MTL TR 92-30

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HIGH STENGTH GLASS SECOND SOURCE QUALIFICATION TO COMPOSITE ARMOR SPECIFICATION MIL-L-46197(MR)

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COMPOSITES DEVELOPMENT BRANCH

April 1992

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92-15365

US ARMY
LABORATORY COMMAND
MATERIALS TECHNOLOGY LABORATORY

U.S. ARMY MATERIALS TECHNOLOGY LABORATORY
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SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MTL TR 92-30	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* HIGH STRENGTH GLASS SECOND SOURCE QUALIFICATION TO COMPOSITE ARMOR SPECIFICATION MIL-L-46197(MR)		5. TYPE OF REPORT & PERIOD COVERED Final Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR*(s)* William E. Haskell, III		8. CONTRACT OR GRANT NUMBER*(s)*
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Materials Technology Laboratory Watertown, Massachusetts 02172-0001 SLCMT-MEC		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS Code: 728012.12
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Laboratory Command 2800 Powder Mill Road Adelphi, Maryland 20783-1145		12. REPORT DATE April 1992 13. NUMBER OF PAGES 10
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

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17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Composite armor	Ballistics	Armor
Reinforced plastic	Weight reduction	Ballistic testing
Ground vehicles	Spall reduction	Polymers

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

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ABSTRACT

Vetrotex RH™ glass woven roving fabric impregnated with Cyanamid CYCOM™ 4102 polyester resin was evaluated for structural armor applications. The mechanical and ballistic properties of this system were compared to MIL-L-46197 (MR) requirements. The specific lot of RH glass evaluated under this effort met MIL-L-46197 (MR) requirements. S-2™ and RH fiberglass/polyester systems should meet specification requirements when manufactured and processed in strict compliance with MIL-L-46197 (MR). The identification of this second high strength fiberglass source will generate pricing competition and cost savings for the Government. MIL-L-46197 (MR) has been amended and is now entitled *LAMINATE: HIGH STRENGTH GLASS, FABRIC-REINFORCED, POLYESTER RESIN IMPREGNATED, Amendment No. 1, 22 November 1991.*

OBJECTIVE

The objective of this U.S. Army Materials Technology Laboratory (MTL) technical report is to present the test results from evaluation of the Vetrotex RH™ glass woven roving to MIL-L-46197 (MR) requirements. The specific lot of RH glass/polyester material purchased for this evaluation met the MIL-L-46197 (MR) performance requirements. The specification has been formally amended and is now entitled *LAMINATE: HIGH STRENGTH GLASS, FABRIC-REINFORCED, POLYESTER RESIN IMPREGNATED*, Amendment No. 1, 22 November 1991.

INTRODUCTION

MTL is a prime developer of fiber-reinforced, organic matrix armor systems offering both ballistic efficiency and structural capability. The initial research included combinations of glass fiber and aramid reinforcement, fiber finishes, and resin systems.[1,2] Since that time the structural armor development and demonstration efforts have included flat laminates, hatchdoors, turret structures, and armored vehicles.[3-5] Mobility and transportability requirements for future combat vehicles demand that system weights be reduced. The primary goal of MTL's efforts is to reduce vehicle weight while maintaining ballistic protection levels and enhanced crew survivability. Structure fabrication costs must also be considered early in materials selection, process development, and vehicle design.

The MTL Composite Infantry Fighting Vehicle (CIFV) program, with FMC Corporation, has successfully demonstrated the weight savings and durability of S-2™ glass/polyester structural armor.[6,7] The CIFV prototype incorporated over 4700 lbs. of S-2 fiberglass woven roving/polyester composite. Cyanamid CYCOM™ 4102 and SP Systems IFRR™ polyester resins were both evaluated for this application. SP Systems was formerly known as FERRO Composites Division. Both resins are modified diallyl phthalates that are flame resistant and offer self-extinguishing flammability characteristics.[8,9] Detailed flammability characterization has been completed and these resin systems do not present an undo hazard for combat vehicle application.[10,11]

Under the CIFV contract a comprehensive characterization of these S-2™ glass/polyester systems was conducted. The Military Specification entitled *LAMINATE: S-2 GLASS, FABRIC-REINFORCED, POLYESTER RESIN IMPREGNATED* was written to cover this application. This specification was formally accepted by the military on 23 December 1987 and assigned the designation MIL-L-46197 (MR). The Owens Corning Fiberglass (OCF) S-2 glass woven roving product has set the standard for this application to structural armor. The ballistic efficiency and spall reduction capability of the S-2 composite is well documented.[12,13]

MATERIALS

In 1986 MTL acquired a sample of Saint Gobain's Vetrotex R glass, 24 oz/yd woven roving fabric for ballistic evaluation. This reinforcement was fabricated into a ballistic test laminate using a wet layup process. The resin system used was the OCF E-701 polyester. Ballistic data for E and S-2 glass/polyester laminates evaluated with the 207 grain (.50 cal) fragment simulating projectile (FSP) were available for comparison. The results of these tests are summarized in Table 1. This limited data showed that the R glass laminate ballistic limit (V_{50}) was higher than E but lower than that of an S-2 laminate of similar areal density.

Table 1. PRELIMINARY E, R, AND S-2 BALLISTIC COMPARISON

Fiber Type	E	R	S-2
Test No.	245-81	433-86	176-82
Plies	53	53	53
Projectile		..................207g FSP (.50 Cal)...................	
Areal Density (PSF)	11.8	11.4	11.9
Ballistic Limit (V_{50})	2484	2712	3233
Shots/Spread	2/42	2/165	2/90

In 1988 a newly available Saint Gobain product designated Vertrotex SRT 810-2295 was obtained by MTL for ballistic evaluation. This fiber was claimed to have a higher tensile strength than the previously tested R glass fiber, and the fabric had a weight of 23.8 oz/yd (810 g/m) and an epoxy compatible finish. This fabric was fabricated into several different areal density laminates, again using the OCF E-701 resin. The results of this round of evaluation are given in Table 2. Comparing the results from Test No. 176-82 in Table 1 to Test No. 89-049 in Table 2 shows that the SRT product had ballistic efficiency comparable to S-2. The SRT product was assigned the new RH glass designation shortly after this MTL evaluation.

Table 2. SRT GLASS/E-701 RESULTS

Test No.	FSP (g)	A. D. (psf)	V_{50} (fps)	Shots/SPR
89-074	17	2.26	1740	4/52
89-047	44	5.65	2597	2/124
89-050	207	5.65	1613	2/145
89-049	207	12.45	3486	2/86

The higher ballistic performance of the RH glass laminates over the previously obtained R glass, and the similarity to the OCF S-2 glass, is further explained by comparing the filament property data in Table 3. These glass filament properties were taken from the manufacturer's data sheets.[14,15]

Table 3. GLASS FILAMENT PROPERTY COMPARISON

Filament Type	Density (g/cc)	Tensile (ksi MPa)	Modulus (Msi GPa)
E	2.60	500 3448	10.5 73
R	2.53	638 4400	12.5 86
S-2	2.49	665 4563	12.6 87
RH	2.49	685 4700	13.0 90

In 1990, the MTL Composites Development Branch received military funding to evaluate the higher strength Vetrotex RH™ glass fiber to the MIL-L-46197 (MR) performance requirements. As discussed previously, this specification was written for applications requiring both ballistic and structural performance. At that time, the only product that met the mechanical and ballistic minimum performance levels was OCF S-2 glass. The 24 oz/yd, 5 x 5 plain weave, S-2 glass fabric has an OCF 463 epoxy compatible finish. MTL procured 233 yards of the RH glass product preimpregnated by Cyanamid with CYCOM™ 4102 polyester resin. The Vetrotex RH™ glass had an epoxy compatible finish designated P-109. The weaving and impregnation of the fabric was conducted by Cyanamid in strict compliance with the MIL-L-46197 (MR) roving, fabric, and prepreg specifications.

PROCESSING

The glass/polyester structural armor proposed for future combat vehicle structures is cured using a vacuum bag molding process with oven cure. It is MTL's goal to keep the cost of the capital equipment to a minimum when molding armored vehicle hulls. The vacuum bag/oven cure process eliminates the need for expensive autoclave systems. The vacuum bag process does, however, produce composite laminates with slightly higher void contents than those normally obtained from a high pressure autoclave cure. This higher void content (1% to 3%) does, however, produce the best combination of ballistic and mechanical properties.

The RH glass/CYCOM™ 4102 prepreg was fabricated into nine and 69 ply test laminated. Assigning the warp rovings to the 0 direction, the nine ply laminates had a quasi-isotropic construction or stacking sequence of 0/-45/+45/90/0/90/+45/-45/0. This quasi-isotropic construction was required since mechanical properties were to be determined in addition to the ballistic properties. The laminates having 69 plies were fabricated using a 0/90 stacking sequence. Since only the ballistic limit was to be obtained, this construction saved material and eased fabrication of the laminates. The prepreg was laid onto flat aluminum caul plates covered with a suitable release film. The bagging sequence incorporates perforated release film, bleeder felt, barrier release film, breather felt, and a nylon vacuum bag. This bagging sequence for a complex part, versus a flat laminate, is shown in Figure 1. A thermocouple was placed at the center of the thicker laminate to monitor the mid-laminate temperature during cure.

The cure cycle for the 69 ply laminates (see Figure 2) requires three temperature changes to produce acceptable test laminates.[16] The first step is a 150°F soak that allows resin flow and fiber wetout without initiating the cure reaction. The next step is a 170°F soak which initiates the cure reaction. The development of residual stresses during thick laminate cure is also strongly influenced by processing and should be minimized.[17] At this 170°F oven temperature, the mid-laminate exotherm was in a range from 230°F to 260°F. After the exotherm has peaked the oven temperature is raised to 250°F for post cure.

PHYSICAL CHARACTERISTICS

The resin content of the nine ply laminate was determined using ASTM D 2584-68, Standard Test Method for Ignition Loss of Cured Reinforced Resins. Three 1" x 1" specimens were subjected to this burnout test procedure and yielded an average resin content of 32.8%. This particular RH glass/polyester laminate met the MIL-L-46197 (MR) specification requirement of 34 ± 3% resin by weight.

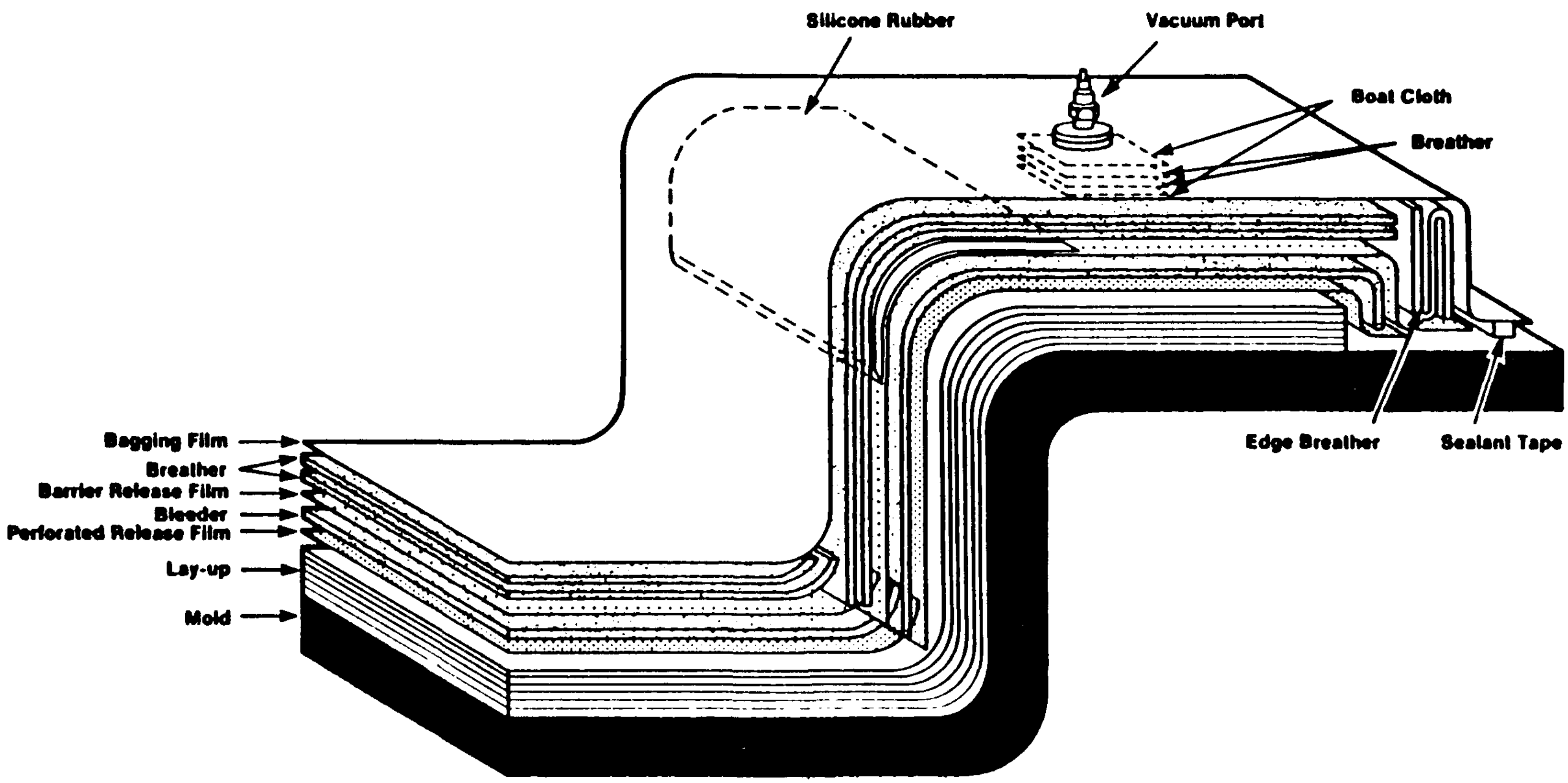

Figure 1. Bagging sequence.

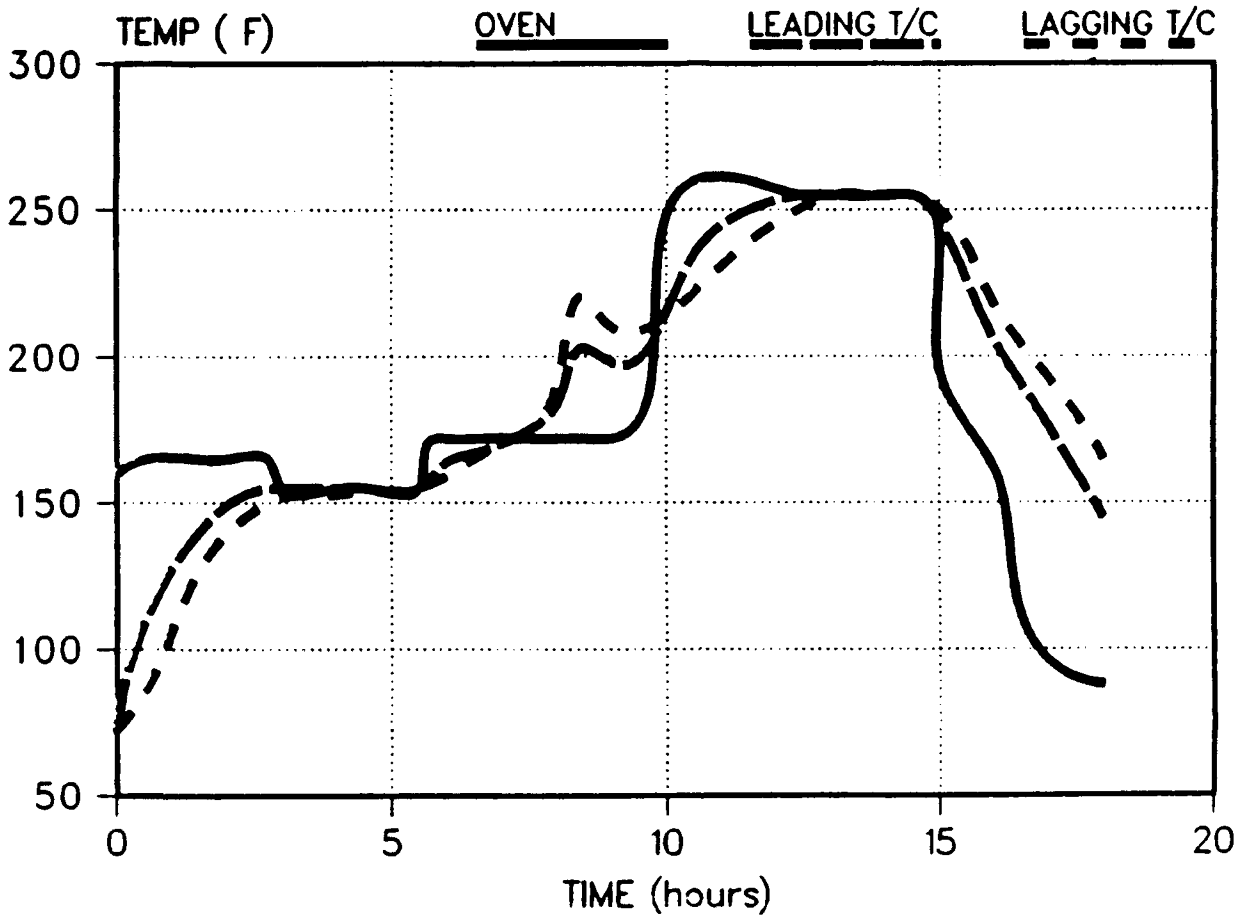

Figure 2. Cure cycle, 69 plies RH glass/polyester.

Although not required, the water absorption characteristics of this RH glass/polyester laminate were evaluated. Specimens having dimensions of 1" x 3" were machined from the nine ply laminate. The machined edges of the specimens were left unprotected during the long-term immersion in room temperature water. Figure 3 plots the moisture gain of these specimens over a one year period. The maximum average weight gain was slightly above 0.3%.

MECHANICAL PROPERTIES

Tensile, flexure, compression, and short beam shear tests were conducted on the nine ply laminate. Table 4 compares the MIL-L-46197 (MR) requirements to the results of the RH glass laminate testing.

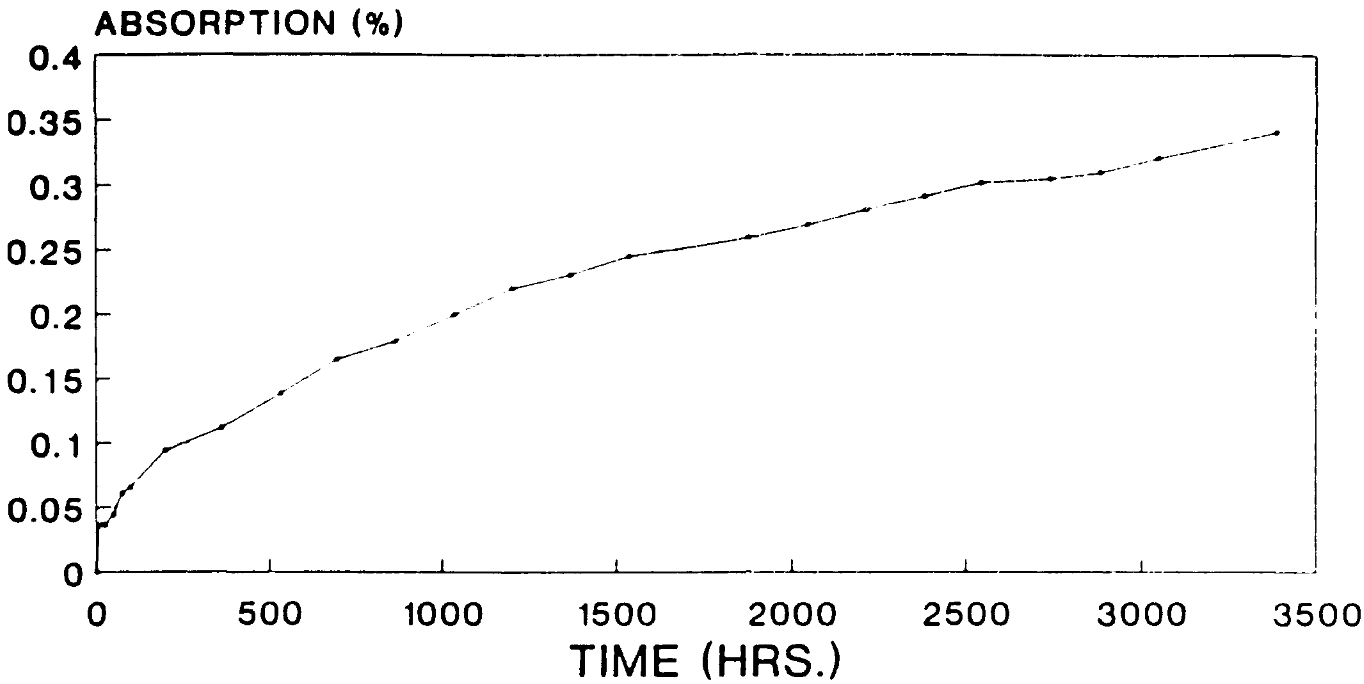

Figure 3. RH glass/polyester water absorption.

Table 4. REQUIREMENT VERSUS RH GLASS MECHANICAL PROPERTIES

Property	Requirement	RH Glass
Tensile Modulus (D638)	2.3 Msi (15.8 GPa)	3.5 ± .25 Msi (24.1 GPa)
Tensile Strength (D638)	43 ksi (296 MPa)	42.4 ± 1.1 ksi (289.6 MPa)
Flexural Modulus (D790)	2.5 Msi (17.2 GPa)	3.7 ± .07 Msi (25.4 GPa)
Flexural Strength (D790)	32 ksi (221 MPa)	43.4 ± 2.0 (299.3 MPa)
Compressive Strength (D695)	20 ksi (138 MPa)	29.3 ± 1.6 ksi (202.1 MPa)
Short Beam Shear (D2344)	2.5 ksi (17.2 MPa)	4.0 ± ksi (27.6 MPa)

BALLISTIC EVALUATION

Ballistic screening of the high strength glass laminates with a 20 mm fragment simulating projectile is required under MIL-L-46197 (MR).[18,19] The large 69 ply RH glass laminates were cut into 1' x 1' targets which were impacted with one center shot per target. The ballistic limit velocity (V_{50}) must meet or exceed 2380 fps (740 mps). The targets had an average areal density of 17.55 psf. The limit velocity easily meets the 2380 fps requirement with a value of 2755 fps. The detailed ballistic results are reported in Table 5.

Table 5 BALLISTIC SCREENING RESULTS

Shot No	Velocity Grid	Velocity X-Ray	Yaw Angle	Result On Target	Comment (Bulge)
1	2163	2206	.75	Partial	Medium
2	2423	2406	.83	Partial	Large
3	2545	2524	.90	Partial	Large
4	2630	2619	.53	Partial	Large
5	2798	2776	1.83	Complete	
6	2724	2708	.79	Partial	Large
7	2738	2734	.53	Partial	Large

MTL Test No = T-13-91
Limit Velocity = 2755 fps
Spread (2 Shot) = 42 fps
High Partial = 2734 fps
Low Complete = 2776 fps

CONCLUSIONS

References to trade name glass fiber products were deleted from the subject military specification and substituted with the term *high strength glass*. The title for MIL-L-46197 (MR) is now *LAMINATE: HIGH STRENGTH GLASS, FABRIC-REINFORCED, POLYESTER RESIN IMPREGNATED*, Amendment No. 1, 22 November 1991. The particular lot of RH glass evaluated under this research effort meets the performance requirements of the specification. The S-2 and RH fiberglass/polyester products should both meet the specification requirements when manufactured and processed in **strict compliance** with MIL-L-46197 (MR). The identification of this second source product will generate pricing competition and cost savings for the Government. The test detailed in the specification should be conducted on individual lots of both products to assure minimum performance levels.

ACKNOWLEDGMENTS

The author would like to acknowledge the following personnel for their assistance during this evaluation: Messrs. Herb Gasset, Richard Laporte, and Elias Rigas for laminate fabrication; Mr. Gerald Libby for specimen machining; Mr. Elias Pattie for mechanical testing; Mr. Robert Klinger for water absorption testing; and Messrs. James Brown, Robert Muller, John Loughlin, and John Segalla for conducting ballistic testing.

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Vetrotex RH™ glass woven roving fabric impregnated with Cyanamid CYCOM™ 4102 polyester resin was evaluated for structural armor applications. The mechanical and ballistic properties of this system were compared to MIL-L-46197 (MR) requirements. The specific lot of RH glass evaluated under this effort met MIL-L-46197 (MR) requirements. S-2™ and RH fiberglass/polyester systems should meet specification requirements when manufactured and processed in strict compliance with MIL-L-46197 (MR). The identification of this second high strength fiberglass source will generate pricing competition and cost savings for the Government. MIL-L-46197 (MR) has been amended and is now entitled *LAMINATE: HIGH STRENGTH GLASS, FABRIC-REINFORCED, POLYESTER RESIN IMPREGNATED, Amendment No. 1, 22 November 1991.*