2004-01-1518

Ballistic Armoring of Passenger Cars on the Assembly Line Adds Quality and Passengers Comfort by using Advanced and Light Weight Composite Materials.

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ABSTRACT

Light weight composite materials were developed to provide ballistic protection to automobiles against handgun bullets and to increase passengers comfort by the elimination of UV radiation and reduction of infra-red solar energy and interior noise, without compromising the driving performance of the car. Structural designs were incorporated to be able to armor the car on the assembly line with the added benefits of turn-over time, cost reduction and quality of the finished assembly.

Weight reduction of armor materials have been achieved with CrystalGard® and YellowGard®. For windows and windshield, CrystalGard® 17mm provides better ballistic protection against NIJ Level IIIA with a 27% weight reduction than the standard 21mm glass solution by using a double layer of polycarbonate. SolarBlock® eliminates the UV radiation and reduces 95% of the infra-red solar energy for added passengers comfort.

For the ceiling, doors, dashboard and trunk, YellowGard® provides more than 80% weight reduction when compared with steel and reduces interior noise. YellowGard® is a thermo-formable Kevlar® fabric coated with a thermoplastic resin developed for ease of installation during assembly, resistance to high temperature and humidity, and reduced delamination upon multiple bullet hits.

Advantages of online assembly of ballistic protection include the reinforcement of the door latch and column areas for durability, the adjustment of the suspension system to the original driving performance changed due to the extra weight, and the installation of the Kevlar® panels to the frame and doors during the assembly of the car to avoid cutting and welding the frame structure.

INTRODUCTION

As the population density of large metropolitan areas around the world has increased, so has crime. Since robbery assaults and kidnappings are daily events now in some major cities, protection against small arms threats is becoming a significant segment of the car armoring business.

Traditionally, the car armoring business has been hardening vehicles to protect diplomats, government personnel, VIP's and the transport of money. This paper addresses the Light Vehicle Armoring (LVA) market as the segment of the car armoring business where the level of ballistic protection required is mostly against 9 mm, .357 magnum, and .44 magnum ammunition from handguns or sub-machineguns.

In Latin America alone, 80% of the opportunities for the car armoring business are in Mexico, Colombia, and Brazil. During the past 5 years the number of small armoring companies within each of those countries have multiplied 3 to 5 times. Most of them are very small companies handling 5 to 8 cars per month, and only a handful of well-established companies armor more than 25 cars per month. We estimate a conservative total volume of 4000-6000 cars per year.

The high profit margins built in an armored car, the low capital investment required to run a garage like operation, the absence of quality assurance of the finished product and the non-existence of local business laws for armoring operations have fueled the proliferation of small vehicle armoring companies.

BACKGROUND ON STANDARDS FOR BALLISTIC RESISTANT MATERIALS

In the US the officially recognized standard for non-transparent ballistic resistant materials (armor) is the National Institute of Justice (NIJ) protocol 0108.01 (1) that includes a classification of six levels of ballistic protection and a test method to certify an armor system.

Level of Threat	Caliber Ammunition	Weight Grains (gr)	Velocity feet/s	Velocity m/s
I	22 LRHV Lead 38 RN Lead	40 (2.6) 158(10.2)	1050±40 850±50	320±12 259±15
IIA	9mm, FMJ . .357 Magnum, JSP	124 (8.0) 158(10.2)	1090±40 1250±50	332±12 381±15
II	9mm, FMJ .357 Magnum, JSP	124 (8.0) 158 (10.)	1175±40 1395±50	358±12 425±15
IIIA	9mm, FMJ .44 Magnum, SWC	124 (8.0) 240(15.6)	1400±50 1400±50	426±15 426±15
III	7.62x51mm,FMJ 308 Winchester	150 (9.7)	2750±50	838±15
IV	30-06 AP M2	166(10.8)	2850±50	868±15

Table 1 NIJ Standard 0108.01

Once the threat level has been selected, the ammunition and impact velocities are defined. The ballistic test procedure is a simple pass/fail test. The test requires five fair hits per panel, except Level IV that requires one hit.

The test specimen must be 5m from the muzzle and all shots must hit at least 7.6 cm (3 inches) from any edge and at least 5 cm (2 inches) from each other. To be certified, no complete penetrations are allowed at the specified impact velocities.

In Europe, the most recognized protocol for non-transparent ballistic resistant materials is the European Standard NE 1522:1998 (2). In contrast with the NIJ standard, the European standard includes a classification of seven levels of ballistic protection, from FB1 through FB7. The standard includes the 5.56 x 45 mm ammunition on threat levels FB5 and FB6. However, for rating bullet resistant glass (glazing) in the US, the Underwriters Laboratories (UL) Standard for Safety for Bullet-Resistant Equipment, UL 752, is the most popular standard (3), Table 3.

As the Tables show, although standards exist for rating ballistic resistant materials, there is not a worldwide accepted ballistic standard specifically for armoring vehicles, because all standards were developed having in mind applications other than armoring passenger cars. From country to country, arbitrary names are used to describe the ballistic level of protection. Non-standard ballistic testing allows for misinterpretation of velocities, number of hits, spacing between hits, and the bullet description.

Rating	Ammunition	Weight Grains (gr)	Velocity f/s (m/s)	Number of Shots
Level 1	9 mm FMJ	124 (8.0)	1,175 (358)	3
Level 2	.357 Magnum, JSP	158 (10.2)	1,250 (381)	3
Level 3	.44 Magnum , SWC	240 (15.6)	1,350 (411)	3
Level 4	.30 Caliber, JSP	180 (11.7)	2,540 (774)	1
Level 5	7.62 x 51mm, FMJ M80 military ball	150 (9.7)	2,750 (838)	1
Level 6	9 mm, FMJ	124 (8.0)	1,400 (427)	5
Level 7	5.56 x 45mm, FMJ	55 (3.56)	3,080 (939)	5
Level 8	7.62 x 51mm, FMJ M80 military ball	150 (9.7)	2,750 (838)	5
Supplementary Shotgun	12-Gauge rifle lead 12-Gauge 00 Lead buckshot (12 pellets)	437 (28.3) 650 (42)	1,585 (483) 1,200 (366)	3 3

Table 3 Underwriters Laboratories (UL) Standard for Safety for Bullet-Resistant Equipment, UL 752.

BULLET RESISTANT GLAZING

The most common ballistic resistant glass in the market is made out of layers of flat glass bonded with Polyvinyl Butyral on the striking side plus one layer of polycarbonate in the back bonded to the glass with polyurethane. The manufacturing process often involves vacuum bagging the whole glass-polycarbonate composite and laminating with a prescribed temperature and pressure in an autoclave.

Upon the bullet impact, the glass is broken by the projectile impact and by the compressive and reflective pressure waves that travel across the thickness. The polycarbonate layer in the back, a high tenacity thermoplastic, absorbes the energy by its plastic deformation and catches all the glass fragments as a spall liner.

The most common glass-polycarbonate composite in the automotive market today that meets the ballistic NIJ Level IIIA is 21 mm thick and weighs 49.8 kg/m^2. The construction is comprised of three layers of glass, each 6 mm thick, plus a 3 mm thick layer of polycarbonate on the back.

Since glass weight accounts for 70% of the weight increase when armoring a car, Gepco has developed the CrystalGard® *High Performance* (CG HP) glass technology that utilizes two layers of polycarbonate that provides a better ballistic performance when compared with standard laminated glass that uses only one layer of polycarbonate.

The CrystalGard® *High Performance* (CG HP) glass that meets the NIJ Level IIIA is 17 mm thick and weighs 38.0 kg/m2. The CrystalGard® HP laminated construction is comprised of two layers of glass, each 6 mm thick, and two layers of polycarbonate, 2 mm and 3mm thick respectively.

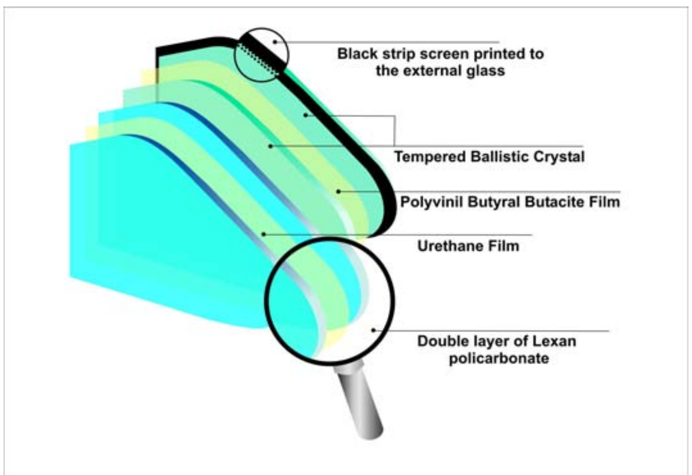


Figure 1. Automotive Laminated Glass Structure

When armoring a car, data shown in Table 4 demonstrate that CrystalGard® 17mm *High Performance* glass can be 27% lighter than the standard 21mm because the specific weight of polycarbonate (1.60 kg/m^2) is close to half the specific weight of glass (2.50 kg/ m^2).

Vehicle Model	**Original Glass**	**Conventional 21mm**	**CG4 HP 17mm**	**Weight Reduction**
Omega	44.87	168.16	122.56	27.12%
Montero	40.50	171.84	125.94	26.71%

Table 4 Weight (kg) comparison between standard 21mm laminated glass and the CrystalGard® 17mm High Performance for NIJ Level IIIA

In addition to weight and thickness reductions, the CrystalGard® *High Performance* laminate also has an improved delamination resistance and optical distortion characteristics obtained by bonding the 2mm thick layer of polycarbonate to the glass. This architecture allows the thinner 2 mm polycarbonate layer to reduce thermal stresses which are responsible for optical distortion and delamination that develop with normal use in laminated bullet resistant glass.

Those thermal stresses, which are proportional to the thickness of the polycarbonate layer bonded to the glass, come from the rather large temperature gradient between the interior of a vehicle and the outside, both during hot summer days and cold winter nights.

Worth noting is the fact that the last polycarbonate layer does not contribute to the thermal stresses generated at the glass-polycarbonate interface because of the compliance of the polyurethane thermoplastic adhesive. Therefore, its thickness can be adjusted to the ballistic requirements. By the same token, it is a limitation for the laminated glass that uses only one polycarbonate layer in the back.

BALLISTIC CHARACTERISTICS OF GLASS LAMINATED COMPOSITES

To further understand the ballistic performance of bullet resistant glass, a study was undertaken to investigate the influence of projectile energy, the sequence of the shots, and the thickness and sequence arrangement of the glass layers(4).

Samples of 50cm x 50cm in size and 49.1 ± 0.3 kg/m^2 of areal density were made utilizing three layers of flat glass with 4mm, 6mm, and 8mm in thickness and one 3mm thick layer of polycarbonate in the back. For lamination in an autoclave, 0.38mm Polyvinyl Butyral and polyurethane films were used. All samples with a 21mm nominal thickness (21.8 ± 0.2 mm) were tested against .44 Magnum JSP ammunition at NIJ Level IIIA velocities and all tested samples met the NIJ Level IIIA requirements with no-penetrations observed.

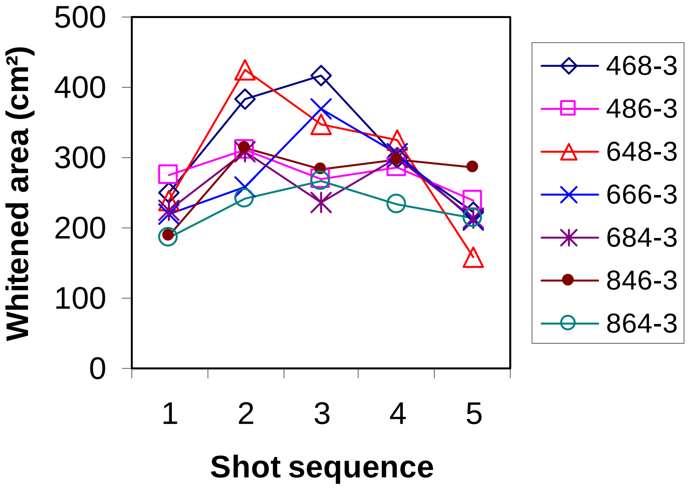


Figure 2(a). Delaminated area (cm^2) of the polycarbonate after each shot from laminated glass samples with different glass layers sequence of 4mm, 6mm, and 8mm thick glass.

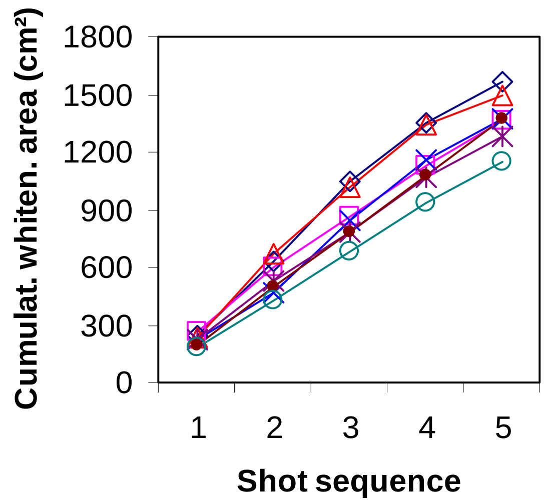


Figure 2(b). Accumulated delaminated area (cm^2) of the polycarbonate after each shot from laminated glass samples with different glass layers sequence of 4mm, 6mm, and 8mm thick glass.

The sequence of five shots was placed over the corners of a 20 cm square and the fifth at the center. Records included pictures from the front and from the back of the sample after every shot. For this study, samples were made with the following construction sequence: 468-3, 486-3, 648-3, 666-3, 684-3, 846-3, and 864-3. Where the first three numbers represent the thickness in mm of the glass layers and the number 3 is the thickness of the polycarbonate.

Digital image analysis was used to measure the damage area or area of delamination of the polycarbonate produced by each shot. Figure 2(b) clearly shows that, based on the accumulated area of delamination, the samples 468-3 and 648-3 were the worst and sample 864-3 had the best delamination characteristics. Sample 486-3 also had poor delamination characteristics.

The sample 864-3 displayed the smallest area of delamination per shot as shown in Figure 2(a) and the smallest accumulated area as shown in Figure 2(b). This observation demonstrated that the best ballistic performance of a laminated bullet resistant glass is achieved when the glass layer at the striking face has the largest thickness.

Figure 3 below shows the sequence of .44 Magnum shots on sample 666-3.

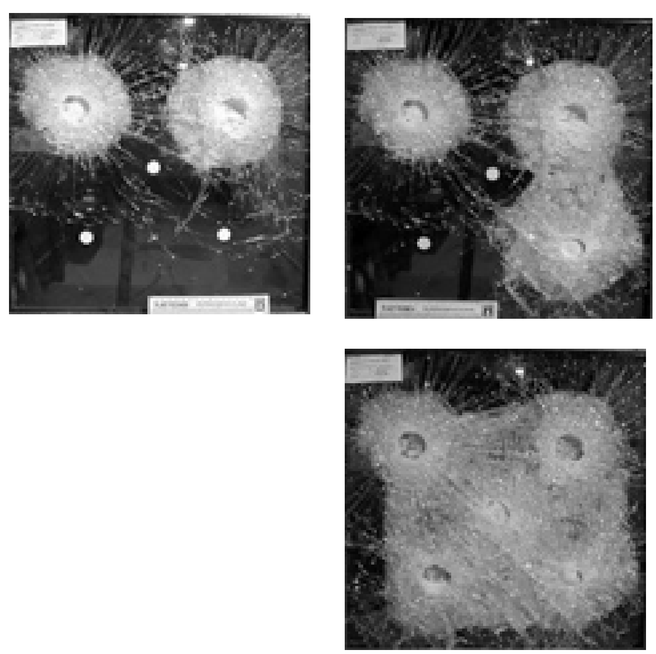


Figure 3. Sequence of .44 Magnum shots on sample 666-3.

GLASS-STEEL CLADDING FOR AUTOMOTIVE WINDOWS

It is common practice when armoring a vehicle to design an overlap between the side glass and the window frame by welding a 3 mm thick ballistic resistant steel plate to the inside of the window frame as part of the window slot and as a support for the thick glass when the window is closed. Figure 4.

However, many laminated glass manufacturers use a steel insert in the back set of laminated glass for side windows to replace the steel overlap. We have demonstrated that there is a high risk of bullet penetration in the overlap area if the steel overlap is replaced by glass-steel clad on the laminated glass back set.

Figure 4. Steel overlap welded on the window frame.

Ballistic testing was conducted against .44 Magnum JSP ammunition at NIJ Level IIIA velocities using flat glass samples 4 mm, 5 mm, and 6 mm thick bonded to 2 mm steel, and glass samples 4 mm and 5 mm thick bonded to 3 mm steel. All glass samples bonded to 2 mm steel experienced complete penetrations, while the glass samples bonded to 3mm steel did not have any complete penetrations.

Therefore, if steel is going to be laminated to the side glass to replace the steel overlap designed on the window frame, the first layer of glass on the striking face has to be 4 mm thick or less, so the whole back set can fit into the slot of the window frame. As a result, as we just have demonstrated it, having the first glass layer at the striking face with 4mm of thickness is the worst ballistic performance case for a laminated bullet resistant glass composite.

PASSENGERS COMFORT WITH LAMINATED BULLET RESISTANT GLASS – SOLARBLOCK®

The *SolarBlock®* technology (5) is a laminated bullet resistant glass architecture that combines two or three glass layers in the striking face with one or two polycarbonate layers in the back to control the solar energy transmitted into the vehicle's interior to reduce the heat accumulation and to increase passengers comfort.

The main characteristic of the *SolarBlock®* technology is the high capacity to block solar energy into the vehicle interior through a wide range of the light wavelength spectrum including UV (295-380 nm), visible (380-780 nm) and IR (780-2150 nm), by using a combination of clear, green, and reflective glass layers.

The largest contribution to the reduction of solar energy transmittance within the infrared (IR) light wavelength range comes from the green glass. By using the reflective glass technology further energy transmittance reductions of 17% are obtained within the visible light spectrum and 10% within the IR spectrum.

The reflective glass is a commercial bronze-coated glass developed by CEBRACE(6). The CEBRACE glass is made by using a metal organic spray pyrolysis deposition (MOSPD) at 600 ^{o}C after the float bath zone during the float glass manufacturing. The coating is achieved by a spray gun system that supplies chrome, cobalt, and iron acetate dissolved in methyl acetate. Under reducing conditions and enough temperature, metals diffuse onto the glass surface where they are incorporated into the oxide glass matrix as an amorphous structure of 6µm thick without porosity. The coating is very stable and resistant to cutting, grinding, silk-screening, heating, bending and tempering.

Samples were made to compare the energy transmittance reduction of the SolarBlock® technology with commercially available products (7). The SolarBlock® laminated glass construction was made with a 6mm clear glass as the striking face, a 5mm green glass, a 6mm reflective glass, and a 3mm polycarbonate in the back. The two commercially available laminated glass samples were: one with a reflective polyester film and the other, without the reflective film. Both samples we tested had an anti-spall film in the back.

To measure the effect of the reflective coating technology against the green glass, a fourth sample was made similar to the SolarBlock®, where the reflective glass layer was replaced by a 5mm clear glass.

has 55% of light transmission. This level of light transmission has such clarity and external visibility that it is used in armored curved glass for side windows.

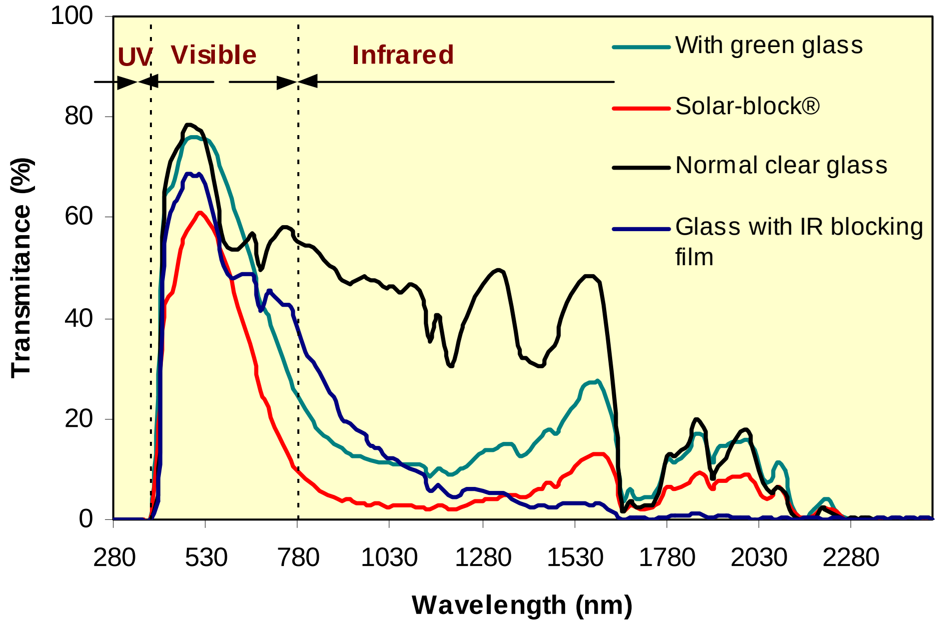


Figure 5. Transmittance spectrums of laminated armored glass samples: SolarBlock®, Normal clear glass, commercial with polyester film to block solar energy, and sample with green glass.

Figure 5 shows the transmittance spectrum of the four laminated glass samples across the UV, visible, and Infra Red light wavelengths. Within the UV wavelength range, all samples displayed minimal transmittance because all samples use Polyvinyl Butyral thermoplastic resin for bonding the glass layers. The commercial sample without reflective film showed the largest transmittance in the visible light and IR wavelength range.

The commercial sample with reflective polyester film showed significant reduction of transmitance when compared to the sample without the reflective polyester film and similar characteristics to the sample that use a green glass layer. However, the SolarBlock® sample showed the largest transmittance reduction of them all by using a combination of green and reflective coated glass.

Table 5 shows the % of light transmission, the % of energy blocked within the IR wavelength spectrum, and the % of total energy blocked by each of the laminated glass samples. The data demonstrate that the SolarBlock® technolgy not only has the highest level of energy blocked through the entire wavelength range of the light spectrum analyzed, 295-2150 nm; but also, it

Illumination A NBR 9491	**Light Transmission (%)**	**Infrared Blocking (%)**	**Total Energy Blocking (%)**
Armored Glass SolarBlock®	52	95	75
Armored Glass with Green Glass	69	85	62
Armored Glass Commercial Normal	62	56	48
Armored Glass with Polyester Film to Block Energy	55	85	65

Table 5. Results of light transmission, energy blocking within the Infrared wavelength, and total energy blocking (295-2150 nm wavelength) from laminated glass samples: SolarBlock®, commercial Normal, commercial with polyester film to block solar energy, and sample with green glass.

As always, when changes and improvements are incorporated in any laminated bullet resistant glass, the ballistic performance is what counts the most. As a result, a SolarBlock® sample 50cm x 50cm in size was prepared and tested against .44 Magnum JSP ammunition at NIJ Level IIIA velocities.

Figure 6 is showing the sequence of .44 Magnum JSP bullet shots on a SolarBlock® laminated glass sample. The pictures were taken from the striking face of the glass sample. The SolarBlock® sample did not have any complete penetrations and the product is now certified by H.P. White Laboratories, the most recognized independent ballistic laboratory in the US.

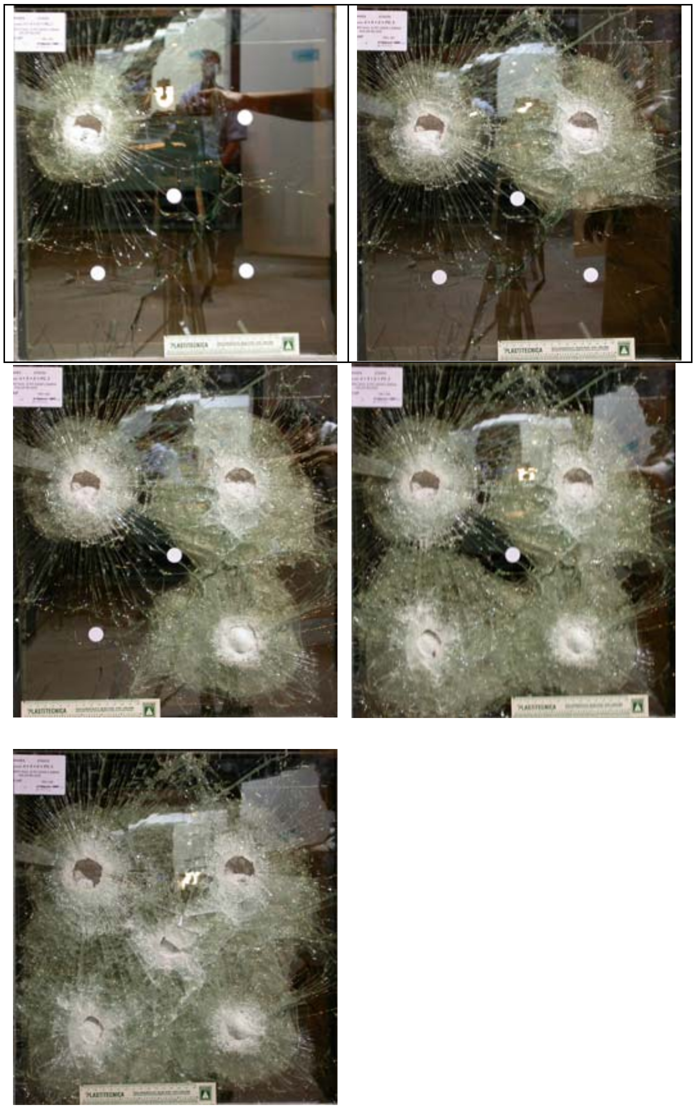


Figure 6. Pictures showing the sequence of .44 Magnum JSP bullet shots on a SolarBlock® laminated glass sample. The pictures were taken from the striking face of the glass sample.

NON-TRANSPARENT ARMORING

The most popular non-transparent materials for light vehicle armoring are thermoplastic resin or rubber coated fabrics of aramid fibers such as Kevlar® and Twaron®, laminated non-woven of ultra high molecular weight (UHMW) polyethylene fiber, polyester or epoxy impregnated fiberglass fabrics, and steels.

YellowGard®, developed in cooperation with DuPont, is a bullet resistant, thin, and flexible panel made with multiple layers of fabric of 3000 denier Kevlar® 29 fiber coated with a DuPont proprietary thermoplastic resin. The multiple layers YellowGard® panels are manufactured under pressure and temperature in an autoclave, cut to size and installed with adhesives in the various locations of the vehicle such as doors, floor, and ceiling. Figure 7.

YellowGard® panels have excellent ballistic performance, bond very well to steel, can take multiple hits, and delaminate less than panels made with laminated UHMW polyethylene. The YellowGard® panels are stable at high temperatures, don't spread fire, and also are waterproof and resistant to humidity.

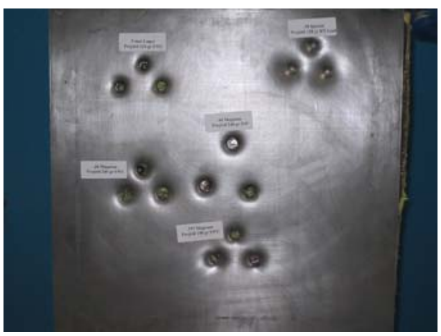
Comparing ballistic performance per unit weight, the YellowGard® panels are five times more efficient than steel. As an example, we have data for comparison between an Audi A3 armored with YellowGard® and an Audi A3 armored with 3mm thick ballistic steel. The non-transparent area of the Audi A3, armored to meet the NIJ 0108.01 Standard Level IIIA, was 6.25 m2 excluding the car's column and the doors locks. The armored weight with YellowGard was 27.5 Kg and 147.25 Kg with 3mm ballistic steel. Resulting in 119.75 Kg of vehicle weight reduction.

Figure 7. YellowGard® installed inside a door.

Since weight is not the only selection criteria for armoring panels, YellowGard® panels are thin, flexible, and thermo-formable, which help during the installation inside the car doors, Figure 7 and Figure 8(a). They have been tested for multiple hit capability, bonding strength to steel and delamination characteristics, as shown by the pictures in Figure 8(b) and 8(c).

(a) Flexible and Thin

(b) Bonding Strength to Steel



(c) Multiple Hits Capabilities

Figure 8. YellowGard® panels are displaying their characteristics. Thin and flexible (a), bonding strength to steel (b), and multiple hit capability (c).

Often, the car armoring companies design the ballistic protection taking into consideration the ballistic contribution made by the steel from the car door, which is a Cold Rolled (CR) 20 gauge steel. In cases where the external car body parts are made out of plastic or fiberglass, the YellowGard® panels are designed to provide the total ballistic protection in a "stand alone" fashion, as shown in Table 6.

Product Reference	NIJ Threat Level	Number of Layers	Panel Thickness (mm)	Panel Weight (kg/m^2)
YG 300	II	8 + steel	3.90	4.14
YG 400	IIIA	9 + steel	4.40	4.66
YG 500	IIIA	10 + steel	4.90	5.18
YG 700	IIIA	12	5.90	6.22

Table 6. YellowGard® Products for Light Vehicle Armoring.

Where "+steel" means that the panel is matched with the vehicle's plate, a 20 gage CR steel plate 0.60 mm thick.

As far as other armoring materials, fiberglass and steel o not fair well against YellowGard® in the Light Vehicle Armoring segment because of the ballistic performance and weight. However, because of their low cost, they still are very popular among less sophisticated small car armoring outfits.

Although light in weight and with excellent ballistic performance, the UHMW polyethylene non-woven unidirectional materials have poor bonding strength to steel, delaminate easily upon multiple shots, and experience significant drop in performance (lower V50) when exposed to temperatures in excess of 70^{o}C. These temperatures are easy to reach inside a vehicle under the sun in certain summer climates.

GEPCO-MITSUBISHI ON-LINE ASSEMBLY PROGRAM

Gepco and MMC Automotores do Brasil (Mitsubishi) agreed since August 2002 to combine efforts to engineer a system to armor cars on the assembly line that meet the NIJ Level IIIA ballistic protection level. A 2002 Mitsubishi Montero SUV was selected (Pajero TR4) for the demonstration phase. The armored SUV was successfully launched in August, 2003. Figure 9 below displays an assembly set of glazing and aramid ballistic panels for car armoring on line that Gepco supplies to Mitsubishi.

For twelve months, the major design and assembly challenges for Mitsubishi were:

1. Redesign and reinforce the window lift mechanism to accommodate the glass weight increase and redesign the window frame to install a 3mm thick stainless steel

overlap with the glass when the window is closed. This design change allows the installation of thicker and heavier armored glass directly on line improving the quality of the assembly and the durability of the armored glass.

2. Reinforced the hinge and latch areas of the door and the columns with 3mm thick ballistic steel. When the reinforcements are done before the body structure is treated for anti-corrosion, the quality improves because both the reinforcement and the welding are also protected against corrosion.

3. Built aluminum molds to form under pressure and temperature in an autoclave YellowGard® panels for perfect fit during installation of the panels in the doors, floor, and ceiling. This design change allowed the installation of the YellowGard® panels by one person during one 8 hour shift. In contrast with 3-4 weeks it takes most car armoring companies to take the car apart, install all the armor including the glass, and assemble the car back together.

The assembly of the panels on line improves the quality of armoring in many ways including the elimination of the cutting and welding of the door structures and the installation of the panels to the steel with a uniform bonding. Recognizing that the bonding strength of the panels to the steel contributes greatly to the ballistic performance of the assembly. In addition, the on line assembly allows the finishing of the car interior as a standard original vehicle.

Figure 9. Assembly set of glazing and aramid ballistic panels for car armoring on line.

4. Develop a suspension tuning to maintain the same basic ride and handling characteristics of a standard vehicle, because the weight increase due to the glazing and non-transparent armoring materials has implications on the vehicle dynamics.

The extra weight lowers both front and rear suspensions and changes the vehicle attitude. The non uniform distribution of the extra weight front to rear could result in a more nose-up appearance from the armoring. The extra weight also decreases the available jounce travel of front and rear suspensions which may create some bottoming concerns, especially when the vehicle is fully loaded.

More critical were the handling and safety concerns resulting from a dramatic change of location of the center of gravity (CG) of the vehicle and a significant displacement of the CG toward the rear due to the placement of the heavy armored glass in very high positions in the vehicle body. Those handling and safety concerns were:

Vehicle Body Roll: Armored vehicles, with the regular suspension tuning, present a much greater body roll in turns. This is noticed in constant speed cornering, but is even more critical in transient situations like a double lane change maneuver.

Vehicle Dive and Squat: Although both conditions deteriorate with armoring, dive is more critical and unpleasant to customer.

Stability: The combination of the increase in body roll, plus the CG move to the rear, change vehicle balance and generate an over steering behavior in turns and lane change maneuvers.

Confidence: The above mentioned deterioration in body roll plus the over steering tendency, reduce greatly the driver confidence in the vehicle. Especially annoying is the combination that results of both dive and roll when entering a curve in deceleration, which reduces greatly the feel, even at relatively low speeds.

A suspension package was successfully tested that provided the SUV with a ride and handling characteristics similar to the standard vehicle. That suspension package included increasing the stiffness and height under load of the front and rear springs, and adjusting the set-up of the rear shock absorbers and the pressure of the tires.

CONCLUSION

Armoring light vehicles utilizing CrystalGard® High Performance, SolarBlock®, and YellowGard® will provide an optimum balance of light weight, comfort and ballistic protection that is needed against the multitude of threats that are encountered in the cities around the world. Our research objectives are to continue advancing the science of light weight composite materials for ballistic protection and comfort for vehicle armoring and to provide the newest in technology solutions in the years to come.

ACKNOWLEDGMENTS

Gepco would like to thanks Mr. Aloysio S. Coelho from MMC Automotores do Brazil, Mitsubishi, for sharing their learning and experience during the design, development, and testing of ballistic armoring vehicles on the assembly line.

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CONTACT

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Dr. Folgar received a PhD in Mechanical Engineering from the University of Illinois at Urbana-Champaign in 1982. For the past 20 years he worked at E.I. DuPont de Nemours and Co., Advanced Fibers System. He was involved in metal matrix composites R&D for automotive applications; in the design, manufacturing and testing of the KM2 Kevlar® light weight US Army helmet; and more recently, in the development of Kevlar® technology for car armoring. In 2002, he retired from DuPont and started his own consulting company, INTER Materials, LLC. At present, Dr. Folgar provides R&D support to Gepco Indústria e Comércio, Ltda., in the field of composite materials for vehicle ballistic armoring and represents Gepco laminated armor glass products in Mexico, USA, and Canada. He can be contacted at 623 Muirfield Court, Richmond, VA 23236. Phone: (804) 378-6034. E-mail: ffolgar@comcast.net.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

Ballistic Limit, V50(f/s). The ballistic limit V50(f/s) is measured to determine the ballistic performance of a material or system. The V50 ballistic limit velocity is defined as the velocity at which the probability of penetration of a bullet or projectile is 50 percent. The test procedure is specified on the MIL-STD-662F latest revision dated December 18, 1997.