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Technical Report ARMET-TR-13040

GLOVE TESTING FOR PERFORMANCE AGAINST FLYING GLASS SHARDS

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14. ABSTRACT

In this work, cut-resistant gloves were tested against flying glass from a small-scale detonation. A range of gloves were selected with low, medium, and high cut resistance all of varying dexterity. The goal was to determine if gloves with superior dexterity to those with leather palms could still provide protection from flying shards of glass.

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INTRODUCTION

To determine the ability of new personal protective equipment (PPE) materials to protect against glass from accidental detonation or explosion in a glass chemical apparatus or beaker, a series of gloves were purchased and tested. The main goal was to protect the hands of an operator during the preparation of energetic materials and to prevent or lessen the severity of hand injury from flying glass if the contents of a container or apparatus undergo an unexpected reaction.

This testing is based on an unpublished evaluation of a series of gloves for the same purpose described above (ref. 1). The only gloves that survived that testing were mixed woven Kevlar®/steel fiber and woven Kevlar® fiber gloves. In both cases, glass shards were stuck in the fibers but had not penetrated the test glove. The gelatin hand inside of the test glove was subject to significant scorching. It was decided that a woven Kevlar® fiber glove with a leather layer, covering both the palm and the fingers, would offer the best protection for the wearer. Please note that full protection from the detonation or blast overpressure was not the goal of the previous or present investigation.

There were two priorities for glove selection: protection and dexterity. The previously identified leather-palmed gloves were considered too bulky for use by personnel with small hands, greatly decreasing dexterity. The wearer could not comfortably and efficiently handle a piece of glassware while wearing the gloves, increasing the risk of accidental mishandling. In this work, large, thick leather gloves were not considered due to their similar cumbersome bulk and cotton gloves were excluded due to lack of protection. Gloves constructed of either Kevlar® (DuPont) or Dyneema® (DSM) materials were considered.

Kevlar® and Dyneema® fibers are used to make an array of clothing materials for safe equipment use and cut resistance. Kevlar®, which is five times the strength of steel on an equal-weight basis, is primarily known for its use in ballistic and stab-resistant body armor (ref.2). Dyneema® is an ultra-high molecular weight polyethylene (UHMWPE) used in a variety of applications from vehicle armor to sailing (ref. 3). It is a flexible, chemical resistant material 15 times stronger than steel and up to 40% lighter than materials like aramids.

Gloves were selected based on cut resistance of the materials. Industrial PPE is measured by the test procedures in EN 388 (ref. 4), ISO 13997 (ref. 5), and ASTM F1790 (ref. 6).

EN 388 compiles data for a material's abrasion, cut, tear, and puncture resistance to determine the material's level of mechanical protection. The PPE with an EN 388 rating are marked with a Conformité Européenne (CE) label and four numbers corresponding to the correlating tests (fig. 1) and given a ranking for each test. Abrasion, puncture, and tear resistance are rated on a scale of 1 (low) to 4 (high) while cut resistance is rated on a scale of 1 to 5. EN 388 measures cut resistance via the Coup Test in which a circular blade with a fixed load is moved back and forth over the sample while rotating in the opposite direction to the linear movement of the mounting device. Results are determined by calculating how many revolutions are needed to cut through the material. This is then compared to the cut index in order to give the material a rating from 1 to 5 (table 1).

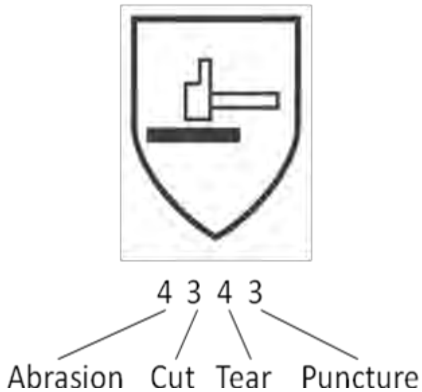

Figure 1
EN 388 cut protection symbol with numbering description

Table 1
EN 388 cut resistance levels

EN 388 cut resistance levels		
Cut level	Weight (g) needed to cut with 1-in. (25-mm) blade travel	Average cut index (10 measurements)
0	< 119	< 1.2
1	120 to 249	1.2 to 2.4
2	250 to 499	2.5 to 4.9
3	500 to 999	5 to 9.9
4	1000 to1999	10 to19.9
5	> 2000	> 20

The ASTM F1790 and ISO 13997 test methods for cut resistance use a straight cutting edge with a specified load that is moved one time across a material. The distance to cut is recorded, which is determined by electrical contact with the support. A load versus distance to cut curve is generated and used to determine cut resistance. The ASTM test method results are referenced by the ANSI/ISEA to determine the performance level of gloves shown in table 2.

Table 2
ANSI-ISEA 105-2005 mechanical ratings

ANSI-ISEA 105-2005 mechanical ratings							
Rating	**Level 0**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 6**
Abrasion resistance (cycles)	0 to 99	100 to 499	500 to 999	1000 to 2999	3000 to 9999	10000 to 19000	20000+
Cut resistance (g)	0 to 199	200 to 499	500 to 999	1000 to 1499	1500 to 3499	3500+	
Puncture resistance (N)	0 to 9	10 to 19	20 to 59	60 to 99	100 to 149	150+	

In this work, cut-resistant gloves were tested against flying glass from a small-scale detonation- a situation not adequately represented by the EN 388, ISO 13997, or ASTM F1790 tests. A range of gloves were selected with low, medium, and high cut resistance, all of varying dexterity. The goal was to determine if gloves with additional dexterity as compared to those with leather palms could also provide protection from glass shards.

MATERIALS AND TEST METHODS

Ballistic Gel Hand Preparation

Hand models were made from ballistic gel molded in a KleenGuard®, powder-free, blue nitrile glove, size medium. Ballistic gelatin was prepared by mixing a small aliquot of water from a premeasured volume of 1,800 mL DI H_2O, to 300 g gelatin (ref. 7) to make a thick goo. The remainder of the water was heated to 54.4°±5.6°C in a large beaker. The gelatin goo was then added slowly with copious stirring until the mixture became a clear solution. Foam on the top of the solution was removed and then approximately 300 to 325 mL of the gelatin was poured into each nitrile glove.

To form a palm and fingers in the position of a hand holding a beaker, the filled nitrile glove was draped over a beaker and was cooled for 1 hr at an ambient temperature. After the "hand" had cooled enough, the fingers were then taped around the beaker making sure that gelatin was present in all of the joints. The hands were cooled for 4 hr at an ambient temperature then placed into a refrigerator for 24 hr upon which they were removed from the beaker and stored under refrigeration until use. The ballistic gel hands remained in the nitrile gloves throughout the test. Before testing, the protective, cut-resistant gloves were place over the nitrile glove hands.

Selected Gloves

Selected gloves to be tested include both Kevlar® and Dyneema® gloves manufactured by Memphis, UltraPro, and AnsellPro. Tested were the

- HyFlex ® 11-518 polyurethane coated, Dyneema® glove by AnsellPro
- HyFlex ® 11-435 polyurethane coated, Dyneema® glove by AnsellPro
- Ultratech® 9676 polyurethane coated, Dyneema® glove by Memphis Gloves
- Ultratech® 9696 nitrile coated, Dyneema® glove by Memphis Gloves
- T-Flex® 8115 noncoated, Dyneema® and AlphaSan® engineered fiber by Showa Best Glove, Inc.

Explosive Testing

The glove testing was conducted in one of the detonation chambers in the explosives development facility at the U.S. Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ. Each glove was fitted over a "hand" made from ballistic gelatin in a standard nitrile glove. The gloved "hands" were stored in the refrigerator before testing so they were allowed to warm up in room temperature air prior to testing. For each test, one of the gloved hands was placed on a ring stand with a three-finger clamp holding it by the wrist so that the pinky finger and side were resting on the stand and the thumb and all other fingers were not in contact with the stand. The fingers and thumb were then manipulated to "hold" an empty glass vial (22 mL in size, volume-wise) with the fingers wrapping around the vial and the thumb holding the vial from the other side. Duct tape, in varying amounts, was used to keep the fingers and thumb in position so that the vial was in contact with the fingers and the palm of the glove with a grip that approximated normal hand position (see appendix).

Once each gloved “hand” was in position, the empty glass vial was removed and replaced with a glass vial containing a measured amount of RD-1333 lead azide (LA). This sensitive primary explosive, from lot G03120030 of stockpile LA (produced before 1980), had been fully dried for this testing and was added to the vials as a dry powder in the amounts listed in table 3. Please note that the operators weighing the LA and transferring the vial to the test chamber to the test glove wore extensive PPE (including face shields, leather welder jackets, and leather palmed gloves) to protect themselves from shards of glass that could be formed if the explosive prematurely detonated. At this point, photographs of each of the tested gloves in the final test position were taken. Then, a small coil of thin nichrome wire with long leads was lowered into the vial so that the coiled wire was in contact with the LA (appendix). The nichrome leads were attached to the chamber end of a shorted firing line that was held by another clamp on the ring stand supporting the gloved “hand.” The chamber was evacuated of personnel and shut. The LA was remotely initiated by applying voltage to the firing line at its far end in the control room. The reaction of the LA shattered the glass vial, generating shards of glass. After the voltage had been discontinued and the firing line was shorted again, the chamber was reopened. Photographs of the gloved “hand” were taken and the glove was then examined for damage by visually inspecting the protective glove and then by removing the protective gloves and looking for cuts in the interior nitrile glove (see appendix).

Table 3
LA weights

Test no.	Weight LA (g)	Protective glove	Comments
1	0.1768	Memphis 9693	
2	0.1769	Memphis 9676	
3	0.1705	AnsellPro 11-518	
4	0.1742	Showa Best 8115	
5	0.1724	AnsellPro 11-435	
6	0.1723	Showa Best 8115	Repeat of test 4
7	0.1728	Memphis 9693	Repeat of test 1
9	0.1718	Nitrile glove only	Bare “hand”

RESULTS

The detonation produced a large size distribution of glass shards up to 1 cm in length (appendix). The control nitrile glove, or the bare “hand,” had two large cuts: one in which glass penetrated the palm of the hand and one in the ring finger (appendix). Results from the protective gloves and corresponding ANSI and EN 388 ratings can be seen in table 4. The Memphis and AnsellPro gloves, all of which have either a polyurethane or nitrile coated palm, represent a successful test. After detonation, there was glass present on the gloves; however, this glass was easily brushed away and did not penetrate the coating, Dyneema®, or Kevlar® weave; the witness nitrile glove was not cut. The Memphis 9693 glove test was repeated with the glass vial held tightly against the palm, since in test no. 1 it was positioned a slight distance away from the palm. No difference was seen in the test results. Scorch marks were present in all tests. The Showa Best T-Flex glove was the only unsuccessful test. The first trial resulted in a misfire. The second trial showed scorching and deep glass penetration through the witness nitrile glove and into the ring finger (appendix).

Table 4
Glove parameters and testing results

Manufacturer	AnsellPro	AnsellPro	Memphis gloves	SHOWA Best glove	Memphis
Brand	Hy Flex ®	Hy Flex ®	UltraTec h®	T-Flex	UltraTech ®
Model	11-518	11-435	9676	8115	9693
Coating	Polyurethane	Polyurethane	Polyurethane	none	nitrile
Material	Dyneema®, Diamond Technology Fiber, Nylon, Spandex	Dyneema®, Nylon, Lycra, Glass Fiber (antistatic)	Dyneema®*	Dyneema®* and AlphaSan	Kevlar®*
Gauge	18	no data	13	15	13
ANSI					
Cut	2	3	2	3	2
Abrasion	3	4	no data	0	no data
Puncture	no data	no data	no data	0	no data
EN level 388					
Abrasion	3	4	4	0	3
Blade cut	3	5	3	3	2
Tear	3	4	4	4	2
Puncture	1	2	3	2	1
Result after ~170 mg lead azide	no glass penetration	no glass penetration	no glass penetration	glass penetrated glove, ripping apart the ballistic gel ring finger	no glass penetration
	Acceptable	Acceptable	Acceptable	Unacceptable	Acceptable
	* did not specify other materials				

Dexterity of the protective gloves does decrease as the cut resistance increases. Users were tasked with wearing the gloves throughout the work day to determine the ability to manipulate fine objects and perform laboratory tasks while wearing the gloves. Because of the laboratory environment that includes solvent use, nitrile gloves are worn over the protective gloves. The AnsellPro HyFlex® 11-518 gloves and Memphis UltraTech® 9676 were considered the most dexterous of the gloves by the users. The thicker AnsellPro HyFlex® 11-435 gloves, although less dexterous, offer more range of motion and finer motor skills than leather palmed Kevlar gloves.

CONCLUSIONS

Protective gloves with a minimum of EN level 388 cut resistance level 3 and ANSI cut resistance level 2 reduced the damage from flying glass under a controlled detonation of lead azide in a glass vial. In a chemical laboratory environment, all gloves tested are easily worn underneath nitrile gloves. It will be noted that this test only represented a reduction of damage from glass shards resulting from an accidental reaction and that protection from detonation or blast overpressure was not the goal of the investigation.

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3. DSM. Dyneema. [Online] DSM, 2013, [Cited: 05 28, 2013]. http://www.dyneema.com/

4. European Committee for Standardisation, *Standard EN 388, Protective Gloves Against Mechanical Risks.* CEN Secretariat, rue de Stassart 36, B-1050, Brussels.*EN 388,* 1994.

5. ISO Standard 13997, 1999(E), "Protective clothing – Mechanical properties – Determination of resistance to cutting by sharp objects," Internation Orginazation for Standardization, Geneva, Switzerland, 1999. www.iso.org.

6. ASTM Standard F 1790 – 05, 1997 (2005), "Standard Test Method for Measuring Cut Resistance of Materials Used in Protective Clothing," ASTM International, West Conshohocken, PA, 2005, www.astm.org.

7. 250 Type A Ordnance gelatin (ballistic gel): GELITA USA Inc., 2445 Port Neal Industrial Rd., Sergeant Bluff, IA 51054.

APPENDIX
BACKUP DATA

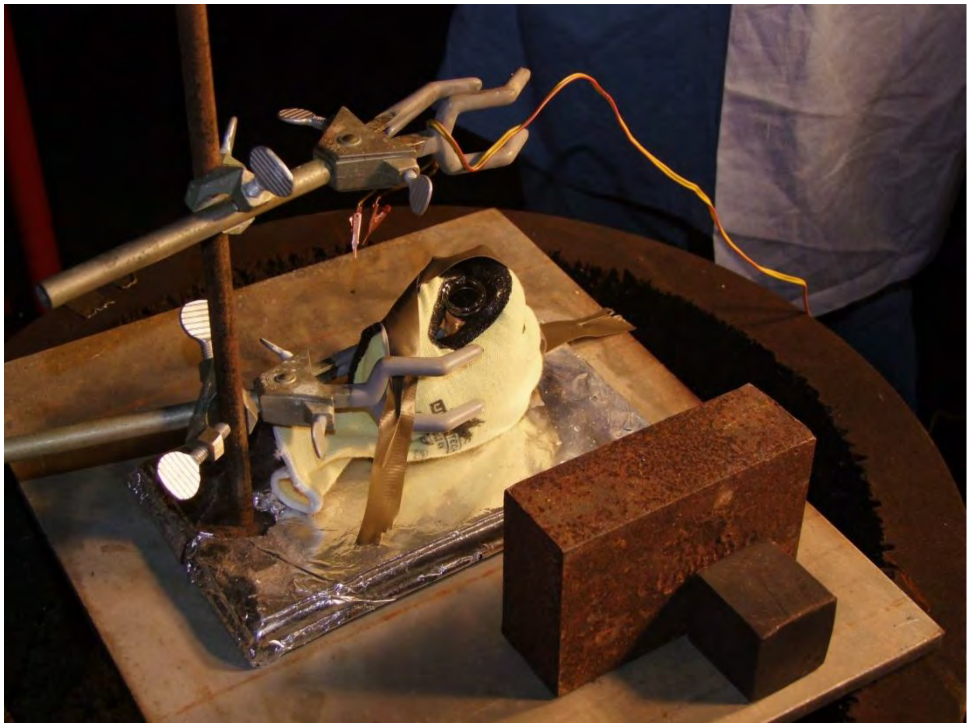

Figure A-1
Test apparatus with the Memphis UltraTech® 9693 glove

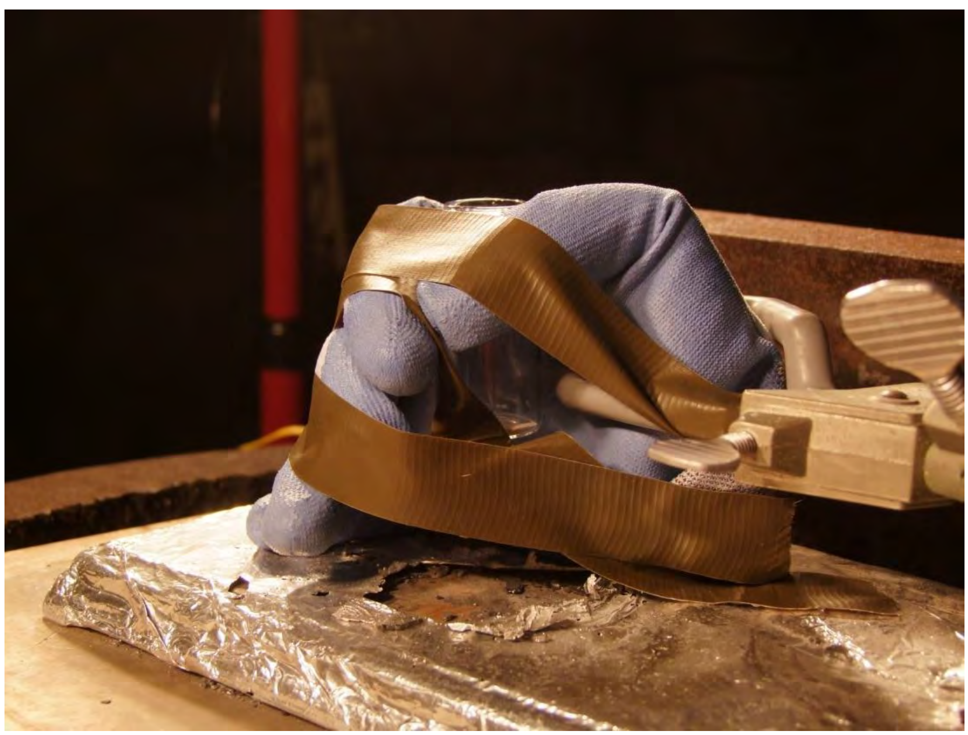

Figure A-2
Test apparatus with the AnsellPro HyFlex® 11-518 glove, showing glove's palm and lead azide

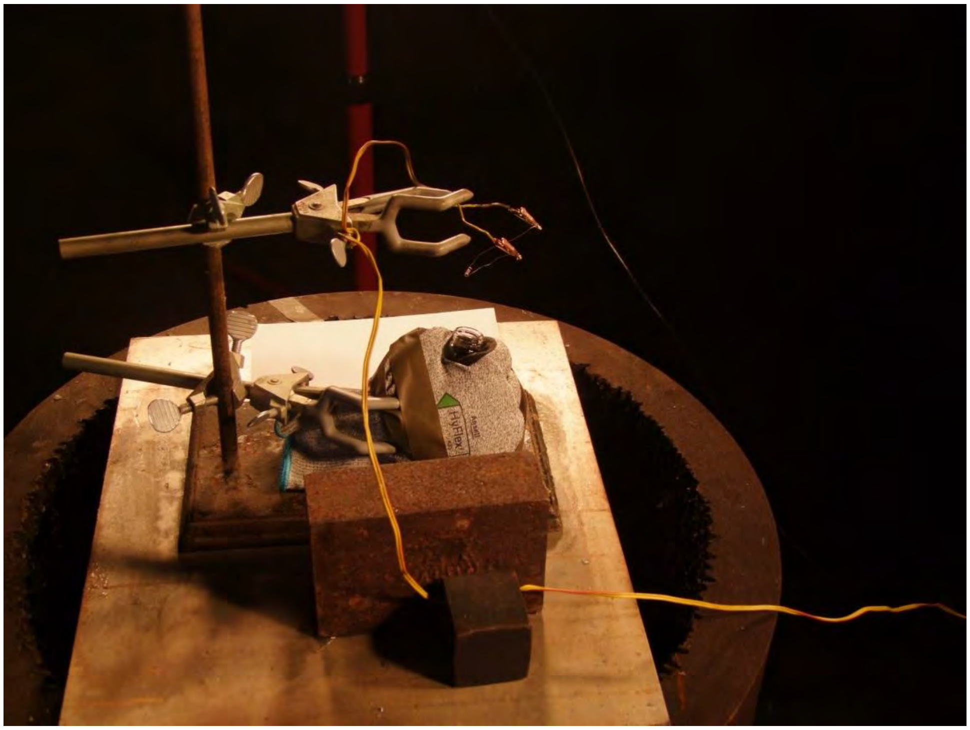

Figure A-3
Test apparatus with the AnsellPro HyFlex® 11-435 glove, also showing the nichrome wire with leads prior to being lowered into the vial

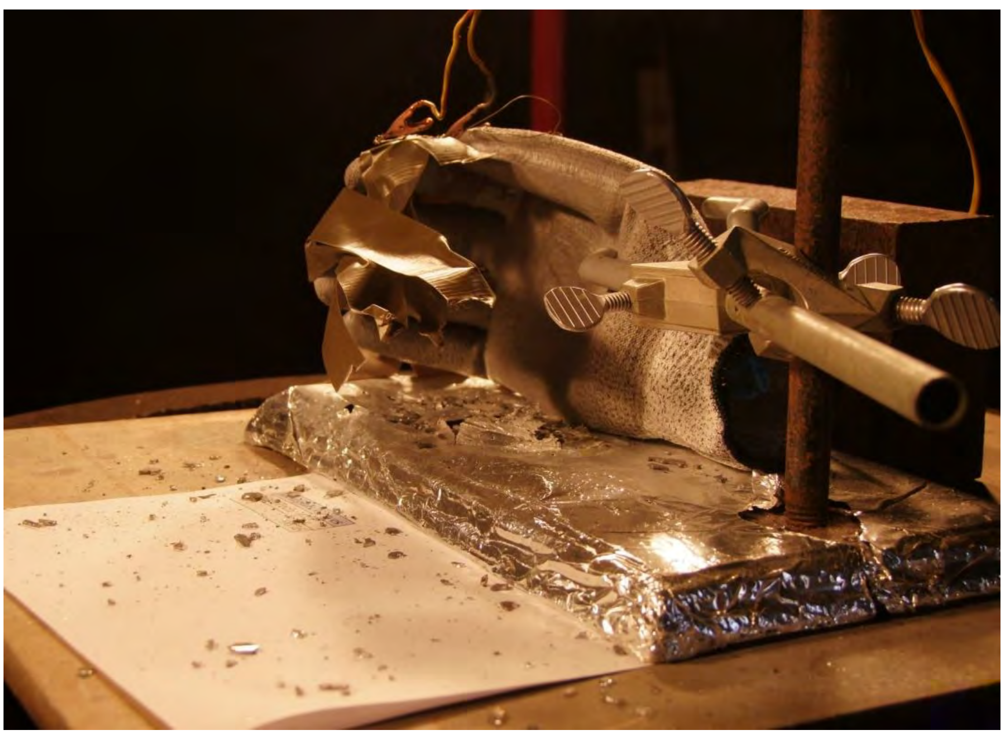

Figure A-4
Memphis UltraTec h® 9676 glove after detonation, showing scorching

Figure A-5
Memphis UltraTech® 9693 glove after detonation, showing scorching

Figure A-6
Representative of glass particulate size from detonation of 20 mL vial

Figure A-7
Test of bare “hand” (nitrile glove only) with large laceration in ring finger

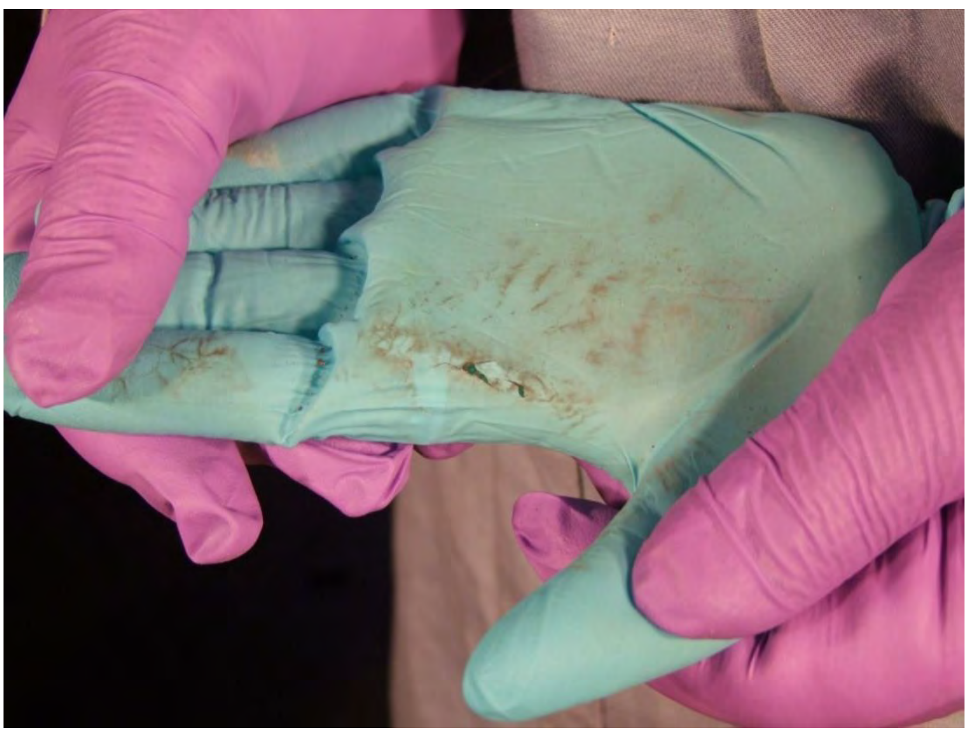

Figure A-8
Test of bare “hand” (nitrile glove only) with large laceration in palm

Figure A-9
Shows a Best T-Flex 8115 glove after detonation

DISTRIBUTION LIST

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January 6, 2016

RDAR-CIS

MEMORANDUM FOR Robert Stokes, Technical Information Specialists Defense Technical Information Center, 8725 John J. Kingman Rd, Fort Belvoir, VA 22060

SUBJECT: Glove Testing for Performance Against Flying Glass Shards Report

This letter is to request that the previously submitted technical report ARMET-TR-13040 by authors Peggy Sanchez, Emily Cordaro-Gioia, Tina Stouch, Anne Marie Petrock, and Daniel Stec entitled, "Glove Testing for Performance Against Flying Glass Shards" be changed from Distribution B to Distribution A. This change has been approved at the directorate level per the attached 3002f form. The original submission date was 9/10/2014 with e_doc no. 1410361601. We have resubmitted the report as e_doc no. 1449756300 as the cover and footers needed to be updated to reflect the requested change.

ANDREW J PSKOWSKI
Technology Protection Officer
US Army ARDEC