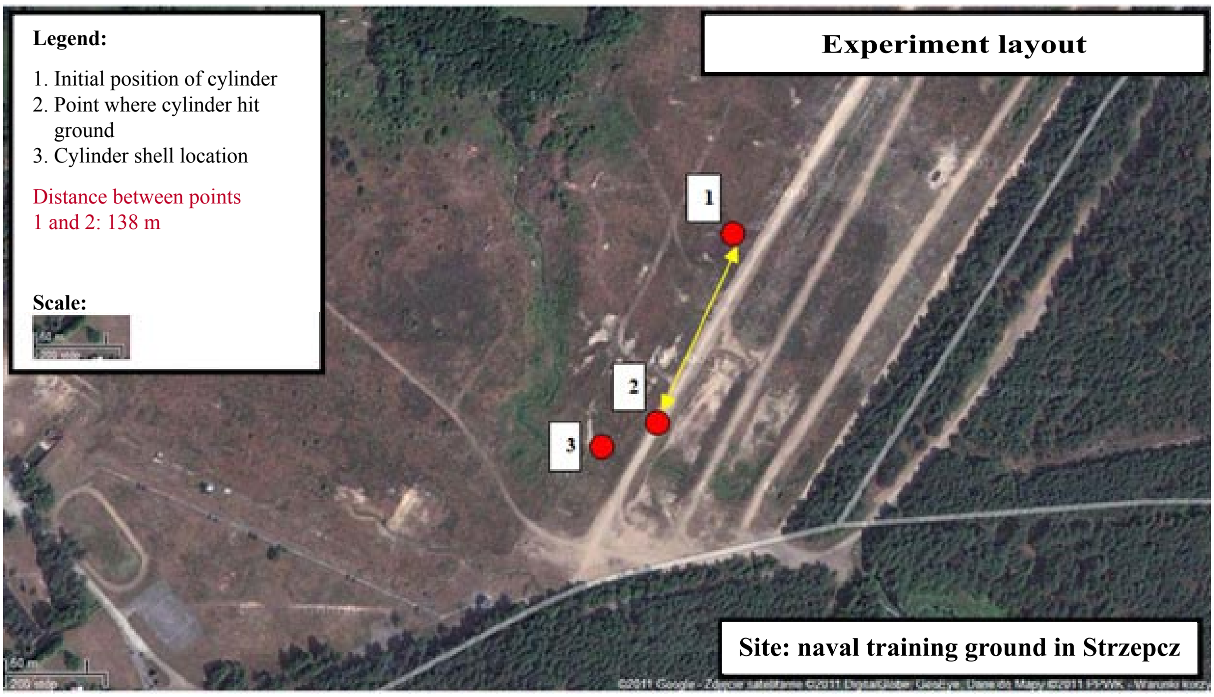

Fig. 7. Map of the area where the experiment was carried out
(Source: Google Maps)

The analysis of the film and measurements of the distance between the fragments and the place of explosion, indicated that the time from decompression to the landing of the cylinder shell at a distance of 138 m was 2.686 s.

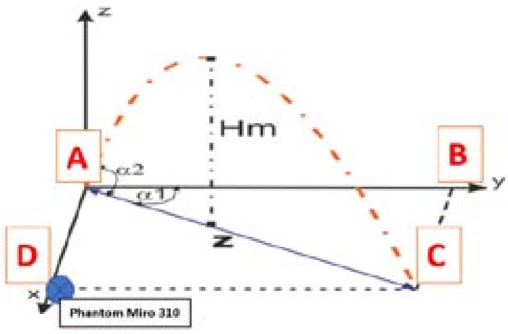

Fig. 8. Oblique throw – diagram (authors' study)
Description: x, y, z - coordinates of the reference system, AC = Z - range,
Hm - maximum altitude, AD - distance of the camera from the location of the cylinder,
AB - distance of the test stand from the road

The aim of the experiment was to determine the maximum velocity of the largest of the cylinder fragments, which would allow to calculate its kinetic energy. While the measurement of the velocity of, for example, bullets fired from rifles is relatively simple to carry out using special gates/measuring radars, in the case of cylinder explosion, there are many variables that prevent the use of this method, i.e. it is not possible to predict in which direction or at what angle will the cylinder fly after the acetylene explosion. Therefore, it is necessary to use the method presented in the paper.

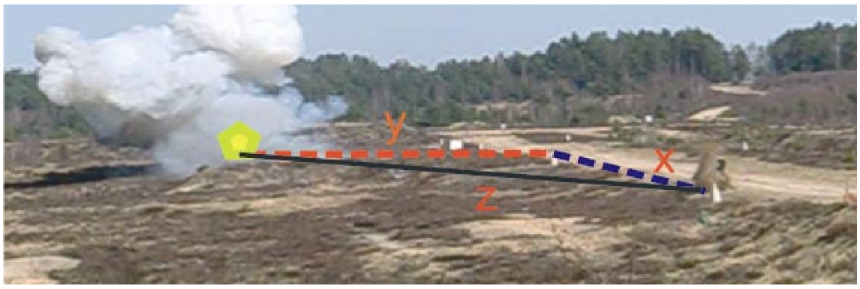

Fig. 9. Diagram of the cylinder shell landing

To estimate the cylinder speed, the distance(s) of the location of the test stand from the road AB = 80 m was measured in the adopted coordinate system. The distance of the cylinder shell landing point on the road to the test stand AC = (z) was 138 m. The distance between the Phantom Miro 310 camera and the test stand (AD) was 270 m. On the basis of points characteristic for the military shooting range on which the tests were performed, the maximum flight height was estimated at 13.1 m.

The range of oblique throw is given by the formula:

$$z = \frac{V_0^{\,2} \cdot \sin 2\alpha}{g} \tag{1}$$

The maximum flight altitude and time are given by:

$$Hm = v_o^2 \cdot \sin^2\alpha \,/\, 2 \cdot g \tag{2}$$

$$t = 2 \cdot v_o \cdot \sin\alpha \,/\, g \tag{3}$$

Velocity can be derived from equations 1-3:

$$V_o = 68.9 \text{ m/s} = 248 \text{ km/h}$$

The weight of the largest fragment of the cylinder was 19.1 kg. Assuming that the cylinder causes the greatest damage at the start of the explosion (e.g. puncture of the wall of a warehouse), the kinetic energy of the cylinder shell was estimated at 45.3 J. Taking into account the fact that the cylinder fragments are additionally characterized by irregular and usually sharp edges, and that the fragment moves at a speed of about 248 km/h, the value of this energy is sufficient not only to cause very severe injuries, but even substantial damage to the small buildings.

It should be remembered that in addition to the kinetic energy of the fragment itself, the shockwave resulting from the explosion pressure and the temperature associated with the fire will additionally act on the structure of the building.

4. CONCLUSIONS

During the experimental research, the possibility of using an ultra-fast camera to analyze the kinematic parameters of an acetylene cylinder explosion was confirmed. It was found that with this type of experiments, the safe zone for the research team should be at least 250-300 m.

A number of simplifications have been made for calculations, including assumptions that there is no air resistance during the flight of the cylinder fragment. However, combining the calculations would be very difficult due to the irregularity of the fragment and additionally its rotation during the flight. Moreover, an assumption was made that the cylinder causes the greatest damage in the first phase of the explosion, where the air resistance during the first metres of the flight can be neglected. It was confirmed that the threat that an acetylene cylinder poses is very high, and the potential damage associated with both the high velocity of the flight of fragments and the kinetic energy associated with their large weight can be very serious not only for people, but also for building structures.

A complete description of the phenomena occurring during decompression of acetylene cylinders requires further research to identify and describe, among others, the explosion pressure distribution, the nature of the shockwave and the manner of its spreading and the map of cylinder fragmentation.

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