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

Sub-Committee of Experts on the Transport of Dangerous Goods **17 June 2014**

Forty-fifth session
Geneva, 23 June – 2 July 2014
Item 2 (b) of the provisional agenda
Explosives and related matters: review of test series 6

Properties of Aluminium witness screens

Transmitted by the expert from Germany

Introduction

1. Section 16.6.1.2 of the Manual of Tests and Criteria (ST/SG/AC.10/11/Rev.5) specifies an aluminium witness screen for the UN 6(c) test which serves to determine the kinetic energy of projectiles. The material is referred to as “1100-0 aluminium”, is 2 mm strong and is further specified with the additional information “Brinell Hardness 23, tensile strength 90 MPa”.

2. These aluminium witness screens are erected at a distance of 4 m from the packages and serve to assess the kinetic energy of projections that might occur and hit the witness screens during the performance of the tests. The depth of the indentations or perforations shall be a measure of the kinetic energy of the projections.

3. Recently, it has been discussed how reliable the determination of the kinetic energy of projections on the basis of this procedure is. Besides the question of what influence the mounting and installation of the witness screen might have, there is evidence that different temperatures of the aluminium, as might occur under experimental conditions, have an impact on the strength properties. In addition, material in accordance with standard 1100-0 is not available in all countries, and it is thus necessary to fall back on aluminium with equivalent mechanical properties.

4. One of the criteria driving the decision of whether to assign a substance to class 1.4S or 1.4 (other than S) or to 1.4 on the one hand, and to 1.3 or 1.2 on the other hand, is the assessment of the kinetic energy of projections. If this assessment is to be based on the indentations of the aluminium witness screens, the relation between the indentation and the kinetic energy should be sufficiently well defined.

5. It is the objective of this document to provide an overview of the data and findings regarding the material of the aluminium witness screens and make them available to the explosives working group for revising test series 6.

Discussion

6. In 1995, the expert from Canada (UN/SCETDG/12/inf-50) presented findings of tests during which different aluminium sheets had been fired at with cylindrical projectiles by means of a slingshot. They found that 1100-0 aluminium, which was fired at with a 25-gram projectile and 6 J, exhibited indentations with an average depth of 4.2 mm. The firing of 150-gram projectiles with an energy of 11 J resulted in indentations of 4.8 mm. It was

also found that, up to a point, the depth of the indentation was proportional to the projectile energy. The projectiles perforated the 2 mm 1100-0 aluminium at 15-20 J.

7. The Federal Institute for Materials Research and Testing (BAM) as the inspection agency and competent body for dangerous goods classifications for goods of Class 1 in Germany reproduced the Canadian results in its own tests performed in 2012 and 2013 and generated its own data using the witness screen used in Germany. Tests with a drop hammer and projectiles with different shapes and energies were performed. The temperature of the sheet was also varied. An excerpt of the findings can be found in Annex I. Moreover, impact (projectile) tests were performed to achieve higher impact velocities than with a drop hammer. The results are set out in detail also in Annex I. It is conspicuous that, in the tests, the aluminium witness screen does not respond with an indentation of 4 mm to a projectile energy of 8 J, as the testing provisions suggest, but that, similar to the original data from Canada, the indentations that occur at 8 J tend to be deeper. It also becomes clear that a slow deformation, as produced by the drop hammer, results in deeper indentations than a rapid deformation, as caused by lighter projectiles.

8. Tests performed by TNO in the Netherlands in November 2001 showed that on average the Dutch aluminium sheet is perforated at a projectile energy of 16 J. In these tests, an FSP[1] projectile with a weight of 1.1 g and a velocity of 171 m/s was used which was fired with 7.62 mm ammunition. The distance between the muzzle and the aluminium sheet was 0.5 m. Further information cannot be provided here for reasons of confidentiality and would have to be requested via the Laboratory for Ballistic Research (LBO) of the TNO. There is *n*o information available about the indentation behaviour in the low energy range.

9. The procurement of equivalent aluminium witness screens in different countries of the world is not always easy and differences with regard to the material properties might result in diverging results. For this reason, the strength data of aluminium sheets of different origins which (are supposed to) meet the specifications of the Manual and are used as witness screens were compared. The findings are set out in Annex II and show that, e.g., the material available in Germany matches well with the material available in the USA despite differing specifications in the data.

10. As another aspect of the relation between the projectile energy and the indentation in the aluminium witness screen, thermal effects on the material properties of aluminium were considered. Besides the temperature dependence of the material properties, the question arises of what temperatures can occur experimentally in the first place. To address this issue, a separate paper will be presented from which it also follows that the assessment of the energy of projectiles by means of the aluminium witness screen should be discussed within the framework of the revision of the Manual.

Conclusion

11. The data and findings mentioned here indicate that the assessment of the energy of projectiles produced during the UN 6(c) test by means of indentations in the aluminium witness screens is liable to a certain level of inaccuracy. It becomes clear that the indentations in the witness screens might only provide an indication of the kinetic energy of projections and that the decision for a classification in terms of the energy of projections should not only be taken on the basis of the assessment of indentations. The following analysis shows that the assessment cannot be based on a simple evaluation of the

[1] FSP = Fragment Simulating Projectile in accordance with STANAG 2920

indentations as to whether they are greater or smaller than 4 mm: For indentations smaller than 4 mm, it **has to** be considered whether fragments with a higher energy could have flown past the witness screens and whether these can be evaluated. On the other hand, indentations greater than 4 mm have to be assessed in accordance with their depth and frequency based on the experience of the inspecting agency and **do not** automatically **mean** that the 8 J criterion has been violated. This matter should be considered in the ongoing revision of the testing requirements.

Annex I

12. **Drop hammer tests performed by BAM**

For the tests, specimens of approx. 140 mm x 140 mm were cut from the aluminium witness screens and mounted on a support ring with an internal diameter of 90 mm. The interchangeable impact insert was fitted to the lower end of the drop hammer, centred and aligned with the sheet and the ring (see Figure 1).

Fig. 1: Drop hammer with impact insert, sheet and support ring

The total mass of the drop weight including the impact insert was 1.15 kg. By means of different drop heights, it was possible to achieve impact energies of up to approx. 8 J. However, compared with free-flying light projections, the impact velocity is very low (at a large mass).

Table 1 below shows typical data from impact tests at ambient temperature. The data apply to NATO standard fragments (in accordance with STANAG 2920). The variation of the shape of the impact insert results in differences in the indentations of approx. 15% depending on whether the tip was rounder or more angular.

Table 1: Indentations in the witness screen depending on the energy

Drop height [cm]	***Drop speed [m/s]***	***Energy [J]***	***Indentation depth (mm)***
71	3.73	8.0	9.0
60	3.43	6.8	7.8
30	2.43	3.4	5.3
10	1.40	1.1	2.7

Moreover, the influence of the temperature of the sheet was examined for temperatures of -20 °C and 45 °C. The results are set out in Table 2 and show that, for this temperature range, the influence is not very pronounced.

Table 2: Indentations in the witness screen depending on the energy and temperature

Drop height [cm]	*Energy [J]*	*Indentation depth at -20 °C [mm]*	*Indentation depth at +45 °C [mm]*
71	8.0	8.9	9.4
60	6.8	8.2	8.6
30	3.4	5.6	6.0
10	1.1	2.8	3.3

12. Projectile impact tests performed by BAM

Due to the test setup of the drop hammer tests, only very low velocities occur. The deformation behaviour of the sheet might be different depending on the impact velocity, and in order to experimentally capture this influence, tests with faster projectiles were performed. An arrow projectile with a cylindrical head having a diameter of 5 mm was fired at the aluminium witness screen. The screen was mounted to the frame also used for UN tests. The impact velocity was determined by means of high a speed camera.

Table 3 sets out the resulting indentation values depending on the projectile energy. The projectile had a mass of 22.8 g. Perforations, which were not covered by this investigation, were also observed, but they only occurred at values exceeding 25 J. For 8 J, a regression line in the data of Table 3 would yield an indentation of exactly 5 mm.

Table 3: Indentations produced by projectiles in the witness screen depending on the energy

Energy [J]	*Indentation depth (mm)*
3.9	2.9
6.2	3.7
8.3	5.8
10.3	6.2
12.2	6.9

Annex II

13. The aluminium witness sheets of various testing institutions in various countries were collected and examined at BAM Division 5.2 "Experimental and Model Based Mechanical Behaviour of Materials" with a view to their material properties. Table 4 gives an overview of the results. The sheet metal of the USA was made available by SMS (Safety Management Services, Utah) and complies nominally with the required standard for *1100-0 aluminium*. It is not known to what extent the following aluminium sheets comply nominally with the given standard or are defined in accordance with comparable standards. The sheet metal from Canada comes from CERL (Canadian Explosives Research Laboratory in Ottawa), the sheet metal from the United Kingdom from HSL (Health and Safety Laboratory in Buxton).

The sheet metal from Germany complies with the requirements set by EN 485 for the material EN AW-1050A [Al 99.5], which comes closest to the indicated 1100-0 standard.

Table 4: Properties of aluminium witness screens

Property	***Nominal value according to Manual***	***USA***	***Canada***	***UK***	***Australia***	***Germany***
Brinell hardness HBW	23	23.7	25.7	31.2	21.4	21.7
Tensile strength R_m [MPa]	90	86.2	92.8	110	80	76
Proof strength, plastic extension $R_{p0,2}$ [MPa]	-	40.4	48.8	100	40.4	38.6
Percentage elongation after fracture A [%]	-	36.4	36.9	14.3	40.2	46.5

The Brinell hardness test was performed in accordance with standard EN ISO 6506-1. The tensile strength was determined in accordance with EN ISO 6892-1; at the same time, the proof strength R p0.2 was established. The percentage elongation after fracture A is not mentioned in the Manual, but we consider it relevant for the relation between impact and deformation.

The standard for 1100-0 aluminium specifies a percentage elongation after fracture of approx. 35 to 45% depending on material thickness. It is not fully possible to reconcile the proof strength with one specification for 1100-0 aluminium. In the standard, a tensile yield strength of 34.5 MPa is indicated; this could be considered equivalent to the proof strength. The other nominal values, as indicated in the UN Manual of Tests, correspond with the specifications for aluminium 1100-0.

The overview in Table 4 shows that by and large aluminium is used that exhibits the required data. Only the sheet metal from the UK deviated a little, exhibiting properties of a harder material.