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TECHNOLOGY REPORT:
Ballistics
&
Polyurea Coatings

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The Impact: Traveling Faster than the Speed of Sound, Protective Coatings at Work

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Learning Objectives: *Discuss history and new advances related to polyurea spray coating systems in ballistic applications, present the history of this application work, achieve an understanding that the polyurea technology is: not bullet proof, offers elastomeric qualities for protection, protects crucial substrates, and possess ballistic qualities.*

Abstract: When protective coatings are considered for application work, normal uses such as concrete coating, waterproofing, abrasion protection; steel corrosion protection; and, other protective applications are the norm. However, there is a whole world of other uses for protective coatings including personal protection applications. The reality is that coating systems are being used for a variety of government, military, police and personal protection applications with excellent results. And the "polyurea" technology has been leading the way in this application area. And while there has been some misleading information presented or implied over the years, this presentation will discuss the history related to this subject and polyurea, and will present the truth and facts, polyurea coating and lining systems are NOT bullet proof, but does have ballistic qualities!

INTRODUCTION

"The heart Ramon. Don't forget the heart. Aim for the heart, or you'll never stop me." Those iconic words were spoken by the poncho-clad Joe, the Stranger, when facing off against the bad guy Ramon Rojo in the original spaghetti Western.[1] With a steel chest-plate hidden beneath his poncho, he taunts Ramon, who becomes very distressed as the rifle shots bounce off the hidden "ballistic steel-plate."

For centuries, people have been trying to protect themselves from projectiles. This has evolved from hand-held shields made of stretched leather over wooden frames, complete wooden shields to shields made of steel, coupled with chain-mail body armor, specialty woven silk fabric, to specialty metals. This progression has come about as the type and speed of projectiles used in combat have also evolved.[2]

The type of protection required was based upon the type of projectiles being delivered. Initially these were handheld clubs or spears, with developments later that would project an object through a mechanical means, such as hand drawn bow and arrow or mechanical crossbows. Currently protection is based upon projectiles delivered at very high velocity through handheld devices commonly referred to as firearms. For reference, the average speed of sound is 1126 feet/sec (343 meters/sec, or 768 miles/hour, or 1215 km/hour) at 20°C.

The National Institute of Justice (NIJ) notes various levels of body armor classification. This is based up projectile speed and weight with a certain kinetic energy. For example, a baseball thrown by the average professional pitcher will develop a kinetic energy of about 85.5 ft-lbs (116 joules). This is based upon a weight of 5 – 5.25 oz (155 – 165 grams), thrown at a speed of 90 miles per hour (mph), or 40 meters/sec. Getting hit by that baseball will cause a great deal of pain and possible injury including bruising and chipped or broken bones.

In ballistics, a common 9mm pistol round will develop a kinetic energy of about 350 ft-lbs (475 joules). This is based upon a weight of 115 grains (7.5 grams) traveling at over 1100 feet/second (335 meters/second). Upon impact, this projectile will do considerable more damage than the thrown baseball.

Current ballistic armor is rated based upon the above into several types of protection levels.[3] There are similar ratings through Euronorm EN Standards, DIN standards (Deutsches Institute for Normung) and British Standards (BS). These ratings are provided in Table I below:

Table I

NIJ Body Armor Classification

Classification	**Projectile Type**
Type I	.22 L.R., .380 ACP
Type IIA	9 mm, .40 S&W
Type II	9 mm, .357 Magnum, .45 ACP
Type IIIA	9 mm +P, .44 Magnum
Type III (Rifles)	5.56 X 45 mm, 7.63 X 51 mm
Type IV (Armor Piercing)	7.62 X 63 mm

* L.R. = Long Rifle; ACP = Automatic Colt Pistol; S&W = Smith & Wesson; +P = High Velocity

In Figure 1, these various cartridges are shown with mm scaling for reference.

Figure 1, Cartridge Comparison
L. to R., .22 LR, .380 ACP, 9 mm, .45 ACP, .357 Magnum, .44 Magnum,
5.56X45 mm, 7.62X35 mm, 7.62X51 mm

Various polymeric materials have been proposed for use in a protective armor to produce these blast or shrapnel-resistant structures and components. Materials such as ceramic plates, ultra-high molecular weight polyethylene (UHMWPE), poly-aramid materials, which are commonly referred to as "KEVLAR" as well as polymeric matrixes that are fiber-reinforced, formed from one or more of the aforementioned polymers, and have been found to exhibit ballistic dampening characteristics.

Examples of the various current armor systems are provided in Figures 2, 3, & 4.

Figures 2, 3 & 4
L to R: Soft Armor, Composite Armor & UHMWPE Armor

An example of this protective type soft armor first evolved in 1943, and was referred to as a "flak jacket" to minimize wounds and effects of shrapnel during World War II. With much development in place, the late 1950's provided the soft armor protection, though somewhat heavy, as the Vest M-1951 and the Armored Vest M-1955. The protective vests were a combination of layers of poly-aramid fabric and composite plates made of compressed fiberglass laminates, called the Doron Plate.[4] These composite plates were covered in fabric, and the purpose for that will be discussed later in this text. An example of the M-1955 vest is given in Figure 5.

Figure 5
M-1955 Armored Vest

While exhibiting favorable physical and performance characteristics, including but not limited to high strength-to-weight ratios, high tensile and high impact resistance and resistance to shock loading, these materials are not without drawbacks and challenges. Among these are friable and susceptible to surface chipping and flaking. It is also difficult to provide a durable, long lasting aesthetic or protective coated surface to such materials.

These drawbacks are particularly noteworthy in applications such as the production of blast and shrapnel armor for location in various wear and traffic regions; for example in the floors and wall regions of aircraft and various motorized vehicles. Panels and other constructs formed from a suitable armor material are attached to the associated vehicle structure to provide protection to the occupants. While these panels impart elevated armored protection, the materials are susceptible to wear such as gouging, chipping and flaking as items such as cargo or ordinance related items are dragged or dropped on panel surfaces during routine use and operation. Additionally, such materials are difficult to paint or coat due to lower adhesive characteristics inherent in the polymeric materials composing the panels. [5]

Thus, it would be desirable to provide a coating composition that could be used to coat at least a portion of the surface of a friable substrate. It is also desirable to provide a coating composition that can be employed to encase a suitable substrate and adhere thereto. It would also be desirable to provide a coating composition that can adhere effectively to a substrate with challenging adhesion characteristics. Finally, it would be desirable to provide a coating composition that could be used with an associated armor panel without unduly compromising the ballistic or blast resistance of the panel or other such structural component.

The level of armor protection is achieved by using various layers of the UHMWPE and / or polyaramid fiber sheets. To achieve the Type IIA would require approximately 18 sheets, Type II with 21 sheets and Type IIIA at about 35 sheets or layers. Interestingly enough, soft armor panels are being sold as brief case and back pack inserts for students.

Protective Coatings In Play

Since the spray applied, plural-component polyurea elastomeric technology (PUA) was developed and introduced in the late 1980's a variety of application interests have been demonstrated. While most related to protective coating work, there were some unusual application areas. One included the use of spray applied technology to produce shooting targets, called "Ivan's," for the US Military in training.[6]

The elastomeric polyurea system was spray applied into an open mold to produce a variety of shape and "human-form" targets for military training exercises. The polyurea was applied at dry film thickness (DFT) of 125 to 250 mils (3.1 to 6.4 mm). Shooting at these polyurea targets with Type IIA through Type IV classifications (from Table 1) did exhibit complete penetration of the projectile. Due to the elastic qualities of the polyurea though, multiple shots could be taken without considerable damage to the target. While there was no projectile stopping power with the polyurea, an interesting result was achieved with the holes "re-sealing" themselves. Later, the use of chopped aramid fiber was the introduced into the spray pattern of the polyurea system to provide for true ballistic qualities.[7 - 8]

Figures 6 & 7 show the effect of entrance and exit areas of a panel of aromatic polyurea applied at a DFT of about 250 mils (6.4 mm).

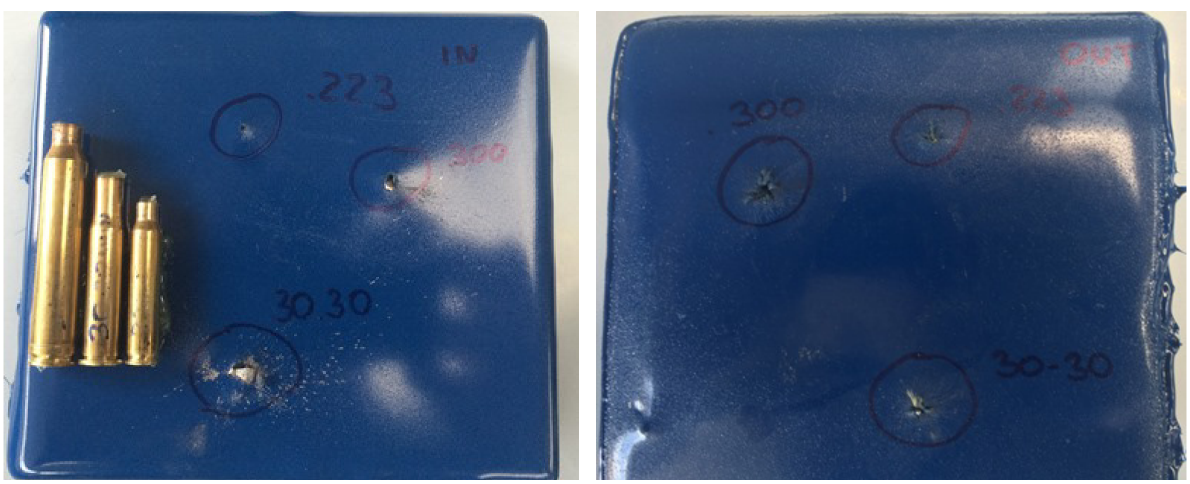

Figure 6 & 7
Ballistic Entrance and Exit in Polyurea Panel
Photos courtesy of Hercules, GmbH

Work in recent years has shown the same results as those identified back in the late 1980's. The polyurea system could be applied to existing steel components of military vehicles to help reduce the effect of blast shrapnel and small arms fire, but the polyurea itself is NOT BULLET PROOF! [9 - 13] In order to actually stop the bullet travel, the polyurea by itself would have to be applied at a thickness of well over 1-inch (2.54 cm), adding considerable weight and dimension, given that a 1 ft^2 piece of polyurea (0.1 m^2) at 1-inch thickness would weigh over 5.5 lbs (2.8 kgs).

In illustrating this, various thicknesses of a typical aromatic polyurea elastomer were subjected to impact from various projectiles identified in the NIJ Classification (Table I). An 80 mil layer (2 mm) was subjected to three rounds of a .22-cal projectile (Type I Classification), with the polyurea at 80° F (27° C). A similar piece, but at 6° F (-15° C) was subjected to the same to show the retained flexibility of the PUA at low temperature exposure. These are shown in Figure 8 and 9. For the 6° F testing, both a Shore A 80 (soft) and a Shore D 50 (hard) sample was used. [14] The harder system (Shore D 50) exhibited cracking at the high velocity impact area, whereas the softer system (Shore A 80) did not. This is somewhat expected given the high velocity projectile.

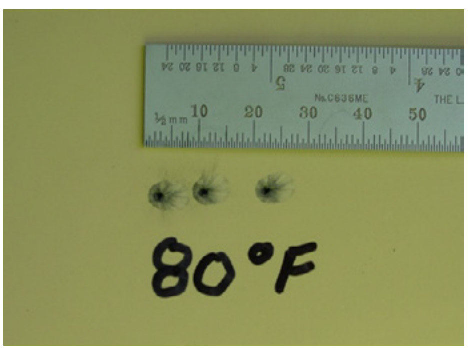

Figure 8
Soft, 80° F Temperature

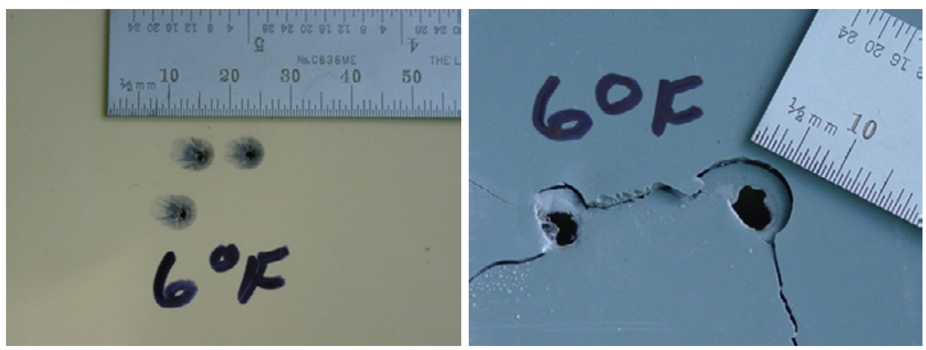

Figure 9
Soft and Hard System, 6° Temperature

Note that for both samples, the projectiles completely passed through the 70 mils (1.8 mm) of PUA. The projectile at 40 grains (2.6 gms) weight, traveling at 1200 ft/sec (365 m/sec) and generating about 140 ft-lbs (190 joules) of energy at impact.

Taking this further, 3 different NIJ Classification projectiles were tested with the same aromatic PUA to determine the level of penetration. These results are shown in Table II

Table II
Effect of Type I, IIA, II & IIIA Ballistic Classifications on PUA

	.22 Cal	9 mm	.45 ACP
Diameter	.22 in / 5.56 mm	0.354 in / 9 mm	0.45in / 11.4 mm
Weight	40 grains / 2.6gms	115 grains / 7.5 gms	230 grains / 14.9 gms
Velocity	1200 ft/sec / 365m/sec	1100 ft/sec / 335 m/sec	853 ft/sec 260 m/sec
Energy	140 ft-lbs / 190 joules	350 ft-lbs / 475 joules	372 ft-lbs / 504 joules
Layers Penetrated	8	36+	32 (trapped)

** 70 Mils (1.8 mm) Dry Film Thickness per Layer*

Protecting the "Plates"

So given the above discussion and that polyurea by itself is not bullet proof, where does this technology fit? Since most ballistic plates are either soft armor with the polyaramid fiber, or composite pieces of fiber, ceramic or steel, the panel must be protected from damage that may render it ineffective. The big concern with ballistic plates is bullet fragmentation, thus causing injury, or plate shattering after multiple hits. So the applied polyurea coating system is not the ballistic part, but to protect the plates and trap any bullet fragmentation that may cause subsequent injury or damage.[15]

As referenced earlier, the "Flak Jacket" of the 1950's contains both soft and rigid armor. The rigid armor included the 130 mil (3.3 mm) Doron plates encased in nylon and cotton fabric rapping and placed in pocket cavities of the vest. The purpose of the rapping is to assist in the trapping of the projectile fragments. This means that encapsulating the ballistic panel with a trapping material is not a completely novel idea. Figure 10 shows the fabric encapsulated plate, while Figure 11 shows the same plate after impact from a Type IIIA projectile. In this case a .45 ACP, common round of that era. But as shown, the fabric panel is effective, but significant damage to panel is noted.

Figure 10
Bare Plates

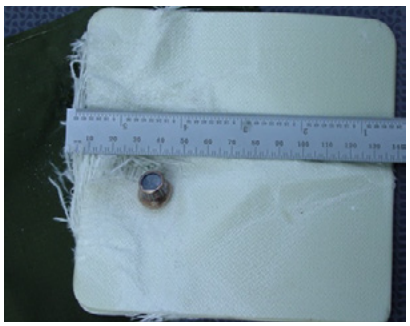

Figure 11
45ACP Impact

Using a .22-cal Subsonic round though with 1000 ft/sec (305 m/sec) and 93 ft-lbs energy (126 joules), the plates are effective. Hence the primary use of these for "flak" or low velocity fragmentation, Figure 12

Figure 12
Subsonic impact

Figure 13 provides an example of a current polyurea composite panel used by the US military to help protect our troops in combat situations, reaching a classification level of Type IV.

Figure 13
Polyurea Encapsulated UHMWPE Composite Panel

To show the effectiveness of these polyurea protected UHMWPE composite panels, a 10" X 10" (25.4 cm X 25.4 cm) composite panel of overall thickness of 20 mm was subjected to 3 rounds of 7.62 rifle caliber projectile. The 20 mm plate was composed of 18 mm thickness of UHMWPE, encapsulated with 40 mils (1 mm) of polyurea. The projectiles were 155 grains (10 grams) each with a velocity of 2000 ft/sec (610 m/sec) and energy of 1365 ft-lbs force (1850 joules). This represents a Type III (rifles) classification

The composite panel trapped all 3 rounds within the first of the total panel thickness, with no complete penetration. The entrance hole in the polyurea coating was only 2 mm. The back side of the panel was bulged for the impact, with no breach in the applied polyurea coating. The following series of figures show the effectiveness of this polyurea composite panel from a bullet proof nature.

Figure 14
Composite Panel Tested

Figure 15
Entrance holes in Composite Panel

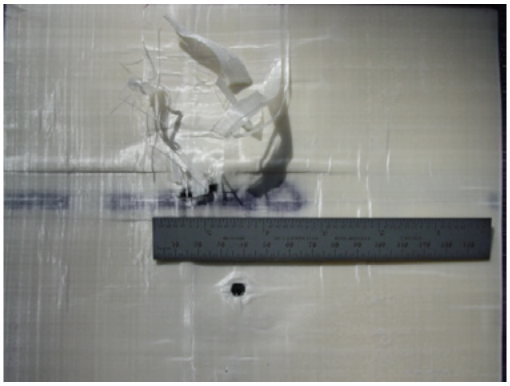

Figure 16
Front Side

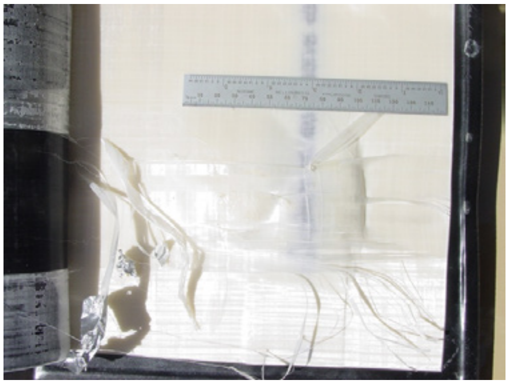

Figure 17
Back Side

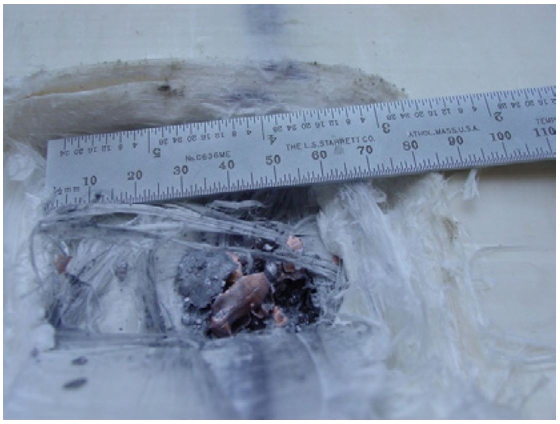

Figure 18
Lodged / Disintegrated Projectiles

So what happens when a high velocity projectile impacts a hard ballistic plate? The projectile completely disintegrates and will splatter high velocity shrapnel 90-degrees (perpendicular) to the direct impact area. Traveling at high velocity, the shrapnel will in effect do considerable damage to the outlining areas. The following series of figures show the effect of both uncoated ballistic panels and polyurea protected ballistic panels with respect to projectile fragmentation and the "trapping" effect.

Figures 19 and 20 show the effect of high velocity impact on a ballistic steel panel. The panel was surrounded in a "soft" area using paper and cardboard. Note that in Figure 20, the outlying "soft" area is completely cut like using a sharp knife, or more descriptively, a buzz saw.

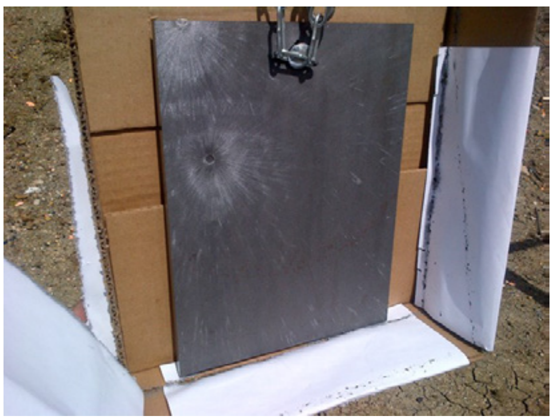

Figure 19
Ballistic Panel Impact

Figure 20
"Soft" area Damage from Shrapnel

In order to minimize, or even eliminate the dispersion of shrapnel from the projectile impact on the ballistic panel, and application of a tough, eleastomeric polymer system, such as polyurea spray coating, can be used. This coating can be applied at varying thicknesses depending upon the NIJ classification level. This layer of coating will either dissipate the shrapnel effect, or even trap the projectile completely.

Figures 21 and 22 show the effect of projectile impact on a polyurea coated ballistic panel. Note that no shrapnel splatter occurred (Figure 21) and the projectiles were completely trapped between the coating layer and the ballistic panel (Figure 22).

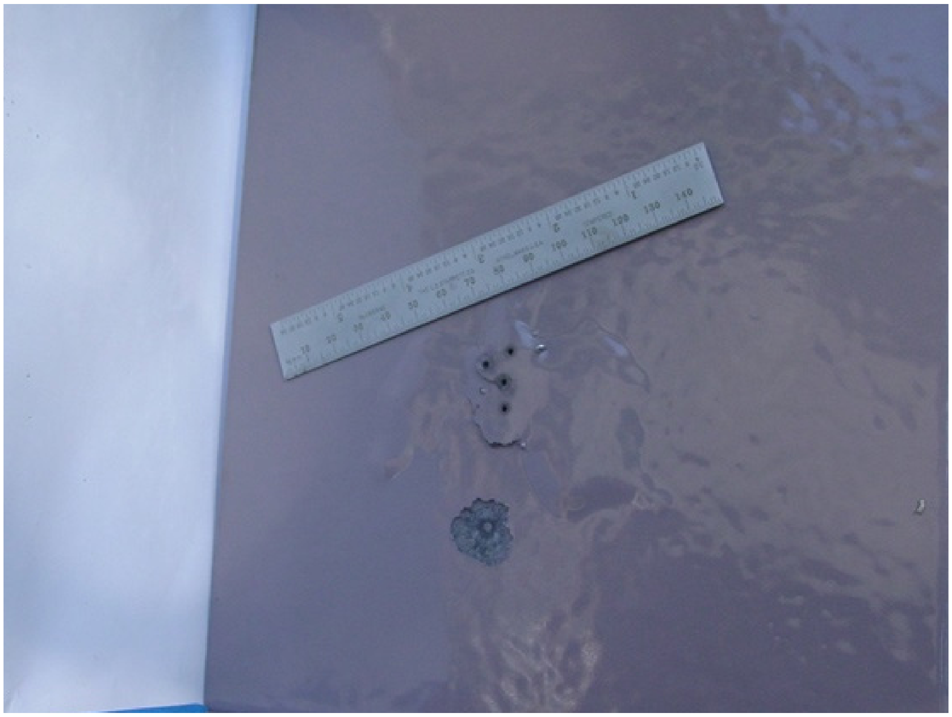

Figure 21
Polyurea Coated Ballistic Panel, no Shrapnel

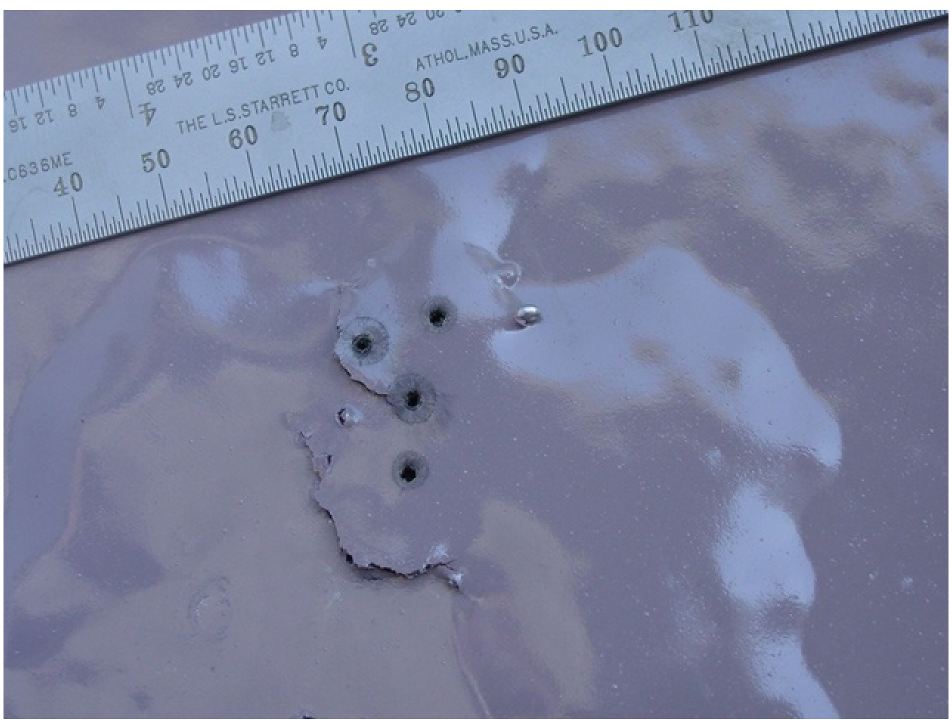

Figure 22
Trapped Shrapnel and Projectile

The Sealing Effect

Noted previously, one of the unexpected advantages of the polyurea technology from the earlier ballistic work of 1987, after the projectile passed through, the elastomeric qualities of the system allowed for the penetration to reseal itself. This is an interesting lubricating effect by the polymer on the projectile, and is a very important characteristic in normal coating and lining work. In many cases, nails or bolts may be driven through the coating, and the re-sealing effect minimizes leakage through the membrane. This is especially important in the common waterproofing work the technology is typically used in.

But how can this apply to ballistic applications? In many situations, storage tanks either permanent or moving, may contain highly flammable materials. If these tanks are located in hostile zones, they may be shot at. While an explosion or fire would not necessarily occur, a subsequent projectile may then cause a spark and ignite the leaking flammable fuel. By coating these structures with an elastomeric polyurea system, the leakage is minimized, and the steel substrate is shielded from sparking from a projectile.

To illustrate this, a 1/8-inch (3.18 mm) steel plate was coated with approximately 100 mils (2.5 mm) of an elastomeric aromatic polyurea system. The steel plate was prepared as per SSPC-SP 5 White Metal Blast Cleaning, with a profile of 2 mils (50 microns). [16]

The following figures illustrate the sealing effect of the polyurea system applied to a substrate after subjecting to projectile impact. The two projectile cartridges used represent that most common in in hostile areas (Type III Rifles).

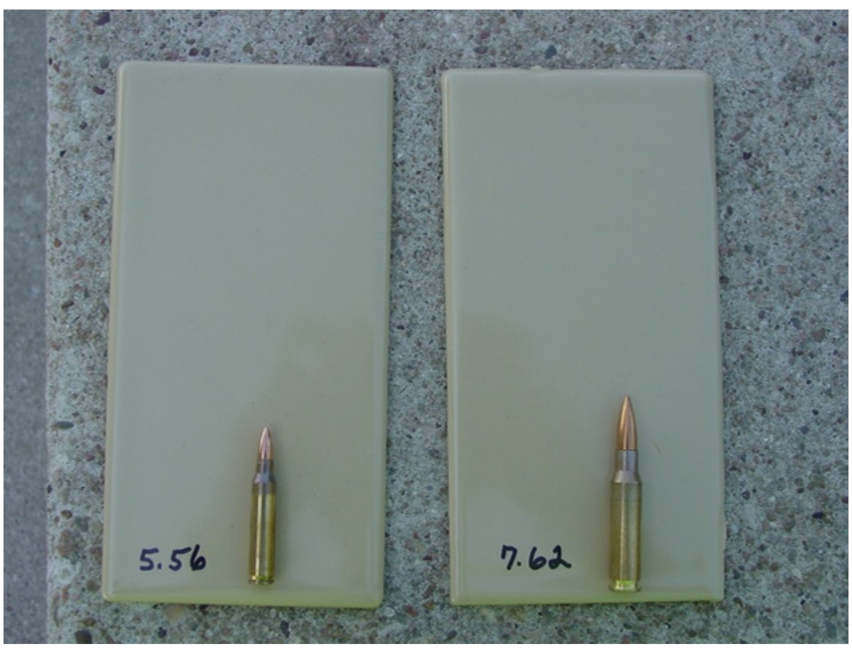

Figure 23
Polyurea Coated Steel Panels for Testing

Figure 24
5.56 mm Projectile Entrance

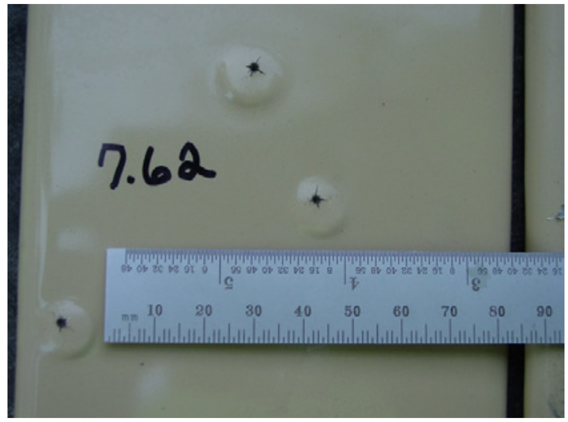

Figure 25
7.62 mm Projectile Entrance

Figure 26
5.56 mm Projectile Exit


Figure 27
7.62 mm Projectile Exit

Note that the exit holes in the steel plate are larger in diameter than the actual diameter of the projectiles. However, the applied polyurea remains well bonded to the steel area around the holes, and has "re-sealed" the projectile entrance hole.

To test the sealing effect, a device was fitted to the back side of the steel panel around the exit hole. Fluid was introduced into the device, and then pressurized to determine the required pressure to show fluid leakage from the projectile entrance area (Figure 28). The liquid used had a viscosity of 1 centipoise (cps), 1 millipascal) at a fluid temperature of 77°F (25°C). These results are shown in Table III.

Figure 28
Simple Pressure Device for Leak Testing

Table III
Sealing Effect of Applied Coating

	Projectile	
	5.56 mm [a]	**77.62 mm [a]**
Weight, grains	55	150
Grams	2.56	9.72
Velocity ft/sec	3200	2800
m/sec	975	853
Energy, ft-lbs	1250	2650
joules	1695	3593
Coating adhesion to Steel, psi	> 500 [b]	> 500 [b]
MPa	> 3.4	>3.4
Exit hole diameter, mm	6.85	8.15
Sealing effect, fluid pressure, psi [c]	6 - 8	5 - 7
kg/cm^2	0.41 - 0.56	0.35 - 0.48

[a] Full Metal Jacket (FMJ) Ball Ammunition.
[b] Cohesive failure of the coating surface, no adhesion loss.
[c] Testing at 77°F (25°C) using a liquid with 1 cps (1 millipascal) fluid viscosity.

The Polyurea Technology

Polyurea is a technology and not a product. Just like with other coating technologies, there is not a "one-size-fits-all system." For the polyurea technology, and there are two basic type systems for this application area; one which provides the ballistic trapping effect, and one for the sealing effect. Table IV provides the general characteristic of both systems.

Table IV
Polyurea Systems for Ballistic Applications

Physical Property	PUA System 1 (VF 330™) Ballistic Composite Coating	PUA System 2 (VF 380™) Sealing Effect
Tensile Strength, psi	3670	1500
MPa	25.3	10.3
Elongation, %	285	350
Shore D Hardness	55+	38
Shore A Hardness	---	85
Tear Strength, pli	520	~ 385
Modulus of Elasticity, psi	not reported	~ 1000
MPa	not reported	6.9
High Temperature Cyclic Storage[17]	pass	NA/NT
Low Temperature Storage[17]	pass	NA/NT
Contamination by Fluids Immerson[17]	pass	NA/NT
Resistance to Bacterial Growth[17]	pass	NA/NT
Fire Resistance[17]	pass	NA/NT
Adhesion, ASTM D 4541 psi/MPa[18]	NA/NT	>500 / 3.4

* NA/NT = Not Applicable / Not Tested

CONCLUSION

This paper shows how applied protective coating systems, such as the polyurea elastomer coating technology, can also provide a level of personal protection. Polymeric composition systems are suitable for use in a variety of coating applications for use with friable or easily damaged substrates and with materials having poor adhesion characteristics. More particularly, the compositions presented here relates to materials that can be used to coat blast resistant and shrapnel resistant panels and the like. As this world seems to grow more violent, the need to protect our military, law enforcement, as well as citizens is important. Protective coatings, such as the polyurea technology, play a key role in this application area. But before you decide to spray yourself a suit of polyurea, just remember, polyurea by itself is NOT bullet proof! Oh and Joe the Stranger? Lucky for him his metal ballistic plate was covered with his heavy wool poncho, otherwise he could have suffered injury from the fragmentation of the projectiles.

Acknowledgement

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