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THE USE OF RESISTANT GLASS IN SPECIAL AGRICULTURAL MACHINERY AND THE LOGISTIC SUPPORT DEPENDING ON OPERATING TEMPERATURES

Tomáš Binar[1], Jiří Švarc[1], Stanislav Rolc[2], Petr Dostál[3], Michal Šustr[3]

[1]Department of Logistics, University of Defence, Brno, Kounicova 65, 662 10 Brno, Czech Republic
[2]Military Research Institute, Brno, Veslařská 230, 637 00 Brno, Czech Republic
[3]Department of Technology and Automobile Transport, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

Abstract

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The paper is concerned with quality assessment of bullet-resistant glass in relation to ambient temperatures. The measurement results provided below may be drawn on in the field of logistics when transport, special as well as special agricultural machinery are operated at fluctuating temperatures. In the paper, data from shooting tests, monitoring the projectile velocity, penetration through the glass and projectile fragmentation at various ambient temperatures, is presented. For perfect protection of agricultural machine operators not only the bullet-resistance of glass panels, but also their further use in work is of great importance. Hence, emphasis is put on active safety of these machinery, where a perfect transparency of the bullet-resistant panels is one of crucial factor. In the paper, the extent of damaged areas is compared; these are divided into three zones according to significantly differing temperatures. The paper results may have influence on agricultural machinery in thermally extreme areas.

Keywords: test temperature, life cycle of bullet-resistant glass, ballistic protection, active safety of bullet-resistant glass, agricultural machinery

INTRODUCTION

The protection of machine operators and equipment in special agricultural machinery is a top priority. Special agricultural machinery are manufactured according to specified ballistic-resistance requirements in compliance with standards in force, in particular NATO AEP-55 STANAG 4569 (NATO, 2012). The required ballistic resistance is achieved through the selection and processing of a material. The ballistic resistance depends on the strength, hardness, toughness and the capability of maintaining these properties at various temperatures (thermal resistance of a material) (Binar *et al.*, 2015; Bhadeshia, 2005; Binar *et al.*, 2011; Data sheet, 2011; Binar el al., 2011). Armour is manufactured from a wide variety of materials, from steel to glass, plastic or ceramic. The purpose of this article is to analyse possible damage to bullet-resistant composite glass with a ballistic protection against kinetic energy threats, i.e. projectiles from firearms, and splinters from artillery shell calibre 155 mm. The glass panels were produced in compliance with body armour resistance standard Level 2 and Level 3, and the conditions of kinetic energy threats tests and the test methods proving the resistance to kinetic energy threats were adopted from NATO AEP-55 STANAG 4569 Annex A and Annex B (NATO, 2012; Binar *et al.*, 2014; Binar *et al.*, 2015; Křesťan *et al.*, 2016).

MATERIALS AND METHODS

The experiment was based on measurement of real bulletproof glass removed from DINGO vehicle.

Laboratory measurements were carried out in three temperature ranges in order to identify possible changes in the ballistic resistance of the material tested in relation to differing ambient temperatures (Bhadeshia, 2005; Data sheet, 2011; Binar *et al.*, 2015). Set A of the shooting tests was carried out at room temperature, i.e. between 20 °C and 25 °C. Set B of the shooting tests was carried out at a higher ambient temperature of 55 °C, and set C of the shooting tests was carried out at a lower ambient temperature of –32 °C.

Set A – shooting tests at room temperature

The shooting test programme was based on the specifications for bullet-resistant glass panels used in DINGO mechinery, requiring Level 2 of ballistic protection as per NATO AEP-55 STANAG 4569 with the machine operator protection against ammunition 7.62 mm × 54R B32 API and the shooting parameters defined by NATO AEP-55 STANAG 4569 with the minimum distance between two adjacent hits 500 mm (NATO, 2012).

Side glass

Preliminary tests were carried out on a right-side door glass panel (serial no. GuS 554 02/08 064-121-21-10-00-01728313). In total, there were 5 shots with projectile 7.62 × 54R B32 API at the distance of 505 mm.

Windscreen glass

In the left part of the windscreen (serial no. GuS 422 10/07 064-121-21-10-00-017236), the level of machine operator protection against projectile 7.62 × 54R B32 API was tested with the minimum distance of two adjacent hits 500 mm.

Set B – tests at high temperatures

The information about the effect of high temperatures on the level of machine operator protection provided by bullet-resistant glass in DINGO machinery. Order to obtain the information, shooting tests were carried out on glass heated to high temperatures. The shooting tests were carried out on glass conditioned in climatic chambers HERAEUS GmbH and THERMOTRON Industrie Ltd. Company with the temperature range –70 °C to 180 °C. The glass was conditioned for min. 12 hours, and the temperature in the chambers was set to 55 °C. In spite of the glass handling being very complicated, the testing time did not exceed 5 min., and the glass surface temperature did not drop by more than 10 %. The glass surface temperature was measured using a Service Systeme infrared thermometer. The glass was tested for resistance at Level 2 as per NATO AEP-55 STANAG 4569 (NATO, 2012).

Windscreen glass

The test was carried out on windscreen glass (serial no. GuS 542 05/08 064-121-21-10-0001723600) heated to 55 °C.

Side glass

The test was carried out on side glass (serial no. GuS 598 04/08 064- 121-21-10-00-01728313) heated to 55 °C. The protective effect against multiple shots by projectile 7.62 × 54R B32 API was tested with the distance between hits 385, 426 a 505 mm.

Set C – tests at low temperatures

The information about the effect of low temperatures on the level of machine operator protection provided by bullet-resistant glass in DINGO machinery. Order to obtain the information, shooting tests were carried out on glass cooled to a low temperature. The shooting tests were carried out on glass conditioned in climatic chambers HERAEUS GmbH and THERMOTRON Industrie Ltd. Company with the temperature range –70 °C to 180 °C. The glass was conditioned for min. 12 hours, and the temperature in the chambers was set to –32 °C. The testing time did not exceed 5 min.

Side glass

The influence of low temperatures on the bullet-resistant glass resistance was tested on a side glass of a DINGO machinery (serial no. GuS 619 04/08 064-121-21-10-00-01727802) cooled to –32 °C. The protective effect against multiple hits by projectile 7.62 × 54R B32 API was tested with the distance of hits 365, 415 a 495 mm. The glass was tested for resistance at Level 2 as per NATO AEP-55 STANAG 4569 (NATO, 2012).

Side glass

The test was carried out on a side glass of a DINGO machinery (serial no. SVOS1411183). The glass was tested for resistance to projectile 7.62 × 54R B32 API with the minimum distance of hits 500 mm.

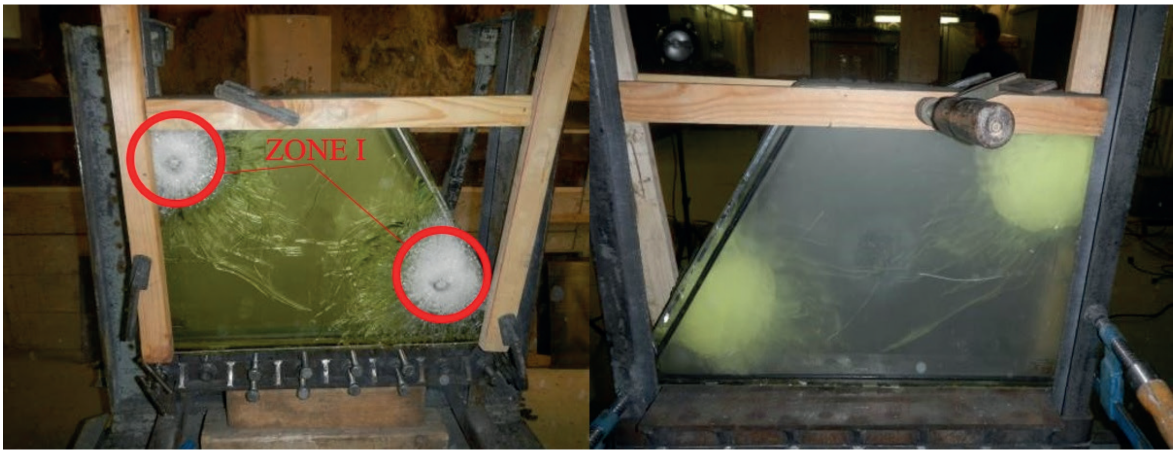
The glass was tested for resistance at Level 2 as per NATO AEP-55 STANAG 4569 (NATO, 2012).

RESULTS AND DISCUSSION

Set A – shooting tests at room temperature

Despite extensive degradation, the DINGO side glass (serial no. GuS 554 02/08 064-121-21-10-00-01728313) (Fig. 1) resisted the shots. The polycarbonate layer remained free of any deformation. In Tab. I, results of the shooting tests are stated.

Windscreen glass (serial no. GuS 422 10/07 064-121-21-10-00-017236) (Fig. 2) resisted even though the distance of hits was below the lower limit of required minimum distance. In Tab. II, shooting tests results are stated.



1: *Glass after shooting tests using projectile 7.62 × 54R B32 API*

I: *Shooting tests results for side glass GUS 554*

Shot no.	Velocity [m/s]	Penetration [YES/NO]	Splinters [YES/NO]
1	864.5	NO	NO
2	865.8	NO	NO
3	865.2	NO	NO
4	865.5	NO	NO
5	864.9	NO	NO

2: *Glass after shooting tests using projectile 7.62 × 54R B32 API*

II: *Shooting tests results for windscreen glass GUS 422*

Shot no.	Velocity [m/s]	Penetration [YES/NO]	Splinters [YES/NO]
1	852.4	NO	NO
2	862.8	NO	NO
3	855.3	NO	NO
4	858.6	NO	NO
5	854.5	NO	NO

3: *Glass after shooting tests using projectile 7.62 × 54R B32 API (shots 1–3) and 7.62 × 39 API BZ (shots 4–10)*

4: *Glass after shooting tests using projectile 7.62 × 54R B32 API and 7.62 × 39 API BZ inner side*

III: *Shooting tests results for windscreen glass GUS 542*

Shot no.	Velocity [m/s]	Penetration [YES/NO]	Splinters [YES/NO]
1	860.9	NO	NO
2	853.3	NO	NO
3	859.3	NO	NO
4	695.3	NO	NO
5	691.1	NO	NO
6	692.3	NO	NO
7	693.2	NO	NO
8	698.3	NO	NO
9	695.3	NO	NO
10	695.6	NO	NO

5: *Glass after shooting tests using projectile 7.62 × 54R B32 API*

IV: *Shooting tests results for side glass GUS 598*

Shot no.	Velocity [m/s]	Penetration [YES/NO]	Splinters [YES/NO]
1	856.5	NO	NO
2	850.1	NO	NO
3	856.7	NO	NO
4	852.8	NO	NO
5	856.2	NO	NO

Set B – tests at high temperatures

Windscreen glass (serial no. GuS542 05/08 064-121-21-10-0001723600) (Fig. 3) resisted to all 10 shots without any deformation of the polycarbonate layer (Fig. 4). In Tab. III, shooting tests results are stated.

In Fig. 5, side glass is shown (serial no. GuS 598 04/08 064- 121-21-10-00-01728313) that resisted the shots without any deformation of the polycarbonate layer. In Tab. IV, shooting tests results are stated.

Set C – tests at low temperatures

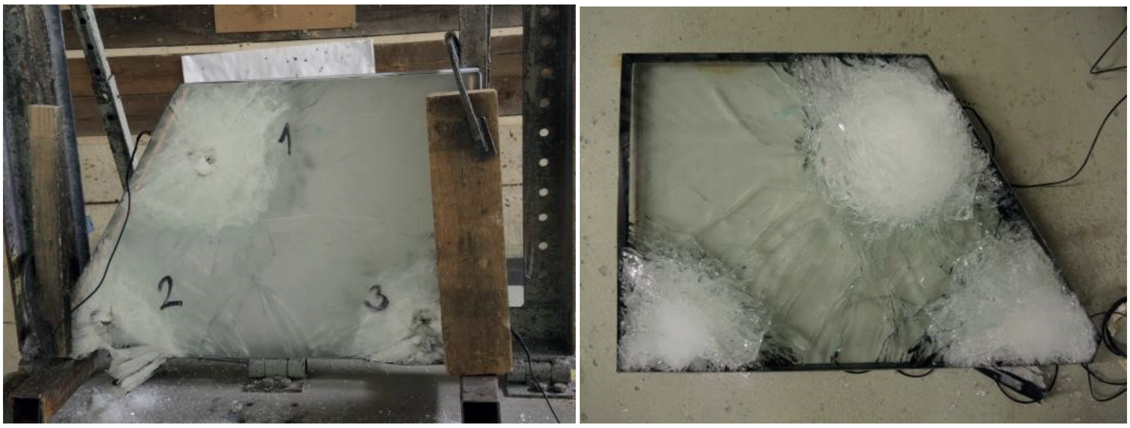
Side glass (serial no. GuS 619 04/08 064-121-21-10-00-01727802) (Fig. 6) resisted without any deformation of the polycarbonate layer. In Tab. V, shooting tests results are stated.

Side glass (serial no. SVOS 1411183) (Fig. 7) resisted the shots without any deformation of the polycarbonate layer even though the distance of the hits was below the minimum distance limit. In Tab. VI, shooting tests results are stated.

6: *Degraded side glass after shooting tests using projectile 7.62 × 54R B32 API at the temperature of –32 °C*

V: *Shooting tests results for side glass GUS 619*

Shot no.	Velocity [m/s]	Penetration [YES/NO]	Splinters [YES/NO]
1	860.5	NO	NO
2	853.9	NO	NO
3	861.4	NO	NO
4	858.2	NO	NO
5	854.3	NO	NO



7: *Side glass after shooting tests using projectile 7.62 × 54R B32 API at the temperature of −32 °C*

VI: *Shooting tests results for side glass GUS 1411183*

Shot no.	Velocity [m/s]	Penetration [YES/NO]	Splinters [YES/NO]
1	862.0	NO	NO
2	858.6	NO	NO
3	852.5	NO	NO
4	856.1	NO	NO
5	859.2	NO	NO

CONCLUSION

At all the test temperatures, the material tested resisted to the ammunition used (no penetration was identified). Nevertheless, a significant influence of the ambient temperature on the occurrence and extent of the monitored zones (I, II, III) at the point of a hit was proved. The extent of these zones at various temperatures was then compared and statistically verified. It follows from the results that that zone I (at 20–25 °C) is by 61 % smaller than zone III (at −32 °C) and zone II (at 55 °C) is by 20 % smaller than zone III.

It is evident that monitored zones I, II and III significantly influence the transparency of the bullet-resistant glass thus impairing or even restricting the special agricultural machine operators' orientation in the terrain. Therefore, great emphasis should be put on the selection of a suitable material with regard to its thermal resistance, even in damaged condition, in order to ensure the best possible active and passive protection.

For future research in this field, it would be recommendable to have more verified measurement data, such as non-destructive defectoscopy signals from an acoustic emission apparatus. Based on these values, it would be possible to conduct real-time detailed monitoring of the occurrence and propagation of microcracks in the material tested at various temperatures.

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Contact information

Tomáš Binar: tomas.binar@unob
Jiří Švarc: jiri.svarc2@unob.cz
Stanislav Rolc: rolc@vvubrno.cz
Petr Dostál: petr.dostal@mendelu.cz
Michal Šustr: michal.sustr@mendelu.cz