Test Report
on the Behaviour of Acetylene Cylinders Involved in Fire

Our reference	II-213/2009 E
Copies	Copy 1 of 2
Applicant	Umwelt-Technik-Metallrecycling GmbH Alt Herrenwyk 12 23569 Lübeck
Your order of	26th January 2009
Receipt of order	27th January 2009
Test location	BAM Test Site Technical Safety
Execution	2nd/3rd February 2009 and 23th/24th March 2009
Adopted norms and technical regulations	ISO 3807-2:2000 – „Cylinders for Acetylene – Basic Requirements – Part 2: Cylinders with Fusible Plugs“ CGA C- 12-2002 – “Qualification Procedure for Acetylene Cylinder Design”

1 Tests objectives

The company “Umwelt-Technik-Metallrecycling GmbH (UTM)” commissioned to the “BAM Federal Institute for Materials Research and Testing” the realisation of tests with acetylene cylinders involved in fire with the order of the 26th January 2009. The experiments are intended to analyse the behaviour of compressed gas cylinders with different fillings of acetylene when exposed to fire.

The applicant provided the acetylene cylinders to be tested. Five cylinders were tested each in a bonfire under the adoption of the international Standard ISO 3807-2:2000 – „Cylinders for Acetylene – Basic Requirements – Part 2: Cylinders with Fusible Plugs“ and of the CGA-Standard CGA C- 12-2002 – “Qualification Procedure for Acetylene Cylinder Design”. Moreover, two cylinders were exposed to fire with help of a system of gas burners in two further experiments.

This test report consists of page 1 to 17.

2 Experimental facility and procedures

The gas cylinders to be tested were set in the fire wall facility of the explosion test ground of the BAM Test Site Technical Safety (TTS) (
Figure **1**, Position a). The tests were filmed from various perspectives with video recording devices (
Figure **1**, Positions b, c, d, e).

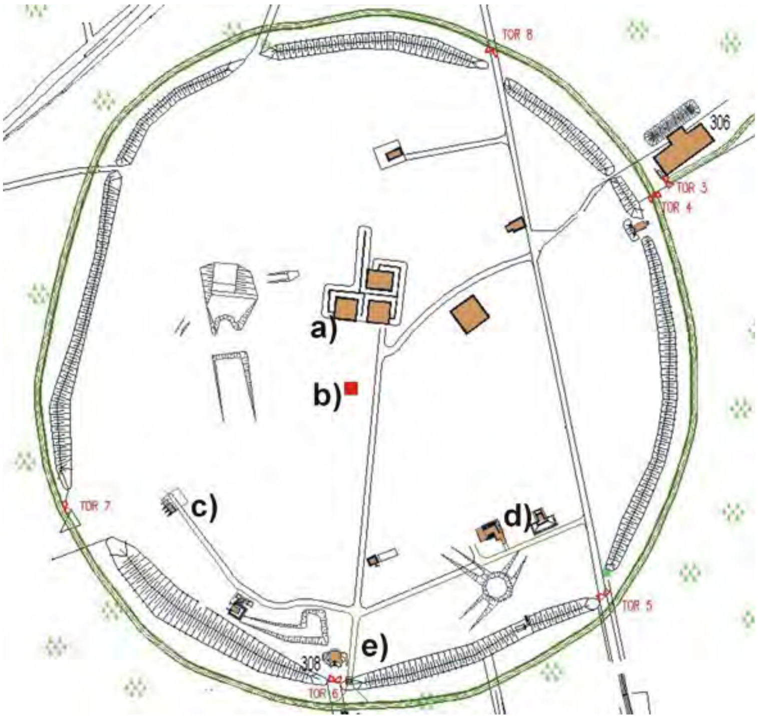

Figure 1: Schematic representation of the arrangement for the fire tests with compressed gas cylinders on the explosion test ground of the BAM TTS

a) Fire wall facility (both left and right walls were used)
b) Weatherproof test box with temperature and pressure signal amplifiers (Distance to the fire wall facility: ~40 m)
c) Video camera (Distance to the fire wall facility: 150 m)
d) Video camera (Distance to the fire wall facility: 150 m)
e) Observation platform and bunker equipped with measurement acquisition system, a camcorder und various digital cameras (Distance to the fire wall facility: 200 m)

In the bonfire tests softwood cribs with 2000 x 28 x 48 mm or 2000 x 48 x 48 mm in dimensions were piled regularly around the cylinders (Figure 2). The gas cylinders were fixed on supports, in order to prevent movements and, especially for cylinders in the standing position, to avoid tilting over during the tests (Figure 2). In the experiments with cylinders set horizontally the cribs were piled in a height of about 600 mm from the ground level, so that the lower edge of the support was reached by the wood. The same height of the pile was also used in the tests with vertically placed cylinders, as to guarantee that the same amount of wood was used in the experiments. This ensured a burning time of ca. 20 min or ca. 40 min with cribs with smaller or larger dimensions, respectively.

Figure 2: Supports in the wood crib pile for the exposition to fire of cylinders placed horizontally (left picture) and vertically (right picture)

For the ignition of the wood pile a small pyrotechnic unit containing an additional gun powder charge, from now on referred to as detonation cap, was used (Figure 3). The detonation cap could be remote controlled to initiate the ignition of the wood, which was previously wetted with a diesel-gasoline mixture.

Figure 3: Detonation cap for the ignition of the wood pile

During the tests the temperature of the wall or in the porous material inside the gas cylinder was to be measured. For this purpose 1.5 mm NiCr/Ni-thermocouples (K-type, length: 15 m) were employed. For the measurements of the wall temperature a thermocouple was fixed in the shoulder area and another at ca. 1/3 of the total cylinder height. As to ensure the quality of the measurements, both sensors were insulated from the flame with mineral wool (Figure 4).

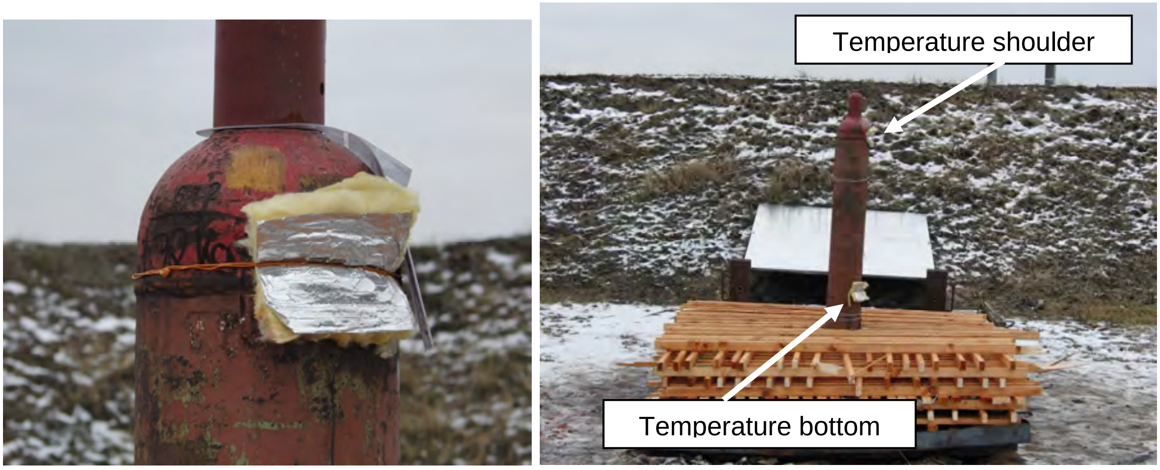

Figure 4: Fixing of the thermocouples for the temperature measurements on the cylinder wall

Some of the gas cylinders were prepared by the applicant in such a way as to allow measurements of the temperature in the cylinder inside (Figure 5). For this purpose three bore holes pro cylinder were realized, in which adapters with 1/8'' to 1/16'' NPT-threads were screwed in. Finally, on the 1/16'' fitting 1.5-mm-NiCr/Ni-thermocouples (K-type, length: 15 m) could be airtight connected (Figure 6).

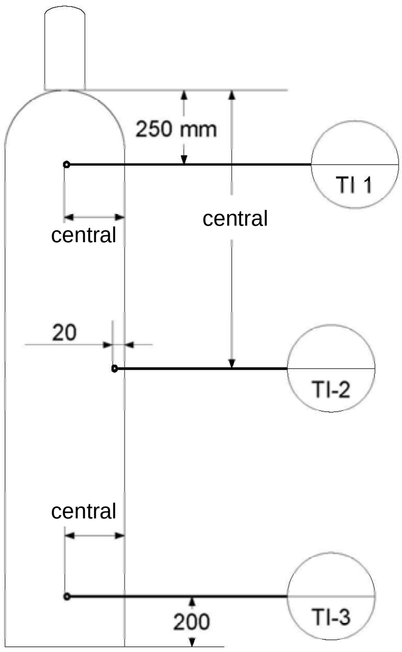

Figure 5: Location of the thermocouples for the measurement of the temperature inside a gas cylinder

Figure 6: Set-up of the thermocouples for the temperature measurement in the cylinder inside (left picture) and detail of the modified gas cylinder valve for the pressure measurements (right picture)

The temperature signals were sent to an A/D-converter (company Jet Systemtechnik GmbH, type MCL-USB, 16 channels 12 Bit A/D, overall sampling rate 500 kHz) connected to a PC, so that the temperature evolution could be real-time checked and stored as digital data.

In some experiments measurement of the pressure in the acetylene cylinder were performed, as to provide basic information on the rupture due to fire exposure. A modified cylinder valve was connected to a ca. 5 m long stainless steel pipe, 1/4'' diameter (Figure 6, right picture), at which end a piezoresistive pressure transducer (company Keller; type PA-10; range 0 to 200 bara; cut-off frequency > 30 kHz; resolution > 0.02 bara; linearity > 0.5 %) was placed.

The pressure signal was also converted by means of the same A/D-converter used for the temperature signals and then sent to the PC, allowing the real-time check and the storage of the pressure data.

3 Results

Fire tests of a total of seven acetylene cylinders of 40-dm^3 in volume were documented with video recordings as well as temperature and pressure data. In the following paragraphs the results of every single test are described in details.

Test 1: full acetylene cylinder, vertically orientated, exposure to a bonfire

During the first experiment a fully charged, vertically orientated, acetylene cylinder was located in a wood pile. Due to a quite high moisture content of the wood cribs the fire propagated slowly and the flames never reached an appreciable height (Figure 7, first row, left picture). As a consequence, the gas cylinder was only locally strongly heated up and therefore broke at its bottom after 20 minutes. Burning solvent leaking from the cylinder was observed at the end of the test.

Figure 7: Image sequence of the exposure to a bonfire of a full acetylene cylinder in the standing position

Figure 8: Burning solvent leaking from the cylinder after test 1

In Figure 9 the temperature evolutions during the first test are presented graphically. It is easy to notice that, due to the slow propagation of the fire along the wood pile, the wall temperature increased particularly at the cylinder bottom. Furthermore, it can be seen how the signals coming from the thermocouples stopped at the moment of the explosion. In correspondence of that time the maximum temperatures were measured ($T_{max., shoulder} \approx 260$ °C und $T_{max., bottom} \approx 555$ °C).

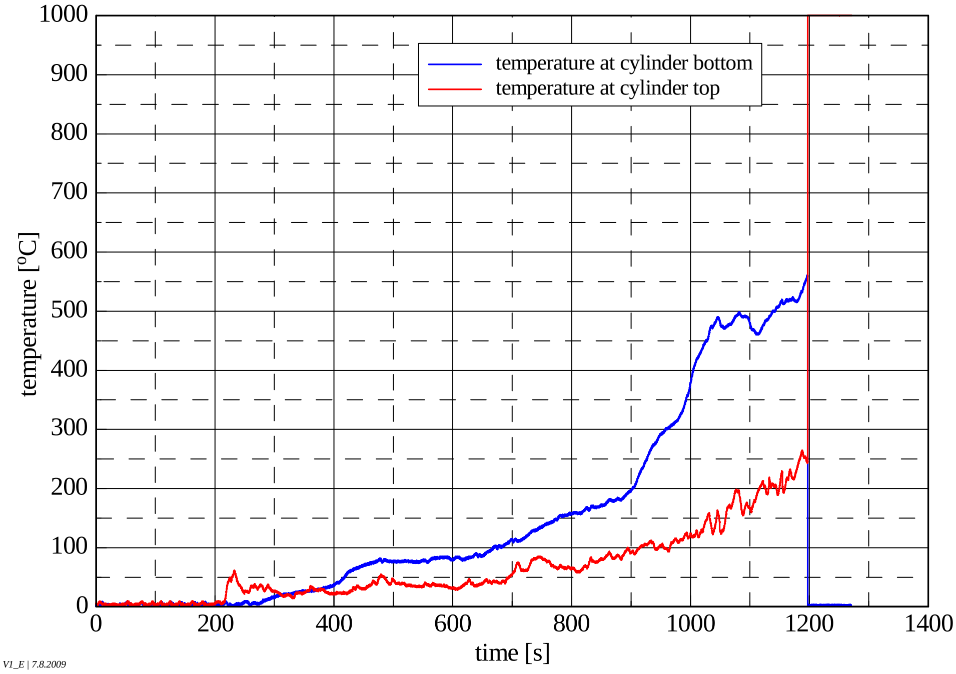

Figure 9: Wall temperatures over time for a full acetylene cylinder exposed to a bonfire in the standing position

Test 2: empty cylinder, vertically orientated, firing with a system of burners

In the second test a vertically orientated gas cylinder was fixed to a metal support equipped with a wok burner and four handheld burners (Figure 10) and exposed to fire. By using the described firing system longer burning times than in the bonfire test could be guaranteed. Also in this experiment the temperatures on the cylinder wall were measured. Unlike in the first test, the gas cylinder analysed in this experiment contained only the amount of acetylene that can be dissolved in ca. 15 kg solvent (in the current experiments acetone) at the atmospheric pressure (ca. 1 bar). From now on, a cylinder with solvent saturated with acetylene at 1 bara will be referred to as empty.

During the experiment it was noticed that with the employed firing systems the heat was transferred at high rates to the gas cylinder only at its bottom, where the wall even started to glow, due to the direct contact with the flames (Figure 11).

Figure 10: Preparation of the installation for the exposure to fire by means of burners of an empty acetylene cylinder in the standing position
Left: adjustment of the wok burner and of the four handheld burners
Right: test set-up before the start of the firing

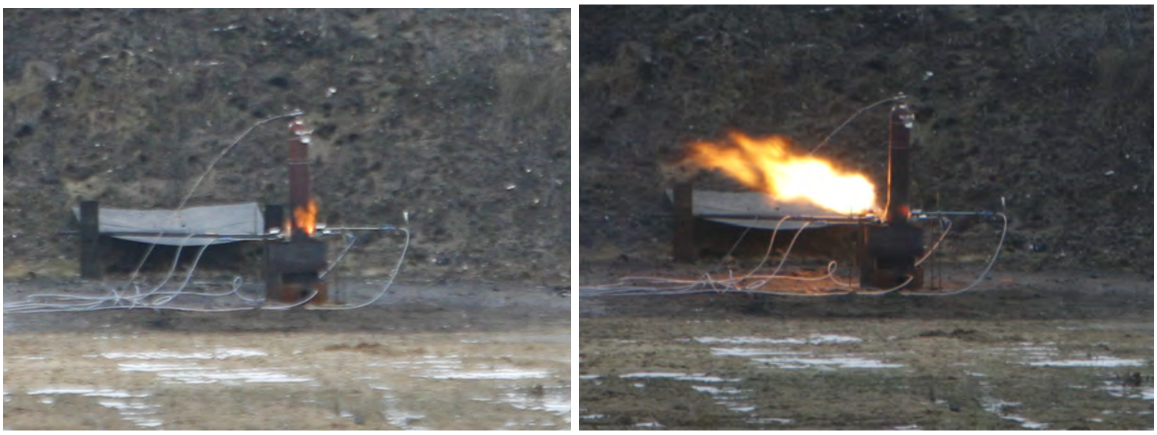

Figure 11: Test 2: gas cylinder with glowing walls during the exposure to fire (left picture) and detail of its later breaking (right picture)

After about 30 minutes (1756 s) the gas cylinder broke in proximity of its bottom (Figure 11, Figure 12). By looking at the cylinder walls in the pictures it is clear to see the strong local heat transfer, generated by the chosen arrangement of the firing system. Due to temperature-induced material wakening, convexities were observed in the wall and the cylinder finally broke in the region in contact with the flame.

In Figure 13 the temperature-time curves of the test are drawn. The temperature near the cylinder bottom rose very fast up to 1000 °C, which is the maximum value permitted by the data acquisition system. This high temperature is registered only when the flame coming from one of the burners aims directly at a thermocouple. On the other hand, the temperature on the cylinder shoulder never exceeded 80 °C.

The evolution of the pressure in the cylinder was recorded, but did not provide valuable data, since the valve connecting the pipe to the pressure transducer remained close during the test.

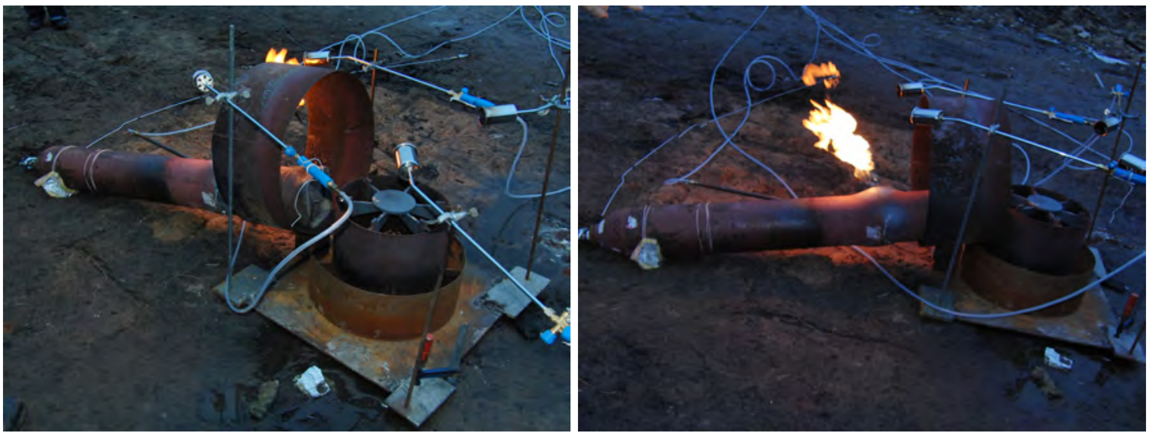

Figure 12: Broken gas cylinder after test 2

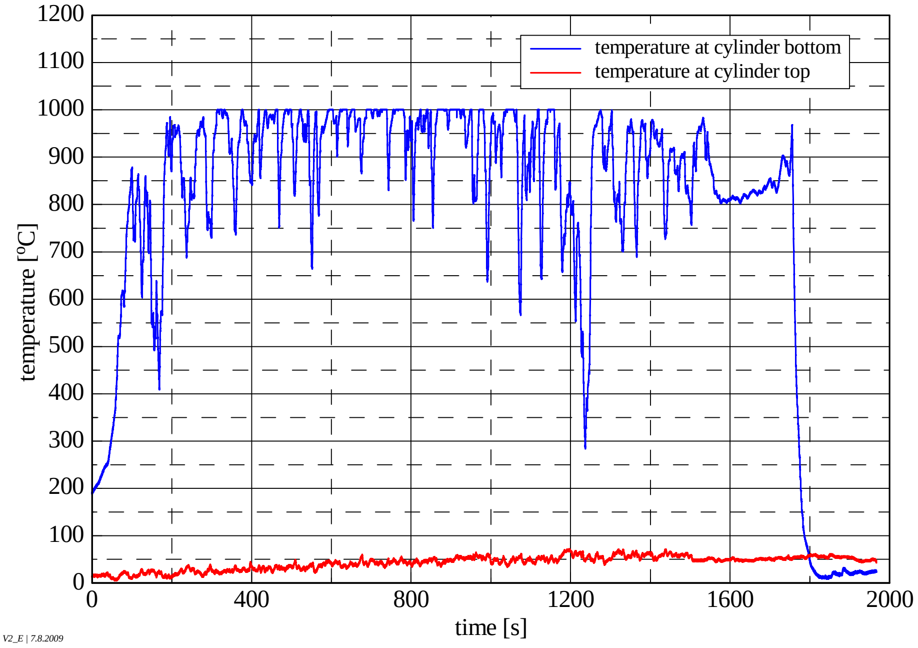

Figure 13: Wall temperatures over time for an empty gas cylinder in the standing position during the exposure to fire by means of a system of burners

Test 3: empty cylinder, horizontally orientated, firing with a system of burners

In a further experiment an empty acetylene cylinder was set in a horizontal position and fixed to the support above the wok burner. Moreover, the four handheld burners were adjusted in such a way that a more homogeneous firing of the cylinder was guaranteed. The experimental set-up is shown in Figure 14 and an image sequence of the test is presented in Figure 15. Also with the described adjustment a local heat transfer occurred, so that the wall started to glow and finally the cylinder broke in the hottest zone. The cylinder contents were released as a fireball.

Figure 14: Set-up of the fire test with burners of an empty acetylene cylinder in the horizontal position.

In Figure 16 the evolution of the cylinder pressure and temperatures are presented graphically. The temperature on the shoulder and near the bottom increased continuously and the maximum values ware achieved shortly before the rupture of the cylinder ($T_{max., shoulder}$ ≈ 356 °C and $T_{max., bottomr}$ ≈ 270 °C). The pressure in the cylinder also increased during the whole test, due to the heating-up. By the time of the cylinder burst the highest pressure (46 bara) was achieved.

Figure 15: Image sequence of the fire test with burners of an empty gas cylinder set in the horizontal position (the left picture in the first row is retouched)

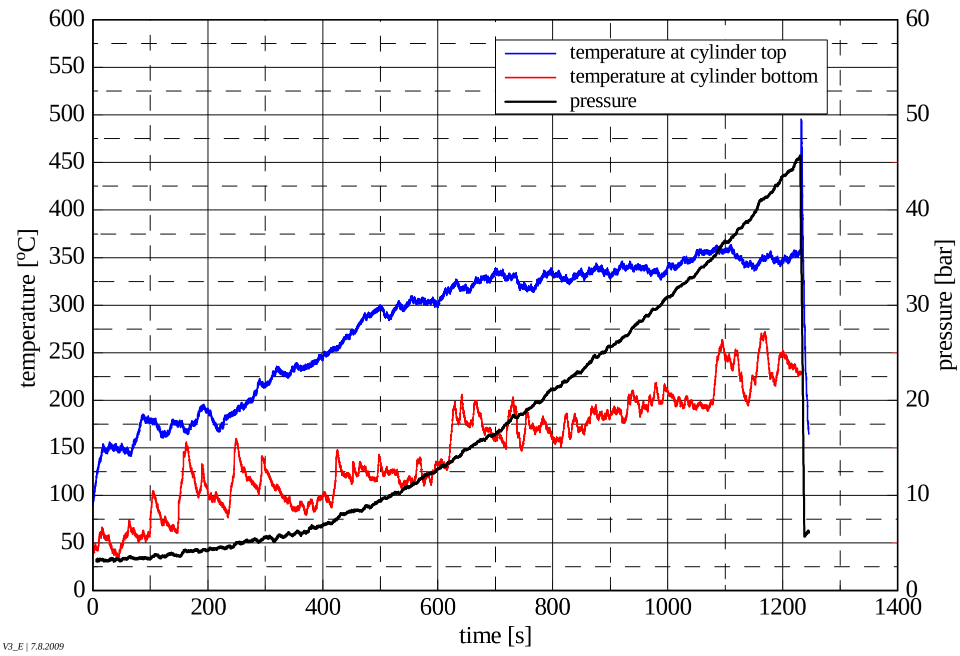

Figure 16: Wall temperature and pressure curves during the fire test with burners of an empty acetylene cylinder set in the horizontal position

Test 4: empty cylinder, vertically orientated, exposure to a bonfire

In the tests 2 and 3, where the system of burners was used, the behaviour of an acetylene gas cylinder exposed to a strong heat source could not be clearly determined, since in both cases the cylinders cracked at the spots at which the burners were aiming. Therefore in a fourth experiment an empty acetylene cylinder set in the standing position was exposed to a bonfire. In order to guarantee a longer burning time of the pile, wood cribs with 2000 x 48 x 48 mm in dimensions were used.

As to obtain further data on the heat transfer during the test, gas cylinders with thermocouples inserted in the porous material were used (see Figure 5 and Figure 6).

In this experiment the firing lasted over 50 minutes. An image sequence of test 4 can be seen in Figure 17. Due to the considerable wood mass, the fire propagated slowly over the pile. Nevertheless, a temperature increase in the porous material was observed (Figure 18). The thermocouple set at the half of the cylinder height registered an increasing temperature during the first 30 minutes up to the maximum values 396 °C. The other two thermocouples showed a much more contained temperature rise, since both measuring points were set deeper in the porous material, which has a very small heat conductivity. In particular, the maximum values reached were 48 °C for the sensor at the cylinder shoulder and 39 °C for the one placed 200 mm from the bottom.

Figure 17: Image sequence of a bonfire test with an empty acetylene cylinder (vertically orientated)

The gas cylinder did not burst or crack, despite of the long burning. With the help of the pressure curves a leak in the wall could be detected. In fact, after 35 minutes the pressure stopped increasing (maximum value achieved 24 bara), and even started decreasing strongly after 42 minutes. After 50 minutes the pressure in the cylinder amounted to 1 bara and the test was stopped.

A survey of the cylinder showed, that the leakages were to be found at the spots where the adapters for the thermocouples were inserted in the wall. Due to the different heat expansions coefficients of the materials constituting the wall and the adapters, the threads lost their sealing properties during the exposure to fire.

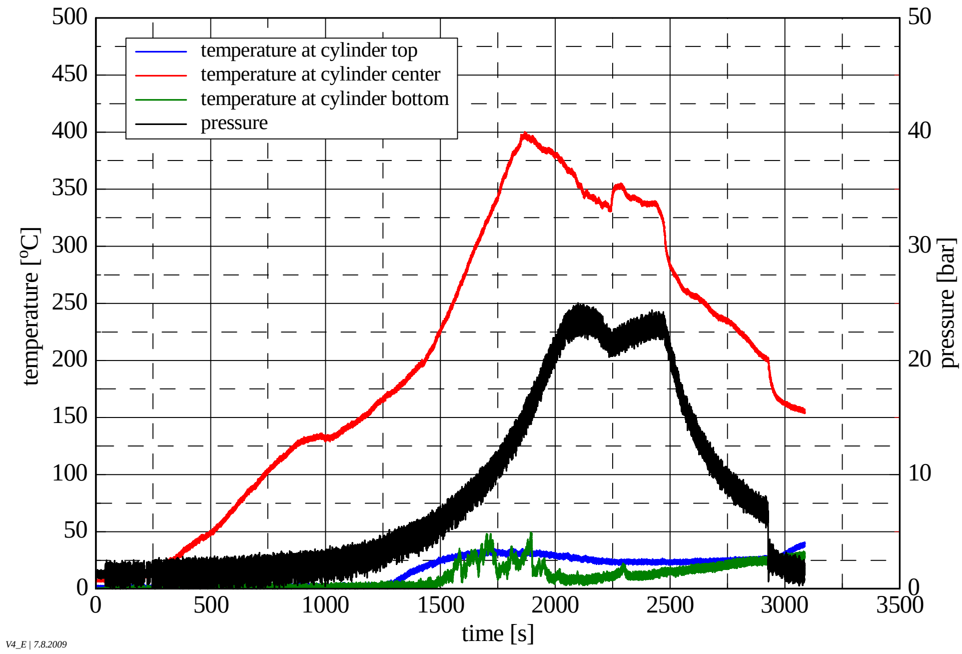

Figure 18: Temperatures in the porous material and pressure for an empty acetylene cylinder standing in a bonfire

Test 5: empty cylinder, horizontally orientated, exposure to a bonfire

In a further test an empty acetylene cylinder disposed horizontally was exposed to a bonfire. In this way the heat transfer in the same unit of time occurred over a larger surface than in the fourth experiment and therefore the overall heat transfer rate from the flame to the gas cylinder was bigger. Also in this experiment the temperatures at three locations in the porous material and the cylinder pressure were recorded. In Figure 19 a sequence of images of the exposure to fire is shown and in Figure 20 the temperature and pressure curves are drawn. After ca. 26 minutes the cylinder burst and flew 103 m away from the bonfire location. Shortly before the explosion the highest temperatures inside the cylinder were achieved ($T_{max,\ up}$ = 106 °C, $T_{max,\ middle}$ = 205 °C and $T_{max,\ low}$ = 48 °C). As expected, the temperatures registered deeper in the porous material were higher than in the previous test. The differences between the temperature recorded at the highest and lowest thermocouple during test 5 are due to the non homogeneous propagation of the fire over the wood pile. Unfortunately, some minutes after the beginning of the experiment a strong snowfall suddenly started, which led to the impossibility of recording valuable pictures of the moment of the explosion.

Figure 19: Image sequence of a bonfire test with an empty acetylene cylinder (horizontally orientated)

The pressure increased during the whole test up to 31 bara, which was the value achieved at the moment of the explosion.

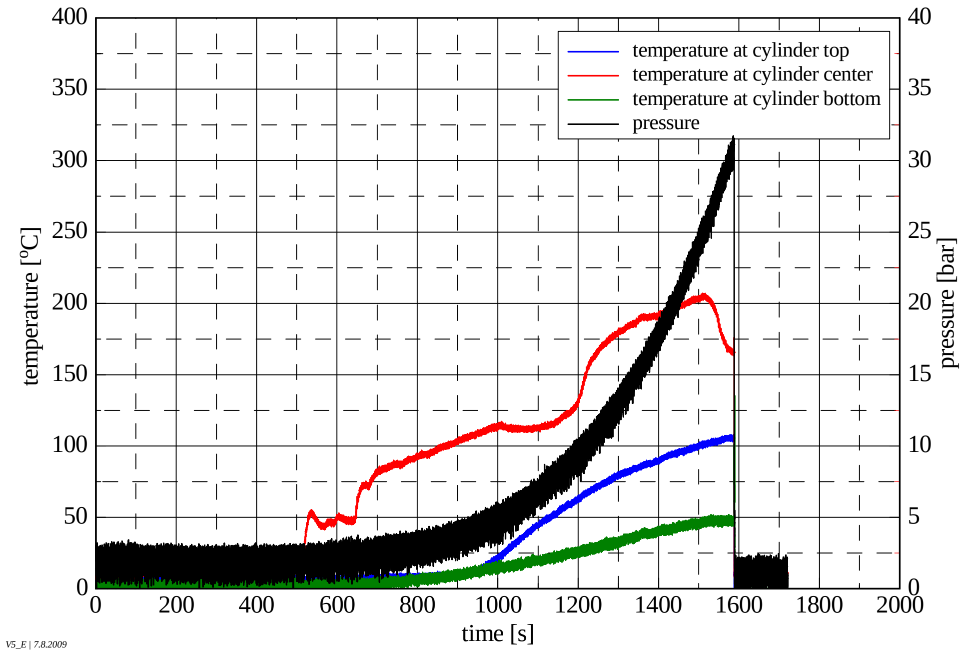

Figure 20: Temperatures in the porous material and pressure for an empty, horizontally orientated, acetylene exposed to a bonfire

In Figure 21 pictures of the cylinder after the test are shown. The wall broke along a whole side and was completely opened by the explosion. All of the adapters for the thermocouples stand still on the wall side not affected by the crack, so that a rupture due to material weakening caused by the inserted sensors is excluded.

Figure 21: Burst acetylene cylinder after test 5

With this test it could be shown that also empty cylinders, i.e. containing only acetone saturated with acetylene at 1 bara, can burst, if an appropriate heat transfer to the inside occurs. The consequences of such an explosion are comparable with the ones of a fully charged acetylene cylinder, except for the appearance of a smaller fireball, since less fuel is available.

Test 6: empty cylinder, horizontally orientated, exposure to a bonfire

Test 5 was repeated, as to validate its results. A sequence of image of the repetition is shown in Figure 22 and the temperature and pressure curves over time are drawn in Figure 23. Unlike in the previous test, the cylinder did not crack along a whole side, since the cylinder valve broke after 39 minutes. Therefore pressure was released from the cylinder, which slipped away from the wood pile, due the received impulse (Figure 24).

Figure 22: Image sequence of a bonfire test with an empty acetylene cylinder (horizontally orientated)

The maximum temperatures achieved in the porous material were with comparable with the previous experiment ($T_{max,\ up}$ = 101 °C, $T_{max,\ middle}$ = 259 °C und $T_{max,\ low}$ = 160 °C). On the contrary, the pressure in the cylinder shortly before the explosion amounted to 17 bara, being about the half than in the test 5.

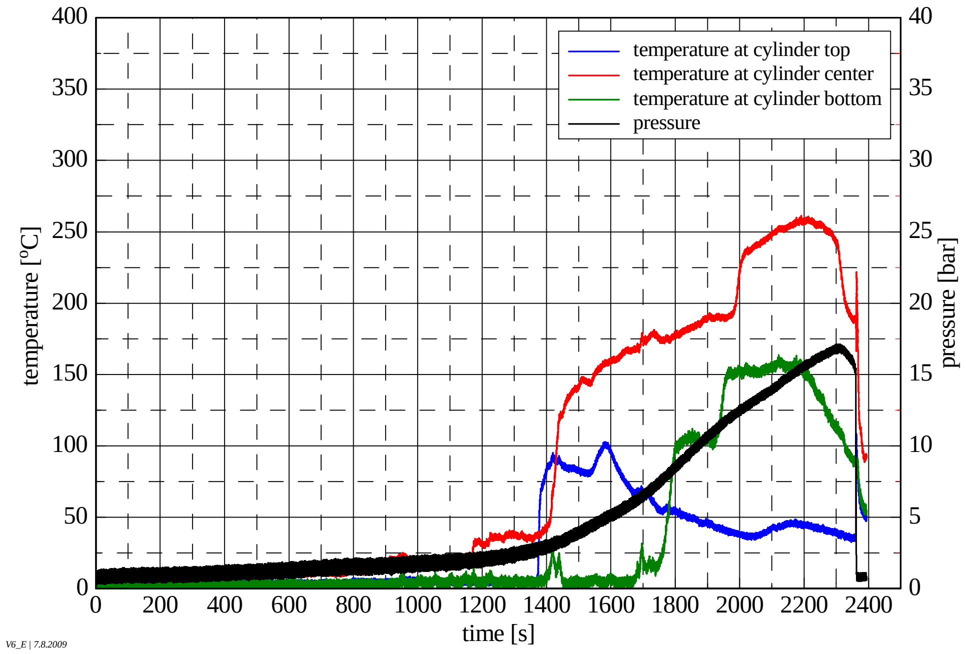

Figure 23: Temperatures in the porous material and pressure for an empty, horizontally orientated, acetylene cylinder exposed to a bonfire


Figure 24: Image sequence of a bonfire test with an empty acetylene cylinder (horizontally orientated)

Test 7: full acetylene cylinder, horizontally orientated, exposure to a bonfire

In the first experiment a full acetylene cylinder set in the standing position was tested in a bonfire. In order to analyse the behaviour of such a gas cylinder with a larger surface of fire exposure, a final test with a horizontally orientated cylinder was released. In Figure 25 a sequence of images of the experiment, in which no measurements were taken, is shown.

The cylinder burst after 17 minutes. By the explosion the cylinder did not flow in pieces, but was found as a whole 126 m away from the wood pile. Glowing granular material constituting the mass inside the cylinder was spread over a wide area around the pile by the explosion.

Figure 25: Image sequence of a bonfire test with a fully charged acetylene cylinder (horizontally orientated)

4 Summary

A total of seven acetylene cylinders with different charges was exposed to fire. The scopes of the experimental campaign, in particular the determination of the behaviour in fire of „empty“ cylinders, i.e. containing only the solvent and the amount of acetylene that can be dissolved in it at the atmospheric pressure, was reached.

It is well known, that fully charged acetylene cylinders, if exposed to a strong heat source, abruptly burst and that the whole content (porous material, acetylene, solvent) is released. Normally the expulsed fuel ignites and a large fireball is formed. The exploding cylinder or at least pieces of it can fly up to 200 m away from the burst location.

On the contrary not adequately studied was the behaviour of empty acetylene cylinders, in which the solvent –commonly acetone but also DMF in different amounts according to the porous material and volume– and the dissolved acetylene –in quantities depending on the temperature and on the atmospheric pressure– are present. In the current experimental campaign, it was shown that also empty acetylene cylinders exposed to fire can break explosively in a short time, provided that the heat transfer occurs over a sufficiently large surface and the cylinder valve is closed, so that the pressure in the inside can increase. The consequences of such an explosion are comparable to the ones in the case of full acetylene cylinders, except for the smaller fireball which is produced, due to the less fuel available. In fact, the cylinder or at least pieces of it can fly further than 100 m away from the burst location.

The performed measurements showed, that the pressure during an exposure to fire of a 40 dm^3 acetylene cylinder can rise up ca. 50 bara. If a sufficient local or global weakening of the wall material occurs due to the heating, burst of the cylinders can happen also at these relatively low pressures. The explosive behaviour of empty acetylene cylinders could be prevented if no closed system is present, i.e. if the pressure is released as soon as it rises. If the opening of the cylinder valve can avoid the explosion was not the aim of the tests performed. Actually, it is possible that an opened valve get obstructed, originating again a closed system. The burst of the cylinder can definitively be prevented if the valve of the empty cylinder is unscrewed and replaced with an adequate pressure release system, for instance a plastic seal, provided the seal opens already at small overpressures.

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