SAFETY TESTING OF PROTECTIVE GLOVES

Thomas M. Klapötke*, Burkhard Krumm, Norbert Mayr, F. Xaver Steemann, and Georg Steinhauser

Department of Chemistry and Biochemistry
Ludwig-Maximilians-University of Munich
Munich, Germany

tmk@cup.lmu.de

Abstract:

When working with explosive materials, the worker's hands are usually the most exposed body part and highly endangered by fragmentation effects. Several kinds of protective gloves are available. Existing standards describe testing procedures for the testing of protective gloves for mechanical risks, but seem to not realistically simulate fragmentation effects. An experimental setup was developed to test the performance of protective gloves under conditions similar to exploding glass ware in direct vicinity to the protected hand. The test should take the effects of fragments and shrapnel on the protected hand into account and be fairly reproducible.

Keywords: *protective gloves, safety testing, test setup, fragmentation.*

1. INTRODUCTION

Manipulating high explosives always puts the operator in a risky position. If the manipulated substance accidentally explodes, the operator had better taken certain protective measures to avoid injuries and restrict the damage to glassware and other materials. Even if the fragmentation radius of the explosion was in the range of approx. 20 cm, where the fragments would probably not harm the operator's upper arms or torso, shards and shrapnel could still inflict wounds on the operator's hands. Therefore even in the manipulation of small amounts of explosives, the wearing of protective gloves would be advisable.

There are several types of protective gloves one could choose. Kevlar® [1] type gloves are usually knitted from Kevlar fabric and may be reinforced with steel core fibers or even interwoven with steel fibers. Leather gloves of a certain thickness are the craftsman's choice of protective gloves but hinder the fine motoric performance to a certain extent. The thickness of armory always decreases the mobility of the protective item and thus of its user, which is, of course, quite critical in the case of skilful finger movements.

When choosing the right protective glove, one might refer to EN 388 or EN 420 and the protection classes thereof [2]. These standards prescribe testing with steel needles with tip diameters of 4.5 mm – a testing procedure that might not realistically simulate the scenario of exploding glassware in or close to an operator's hand. In this work, a testing setup was developed to simulate the effects of exploding glassware on a glove protected hand.

2. RESULTS AND DISCUSSION

2.1. Background and Earlier Experiments

In earlier, yet unpublished, experiments a 5 mL glass container which was fixed directly on protective gloves with duct tape was detonated and evaluated the effect on the gloves. The gloves were filled with artificial filling material to resemble the softness and shape of the human hand.

The results are summarized in Table 1 and Figure 1. It was concluded that steel interwoven Kevlar gloves were best suited to withstand the explosion of up to 1 g lead azide.

Table 1. *Results from earlier experiments.*

	1	**2**	**3**	**4**
Glove Type	Kevlar	Kevlar, single steel core	Leather, welding type	Kevlar, double steel core
500 mg $Pb(N_3)_2$	Torn	No damage	Torn	Partly damaged
1 g $Pb(N_3)_2$	-	Torn	-	Partly torn
Suitability (500 mg $Pb(N_3)_2$)	Not suitable	Suitable	Not suitable	Not suitable

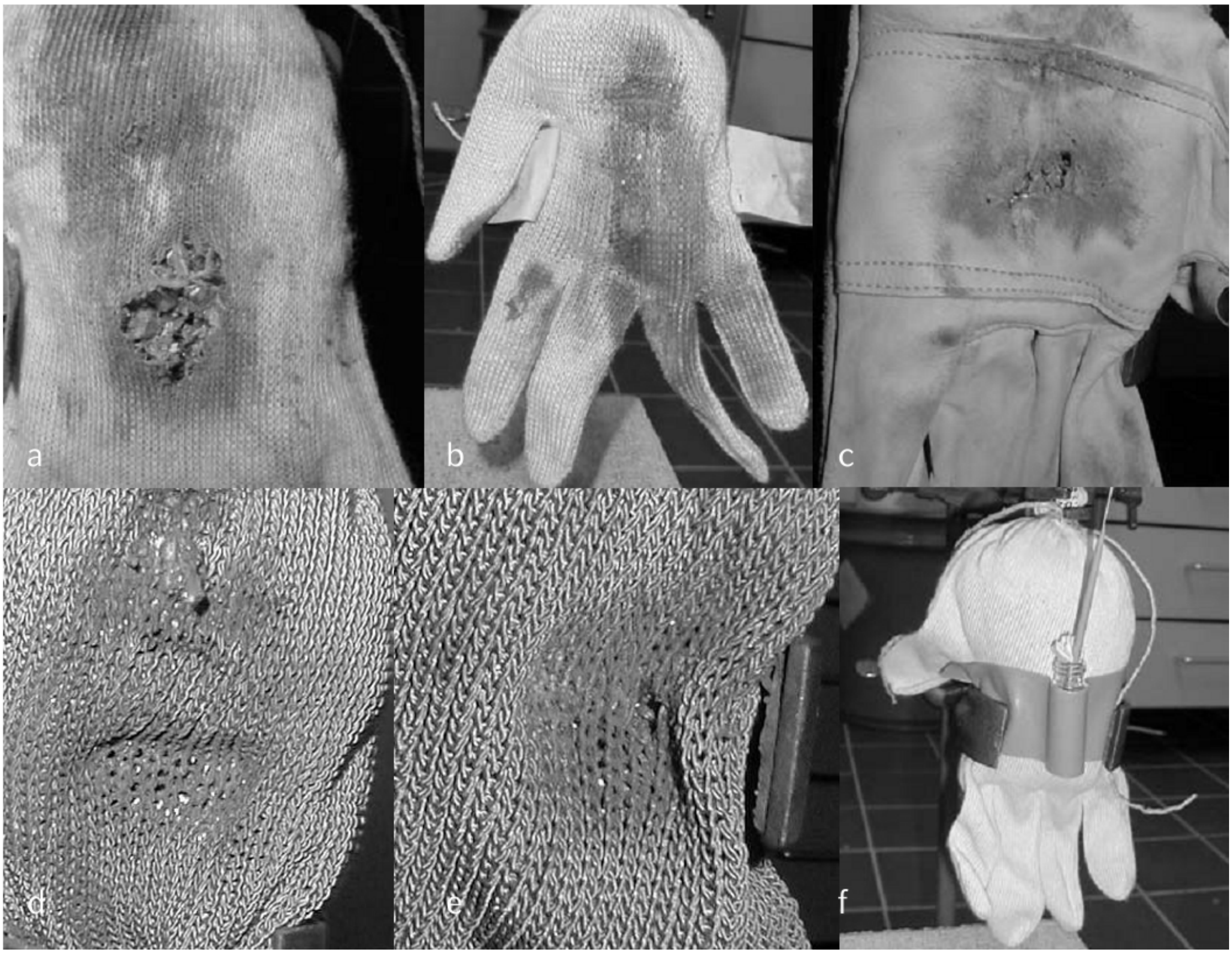

Figure 1. *Results from earlier experiments.*

a–d) 500 mg $Pb(N_3)_2$ on Kevlar glove (a, palm close-up), single steel core Kevlar glove (b), leather welding type glove (c, palm close-up), and double steel core Kevlar glove (d, palm close-up); e) 1000 mg $Pb(N_3)_2$ (palm close-up); f) experimental setup.

This setup allowed evaluation of those fragments, which directly struck the glove material, only. Fragments that passed through mashes of the Kevlar material as well as the effects of the fragments that passed through the material of the glove could not be evaluated. Another point one could object is that fragments accelerate on their way through the air a short time after the explosion and that, therefore, worse scenarios than simulated in these experiments could occur, when, e.g., the glove was positioned in a distance of about 10 cm to the exploding sample. A serious assessment of the effect of fragments, which passed through the glove, was not possible.

2.2. Testing Setup

In a new developed experimental protocol, a dummy hand was used to simulate the operator's hand and a defined sample of explosive was detonated in a 10 mL round necked flask in a distance of 10 cm to the dummy hand. To check for the experiments' reproducibility, a paper witness sheet was placed in 10 cm distance to the explosion, too. In that way, the number of fragments that were supposed to have hit the glove was estimated for each experiment (Figure 2a, b).

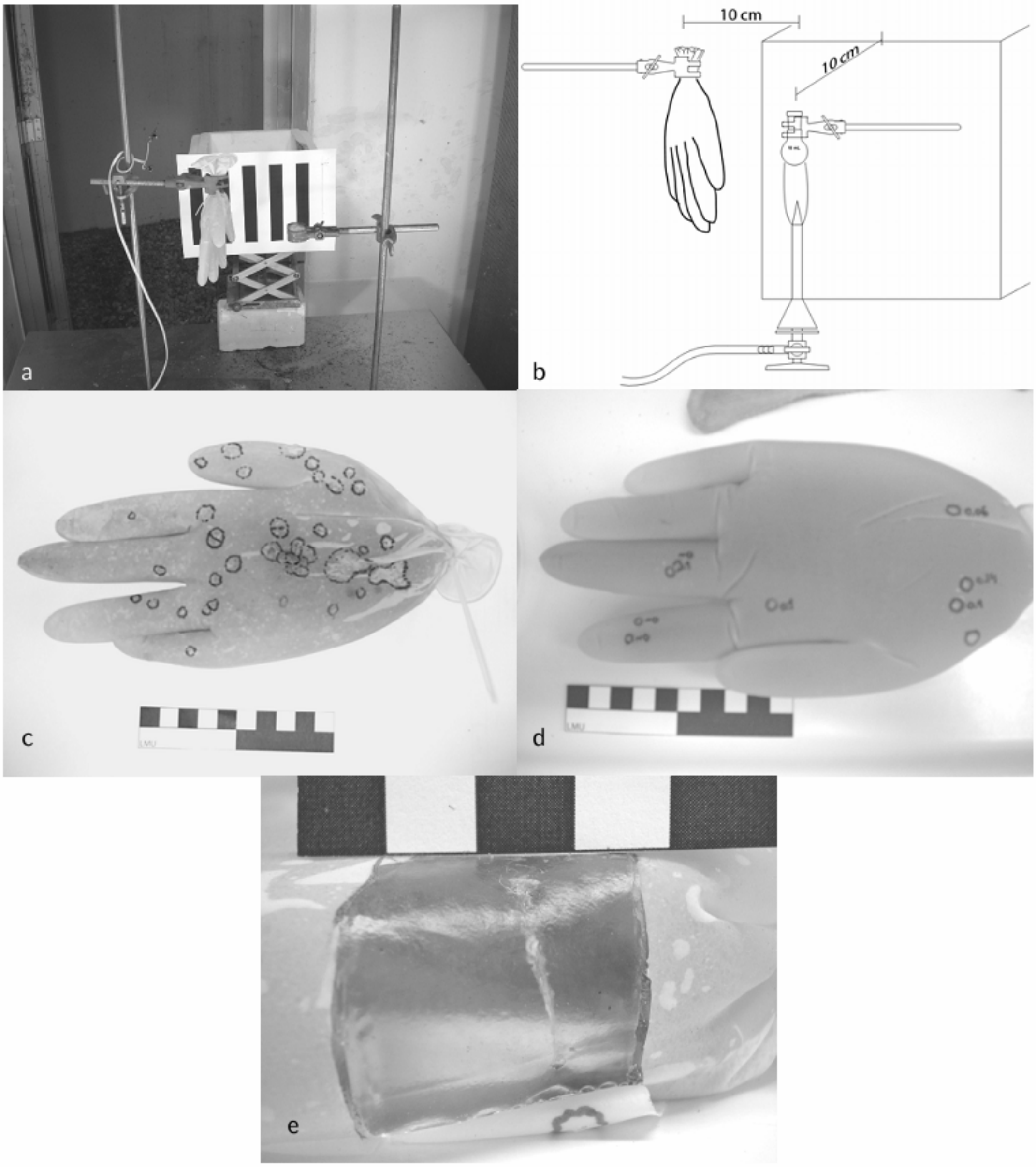

Figure 2. *Experimental setup und shard effects.*

a, b) Setup, c) shard effects on unprotected dummy hand (penetrations encircled), d) shard effects on Kevlar glove protected hand (penetrations encircled), e) close-up of full penetration effect on Kevlar glove protected hand (cp. d, lower right). Scale unit: 1 cm.

2.3. Estimation of the Number of Shards

A 10 mL flask was detonated in the center of a 10 L Styrofoam box to estimate the number of shards produced in the explosion (see below). The overall number of shards counted was 13,575. 1332 (9.8%) thereof were of a diameter larger than or equal to 1 mm. A detailed summary of these results is given in Table 2 and Figure 3.

Table 2. *Shards counted after the explosion of 1 g lead azide in a 10 mL flask placed in a 10 L Styropor® box.*

Box Wall	Shards <1 mm	Shards ≥1 mm
Lid	268	11
Front Side	2295	218
Left Side	2116	190
Back Side	1884	396
Right Side	1240	254
Bottom	4440	263
Sum	12243	1332

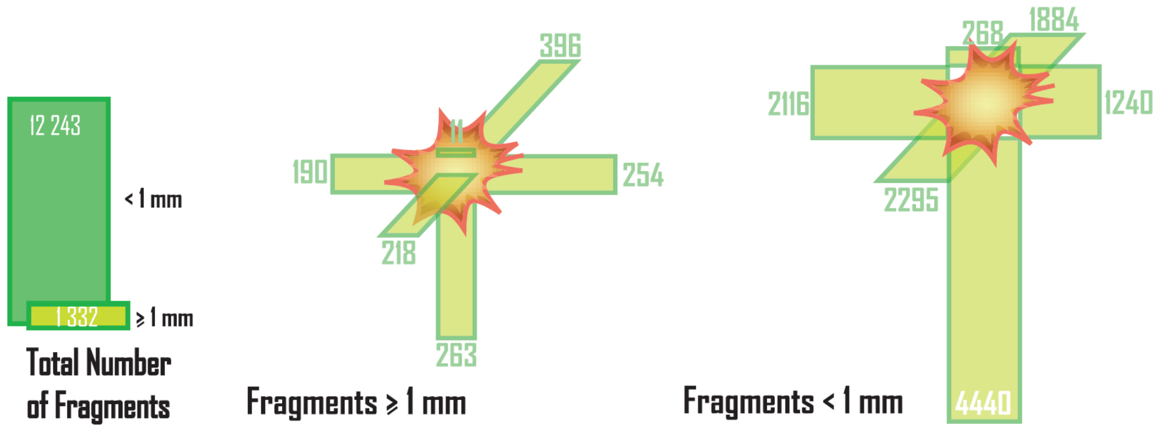

Figure 3. *Visualization of the Styrofoam box experiment*

The fragment distribution confirms that holding a flask on its neck is the safest way of treating bottled explosives, whereas holding it on the bottom would drastically increase the risk of severer injuries.

It is noteworthy that the flask was not sealed with a ground-in glass stopper and thus one would have to take into account, that the shard producing surface was in fact smaller for the top part of the flask. With a flask radius of 1.75 cm, a neck diameter of 1.30 cm, and a distance of 1.45 cm between flask median and neck, one can calculate that an average of 6.4 cm^2 of glass surface forming shards for one of six possible directions (spherical geometry of the flask is assumed). Further, the neck of the round necked flask decreases the inner surface of the flask by 3.3 cm^2, thus there should be 51% less fragments detected in the lid of the Styropor® box and one would expect 1174 small as well as 129 big fragments. In the experiment, significantly less fragments were detected in the lid of the Styropor® box. Another explanation for the small amount of fragments found in the lid of the Styropor® box is that the flask was not fully filled with lead azide: The explosive charge created a large amount of small fragments from the area of the flask it had direct contact to – the bottom – and a smaller amount from those areas, that were not directly "in touch" – the top.

2.4. Evaluation

In order to evaluate the performance of the protective gloves, the shards, which struck the outer surface of the glove without penetrating the Latex lining of the dummy hand, were colleted and then the protective glove was carefully removed to check for shards that did penetrate the dummy hand. To collect the shards, which penetrated the dummy hand, the penetration channels in the gelatin were carefully probed and the penetration depths noted, then

the Latex liner was removed and visually checked for small penetrations. Then the gelatin was removed in small cubes (approx. 1 cm^3) with the aid of a scalpel and the fragments were removed from the gelatin cubes.

For further evaluation, a fragment diameter of 1 mm was chosen at random to classify small (< 1 mm) and big (≥ 1 mm) fragments. To compare the experiments, one must take into account that each explosion did not necessarily create the same number of shards. Therefore the number of shards, which were found on or in the dummy hand, was correlated with the impacts on the paper witness sheet. Table 3 shows the respective results.

One should also note that the number and fraction of shards on the glove does not necessarily equal the number of shards stopped on the glove surface. Shards, which were reflected from the glove, were not taken into account and only shards that somehow stuck to the glove, i.e. in the meshes of the glove fabric, were counted. This fully explains the comparably low fractions of shards adhered on the surface of the leather gloves.

The discrepancy between the two tested welding gloves is obvious and might simply be explained by the fact that the first tested glove already had been in use for several years and thus had been mechanically stressed to a certain degree, whereas the second was new. All other gloves were used but serviceable and all in similar condition (no obvious damages, wholes, or similar).

From the high speed recordings, we estimate the average shard velocity 51±13 m/s.

In contradiction to the earlier experiments, the leather welding gloves provided the best protection to our dummy hand. The difference between our recent and our new study might be a result of the different charge container and the way, the charge was applied. In our earlier study, the charge was tampered to some degree because of the smaller container and the single sided application of duct tape. Additionally, the dummy hand was loosely held by a clamp stand and was allowed to swing back almost freely, whereas in our earlier experiment, the glove was fixed in a clamp stand, which did not allow any movement of the glove.

Apart from the unprotected dummy hand, most shards penetrated the dummy hand, which was covered by the Kevlar gloves. From the penetration depths, rather severe injury (average penetration depths of 2.8 and 1.8 mm, deepest penetration up to 8.6 mm) was estimated and thus the Kevlar glove as suitable protective item had to be rejected –even a 5 mm shard, which penetrated the palm, was detected. It is noteworthy that thin Kevlar gloves work fine as protection against cutting but do not protect against fragmentation. The steel core Kevlar gloves performed much better. Only a relatively low amount of shards managed to penetrate the dummy hands, but maximum penetration depths of 5.0 and 6.0 mm would still have caused serious injury. Although the average penetration depth is slightly higher than in the case of Kevlar gloves, one should keep in mind that the shard stopping effect of the Kevlar gloves is only 11% compared to the steel core Kevlar gloves – 9% of shards penetrated the Kevlar "protected" hand, whereas only 1% penetrated the steel core Kevlar protected hands. Steel reinforced Kevlar gloves performed well although few smaller shards managed to penetrate the hands up to 6 mm deep.

The only protection against smaller shards was given by the leather gloves. Maybe a combination of steel reinforced and welding type gloves would give the best protection – welding type gloves on the outer side do not decrease the grip as much as steel reinforced gloves would do and steel reinforced gloves as inserts would stop larger fragments, which penetrated the leather gloves.

Although the experiment might be more realistic and surely gave more experimental data, the observed effects were not as radical as those obtained from the earlier experiment simulating direct contact of flask and glove protected hand. The advantage of the study described above surely is the ability to evaluate the body tissue penetrating effects.

Table 3. *Fragments in or on the dummy hand and their penetration depths.*

		Unprotected	Kevlar		Kevlar, Steel Core		Kevlar, Steel Reinforced		Leather, Welding Type	
		Exp. I	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II
Number of shards										
- on glove (hand)	≥ 1 mm	0	10	13	17	18	10	14	5	4
	< 1 mm	4	45	12	38	16	8	21	18	13
	sum	4	55	25	55	32	18	35	23	17
- in hand	≥ 1 mm	30[a]	14[b]	13	3	2	0	1	1[c]	0
	< 1 mm	20	0	5	3	0	2	1	1	0
	sum	50	14	18	6	2	2	2	2	0
Impacts / imprints in paper witness sheet	≥ 1 mm	237	200	144	259	207	193	229	185	188
	< 1 mm	1376	1169	1140	1292	1389	1013	1360	1396	919
	sum	1613	1369	1284	1551	1596	1206	1589	1581	1107
Fraction of shards										
- on glove (hand)	≥ 1 mm	0%	5%	9%	7%	9%	5%	6%	3%	2%
	< 1 mm	0%	4%	1%	3%	1%	1%	2%	1%	1%
	sum	0%	2%	2%	4%	2%	1%	2%	1%	2%
- in hand	≥ 1 mm	13%	9%	9%	1%	1%	0%	0%	1%	0%
	< 1 mm	1%	0%	0%	0%	0%	0%	0%	0%	0%
	sum	3%	1%	1%	0%	0%	0%	0%	0%	0%
Penetration Depth (mm)	deepest	15.0	7.0	8.6	5.0	6.0	1.0	6.0	5.0	-
	average	4.9	2.5	2.8	1.8	3.8	0.8	4.5	4.0	-

[a]) 5 shards > 5 mm; [b]) 1 shard penetrated the whole palm; [c]) 1 shard > 5 mm

3. EXPERIMENTAL

Lead(II) azide was prepared by precipitation of stoichiometric amounts of lead(II) nitrate and sodium azide in aqueous solution. The precipitate was filtered, washed and dried at 80°C.

Dummy hands were prepared by filling a standard latex examination glove (size M) with ballistic gelatine. The ballistic gelatin used was prepared according to FBI standards [3] as a 10% aqueous solution of commercially available white gelatine powder ("Gelatine gemahlen weiß" from Ruf Lebensmittelwerk KG, Quakenbrück, Germany) which was cooled at 4 °C for over 10 hours and used within 20 minutes after removal from refrigeration. As a substitute for the bones of the human hand (phalanges and metacarpal bones), wooden sticks (probably pine wood) with a square diameter and 5 mm thickness were used and inserted in the gelatine before cooling the dummy hand.

One experiment with an unprotected dummy hand and each twice with a Kevlar glove, a steel core Kevlar glove, a steel fortified glove, and a leather welding glove were performed (Table 4). In our test setup, 1.00 g of lead azide in a 10 mL round necked flask was initiated 10 cm in front of the dummy hand (see Figure 2). The explosive was initiated by the flame of a remote-controlled Bunsen burner. To check the reproducibility of the experiments, a paper witness sheet (DIN A4) was attached 10 cm of the flask as well. By counting the shards hitting the paper, it could be proven that this setup provides quite reproducible conditions with respect to shard number and size. Additionally, all experiments were recorded by a high speed camera (speedcam visario g2, Weinberger Deutschland GmbH, Erlangen, Germany, time resolution: 3000 fps).

Table 4. *Specification of tested equipment.*

	Dummy Hand	Kevlar	Kevlar, Steel Core	Kevlar, Steel Reinforced	Leather, Welding Type
Type	Latex Examination Glove	*Ansell* Neptune Kevlar® 70-205, lightweight glove	Multi*MEX*® 941	Multi*LUX*® 940	Welding glove (EN 388 Kat. 2)
Size	M	9	9	8	9
Supplier	UNIGLOVE GmbH, Troisdorf, Germany	Ansell Ltd., Brussels, Belgium	Kächele-Cama Latex GmbH (KCL), Eichenzell, Germany	Kächele-Cama Latex GmbH (KCL), Eichenzell, Germany	Wegusta GmbH, Düsseldorf, Germany

In order to estimate the total amount of glass shards accelerated by the explosion of 1.00 g lead azide in any direction, one 10 mL round necked flask (17.418 g) filled with the same amount of lead azide was initiated electrically in the center of a Styrofoam box (volume approximately 10 L). All six walls of the box were lined with paper witness sheets. Following the detonation, each impact (imprint or hole in the witness sheet) was counted. The spots of

impact were classified per size: <1 mm and ≥1 mm. In some cases, the explosion caused a regional complete destruction of the paper, leaving holes of up to 1 cm^2 in the paper. In this case, the whole spot was counted as one single impact ≥1 mm. Therefore, the error of the figures given above was estimated to ±10%. This error includes counting errors as well.

4. CONCLUSIONS

The experimental data from the experiments described herein and from previous experiments indicate, that steel interwoven Kevlar gloves or thick leather welding gloves or a combination of both provide fair protection against fragments from exploded glassware in case that mechanical manipulators are not at hand. The existing DIN and EN standard testing procedures do not seem to simulate fragment effects encountered in the handling of explosive materials, for DIN / EN tested equipment performed rather poorly. From the fragment distribution of exploded glassware detected in the Styropor® box experiment, it can be derived that flasks or containers containing explosive substances should be held at the top if applicable, for most shards seem to origin at the meridian or bottom of the flask.

5. REFERENCES

[1] Kevlar® is a registered DuPont trademark for a para-aramide synthetic fiber.

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