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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/756

Resistance of Various Laminates to Perforation by Fragment-Simulating Projectiles

Regraded Unclassified
by authority of C.O. Watertown
Arsenal
4/6/55 A O Gallagher
date Sec'y, H&L

BY

J. F. Sullivan
Asst. Engineer

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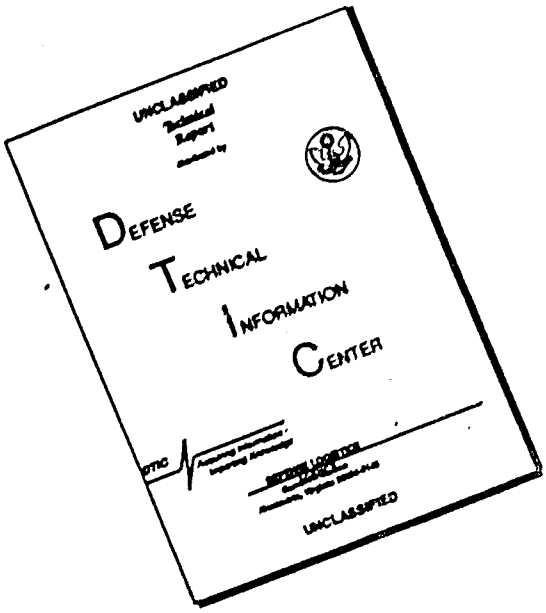

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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 710/756

Partial Report on Problem B-8.2

23 June 1945

Resistance of Various Laminates to Perforation by Fragment-Simulating Projectiles

1. At the request of the Office, Chief of Ordnance[1-8] and the Boston Ordnance District Office[9], tests have been conducted at this laboratory over a period of several months on various laminated materials. As each test has been concluded the results have been reported[10-18], but this is the first attempt to integrate the results of the various tests.

2. In an attempt to simulate in a ballistic limit test the effects of attack by fragments of high-explosive shell, several projectiles have been developed at this arsenal[19-21]. Since the results of actual fragmentation tests have become known, it has become apparent that the results of tests made with these projectiles do not correlate with the results of attack by actual fragments, when the resistance of different materials is being ascertained. There is some evidence, however, that as regards a single material and, perhaps, even a class of materials, the results of these tests may be used to shed light on their resistance to actual fragments. It is with this latter hope that the present report is being prepared so that if such use can be made of the results of these tests, an analysis of them will be available.

3. The results of the various tests conducted here are recited in Tables I through VIII. Tables IX and X list the various samples in order of figures of merit with regard to their resistance to cal. .45 ball projectiles and cal. .22 fragment-simulating projectiles, G-2, respectively. These figures of merit have been determined on the basis of the relationship between the resistance of a subject sample to perforation by a given projectile and that which is characteristic of samples of Hadfield manganese steel of equivalent weight. Tables XI and XII list average figures of merit for general types of laminates.

4. It is thus readily apparent that under both types of projectile impact the Doron (Type 1) samples were superior to other samples tested and those which incorporated a rubber element into their make-up were decidedly inferior. The "X" panels, because of variously efficient adhesion between

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the elements behaved variously but on the whole were above average. The Fiberglas (X1551) samples, which structurally resemble the Doron samples did not attain the efficiency of the latter. However, they exhibited reasonable resistance to perforation by the cal. .45 ball projectiles.

5. Although under actual fragmentation tests of high explosive shell, Doron does exhibit resistance to perforation superior to that of Hadfield manganese steel and this superiority is reflected in the figures of merit listed in Tables IX and XI, with respect to perforation by cal. .45 ball projectiles, this should not be taken to be indicative of a correlation between the two tests. The resistance of other laminates to perforation by actual fragments is not reliably known and it may develop that a material offering low resistance to the subject tests might afford high resistance to actual fragments. In addition there are indications that Doron owes its superiority over Hadfield manganese steel under those two tests to different characteristics. Its superiority under attack by the cal. .45 ball projectile is undoubtedly attributable to its unique ability to absorb projectile energy by delaminating over a wide area prior to local failure. Its superiority under attack by actual fragments seems more to be attributable to its greater thickness, and widespread delamination does not occur.

6. Thus it would appear that until more is known about the resistance of these various types of laminates to actual fragments, no predictions concerning their probable resistance to such attack can be made on the basis of ballistic limit tests.

J. F. Sullivan

J. F. Sullivan
Asst. Engineer

APPROVED:

E. L. Reed

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11. Report No. WAL 710/284. "Resistance of Various Laminates Supplied by U. S. Rubber Co. to Perforation by Cal. .45 Steel-Jacketed Ball Projectiles." J. F. Sullivan. 16 October 1944.

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16. Report No. WAL 710/689. "Resistance of Various Types of Laminates Supplied by U. S. Rubber Co. to Perforation by Flak-Simulating Projectiles." J. F. Sullivan. 21 August 1944.

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18. Report No. WAL 710/732. "Resistance of Various Plastic Laminates, Made by Victory Plastics Co., to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 22 March 1945.

19. Report No. WAL 762/247. "Development of Projectiles to Be Used in Testing Body Armor, to Simulate Flak and 20 mm. HE Fragments." J. F. Sullivan. 17 December 1943.

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21. Report No. WAL 762/314. "Comparison of G-2 Projectiles of Various Manufacture." J. F. Sullivan. 23 May 1945.

TABLE I

(Reference - Report No. WAL 710/641)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Various Plastic Materials (Doron) Submitted by Quartermaster Corp.

Quartermaster Identification	Equivalent Steel Gauge	Ballistic Limits (F/S) Caliber .45[1] Room Temp.	-60°F.	After Immersion	Room Temperature G-1-A[2]	G-1-B[3]	G-2[4]
R-141	.029"	895	-	-	340	760	1161
R-404d	.040"	1041	-	-	475	901	1380
R-404j	.041"	1037	-	1006	435	906	1460
R-158	.041"	-	-	-	508	910	-
R-148	.041"	1105	-	-	495	1009	1478
R-166	.042"	984	-	-	488	973	1283
R-150	.042"	974	-	-	513	1043	1370
R-147	.042"	1060	-	-	475	1030	-
R-117	.043"	1104	-	-	483	1030	-
R-159	.044"	1105	-	-	453	955	-
R-116	.045"	1152	-	-	493	1065	1293
R-124	.045"	1117	1124	-	540	975	1443
R-123	.046"	1098	1123	-	532	955	1430
R-120	.046"	1162	1173	-	468	1165	-
R-113	.047"	1104	1118	-	445	998	1345
For Comparison:							
Hadfield	.030"	704	-	-	-	815	1215
Manganese	.040"	900	-	-	-	900	1600
Steel	.045"	950	-	-	-	1050	1675

1. Caliber .45 (steel-jacketed) ball projectile - 230 grains.
2. Caliber .30 fragment-simulating projectile - 150 grains.
3. Caliber .30 fragment-simulating projectile - 34 grains.
4. Caliber .22 fragment-simulating projectile - 17 grains.

TABLE II

(Reference - Report No. WAL 710/699)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of Doron (Type #1) Which Had Previously Been Subjected to Direct 20 mm. H.E. Fragmentation Tests at Aberdeen Proving Ground

Sample	Ballistic Limit (F/S) Cal. .45	G-2
(Samples fired at room temperature, as-received):		
R474G	1011	1348
R474F	1010	1350
R474L	973	1344
R474O	909	1344
R474N	1035	1404
R474K	1039	1378
R474E	1041	1408
R580A	1060	1346
R575A	1015	1279
R582C	1014	1373
(Samples fired at -65° at end of 4th phase of weathering cycle):		
R573A	1030	-
R582F	1021	-
R580C	1031	-
R583A	-	1363
R577E	-	1460
R579C	-	1344
R575D	-	1285
(Samples fired at room temperature at end of 4th phase of weathering cycle):		
R579C	1065	-
R572B	1117	-
R579D	1175	-
(Samples fired at +175° F. at end of 5th phase of weathering cycle):		
R583A	1057	-
R574B	1096	-
R574D	1060	-
R578E	-	1270
R579D	-	1415
R574	-	1285
R574E	-	1257
R576B	-	1407
(Samples fired at room temperature at end of 5th phase of weathering cycle):		
R577D	1038	-
R577E	1072	-
R574	1046	-
(Samples fired at +175°F. after a hot phase of the weathering cycle during which temperature of cabinet rose above 200°F. for a period of several hours).		
R575E	680	-
R577D	869	-
R583D	836	-
R573A	680	-
R582F	676	-
R574E	805	-

TABLE III

(Reference - Report No. WAL 710/284)

Summary of Tests for Resistance to Perforation Conducted at Watertown Arsenal on Laminates Developed by U. S. Rubber Co.

Sample No.	Type	Weight (Grams)	Weight/Sq.Ft. (Grams)	Thickness	Equivalent Steel Gauge	Ballistic Limit Cal. .45*
1	Nylon-Rubber	1553	1141	15/32"	.062"	606 ± 15
2	Nylon-Rubber	1129	830	11/32"	.045"	569 ± 22
3	Fiberglas-Resin	918	675	3/16"	.036"	425 ± 25
4	Fiberglas-Resin	1093	803	7/32"	.043"	445 ± 50
5	Nylon-Resin	983	723	11/32"	.039"	367 ± 67
For Comparison:						
Doron		-	-	—	.040"	1050
Hadfield Manganese		-	-	—	.040"	900

*Cal. .45 steel-jacketed ball projectile (230 grains).

TABLE IV

(Reference - Report No. WAL 710/689)

Summary of Resistance to Perforation Tests Conducted at Watertown Arsenal on Samples of Laminates Supplied by U. S. Rubber Co.

Sample No.	Type	Bread	Filler	Weight (oz./sq.ft.)	Thickness	Equiv. Steel Gauge	Cal..45[1]	G-22
1	3-decker	8-ply nylon & resin	1/8" cellular rubber	19.7	7/16"	.030"	465	-
2	3-decker	8-ply nylon & resin	.020" neoprene	17.2	5/32"	.026"	460	-
3	3-decker	8-ply fiberglas & resin	1/8" cellular rubber	21.0	13/32"	.032"	447	-
4	3-decker	8-ply fiberglas & resin	.020" neoprene	19.7	3/16"	.030"	416	840
5	3-decker	8-ply nylon & resin	21-ply nylon cured rubber	26.3	1/4"	.040"	395	725
6	3-decker	8-ply fiberglas & resin	21-ply nylon cured rubber	26.2	1/4"	.040"	428	670
7	3-decker	8-ply nylon & resin	rayon pile	14.7	3/8"	.023"	432	-
8	3-decker	8-ply nylon & resin	nylon pile	17.1	1/2"	.026"	449	-
9	single	8-ply nylon & resin	none	3.7	3/128"	.006"		not
10	single	15-ply nylon & resin	none	6.6	5/64"	.010"		fired
11	single	8-ply fiberglas & resin	none	4.3	1/32"	.007"		because of
12	single	21-ply nylon & rubber	none	6.0	1/16"	.009"		lightness

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .22 fragment-simulating projectile - 17 grains.

TABLE V

Summary of Ballistic Tests Conducted on Samples of Plastic Laminates

Submitted by Victory Plastics Co.

(Reference - Report No. MAL 710/732)

Sample No.	Make-Up of Sample	Sample Size	Sample weight (Grams)	Equiv. Steel Gauge	Ballistic Limit: Cal. .45[1] Req.	Cal. .45[1] Act.	G-1-S[2] Req.	G-1-S[2] Act.	G-2[3] Req.	G-2[3] Act.
101944A	11 ply Fiberglass ECC-11-164 coated with 6B Nylon. 11 Ply Hi/ten Rayon 2 oz. Alternate layers. Coated with 6B Nylon solution, molded at 1500 lbs. per sq. in. for 15 min. at 320 F.	2-3/4"x2-3/4"	28.0	.029"	--	--	760	<975	--	--
101944B	14 ply Fiberglass ECC-11-164 coated with 6B Nylon. 14 ply Nylon 6 oz. alternate layers, coated with 6B Nylon, molding pressure 1500 lbs. per sq. in. for 45 min. at 320 F.	2-3/4"x2-3/4"	46.0	.047"	--	--	1120	<860	--	--
102044A	14 ply Fiberglass ECC-11-164 coated with 6B Nylon. 14 ply Hi/ten Rayon 2 oz. alternate layers coated with 6B Nylon, molding pressure 1500 lbs. per. sq. in. for 30 min. at 320 F.	2-3/4"x2-3/4"	33.0	.034"	--	--	860	775±70	--	--
102744A	15 ply Fiberglass ECC-11-164 coated with 6B Nylon. 8 ply Hi/ten Rayon 2 oz. alternate layers in back of sample, coated with 6B Nylon. Molding pressure 1500 lbs. per. sq. in. for 30 min. at 310 F.	3"x3"	48.0	.041"	--	--	1000	<865	--	--
102744B	14 ply Fiberglass ECC-11-164 coated with 6B Nylon. 6 ply Nylon 6 oz. alternate layers in back portion of sample. Coated with 6B Nylon, molding pressure 1500 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	47.0	.041"	--	--	1000	<855	--	--
102744C	15 ply Fiberglass ECC-11-164 coated with 6B Nylon. 8 ply Hi/ten Rayon 2 oz. alternate layers in back portion of sample. Coated with 6B Nylon, molding pressure 1000 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	46.0	.040"	--	--	980	<845	--	--
102744A	14 ply Fiberglass ECC-11-164. Both fabrics coated with Gelva 15. 14 ply Nylon 6 oz. alternate layers. Molding pressure 200 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	65.0	.056"	--	--	1300	<915	--	--
102744B	14 ply Fiberglass ECC-11-164. Both fabrics coated with Gelva-15. 14 ply Hi/ten Rayon 2 oz. alternate layers. Molding pressure 200 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	47.0	.041"	--	--	1000	890±80	--	--
102744C	14 ply Fiberglass ECC-11-164. Both fabrics coated with Gelva-15. 14 ply Hi/ten Rayon 2 oz. alternate layers. Molding pressure 100 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	47.0	.041"	--	--	1000	840 Apx.	--	--
102744A	14 ply Fiberglass ECC-11-164. Heated in oven 2 hrs. at 400 F. and coated with 6B Nylon. Molding pressure 300 lbs. per sq. in. for 30 min. at 320 F.	2-3/4"x2-3/4"	32.0	.033"	--	--	840	<840	--	--
102744B	Same as 102744A except the Fiberglass was not heat treated and the molding pressure reduced to 150 lbs. per sq. in.	3"x3"	39.0	.034"	--	--	860	<785	--	--
102744C	Same as 102744B except the molding pressure was reduced to 125 lbs. per sq. in.	3"x3"	38.5	.033"	--	--	840	<790	--	--
102744D	Same as 102744B and C except the molding pressure was increased to 200 lbs. per sq. in.	3"x3"	38.0	.033"	--	--	840	<780	--	--
102744E	14 ply Fiberglass ECC-11-164. No heat treatment. 14 ply Vinylite (0.004") alternate layers, molding pressure 200 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	44.0	.038"	--	--	940	845±35	--	--

	ed with Gelva-15. 14 ply Hi/ten Rayon 2 oz. alternate layers. Molding pressure 200 lbs. per sq. in. for 30 min. at 320 F.										
102744C	14 ply Fiberglass ECC-11-164. Both fabrics coated with Gelva-15. 14 ply Hi/ten Rayon 2 oz. alternate layers. Molding pressure 100 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	47.0	.041"	--	--	1000	840 App.	--	--
102744A	14 ply Fiberglass ECC-11-164. Heated in oven 2 hrs. at 400 F. and coated with 6B Nylon. Molding pressure 300 lbs. per sq. in. for 30 min. at 320 F.	2-3/4"x2-3/4"	32.0	.033"	--	--	840	<840	--	--
102744B	Same as 102744A except the Fiberglass was not heat treated and the molding pressure reduced to 150 lbs. per sq. in.	3"x3"	39.0	.034"	--	--	860	<785	--	--
102744C	Same as 102744B except the molding pressure was reduced to 125 lbs. per sq. in.	3"x3"	38.5	.033"	--	--	840	<790	--	--
102744D	Same as 102744B and C except the molding pressure was increased to 200 lbs. per sq. in.	3"x3"	38.0	.033"	--	--	840	<780	--	--
102744E	14 ply Fiberglass ECC-11-164. No heat treatment. 14 ply Vinylite (0.004") alternate layers, molding pressure 200 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	44.0	.038"	--	--	940	845±35	--	--
102744F	Same as 102744E except the molding pressure was reduced to 150 lbs. per sq. in.	3"x3"	43.0	.037"	--	--	920	863±18	--	--
103144A	17 ply Fiberglass X-1551. 17 ply Vinylite (0.004") alternate layers, molding pressure 500 lbs. per sq. in. for 30 min. at 310 F.	7-1/2"x7-1/2"	261	.036"	930	>899	--	--	--	--
103144B	Same as 103144A except molding pressure was reduced to 250 lbs. per sq. in.	7-1/2"x7-3/8"	256	.035"	910	804±24	--	--	--	--
103144C	5 ply Duck (0.080"). 4 ply Tenite II H5, alternate layers, molding pressure 500 lbs. per sq. in. for 15 min. at 320 F.	7-1/2"x7-1/2"	334	.046"	1050	<512	--	--	--	--
103144F	5 ply Duck (0.080"). 5 ply Vinylite alternate layers, molding pressure 500 lbs. per sq. in. for 30 min. at 320 F. (0.004").	7-1/2"x7-1/2"	--	.042"	1000	<514	--	--	--	--
103144G	Same as 103144F except 3 plys of each were used in place of alternate layers of 5 each.	7-3/8"x7-1/2"	269	.037"	950	<509	--	--	--	--
113444A	25 ply Fiberglass X-1551. 25" Vinylite (0.004") alternate layers, molding pressure 650 lbs. per sq. in. for 30 min. at 320 F.	7.6"x7.6"	385	.052"	1130	1108	--	--	--	--
113444B	22 ply Fiberglass X-1551. 22 ply Vinylite (0.004") alternate layers. Molding pressure 500 lbs. per sq. in. for 30 min. at 320 F.	7.6"x7.6"	350	.047"	1065	1000	--	--	--	--
114444A	21 ply Fiberglass ECC-128-38. 21 ply Butvar (0.015") alternate layers. Molding pressure 650 lbs. per sq. in. for 15 min. at 330 F.	5"x5"	168	.052"	1130	<1105	--	--	--	--
111344A	22 ply Fiberglass ECC-128-38 coated with 10% T13 P. V. Butyral on both sides. Penetration complete. Molding pressure 500 lbs. per sq. in. for 30 min. at 275 F.	8"x8"	350	.043"	--	--	--	--	1410	1078±63
111344B	23 ply Fiberglass ECC-128-38. 23 ply Saran screen (Velon), alternate layers. Molding pressure 500 lbs. per sq. in. for 35 min. at 340 F.	8"x8"	352	.043"	--	--	--	--	1410	<1025
112344A	24 ply Fiberglass ECC-128-38. 2 ply Styron (H.V.) alternate plys of styron between the 11th and 13th ply of Fiberglass. Molding pressure 500 lbs. per sq. in. for 30 min. at 370 F.	8"x8"	283	.034"	--	--	--	--	1130	952±48
12344B	23 ply Fiberglass ECC-128-38. 2 ply Emery cloth No. 40. 21 ply Butvar (0.015"). Emery cloth placed in alternate layers starting from the 14th ply of Butvar and Fiberglass. Molding pressure 250 lbs. per sq. in. for 30 min. at 280 F.	7"x7"	406	.064"	--	--	--	--	1830	1360
115445A	22 ply X-1551 Fiberglass coated with a Vinyl dispersion. Molding pressure 500 lbs. per sq. in. for 10 min. at 340 F.	8"x8"	359	.044"	1030	>958	--	--	--	--
115445B	15 ply X-1551 Fiberglass coated with a Vinyl dispersion. 7 ply Rayon coated with a Vinyl dispersion alternate layers in center portion of sample; molding pressure 250 lbs. per sq. in. for 5 min. at 340 F.	8"x8"	359	.044"	1030	<828	--	--	--	--
115445C	19 ply X-1551 Fiberglass coated with Vinyl dispersion. 6 ply Butvar (0.006") alternate	8"x8"	353	.043"	1015	<825	--	--	--	--

	(0.015") alternate layers. Molding pressure 500 lbs. per sq. in. for 30 min. at 320 F.										
111444A	21 ply Fiberglass ECC-128-38. 21 ply Butvar (0.015") alternate layers. Molding pressure 650 lbs. per sq. in. for 15 min. at 330 F.	5"x5"	168	.052"	1130	<1105	—	--	--	--
111344A	40 ply Fiberglass ECC-128-38 coated with 10% T19 P. V. Butyral on both sides. Penetration complete. Molding pressure 500 lbs. per sq. in. for 30 min. at 275 F.	8"x8"	350	.043"	--	--	--	--	1410	1078±63
111344B	23 ply Fiberglass ECC-128-38. 23 ply Saran screen (Velon), alternate layers. Molding pressure 500 lbs. per sq. in. for 35 min. at 340 F.	8"x8"	352	.043"	—	—	--	--	1410	<1025
112544A	24 ply Fiberglass ECC-128-38. 2 ply Styron (H.V.) alternate plys of styron between the 17th and 19th ply of Fiberglass. Molding pressure 500 lbs. per sq. in. for 30 min. at 270 F.	8"x8"	283	.034"	—	—	--	--	1130	952±48
112544B	20 ply Fiberglass ECC-128-38. 2 ply Emery cloth No. 40. 21 ply Butvar (0.015"). Emery cloth placed in alternate layers starting from the 14th ply of Butvar and Fiberglass. Molding pressure 250 lbs. per sq. in. for 30 min. at 280 F.	7"x7"	406	.064"	--	--	--	--	1830	1360
11545A	22 ply X-1551 Fiberglass coated with a Vinyl dispersion. Molding pressure 500 lbs. per sq. in. for 10 min. at 340 F.	8"x8"	359	.044"	1030	>958	--	--	--	--
11545B	15 ply X-1551 Fiberglass coated with a Vinyl dispersion. 7 ply Rayon coated with a Vinyl dispersion alternate layers in center portion of sample; molding pressure 250 lbs. per sq. in. for 5 min. at 340 F.	8"x8"	359	.044"	1030	<828	--	--	--	--
11545C	19 ply X-1551 Fiberglass coated with Vinyl dispersion. 9 ply Butvar (0.005") alternate layers in center portion of sample; molding pressure 250 lbs. per sq. in. for 10 min. at 340 F.	8"x8"	353	.043"	1015	<825	--	--	--	--
11545D	Same as 11545A except the molding pressure was reduced to 100 lbs. per sq. in. for 5 min. at 340 F.	8"x8"	375	.046"	1050	824±23	--	--	--	--
11545E	20 ply X-1551 Fiberglass - no coating. 19 ply Butvar (0.005") alternate layers; molding pressure 100 lbs. per sq. in. for 5 min. at 340 F.	8"x8"	332	.040"	990	<809	--	--	--	--
12445A-1	22 ply X-1551 Fiberglass, coated with Vinyl dispersion. Molding pressure 650 lbs. per sq. in. for 15 min. at 340 F.	12"x11-1/2"	846	.048"	1075	860 Face 875 Rear	--	--	--	--
12445A-2	" " "	2 12"x12"	872	.047"	1065	820	--	--	--	--
12445A-3	" " "	12"x12"	890	.048"	1075	821	--	--	--	--
12445B-1	Same as 12445A except molding pressure was increased to 800 lbs. per sq. in.	12"x12"	875	.047"	1065	801	--	--	--	--
12445B-2	" " "	12"x12"	894	.048"	1075	848	--	--	--	--
12445B-3	" " "	12"x12"	891	.048"	1075	817	--	--	--	--
12445C-1	Same as 12445A and B except molding pressure was increased to 1000 lbs. per sq. in.	12"x12"	887	.048"	1075	827	--	--	--	--
12445C-2	" " "	12"x12"	895	.048"	1075	862	--	--	--	--
12445C-3	" " "	12"x12"	886	.048"	1075	819	--	--	--	--
12445C-4	" " "	12"x12"	891	.048"	1075	839	--	--	--	--
12445C-5	" " "	12"x12"	882	.048"	1075	812	--	--	--	--
12445C-6	" " "	12"x12"	876	.047"	1065	817	--	--	--	--

1. Cal..45 steel-jacketed ball projectile - 230 grains
2. Cal..30 fragment-simulating projectile - 34 grains
3. Cal..22 fragment-simulating projectile - 17 grains

TABLE VI

(Reference - Report No. WAL 710/317)

Summary of Tests Conducted at Watertown Arsenal on Samples of Laminates

Submitted by Victory Plastics Company, 20 October 1944

Sample No.	Company No.	Make-Up	Weight (Grams)	Size	Equiv. Steel Gauge	Results with Projectile G-1-S[1] High Complete Perforation	Low Partial Perforation	Ballistic Limit
I	101944A	11 plies 2 oz. rayon alternated with 11 plies fiberglas.	28	2-3/4 x 2-3/4"	.029"	975	-	975
II	102044A	14 plies 2 oz. rayon alternated with 14 plies fiberglas.	33	2-3/4 x 2-3/4"	.034"	845	705	775 ± 70
III	101944B	11 plies 6 oz. nylon alternated with 11 plies fiberglas.	46	2-3/4 x 2-3/4"	.047"	860	-	860
FOR COMPARISON:								
Doron					.029"	-	-	760
"					.034"	-	-	860
"					.047"	-	-	1095

1. Cal. .30 fragment-simulating projectile - 34 grains.

TABLE VII

(Reference - Report No. WAL 710/281)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of "K Panels" Submitted by the U. S. Rubber Company

July Shipment

Name	Make-Up	Lbs. Sq.Ft.	Equiv. Steel Gauge	Ballistic Limits Cal. .45[1]	Ballistic Limits G-2[2]
K Panel	.051" - .062" - .062"	1.93	.047"	880	—
K Panel	.051" - .062" - .062"	1.89	.046"	-	1480
K Panel	.051" - .062" - .062"	1.89	.046"	-	1350
K Panel	.051" - .062" - .062"	1.89	.046"	824	—
K Panel	.040" - .062" - .062"	1.79	.044"	922	—
K Panel	.040" - .062" - .062"	1.84	.045"	-	1332
K Panel	.064" - .051" - .051"	1.86	.046"	865	—
K Panel	.064" - .051" - .051"	2.00	.049"	779	—
K Panel	.064" - .051" - .051"	2.00	.049"	-	1287
K Panel	.064" - .051" - .051"	2.10	.051"	-	1408
K Panel	.072" - .051" - .051"	2.20	.054"	829	—
K Panel	.072" - .051" - .051"	2.10	.051"	793	—
K Panel	.072" - .051" - .051"	1.85	.045"	-	1327
K Panel	.072" - .051" - .051"	2.10	.051"	-	1425
K Panel	.125" - .051" - .051"	2.83	.069"	1026	—
K Panel	.125" - .051" - .051"	2.83	.069"	-	1620
For Comparison:					
Hadfield Manganese Steel	-	—	.045"	950	1675

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .22 fragment-simulating projectile - 17 grains.

TABLE VIII

(Reference - Report No. WAL 710/286)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of "K Panels" Submitted by U. S. Rubber Co.

Nominal Make-Up		Ave. Gross Thick.	Weight (Grams)	Weight Sq.Ft.	Equiv. Steel Thick.	Ballistic Limits Cal..45[1]	Ballistic Limits G-2[2]
.125"-.051"-.051"	A	.262"	1842	1354	.073"	—	1463
	B	.260"	1820	1338	.072"	—	1405
	C	.266"	1844	1355	.073"	—	1570
	D	.265"	1841	1353	.073"	—	1440
	F	.264"	1835	1349	.073"	871	—
	G	.255"	1815	1334	.072"	937	—
	H	.256"	1811	1331	.072"	940	—
	I	.259"	1855	1363	.074"	980	—
.072"-.051"-.051"	A	.226"	1333	980	.053"	—	1320
	B	.203"	1328	976	.053"	—	1328
	C	.213"	1363	1002	.054"	—	1365
	D	.207"	1329	917	.053"	—	1358
	E	.205"	1334	980	.053"	—	1323
	F	.203"	1335	981	.053"	757	—
	G	.198"	1326	97[illegible]	.053"	770	—
	H	.204"	1342	986	.053"	725	—
	I	.210"	1370	1007	.054"	802	—
	J	.211"	1305	959	.052"	837	—
.064"-.051"-.051"	A	.199"	1270	933	.050"	—	1170
	B	.197"	1287	946	.051"	—	1203
	C	.207"	1312	964	.052"	—	1208
	D	.204"	1309	962	.052"	—	1302
	E	.206"	1260	926	.050"	—	1318
	F	.199"	1265	930	.050"	798	—
	G	.202"	1305	959	.052"	702	—
	H	.191"	1273	936	.051"	718	—
	I	.193"	1308	961	.052"	771	—
	J	.201"	1273	936	.051"	683	—
.051"-.064"-.064"	A	.208"	1252	920	.050"	—	1253
	B	.193"	1242	913	.049"	—	1167
	C	.204"	1258	925	.050"	—	1330
	D	.213"	1240	911	.049"	—	1255
	E	.207"	1199	881	.048"	—	1093
	F	.200"	1233	906	.049"	730	—
	G	.201"	1232	906	.049"	723	—
	H	.200"	1242	913	.049"	721	—
	I	.208"	1240	911	.049"	740	—
	J	.199"	1197	880	.048"	778	—
.040"-.064"-.064"	A	.193"	1140	838	.045"	—	1143
	B	.190"	1145	842	.042"	—	1175
	C	.192"	1176	864	.047"	—	1198
	D	.190"	1126	828	.045"	—	1128
	E	.202"	1135	834	.045"	—	1128
	F	.185"	1148	844	.046"	621	—
	G	.192"	1168	858	.046"	715	—
	H	.193"	1173	862	.047"	686	—
	I	.197"	1113	818	.044"	650	—
	J	.190"	1125	827	.045"	655	—
For Comparison:							
Hadfield Manganese Steel		-	—	-	.045"	950	1675

1. Cal. .45 steel-jacketed ball projectile - 230 grains.
2. Cal. .22 fragment-simulating projectile - 17 grains.

TABLE IX

Comparative Resistance of Various Samples of Laminates to Perforation by Cal. .45 Ball Projectiles

Material	Equiv. Steel Gauge	Cal. .45 Ballistic Limit	Cal. .45 Figure of Merit*	Reference
Nylon-Resin Combination	.039"	367	41	Table III
3-Decker, 8-ply Nylon-Resin with 21-ply Nylon Cured Rubber Filler	.040"	395	44	Table IV
Fiberglas-Resin Combination	.043"	445	47	Table III
3-Decker, 8-ply Fiberglas-Resin with 21-ply Nylon Cured Rubber Filler	.040"	428	48	Table IV
3-ply Duck (.080"), 4-ply Tenite #H5, alternate layers	.046"	512	53	Table V
5-ply Duck (.080"), 5-ply Vinylite, alternate layers	.042"	514	56	Table V
Nylon-Rubber Combination	.045"	569	60	Table III
"K" Panel .040" - .064" - .064"	.046"	621	65	Table VIII
"K" Panel .064" - .051" - .051"	.051"	683	68	Table VIII
"K" Panel .040" - .064" - .064"	.044"	650	69	Table VIII
"K" Panel .040" - .064" - .064"	.045"	655	69	Table VIII
"K" Panel .040" - .064" - .064"	.047"	686	71	Table VIII
"K" Panel .064" - .051" - .051"	.051"	718	71	Table VIII
"K" Panel .051" - .064" - .064"	.049"	723	73	Table VIII
"K" Panel .051" - .064" - .064"	.049"	721	73	Table VIII
"K" Panel .051" - .064" - .064"	.049"	730	74	Table VIII
"K" Panel .040" - .064" - .064"	.046"	715	74	Table VIII
"K" Panel .051" - .064" - .064"	.049"	740	75	Table VIII
"K" Panel .064" - .051" - .051"	.049"	779	79	Table VII
"K" Panel .072" - .051" - .051"	.051"	793	79	Table VII
"K" Panel .051" - .064" - .064"	.048"	778	79	Table VIII
"K" Panel .064" - .051" - .051"	.050"	798	80	Table VIII
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 800 p.s.i.	.047"	801	83	Table V

TABLE IX (CONT'D)

Material	Equiv. Steel Gauge	Cal. .45 Ballistic Limit	Cal. .45 Figure of Merit*	Reference
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 800 p.s.i.	.048"	817	83	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.048"	812	83	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.048"	827	84	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.048"	819	84	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.047"	817	84	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 650 p.s.i.	.048"	821	84	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 650 p.s.i.	.047"	820	85	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.048"	839	86	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 100 p.s.i.	.046"	824	86	Table V
"K" Panel .051" - .062" - .062"	.046"	824	86	Table VII
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 800 p.s.i.	.048"	848	87	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.043"	862	88	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 650 p.s.i.	.048"	860	88	Table V
15-ply X1551 Fiberglas coated with Vinyl dispersion; 7-ply Rayon coated with Vinyl dispersion, alternate layers in center portion; 250 p.s.i.	.044"	828	88	Table V
19-ply X1551 Fiberglas coated with Vinyl dispersion; 9-ply Butvar (.005"); alternate layers in center portion; 250 p.s.i.	.043"	825	89	Table V
20-ply X1551 Fiberglas, no coating; 19-ply Butvar (.005"); alternate layers; 100 p.s.i.	.040"	809	90	Table V
"K" Panel .064" - .051" - .051"	.046"	865	90	Table VII
"K" Panel .051" - .062" - .062"	.047"	880	91	Table VII
"K" Panel .040" - .062" - .062"	.044"	962	98	Table VII

TABLE IX (CONT'D)

Material	Equiv. Steel Gage	Cal. .45 Ballistic Limit	Cal. .45 Figure of Merit*	Reference
22-ply X1551 Fiberglas, coated with Vinyl dispersion; 500 p.s.i.	.044"	958	102	Table V
22-ply X1551 Fiberglas, 22-ply Vinylite (.004"); alternate layers; molding pressure 500 p.s.i.	.047"	1000	103	Table V
Doron (Type 1) - R-150	.042"	974	106	Table I
Doron (Type 1) - R-166	.042"	984	107	Table I
Doron (Type 1) - R-113	.047"	1104	114	Table I
Doron (Type 1) - R-123	.046"	1098	114	Table I
Doron (Type 1) - R-404j	.041"	1037	114	Table I
Doron (Type 1) - R-147	.042"	1060	115	Table I
Doron (Type 1) - R-404d	.040"	1041	116	Table I
Doron (Type 1) - R-159	.044"	1105	118	Table I
Doron (Type 1) - R-124	.045"	1117	118	Table I
Doron (Type 1) - R-117	.043"	1104	119	Table I
Doron (Type 1) - R-148	.041"	1105	121	Table I
Doron (Type 1) - R-116	.045"	1152	121	Table I
Doron (Type 1) - R-120	.046"	1162	121	Table I

*Figure of merit determined from the formula: $\frac{V_{SUB} \times 100}{V_{HAD}}$,

where V_{SUB} is the ballistic limit of the subject sample and V_{HAD} is the ballistic limit characteristic of samples of Hadfield manganese steel of equivalent weight.

TABLE X

Comparative Resistance of Various Samples of Laminates to Perforation

by Cal. .22 Fragment-Simulating Projectile, G-2

Material	Equiv. Steel Gauge	Cal. .22 Ballistic Limit	Cal. .22 Figure of Merit*	Reference
3-Decker: 8-ply Fiberglas-Resin; 21-ply Nylon and Rubber	.040"	670	42	Table IV
3-Decker: 8-ply Nylon-Resin; 21-ply Nylon and Rubber	.040"	725	45	Table IV
23-ply ECC-128 Fiberglas; 23-ply Saran screen (velon); alternate layers; molding pressure 500 p.s.i.	.043"	1025	62	Table V
"K" Panel .051" - .064" - .064"	.048"	1093	64	Table VIII
40-ply ECC-128 Fiberglas coated with 10% T19 P.V. Butyral on both sides, complete penetration; molding pressure 500 p.s.i.	.043"	1078	66	Table V
"K" Panel - .064" - .051" - .051"	.050"	1170	67	Table VIII
"K" Panel - .051" - .064" - .064"	.049"	1167	67	Table VIII
"K" Panel - .040" - .064" - .064"	.045"	1128	67	Table VIII
"K" Panel - .040" - .064" - .064"	.045"	1128	67	Table VIII
"K" Panel - .064" - .051" - .051"	.051"	1203	68	Table VIII
"K" Panel - .040" - .064" - .064"	.045"	1143	68	Table VIII
"K" Panel - .040" - .064" - .064"	.045"	1198	70	Table VIII
"K" Panel - .051" - .064" - .064"	.050"	1263	72	Table VIII
"K" Panel - .051" - .064" - .064"	.049"	1255	72	Table VIII
"K" Panel - .040" - .064" - .064"	.042"	1175	72	Table VIII
"K" Panel - .064" - .051" - .051"	.049"	1287	74	Table VII
"K" Panel - .064" - .051" - .051"	.050"	1318	75	Table VIII
"K" Panel - .051" - .064" - .064"	.050"	1330	76	Table VIII
Doron (Type 1) - R-116	.045"	1293	77	Table I
Doron (Type 1) - R-166	.042"	1283	79	Table I
Doron (Type 1) - R-113	.047"	1345	79	Table I

TABLE X (CONT'D)

Material	Equiv. Steel Gauge	Cal. .22 Ballistic Limit	Cal. .22 Figure of Merit*	Reference
"K" Panel .072" - .051" - .051"	.045"	1327	79	Table VII
"K" Panel .051" - .062" - .062"	.046"	1350	80	Table VII
"K" Panel .040" - .062" - .062"	.045"	1332	80	Table VII
"K" Panel .064" - .051" - .051"	.051"	1408	80	Table VII
"K" Panel .072" - .051" - .051"	.051"	1425	81	Table VII
Doron (Type 1) - R-150	.042"	1370	84	Table I
Doron (Type 1) - R-123	.046"	1430	85	Table I
Doron (Type 1) - R-124	.045"	1443	86	Table I
Doron (Type 1) - R-404d	.040"	1380	86	Table I
"K" Panel .051" - .062" - .062"	.046"	1480	88	Table VII
Doron (Type 1) - R-404J	.041"	1460	90	Table I
Doron (Type 1) - R-148	.041"	1478	92	Table I

*Figure of merit determined from the formula, $\frac{V_{SUB} \times 100}{V_{HAD}}$, where V_{SUB} is the ballistic limit of a subject sample and V_{HAD} is the ballistic limit characteristic of samples of Hadfield manganese steel of equivalent weight.

TABLE XI

Average Figures of Merit of Various Classes of Laminates with Respect to Their Resistance to Perforation by Cal. .45 Ball Projectiles

Material	No. Tested	Average Figure of Merit
Doron (Type 1)	13	116
Fiberglas (X1551)	19	87
"K" Panels (Table VII)	6	87
"K" Panels (All)	19	77
"K" Panels (Table VIII)	13	72
Duck	2	55
Rubber Combinations	5	45

TABLE XII

Average Figures of Merit of Various Classes of Laminates with Respect to Their Resistance to Perforation by the Cal. .22 Fragment-Simulator, G-2

Material	No. Tested	Average Figure of Merit
Doron (Type 1)	9	84
"K" Panels	20	73
Fiberglas ECC-138	2	64
Rubber Combinations	2	44

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