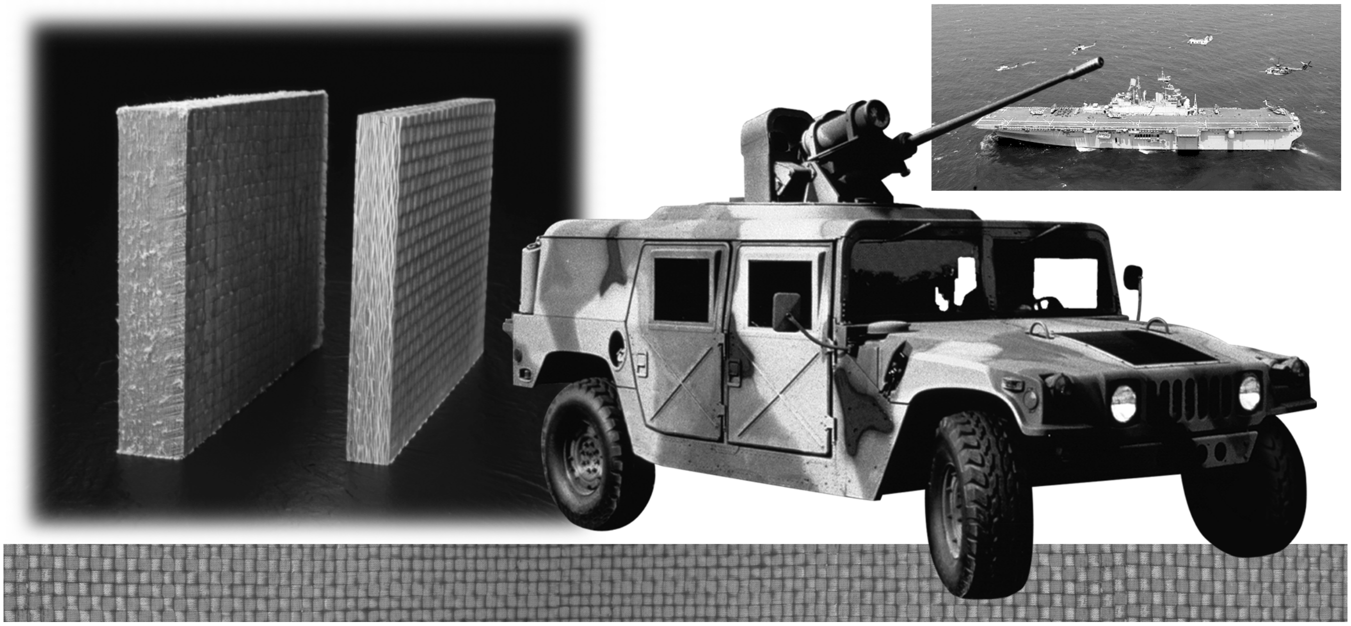
agy

S-2 Glass® Phenolic HJ1 System Information



High-Strength Solutions to Your Toughest Reinforcement Challenges

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. The S-2 Glass® input reinforcement is a woven roving fabric that meets MIL-R-60346C, Type IV. The resin is a phenolic that meets MIL-R-9299C, Grade B. 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. Rights to AGY's technology have been licensed to 10 manufacturing companies, six of which are in the US, to provide consistent, competitive and assured availability of this product which meets MIL-L-64154. These companies are listed in AGY publication LIT-2003-301.

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. A "Value Engineering Change Proposal" (VECP) submitted by Ingalls Shipbuilding, then a division of Litton but now owned by Northrop Grumman, for the use of this system as an alternative to KRP (Kevlar®/brominated vinyl ester) for deck armor on Essex (LHD-2) class ship, was approved by the Navy in 1989. The benefits are equal ballistic performance at the same weight, improved fire/smoke performance, easier fabrication and lower cost. The Army's Tank Automotive Command (TACOM) has initiated an "Engineering Change Proposal" to use the phenolic based S-2 Glass® for spall liners (as an alternative to the KIL-L-62474B aramid system) in the MI13 personnel carrier, manufactured by FMC. The incentives again are its excellent ballistic performance, low structural damage on impact, low cost and excellent resistance to fire and smoke. An example of a recent civilian application is the cockpit doors on all Airbus Industrie and many Boeing aircraft.

Ballistic Performance

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 impact-absorbing 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, such as the Vertical Launch System (VLS).

S-2 Glass® Phenolic HJ1 System Information

AGY work related to other applications also shows that this HJ1 system performs very well against armor-piercing (AP) threats when used in conjunction with a metal or ceramic frontal plate. A ceramic backup study by UDRI (University of Dayton Research Institute), and jointly presented by OCP and UDRI at the Fourth Tacom Armor Coordinating Conference (March 1988), provides additional data in this area. The information is available on a need-to-know basis.

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.

Thermal Characteristics/
Bulk Properties
The inorganic nature of S-2 Glass® fiber and the highly crosslinked aromatic organic nature of the phenolic matrix enhance thermal characteristics required for slow and fast cook-off environments such as in sympathetic detonation VLS canister performance criteria.

The table to the right identifies preliminary data, which supports shock mitigation, thermal stability, insulative qualities and dimensional stability.

S-2 Glass® HJ1 System

	English Units	SI (Metric)
Shock Speed (plate impact)		2.6-3.0 mm/µsec
Speed of Sound	8-9,000 ft/sec	2.4-2.7 km/sec
Coefficient of Thermal Expansion	4-6 in/in/°F x 10^{-6}	7-11 cm/cm/°C x 10^{-6}
Thermal Conductivity	2 BTU x in/hr-ft^2 – °F	0.4 W/m – K
Heat of Ablatement		10-25 MJ/kg

Composite stability is maintained relative to the rate of thermal ablatement. The thermal gravimetric analysis (TGA) shown for the S-2 Glass® HJ1 system was conducted in air at a 30 ml/minute flow rate. Substantial decomposition (weight loss) did not occur until about 400°C. The high thermal oxidative stability of HJ1 coincides with its higher fire and smoke resistance also reported.

Chemical and Corrosion Resistance
The U.S. Army's Belvoir Research, Development and Engineering Center at Fort Belvoir, Virginia, conducted a series of CARC (Chemical Agent Resistant Coating) tests on various laminate constructions. The Test Report 2426, "CARC Finishes on Laminate Armor Materials"[1], points out water absorption and paint blistering problems with aramid composites but not with glass fiber composites.

Fire/Smoke Properties
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. The table below summarizes these requirements for shipboard installations. The source of this information is Naval Surface Weapons Center Report 80-302, "Material Characterization Tests Program."

	ASTM Method	***Requirement For Index***
Flame Spread Index	E-162-75	Less than 25
Oxygen Index	D-2863-74	
(a) 25°C		Greater than 27% oxygen
(b) 150°C		Greater than 27% oxygen
Smoke Obscuration Index	STP-422 (E662)	
(a) Flaming		Less than 250
(b) Nonflaming		Less than 250

[1]Department of the Army
Belvoir Research Department and Engineering Center
Ft. Belvoir, Virginia 22060-5606

Improved Flammability and Smoke Performance
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.

Performance Comparison
The following table is a summary comparison of fire/smoke properties of HJ1 laminate and aramid-reinforced halogenated vinyl ester laminates.

	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.

S-2 Glass® Phenolic HJ1 System Information

The oxygen index is the percent oxygen required to sustain a flame in an oxygen/nitrogen stream of air surrounding a burning 1/8 x 1/4 x 6 inch test specimen. The higher the percent oxygen, the less flammable the material is. The performance of HJ1 exceeds the guidelines by a 2 to 2.7 factor.

Smoke obscuration index results are expressed in terms of specific optical density, or absorbance. As noted, HJ1 far exceeds guidelines established for this test.

The flame spread index is an indication of the rate a fire may spread. Since the glass is an incombustible inorganic and the phenolic resin is non-flammable, this specific test was not run by Owens Corning. For reference, a value published by FMI Corporation is included.

Summary

S-2 Glass® phenolic HJ1 composite armor represents a new generation armor and provides a new low weight alternative to metals. The S-2 Glass® system represents a significant cost saving potential over aramid reinforced systems. In addition to its excellent ballistic performance, it excels in fire/smoke performance. Other benefits include fabrication ease, low structural deformation after impact and capability for higher ballistic protection in confined spaces.

WORLD HEADQUARTERS/AMERICAS
ADVANCED GLASSFIBER YARNS LLC
2558 WAGENER ROAD
AIKEN, SOUTH CAROLINA, USA 29801
PHONE: 888.434.0945 (toll free)
803.643.1501
FAX: 803.643.1180

EUROPEAN OFFICE
AGY – EUROPE
163 BOULEVARD DES ETATS UNIS
69008 LYON, FRANCE
PHONE: 33.4.72.78.1777
FAX: 33.4.72.78.1780

For more information, visit our Web site at www.agy.com

Pub. No. LIT-2006-321 R1 (02/06) Printed in USA