COMPOSITE ARMOR SOLUTIONS FOR STANAG 4569 BALLISTIC PROTECTION LEVELS

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SUMMARY

There are many different battlefield threats that armor on military vehicles must protect against. In order to consolidate these threats for meaningful comparison, various governing bodies have suggested specific protection levels. NATO has recently issued a specification, STANAG 4569, Protection Levels for Occupants of Logistics and Light Armored Vehicles. In this specification, lightweight protection against common threats used against NATO forces is desired. The threats are segregated into 5 levels of increasing magnitude. In order to support material development in this area, composite armor made from *S-2 Glass*® fibers and phenolic resin has been tested against the range of threat levels that this specification encompasses. At the low threat levels, fiberglass composite armor alone defeats the threat; however, at the higher threat levels, a multi-component armor made with a facing material is required. The composition, construction, and ballistic performance of the various composite systems used in this testing will be discussed.

1. INTRODUCTION

The study of terminal ballistics is a large and diverse field. It involves the physical penetration of a broad class of materials by a broad class of projectiles. Some of the projectiles have penetration mechanisms based on high velocities and overwhelming energies, and others on the ability to focus a maximum amount of energy on a very small pinpoint. Regardless of the tremendous number of possible incoming threats, armor designers must develop solutions that make sense to protect the soldiers that are likely to encounter the threat. NATO has recently revised a set of specifications that its forces are likely to encounter around the world. The original specification was written in May 1999, and included five increasing magnitude levels of ballistic protection. In May 2004 it was revised to include fragmentation and grenade and mine blast threats.

The threats that this STANAG 4569 specification covers are typical to the European battlefield. One way to defeat the threats listed in this specification is through the use of traditional monolithic metallic armor systems. These systems are quite well understood, and could easily be adapted to any of the new vehicles under development. The problem is that in order to defeat modern threats, which are becoming more and more lethal, a tremendous amount of the traditional armor is required. This amount of armor

S-2 Glass is a registered trademark of AGY often overwhelms the suspension and drive systems on light armored vehicles, making into slow, cumbersome, and unreliable. This paper is a compilation of work that has been done by AGY of Aiken, SC USA in an effort to develop lightweight armor solutions that can not only stop the ballistic threats, but can also be integrated into the core of the vehicle to provide structural and fire barrier protection as well.

2. MATERIAL PROPERTIES

The S-2 Glass/ phenolic HJ1 composite armor system is a patented system based on AGY's S-2 Glass/ reinforcement and a phenolic resin system. When properly processed, the system represents a new generation composite armor system relative to ballistic and fire/smoke performance. The system has been tailored for producing large flat panels using a compression molding process. Overall economics are attractive in that a 25 percent to 40 percent cost savings over comparable performing aramid armor systems is provided. The S-2 Glass/ HJ1 system was developed in the late 1980's and is now well established in many military applications both in the US and overseas. The benefits are equal ballistic performance at the same weight, improved fire/smoke performance, easier fabrication and lower cost.

Table 1. Mechanical Properties S-2 Glass/Phenolic Resin Composite Armor

Mechanical Properties – Phenolic System (HJ1)

Property	Standard	Average English	Average Metric
Specific Gravity	ASTM D792	1.96	1.96
Water Absorption	ASTM D570	1% (max)	1% (max)
Loss on Ignition	ASTM D2584	16-23%	16-23%
Tensile Strength	ASTM D638	70 ksi	485 MPa
Modulus		3.6 Msi	25 GPa
Elongation		4%	4%
Poisson Ratio		0.26	0.26
Flexural Strength	ASTM D790	26 ksi	180 MPa
Modulus		4.2 Msi	29 GPa
Flexural Strength, Wet		18 ksi	124 MPa
Modulus, Wet		3.9 ksi	27 GPa
Short Beam Shear	ASTM D2344	2.1 ksi	14.5 MPa
Bearing Strength	ASTM D695	38 ksi	262 MPa
In-plane Compressive			
Strength	ASTM D695	24 ksi	165 MPa
Modulus		4.4 Msi	30 Gpa
(0°/90°) Compressive			
Strength	ASTM D695	109 ksi	750 MPa
Modulus		0.5 Msi	3.4 Gpa

NOTE: Mechanical properties were determined from specimens of one-half inch thickness rather than thicknesses called out in ASTM standards.

The high tensile and compressive strengths of S-2 Glass/ fiber-reinforced laminates are key factors to both ballistic and structural performance. The fiber's high ultimate elongation (5.7 percent) plays an important role in the dynamic ballistic impactabsorbing mechanism. S-2 Glass/ fiber-reinforced laminates also allow a degree of design flexibility unavailable with other composite materials. Aramids, such as Kevlar/, typically bond mechanically to resin. S-2 Glass/ fiber reinforcements form both a mechanical and a chemical bond with the resin matrix through the use of chemical surface treatments applied to the glass during manufacturing. The bonding permits good structural performance in a ballistic performing composite laminate.

Ballistic performance of the HJ1 system against fragment simulating projectiles (FSP) is superior to metals and equivalent or better than aramid reinforced systems at the same areal density. The HJ1 armor system has a specific gravity of 1.96 g/cc, which is higher than aramid reinforced systems. The result: at equivalent thickness, the HJ1 will always provide superior ballistic performance to an aramid system. This is an important factor in space-limited applications.

In recent years, the effects of smoke and toxic gases have been singled out as being one of the leading causes of injury and death in fire. The requirements for interior finish materials onboard U.S. Naval ships are stated in MIL-STD-1623.
There are also NAVSEA (Navel Sea Systems Command) requirements for installing aramid-reinforced armor under the FFG-7 armor program. Improved polymer resistance to ignition and reduced rate of burning are key properties to delay or lessen the onset of total obscuration or combustibility for escape and/or rescue. To address this critical area, S-2 Glass/ armor system "HJ1" uses a phenolic resin matrix. Phenolic resins are fire-resistant materials with low smoke emissions and toxicity levels. In addition, the phenolic polymer structure facilitates the formation of a high carbon form structure, or char, that radiates heat and functions as an insulator. Use of a phenolic resin in conjunction with an inorganic glass reinforcement results in superior performance. The following table is a summary comparison of fire/smoke properties of HJ1 laminate and aramid-reinforced halogenated vinyl ester laminates[1]. It is easily seen from these data that the S-2 Glass composite armor system is superior in fire to aramid armor systems.

Table 2. Fire/smoke Properties of Two Composite Armor Systems

	Limiting Oxygen Index	*Limiting Oxygen Index*	*Smoke Obscuration*	*Smoke Obscuration*	*Flame Spread Index*
	23°C	150°C	Flaming	Smoldering	
NAVSEA Guidelines	>27	>27	<250	<250	<25
HJ1*	56	75	30	2	1**
Aramid/Vinyl Ester***	39	39	405	152	13

* Data from Owens Corning reports.
** Data from FMI (Fiber Materials, Inc.) literature on typical glass/phenolic systems.
*** Data from NSWC (Naval Surface Warfare Center) Report 80-302.

3. COMPOSITE ARMOR SOLUTIONS

Composite armor is often considered for applications where weight savings are at a premium. However, fiber-based composite armor requires a hard facing material in order to stop armor piercing projectiles. The system employed in this study for armor piercing threats is ceramic tile facing with composite backing. When multi-component armor is employed, it becomes a macro-composite made up of layers of composite materials. This adds a level of complexity to the situation, and exploring all of the possible iterations for optimization becomes very time and money consuming. However, there are analytical and numerical models available to reduce the amount of expensive ballistic testing that is required. One such solution, based on physical principles, is the Florence model[2]. He observed that when a projectile impacted the ceramic tile, the damage initiated at the point of impact and expanded in a conical crush zone that ultimately distributed the impact energy over a circular area on the backing material. The cone angle of the crush zone was observed to be a consistent 63°. This rudimentary model was used to generate a prediction of the ballistic limit for a two-component armor system by equating the incoming kinetic energy of the projectile to a force distributed over an area on the backing material. When the force exceeds the ultimate tensile strength of the backing material, ballistic penetration occurs.

The ballistic performance of a two-component composite armor system comprised of S-2 Glass fiber/phenolic resin matrix composite backing material faced with alumina tiles was investigated in 2004 by Fecko et. al[3]. In this study, it was determined that the Florence model was a very good predictor of the performance of the aforementioned two-component (ceramic facing and fiber-based composite backing) system against armor piercing .30 cal (7.62mm) M2AP projectiles. The system was shown to be at a maximum effectiveness when the composite backing and ceramic facing were of roughly equivalent thickness. The system could be modified for slightly better structural performance by increasing the backing to facing ratio, and modified for slightly better ballistic performance by decreasing the backing to facing ratio. However, improving the ballistic performance of the system came at the cost of some of the structural performance, and vice versa.

AGY has tested composite panels made using S-2 Glass fibers against a variety of ballistic threats. That data is meant to be used by vehicle developers as starting points for estimation of the required material weights necessary for various environments. AGY does not develop armor, and so the results that are presented here are likely slightly heavier than the solutions that more knowledgeable armor experts could design. It is emphasized that the results presented here are recommended starting points for development, and require further testing and validation to ensure that the armor performs at the desired level.

Table 3. STANAG 4569 Protection Levels

Threat Level	Ammunition	Velocity (m/s)	Threat Type
5	25 mm x 137 APDS-T, PMB 073	1258	Automatic Cannon, APDS Ammunition
4	14.5 mm x 114 API/B32	911	Heavy Machine Gun, AP Ammunition
3	7.62 mm x 51 AP (WC core)	930	Assault and Sniper Rifle, AP WC Core
3	7.62 mm x 54R B32 API	854	Assault and Sniper Rifle, AP WC Core
2	7.62 mm x 39 API BZ	695	Assault Rifles/ AP Steel Core
1	7.62 mm x 51 NATO ball	833	Assault Rifles/ Ball Round
1	5.56 mm x 45 NATO ball	900	Assault Rifles/ Ball Round
1	5.56 mm x 45 M193	937	Assault Rifles/ Ball Round

The STANAG 4569 threat levels are shown in Table 3. The velocity listed in the table is the expected velocity of the ammunition at the minimum range that it is expected to be encountered. The lower number threat levels are the least lethal, in terms of armor penetration ability, and increase as the threat levels numerically increase. In some cases, more than one threat is defined for a specific level. For instance, the two level 3 threats are of roughly equivalent penetrating ability. Both use the highly penetrating tungsten core, both are 7.62 mm in diameter, but one (B32) is slightly heavier at 10.0 g vs. 8.4 g, but has a velocity slightly lower (854 m/s vs. 930 m/s).

The protection level list is based on a 90% probability of providing protection to the vehicle occupants at the given threat as established by using STANAG 4164 testing guidelines. The results of the testing presented in this paper are performed to establish a V50 evaluation, which is the velocity at which the given round will penetrate 50% of the time as defined by MIL-STD 622E. Extrapolation and testing to the 90% protection value required for STANAG 4569 is left to the armor developer.

The results of the testing that may be used as starting points when considering S-2 Glass composite armor are given in the table below. In this study, all composite armor panels were constructed of S-2 Glass fibers and phenolic resin, manufactured by press-curing prepreg material made from 830 g/m^2 plain weave woven roving. For the AP threats, a ceramic facing made of alumina was required. The ceramic was attached using a 0.4mm thick bond line of polysulfide adhesive.

Table 4. Composite Armor Solutions for STANAG 4569 Threats

Threat Level	Ammunition Used	Panel Construction	V50	Areal Density Required (kg/m^2)
5	25 mm x 137 APDS-T, PMB 073	88mm composite, 25mm ceramic facing	1258	276
4	14.5 mm x 114 API/B32	16.5mm composite, 15mm ceramic facing	911	90.5
3	7.62 mm x 54R B32 API	25mm composite, ceramic facing	854	67.5
2	7.62 mm x 51 M2AP	8mm composite, 8mm ceramic facing	917	46.6
1	7.62 mm x 51 M80	Unfaced composite panel	833	48.2
1	5.56 mm x 45 M193	Unfaced composite panel	937	38.4

For the 2 different level 1 threats, three different areal density panels were constructed and tested to determine the V50. The required areal density to stop the stated V50 was then interpolated from these data. The ball rounds displayed a significant amount of deformation during impact. At areal densities near the V50, the impact zone appeared very similar to that described by Bless et. al with a front cavity formation due to compressive flow, and a fiber fracture and delamination in the back of the panels.[4]

For threat level 2 and higher, the ammunition is armor piercing, and the armor required a ceramic facing in order to blunt the penetrator to defeat the threat. The solution suggested in Figure 2 for the level 2 protection is near the maximized value of equivalent thickness of ceramic facing and composite backing suggested by Fecko et. al.

The solution for the level 3 threat is slightly heavy in composite backing when compared to the optimum solution for ballistic performance. This configuration was selected because the vehicle manufacturer desired 25mm of S-2 Glass composite armor for its structural performance, and would add on a parasitic layer containing the ceramic facing depending on the threat that the vehicle expected to encounter. Thus the solution is somewhat heavier than would be required had the structural performance been disregarded.

The solution for the level 4 threat is near the optimum solution, and was selected by testing panels of areal density above and below the desired V50. The solution was then interpolated from the results of the testing. The most recent data, the level 5 testing, was performed on panels of areal density up to 200 kg/m2, which did not meet the required protection. Thus the panel construction suggested in the table for protection level 5 has been extrapolated from the tested panel configurations. In all other levels, the suggested protection has been interpolated from areal densities above and below the suggested protection.

4. CONCLUSIONS

The STANAG 4569 specification was written so that threat levels that NATO light armored vehicles face could be classified into standardized levels. Thus various armor solutions can be evaluated and compared based on known performance criteria. The material system that was focussed on in this study is based on a high-strength glass fiber that has exceptional strength, toughness, and durability. Unlike many of the organic fiber alternatives, it also has excellent fire, smoke, and toxicity performance. This combination of properties makes S-2 Glass composite armor an ideal choice for ballistic protection of land and marine based vehicle systems.

REFERENCES

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