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Blast Testing of Visors Used for Humanitarian Demining

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This article discusses experimental results from blast testing of Security Devices Ltd. polycarbonate visors used by humanitarian deminers. Visors used in the blast testing fell into one of three categories: new visors, manually scratched visors, and scratched and heat-gun-repaired visors. Results show that the visors in all three categories failed to meet the draft international standard for blast testing[1] *relevant at the time, that further research is required to establish pressure profiles for the standard charge size being tested, and that the proposed heat- treatment method does appear to degrade the blast resistance of the visor used in the test.*[2]

In 2007, the Director of the Canadian Centre for Mine Action Technologies received a request to investigate a potentially promising heat-treatment process to extend the operational life of humanitarian-deminer visors

through removal of scratches from the field of view. The heat-treatment procedure was developed by undergraduate students as part of a product-design course and was published in *The Journal of Mine Action*.[3] The authors of that article noted that further testing would be required to determine whether the visor properties were adversely affected by the scratch-repair procedure. In order to allow for an independent assessment of the technique, the authors provided a detailed outline of the procedure in the article that readers could follow independently.

Trial Objectives and Methodology

The objective of this research was to assess the blast and ballistic performance of deminer visors before and after heat treatment. To ensure compatibility with the original student project, the same type of visors were obtained from Security Devices Ltd.

The visors were placed in three categories for blast and ballistic assessment: new, scratched, and scratched and heat-repaired. Following the procedures in the original project as closely as possible, a new visor was scratched by rubbing sand on the outer surface until the visor was opaque, which provided the "scratched" condition. To get the "scratched and heat-repaired" condition, a new visor was scratched as described and then washed and dried in an oven. After cooling, it was treated using a heat gun in the manner described in the students' original project.[3]

The following documents were used as guidance to develop the test methodologies for blast and ballistic assessment:

- Test Methodologies for Personal Protective Equipment Against Anti-Personnel Mine Blast"[4]
- European Centre for StandardizationWorkshop Agreement 15756: "Humanitarian Mine Action (HMA) – Personal Protective Equipment (PPE) – Test and Evaluation"[2]
- Ballistic Test Method for Personal Armour Materials and Combat Clothing"[5]
- Protocols to Test Upper Body PPE Against AP Blast Mines"[6]
- A Methodology for Evaluating Demining Personal Protective Equipment for Antipersonnel Landmines"[7]

Blast Assessment

Extensive research was conducted at DRDC Suffield by Ceh, et al., between March 1999 and November 2000 (published in 2005[6])to develop a protocol for testing and evaluation of upper-body AP blast mine personal

protective equipment. The detailed scientific and technical review resulted in a comprehensive understanding of the physics of a mine blast, factors affecting the performance of PPE, and the nature and severity of injuries depending on the deminer's position at the time of the blast. From those findings a protocol was developed to ensure the repetition of data, good replication of human-body positioning and motion, representative soil characteristics, standardized explosive charges and containers, reference pressure measurement, and relevant data acquisition and processing.

With regard to the physics of an AP mine blast, factors that needed to be controlled included the type of explosive used, the charge container, depth of charge burial, type of soil, distribution of larger soil particles, compaction and moisture content. These parameters contributed to the strength and distribution of the energy of the blast through the soil matrix and expansion of detonation products and soil ejecta[8] away from the center of the explosion.[6]

With regard to the performance of the PPE, it was determined that the shape and surface area of the PPE affected how the blast wave and detonation products propagated around it, thereby affecting how the force was transmitted to the person wearing the PPE. Brittle materials were found to break into fragments that could be propelled at high velocity and cause injury to the person.[6]

Since the mid-1990s, anthropomorphic mannequins have been used at DRDC Suffield for testing of PPE survivability against AP mines. The mannequins are chosen to match the body size and weight of human PPE wearers and allow for instrumented gauges to be placed inside for measurement of body motion.

In the 2005 Ceh study,[6] the position of the deminer in relation to the blast was found to greatly influence injury outcome. Humanitarian deminers often preferred a crouched or kneeling position to a prone position because it improved the field of view, made prodding easier and was less fatiguing. However, from an injury perspective, deminers in a kneeling position experienced more severe injuries from blasts compared to those injured while working in a prone position.

Figure 1: Testing platform and positioning. *All graphics courtesy of DRDC Suffield*

The desire to better control positioning of the mannequin during trials led DRDC Suffield to develop a testing platform and positioning rig. The platform allowed for exact placement of the mannequin a specific distance away from the charge, which was buried to a measured depth in a known quantity of standardized soil. Figure 1 shows the platform and rig placement. The measurement fixture and reference pressure transducer can be seen to the right of the mannequin.

The Hybrid III anthropomorphic mannequin, 5th-percentile female model was used for all of the testing as it approximates the size of typical Asian deminers more closely than the other Hybrid III mannequins at DRDC Suffield. The posture chosen for these tests was a kneeling position, with both knees on the ground. A wooden rig was used to position the hips and knees into the kneeling position, and the positioning rig was then used to adjust the upper body of the mannequin. The joints and neck were adjusted to give a set stiffness, and were then readjusted between shots.

The positioning rig supports the mannequin in the desired position before the blast. As soon as the blast pushes the mannequin backward, the chains go slack and the round crossbars fall from their supports, allowing free movement of the mannequin during the blast event. The measurement fixture is used to ensure repeatable placement of various parts of the mannequin body at specific X, Y and Z distances from ground zero. A reference pressure gauge was placed at 90 degrees to the charge at the same height and radial distance from the blast as the mannequin's visor (60 cm). The soil type used for testing is medium- grain building sand, dried to less than 1% moisture, packed loosely in the testing platform, and held in a container within the platform that is large enough to prevent reflected shock wave interference from the walls of the container, yet small enough in volume to be easily removed and replaced between trials (60cm x 60cm x 60cm).

The charge containers that were used for this study were developed at DRDC Suffield in the late 1990s. They are AP mine surrogate containers made of Dupont Adiprene packed with C4 plastic explosive, boosted with datasheet and center of axis initiated with an RP87 electric detonator. The charge size for the blast testing of visors in this trial was initially set at 200g C4 to match the European Centre for Standardization Workshop Agreement requirement of "an explosive equivalent to (240 ± 1)g cast tri-nitro toluene,"[2] representing the charge size of the PMN mine, which is one of the most frequently encountered AP blast mines. Initial testing demonstrated that the new visors broke at the 200g charge size. This result necessitated scaling back the charge size to 150g then 100g, before a threshold of 75g for visor breakage was found.

Figure 2: Trial test site—heated inflatable tent.

In order to provide a suitable location for blast testing in temperatures that reach -40 C on the Suffield testing site in January, an inflatable tent was erected as shown in Figure 2. A portable heating unit was used to provide a constant temperature of 15 C for testing the visors.

The external temperatures in January in Suffield, Alberta, Canada, average between -31 and -10 C and snowfall averages 22cm. In order to minimize temperature effects on the polycarbonate visors, they were stored in a heated building with the temperature maintained between 15 and 20 C. The visors were then transported in an insulated container to the heated tent and placed on the Hybrid III mannequin. The surface temperature was measured using an infrared digital temperature-measurement device and the trial commenced once the surface temperature reached 15 C.

Ballistic Assessment

The ballistic assessment was performed by an external laboratory, in accordance with Standard Agreement 29209 and International Mine Action Standard 10.30.10 The objective of the V50 ballistic testing was to determine the fragment protection capability of the PPE, with V50 representing the velocity at which half of the projectiles perforate the target material. It is noted in IMAS 10.30 that the STANAG 2920 test for ballistic protection may not provide a realistic assessment of the fragment threats from mine blasts, but it will continue to be used to estimate fragmentation protection until another international standard is developed. At the time these tests were being prepared, the CEN Workshop Agreement was only in a draft form and a formalized version was not available. Hence, the V_{50} testing used the defined 17-grain cold-rolled, annealed-steel fragment-simulating projectile as a threat (type-1) test for each visor tested. As with the blast tests, the ballistic tests were performed on the original (new) visors, the scratched visors, and the scratched and heat-treated visors.

The V_{50} testing was conducted using a V_{50} headform with the visor headband aligned along the part line of the headform. A veil witness paper was taped to the face of the headform and the fixture was aligned such that the FSP struck with zero degrees of strike obliquity to the visor, as determined with laser alignment through the bore of the rifle. A laboratory-grade .22 caliber long-rifle barrel firearm was used to fire the FSP. The range for the testing was set at 5.0m and the distance from the exit of the rifle muzzle to the strike face was 5.0m. A penetration was positive if it resulted in a hole in either the visor or the witness paper.

Blast Test Results

The visor blast testing took place at DRDC Suffield from 15–22 January 2008. In total, 18 visors were subjected to blast testing in the enclosed, inflatable tent facility illustrated in Figure 2 above. External daytime temperatures ranged from a high of -5 C to a low of -23 C, and wind speed ranged from 11 to 65 km/h. Despite these extreme weather conditions, the temperature inside the tent was maintained at approximately 15 C with the assistance of two portable, diesel generators, and wind effects were negligible.

Testing began at the CEN Workshop Agreement's recommended charge size of 200g C4 (240g TNT equivalent). After failure of the visor at 200g, the charge size was decreased to 100g. In an attempt to achieve visor survival at charge sizes closer to the recommended standard, a deminer apron was added to the mannequin. However, with breakage of the visor at 100g even with the apron, it was decided to proceed without an apron and to reduce the charge size to 75g.

Visor Description	Charge Size	Reference Pressure (psi)	Visor Outcome
New 1	200g	59.2	Broke
New 2	100g	32.2	Broke
New 3 + apron	100g	35.3	Did not break
New 4 + apron	150g	42.1	Broke
New 5 + apron	100g	36.1	Broke
Baseline established	at 75g	No apron	
New 6	75g	34.6	Did not break
New 7	75g	12.9	Did not break- misfire
New 8	75g	27.2	Did not break
New 9	75g	30.2	Did not break
1B scratched	75g	34.9	Broke
2B scratched	75g	32.1	Did not break
3B scratched	75g	28.1	Did not break
4B scratched	75g	32.7	Did not break
1A scratched, heat treated	75g	28.0	Broke
2A scratched, heat treated	75g	26.3	Broke
3A scratched, heat treated	75g	35.6	Broke
4A scratched, heat treated	75g	31.6	Broke

(Click image to enlarge)
Table 1: Visor blast test results.

Table 1 summarizes the results of the visor blast trials. Note that visors "New 1" through "New 5" were consumed in attempts to get a charge size at which the new visors would survive. The test data in which the three categories of visor can be compared starts with visor "New 6."

(Click image to enlarge)
Table 2: Visor blast testing post trial photographs.

Photographs and high-speed video were taken of the visor blast trials. The photographs in Table 2 show the extent of damage to the visors that were broken in the trial, as well as the post-blast photos of the visors that did not break. During the trials, the pieces of broken visor were found dispersed throughout the tent area and the pieces were photographed where they landed. All visor pieces were then collected and reconstructed for the photographs as illustrated in Table 2.

Ballistic Test Results

The results of the ballistic tests were much more difficult to interpret. IMAS 10.30 states in paragraph 4.3: "PPE provided to reduce the risk from such a hazard should include, as a minimum … ballistic body armour with a STANAG 2920 V_{50} rating (dry) of 450m/s." It continues, "Eye protection should be no less than that offered by 5mm of untreated polycarbonate."[10] It does not explicitly state that the visor should provide a V_{50} rating of 450m/s, nor does it explicitly define what V_{50} rating provides an acceptable level of protection. Indeed, it is possible to use the note about 5mm polycarbonate to allow any V_{50} rating to be acceptable as long as the visor is made of polycarbonate 5mm or thicker. This ambiguity makes evaluation of the results somewhat problematic.

Description	10N-NEW		V_{50}	234m/s
Bullet	FSP- 17		Vel. Spread	68m/s
			Std Dev	29m/s
Shot	Velocity Strike (m/s)	Velocity Residual (m/s)	Penetration (Y/N)	Used in V_{50} (Y/N)
1	485		Y	
2	437		Y	
3	255		Y	Y
4	261		Y	
5	151	0	N	Y
6	232	0	N	Y
7	262		Y	Y
8	206	0	N	
9	323	216	Y	
10	302	187	Y	
11	254		Y	Y
12	194	0	N	
13	367		Y	
14	301	171	Y	
15	447		Y	
16	249	71	Y	Y
17	360	264	Y	
18	338	233	Y	

(Click image to enlarge)
Table 3: V50 test result example.

Table 3 shows the V_{50} test data for the new visor. The strike velocity is the velocity at which the projectile struck the face of the visor. If the projectile traveled through the visor and kept moving, its exit velocity was shown as residual velocity. Residual velocity was not captured in all cases. To calculate V_{50}, three shots that did not penetrate and three shots that did penetrate were selected, while attempting to keep the strike velocities reasonably similar (the target was within 60m/s). This method prevents the far outlying data such as shot 1 from influencing the V_{50} value.

The V_{50} ballistic tests are summarized in Table 4 below. They show that within the error of one standard deviation, all three conditions of the visors have effectively the same V_{50} rating. If anything, the heat treatment may have improved the V_{50} performance slightly.

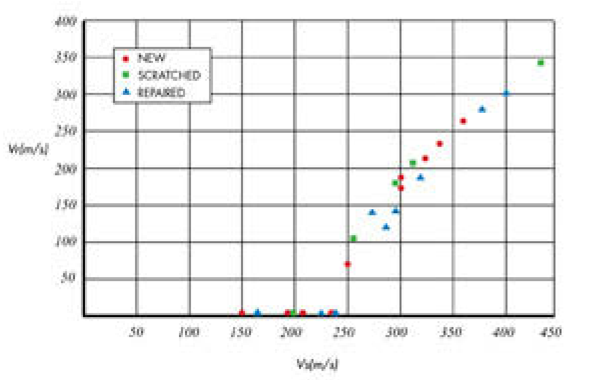
Figure 3 below presents the results of the ballistic testing in a way that allows comparison of the three conditions. The data points along the horizontal axis show the shots in which complete penetration did not occur (residual velocity is zero), while those above the horizontal axis show those that did penetrate completely.

Visor Condition	V_{50} (m/s)	Std Dev (m/s)
New	234	29
Scratched	226	40
Scratched & Heat Treated	247	18

(Click image to enlarge)
Table 4: V50 test result summary.

A variety of trend lines can be drawn through the three data sets, but they are very close to overlapping. With the wide spread of velocities and relatively few data points, there is really little or no significant difference among the three curves. In other words, these tests suggest that neither the scratching nor the heat treatment of the visors degraded the new visors from a V_{50} ballistics standpoint.

Discussion



(Click image to enlarge)
Figure 3: Strike velocity (Vs) versus residual velocity (Vr).

The results of the blast testing illustrate that the threshold for visor breakage for scratched, heat-repaired, and even new visors was far below the recommended charge size, when 200g C4 was used. Comparison of the results of the blast testing of the scratched visors with the scratched and heat-treated visors, as noted in Table 2 above, reflects more extensive shattering of the heat-treated visors. The significance of this difference would require further testing, especially since all three groups of visors were found to break at less than half of the specified CEN Workshop Agreement charge size.

Observations from field experience suggest that visors subjected to detonations of up to 240g TNT do not tend to shatter as they did in these tests. Assuming these observations to be accurate, it could indicate that there was a flaw in the experiment or that the CWA option to use a substitute for TNT needs to be reviewed; either the equivalency criteria need to be changed, or perhaps no substitute for TNT should be allowed. More experimentation will be needed to answer this question.

With regard to the V_{50} ballistic testing of the visors, it was seen that all three groups performed comparably. The estimated V_{50} falls between 225 and 250 m/s for all three groups, with no statistically significant difference among the new visors, scratched visors and heat-treated visors. STANAG 2920 is not clear with respect to what V_{50} rating is required for visors; it may be 450 m/s or it may simply be a 5-mm-thick, untreated polycarbonate visor with no requirement for a specific V_{50} rating. Further, if the CEN Workshop Agreement (CWA 15756) is taken as "an accepted alternative ... developed as an international standard" (IMAS 10.30, para 4.3.a10), then a less damaging fragment may now be more appropriate for future tests of this type.

Conclusions

Following the blast and ballistic testing of the visors, it was determined that:

- Scratching the visors did not appear to have any detrimental effects on the blast resistance of the visors.
- The proposed heat treatment of the scratched visors appears to degrade the blast resistance of the visors.
- All of the visors, including new ones, were broken during blast tests using charge sizes half the size recommended by the relevant standards.
- Neither the scratching nor the heat-treating process appears to have any detrimental effects on the V_{50} performance of the visors under test. The V_{50} ratings for new, scratched and heat-treated visors fall within the 225–250m/s range.
- Contrary to popular opinion, there is actually no requirement to have visors achieve a V_{50} rating of 450m/s.
- There is a need to investigate whether the revised CWA should allow substitutions for TNT, and if so, what equivalency criteria should be applied.

Biography

Capt. Charlene Fawcett was with DRDC Suffield for approximately three years, during which time she worked on various projects relating to protection, neutralization and detection for both military- and humanitarian-demining applications. Since writing this article, she has retired from the Canadian military.

Endnotes

1. It is important to note that this result was because the European Centre for Standardization Workshop Agreement in question (CWA 15756) was misleading and it has subsequently been withdrawn. Security Services devices should not be considered unsafe to use based on the results of this study.
2. **Editor's note**: At the time of the tests in this article the CWA referenced (CWA 15756) was in draft form but was published afterwards. Due to the apparent discrepancy highlighted in this study, the CWA has subsequently been withdrawn. There is a problem with the TNT equivalent amount when plastic explosive or an explosive other than TNT is used to test PPE. However, while highlighting an error in the CWA, it should not be forgotten that the article does conclude on what it set out to measure, namely the effect of surface heat-treating polycarbonate face protection. **The conclusion is that this procedure is not safe to use to repair face protection and so is not recommended.** Further tests will be carried out to find the realistic TNT equivalent that can be used in the recommended tests in the CWA, at which time the CWA will be re-issued.
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8. *Soil ejecta* refers to all debris ejected from an explosion, including dirt, rocks, and soot.
9. North Atlantic Treaty Organization (NATO), NATO Standardization Agency (NSA) Standardization Agreement (STANAG): Ballistic Test Method for Personal Armour Materials and Combat Clothing. STANAG 2920 Edition 2, July 2003.
10. United Nations Mine Action Service (UNMAS). *International Mine Action Standard (IMAS) 10.30, Safety & Occupational Health – Personal Protective Equipment*, October 2001. http://www.mineactionstandards.org/IMAS_archive/Amended/ Amended1/IMAS_1030_1.pdf. Accessed 11 November 2009.

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