

Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals

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Explosives and related matters: review of test series 6

Heating of Aluminium witness screens during UN 6(c)-tests

Transmitted by the Expert from Germany

Introduction

1. Within the framework of their classification, packaged dangerous goods of Class 1 are under certain circumstances subjected to a UN 6(c) test as described in the Manual of Tests and Criteria. In the assessment of the hazard, aluminium witness screens are used. If projections occur when the dangerous good burns and as a result explodes, these may perforate or indent the witness screens. The depth of the indentations is used to measure the kinetic energy of the projections. According to the Manual, indentations of more than 4 mm are interpreted to mean that there were projections with an energy exceeding 8 J and that the dangerous good can thus be assigned to Class 1.4. Smaller indentations permit an assignment to Class 1.4S.
2. The experts of the explosives working group are already discussing the reliability of the assessment of the energy of projections based on the indentations in the aluminium witness screens in a different context. Another decisive factor to be looked into in this paper is the question of the heating of the witness screens by the fire within the framework of the UN 6(c) test (bonfire test). Two questions arise: (1) How much do the aluminium witness screens heat up in practice, and (2) how do the mechanical properties of the aluminium change at the temperatures that usually occur.
3. This paper presents experimental results of the Federal Institute for Materials Research and Testing (BAM). The results of three UN 6(c) test are reported; the second and third test were performed without dangerous goods specially for measuring the temperature. The temperature of the aluminium was measured by means of thermocouples at the back of the screens and in the second and third test, the temperature of the aluminium witness screens was additionally determined by means of a thermal imaging camera and an infrared thermometer. The details of the tests together with pictures are set out in the Annex.

Results

4. The first measurement took place in June 2013, the next two in March 2014, in slightly cloudy and moderate wind conditions. The measurements with an anemometer yielded a wind speed of approx. 5 m/s on both measuring days. These values are confirmed by measurements of a nearby weather station.

5. Anticipating the results, it can be said that the rather different temperatures in July and March of 30 °C and 12 °C did not have a significant impact while a wind speed of only 5 - 6 m/s pushing the flames in the direction of a witness screen, heats up the screen considerably and to a temperature range that has to be considered critical. Thus, at the witness screens not located downwind, temperatures of 30 to 50 °C and 20 to 40 °C occurred in July and in March, respectively. The witness screen located downwind and thus more exposed to the hot gases of the fire occasionally reached a temperature of up to 110 °C; otherwise it reached a temperature of 70, 80 or 90 °C. Here, it has to be noted that the very high temperature values of more than 100 °C always occurred when the flames almost touched the witness screens due to the wind, whose gusts possibly exceeded 6 m/s (see pictures in the Annex).

6. The second measuring campaign in March yielded further results: Several areas of a few square centimetres on the front and back of the witness screens were blackened to make it possible to carry out additional measurements with a radiation thermometer and/or a thermal imaging camera. Otherwise, the bare aluminium screens, due to their low emissivity, do not allow for a temperature measurement based on the emitted infrared radiation. It was found that the aluminium reached considerably higher temperatures in the blackened areas on the front and that the resulting expansion of the material caused significant deformations in the form of bulges (see pictures in the Annex). This indicates that the absorption of infrared radiation by the witness screens may well be a factor, namely if the screens are not bare and shiny but dark or heavily soiled. With deviations of not more than approx. 5 K, the results of the temperature sensing devices and of the thermal imaging camera and/or the radiation thermometer correspond relatively well with each other.

7. For the elongation at fracture, a table with strength and elongation data of an unconfirmed source¹ shows no change of the value of 40% between -28 °C and 24 °C and then an increase to 45% at 100 °C and 55% at 149 °C. As the elongation at fracture is relevant to the depth of the indentations, this means that apparently a significant change occurs above 100 °C. The same applies to the tensile strength, which is largely constant in the range from -28 °C with 97 MPa to 24 °C with 90 MPa. However, with 69 MPa at 100 °C, the tensile strength is already considerably lower and with 55 MPa at 149 °C it is substantially reduced, which means that perforations may occur already at smaller projectile energies.

8. In summary, as regards the influence of the fire within the framework of the UN 6(c) test on the aluminium witness screens and their suitability for assessing the kinetic energy of projections, the experts of BAM state the following:

- (a) Wind may, given the right direction and strength, heat the aluminium to such an extent that deviating properties of the aluminium are to be assumed. Here, first of all, the response characteristics with regard to perforations of the sheet and, in case of further heating, also the response characteristics with regard to the indentation are influenced.

¹ The data were exchanged between SAAMI and BAM, and their origins can be identified, if of interest.

Based on the experience gained, the limit of 6 m/s given in the Manual (16.6.1.3.6) is to be considered as critical. In 16.6.1.3.5, the Manual points out that the downwind quadrant should not be used for screens. In practice, however, it is not always possible to freely readjust the test arrangement. And if the wind direction points towards the only free quadrant in which no witness screen has been erected, this may impede the video recording due to the smoke blown in this direction in that case.

At wind speeds of less than 5 m/s, the discussed influences are to be considered as minor. The recording of the wind speed and direction with regard to the test setup is necessary to be able to correctly interpret indentations in the witness screens. At wind speeds of 5 m/s or more and with the resulting influence on the witness screen, the results regarding the energy of projections obtained from this screen cannot be considered.

(b) Without the influence of wind or the gases of the fire or in rather calm wind conditions, witness screens will only heat up so little that this influence is secondary to the other elements of uncertainty in the assessment of the energy of projectiles.

(c) The heating of the witness screens by the radiation of the fire is only negligible if the surface of the aluminium is bare and reflective. The corresponding increase in temperature of 10 -30 K above ambient temperature is sufficiently low so as not to result in relevant changes to the material properties of the aluminium.

(d) Different temperatures, as may occur at different test locations in the world, are secondary to the influence of wind speed and direction. Extreme ambient temperatures (e.g. tests at -20 °C or at +50 °C) should, however, be avoided in the interest of the comparability of the results.

Annex

9. Temperature measurements were carried out on the aluminium witness screens in two different seasons in order to be able to compare data. The test setup of the UN 6(c) test carried out in July 2013 is shown in Figure 1. The measurement was performed during a regular dangerous goods test in whose framework neither projections nor a significant additional heat input due to the reaction of the dangerous good were to be expected.



Fig. 1: Overview of the 6(c) test after the test performance

From the point of view in front of the test setup, the sheets were designated "left" (L), "center" (C) and "right" (R). Fig. 1 shows, from left to right, the sheets R to the front left, L at the back and C to the right. The backs of the sheets were fitted with thermocouples with a low heat capacity (wire gauge 0.1 mm, spot welded) that were held in place by means of small aluminium plates (20 mm x 30 mm, 5 mm strong). Figure 2 shows the thermocouple and the supporting plate.

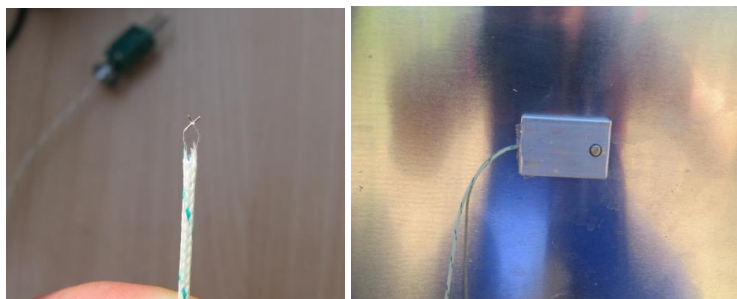


Fig. 2: Thermocouple and supporting plate

The temperature was recorded at a total of 10 measuring points during the course of the test. Figure 3 shows three representative curves:

- I:** On the lower left (looking at the sheet from the front) of sheet L
- II:** On the upper right (looking at the sheet from the front) of sheet C
- III:** On the upper left (looking at the sheet from the front) of sheet R

The temperature curves clearly illustrate the wind conditions. The middle screen "C" was partly downwind and therefore heated up to a significantly greater extent. The wind came from the direction where no witness screen was located and was measured at 5 - 6 m/s. However, as this test focused on dangerous goods testing and measuring the temperature was secondary to that, a number of questions arose which were to be examined in more detail in the second measuring campaign.

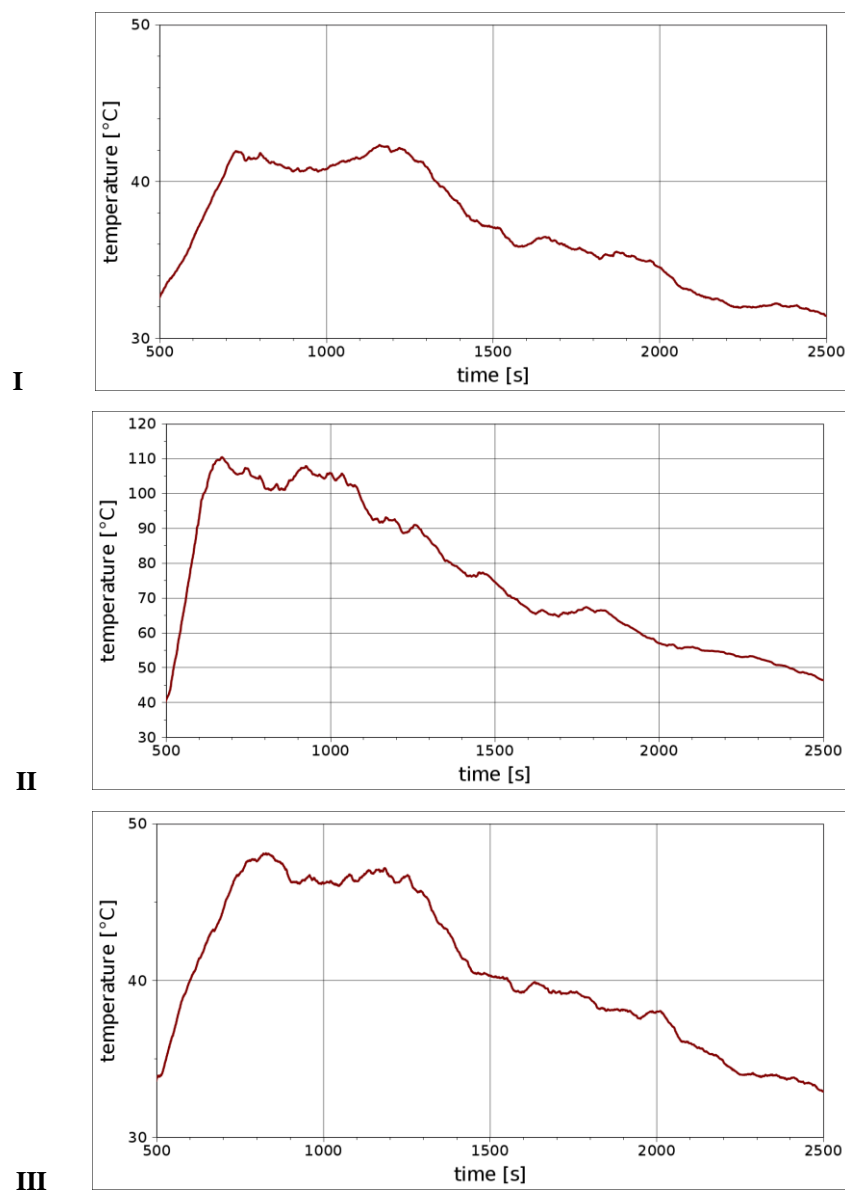


Fig. 3: Temperature curves at 3 selected measuring points, screens L, C, R

10. In the following measuring campaign in March 2014, two stacks of wood were burned down successively and without dangerous goods to make it possible to safely carry out measurements and take pictures even close to the fire and behind the witness screens. The setup is the same as the one shown in Figure 1. In addition to the thermocouples, a radiation thermometer and an infrared camera were used for measuring the temperatures. The latter two measuring methods, however, only work if a known emissivity of the surface is as close as possible to the value 1. To achieve this emissivity, some specific areas of the witness screens were blackened –both on the front and on the back.

Figure 4 is to illustrate the effect of blackening the front. The deformation of the witness screens around the blackened areas can be seen clearly. The picture shows screen "C", that is the middle screen which was exposed the most to the wind-induced heating also within the framework of these measurements. The wind direction varied a little and pushed the flames in the direction of screen "C" or towards the corner between "C" and "R". The picture in Figure 4 was taken during the second test of the second measuring campaign.

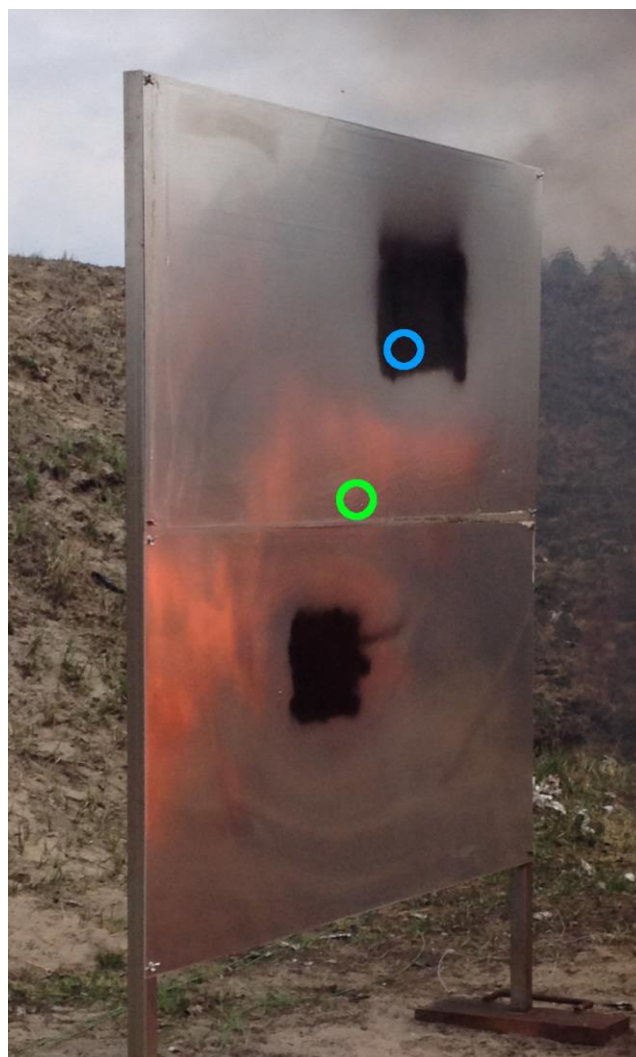


Fig. 4: Deformation of the witness screens by the radiant heat in the case of blackening

There are measuring curves available for the two areas marked in Figure 4 that are shown in Figure 5 (second test of the second measuring campaign). Both marked areas were fitted with thermocouples. Moreover, an area on the back of the screen between the two marks of Figure 4 and overlapping on one corner with the blackened area on the front of the upper aluminium plate was blackened. The temperatures measured by the thermocouples were in line with the values recorded by the radiation thermometer or the thermal imaging camera. The deviations ranged from around 5 to a maximum of 10 K, which can be attributed to the fact that the blackened area and the thermocouples were not positioned exactly on top of each other.

The measurements from the blue circle in Figure 4 (top right) is shown in Figure 5 as curve IV. The measurements from the green circle in Figure 4 (below) is shown in Figure 5 as curve V. It is clearly visible that the blackening on the front causes considerably higher temperatures of the sheet, whereby the measuring point IV being located above the measuring point V has an additional effect.

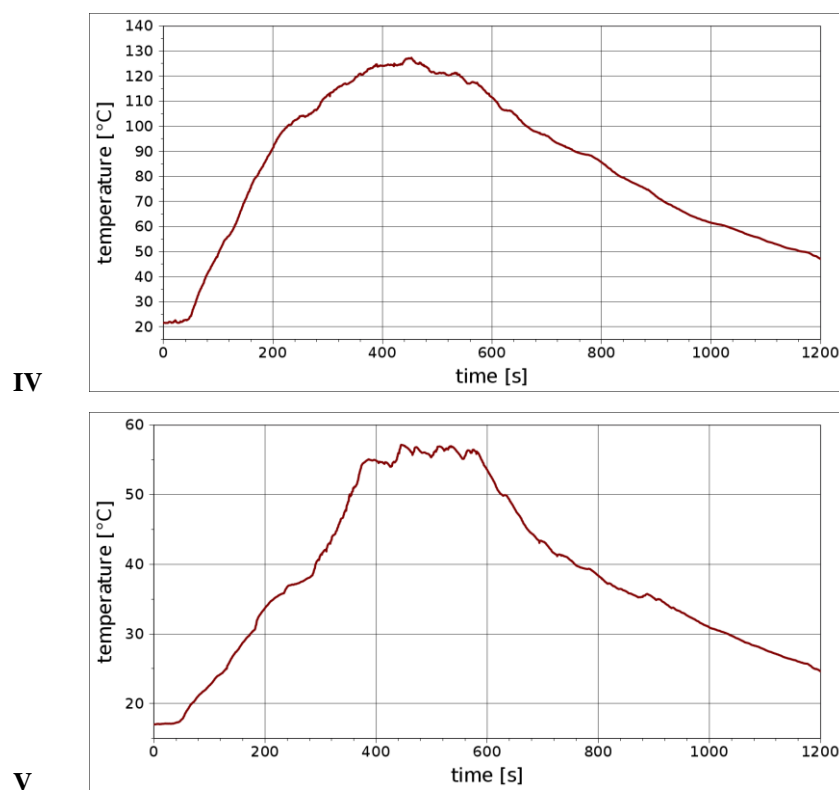


Fig. 5: Temperature curves for measuring points of Figure 4

The highest temperatures in Figure 5 occurred during wind gusts with a recorded wind speed of 6 - 7 m/s. Figure 6 shows from the side how the gases of the fire and the witness screen interact under these conditions. On the back of the screen between the two marked circles of Figure 4 (approx. in the middle of the entire witness screen), a temperature of 73 °C was recorded with the radiation thermometer. Figure 6 is equivalent to time 345 s in curve V of Figure 5.

The corresponding temperatures of the first test of the second measuring campaign are approx. 20 K below the data shown in Figure 5. During the first measurement, winds of 5 - 6 m/s were recorded and the wind direction was oriented in such a way that the gases and flames of the fire were directed towards the corner between screen "C" and "R".



Fig. 6: Conditions at wind speed of 6.6 m/s
