WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/563

Ballistic Characteristics of Various Samples of Experimental Body Armor Materials

BY

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WATERTOWN ARSENAL
WATERTOWN, MASS.

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Partial Report on Problem B-8.2

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1. At the request of the Office, Chief of Ordnance, ~~(O.O. 422.3/100(c) - Wtn 422/9(c), and O.O. 422.3/122(c) - Wtn 422/12(c))~~ ballistic tests of various samples of experimental body armor materials have been conducted at this arsenal.

2. The conclusions of this study to date may be summarized as follows:

a. All plastic materials investigated which were of a weight comparable to steel of the current body armor gage exhibited substantially similar ballistic characteristics when subjected to any one of the ballistic tests conducted, so that no one material can be said to have superior ballistic efficiency to any other. (Material R-141 which was of lighter weight than the other materials exhibited unusually good ballistic characteristics and should be investigated in a weight comparable to that of the other materials).

b. The ballistic efficiency of the plastic materials was superior to that of the magnetic steel investigated and also superior to the decarburized samples of Hadfield manganese steel furnished. It was nearly equivalent to that of good quality Hadfield steel.

c. The mere ballistic equivalence of the plastic material to good quality Hadfield steel does not warrant its substitution for this steel, especially in view of its apparent cost.

d. If the steel currently used in body armor assemblies is decarburized Hadfield manganese steel, the improvement in protection sought by the Air Corps may be assured by the introduction and strict adherence to a specification for the steel components designed to eliminate decarburized material from inclusion in body armor assemblies. Such a specification would necessarily include an inspection device to discriminate between decarburized and undecarburized Hadfield manganese steel. Although metallographic examination, a bend test (Tentative Specification AXS-1025, Revision 2, Paragraph E-5e) or an Olsen cupping test might accomplish this end, the magnetic test devised at this arsenal for this purpose, because of its ability to assign quantitative values to the varying degrees of quality of the steel and because of its inherent simplicity is considered ideally suitable as an inspection tool.

e. If, on the other hand, the steel currently used in these assemblies is Hadfield manganese steel of good quality, improvement in protection can only be realized by increasing the thickness of the components and consequently the allowable weight.

f. However, unless an adequate specification for the material used as the armoring component of the body armor assembly is introduced and adhered to strictly, a large percentage of decarburized steel will inevitably find its way into use in these assemblies and, consequently the protection afforded by them will be seriously impaired. Without an adequate specification for the steel components, the substitution of plastic materials such as those herein investigated warrants consideration.

3. Room temperature tests with the cal. .45 Ball projectile M1911 and with the fragment-simulating projectiles G-1-A and G-1-S developed at this arsenal[1] were conducted and, in view of ambient service temperatures, a sub-zero (-60°F.) test with the cal. .45 Ball projectile was also run. The results of these tests have been summarized in Table I.

4. Items with the prefix "R-" are samples of various assemblies of woven glass fabric and plastic binder material. These samples were measured and weighed and, with the sole exception of R-141, were found to be equivalent in weight per unit area to steel plates currently used in body armor assemblies (.041" to .047" thick). Items B (Full Hard - Rockwell C 35), D (Half Hard - Rockwell C 23) and C (Dead Soft - Rockwell B 75) are samples of a magnetic steel of various hardnesses and Items A (Full Hard - Rockwell C 40), E (Half Hard - Rockwell C 30) and F (Dead Soft - Rockwell B 88) are samples of the nonmagnetic Hadfield manganese steel at different stages of hardness. From a test of these steel samples, it was hoped that an indication of the effect of hardness variations on the ballistic characteristics of body armor steels might be disclosed.

5. Inasmuch as previous experience at this arsenal has shown that decarburization has a decidedly deleterious effect upon the resistance of Hadfield steel to penetration by a cal. .45 Ball projectile, Items A, E and F were subjected to a magnetic test devised at this arsenal to disclose decarburization in this type steel. The results of this test indicated that Item F was free of decarburization whereas Items A and E showed evidence of serious decarburization. Subsequent metallographic examination of the samples (see Figure 1) confirmed these preliminary findings. Thus no valid

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1. Watertown Arsenal Laboratory Memorandum Report No. WAL 762/247 - "Development of Projectiles to Be Used in Testing Body Armor to Simulate Flak and 20 mm. HE Projectile Fragments".

conclusions as to the effect of hardness variations on the ballistic characteristics of Hadfield manganese steel could be based on a study of the performance of Items A and E.

6. Therefore, as an emergency measure, helmets G-2 and H-2, free of decarburization as evidenced by the magnetic test, were annealed for 10 minutes at 1850°F and quenched in water. There were thus made available two samples of good Hadfield manganese steel in a softened condition (Rockwell B 90) to compare with two samples of Hadfield steel hardened as a result of the cold working incidental to forming, helmets G5 and H5 (companion helmets to G2 and H2 respectively). Because of the difficulty of reliably determining the ballistic limits of helmets with a cal. .45 Ball projectile (inasmuch as the dispersion of shots usual in such a test precludes their normal consistent incidence in areas of equal thickness and hardness) it was decided to confine the investigation to a test with the experimental projectile G-1-S in which a high order of accuracy and a small measure of dispersion assures reliable ballistic limit determinations. The results of such testing indicated that under impact of light (34 grain) fragments, striking edge-wise, Hadfield manganese steel in the dead soft condition offers resistance to penetration superior to the same steel hardened as a result of cold working. Previous work at this arsenal has indicated that a variation in hardness has no appreciable effect upon this steel's resistance to penetration by the cal. .45 Ball projectile. However, no valid evaluation of the effect of hardness upon the resistance to penetration by either type of projectile can be made until flat sheet samples of work-hardened Hadfield manganese steel, free of decarburization and other metallurgical defects, have been subjected to ballistic tests conjunctively with good Hadfield steel in the dead soft condition.

7. The ballistic limits of the magnetic steel samples, as determined with the cal. .45 Ball projectile, increased with increasing hardness. Their ballistic limits as determined with the larger fragment-simulating projectile, G-1-A, were substantially uninfluenced by hardness variation. Their ballistic limits with the small projectile, G-1-S, were so low that testing was discontinued. Thus, Hadfield manganese steel of good quality, free of decarburization, is superior in helmet sheet gauge to other steels in resistance to penetration by cal. .45 Ball projectiles (as substantiated by past experience at this arsenal) and fragment-simulating projectiles of the type developed here.

8. The sample of Duralumin tested was inferior in resistance to both the average plastic material and good Hadfield steel.

9. All the plastic materials offered resistance to penetration by the cal. .45 Ball projectile superior to that of the magnetic steel tested and this superiority continued in tests with the fragment-simulating projectiles. The Hadfield manganese steel, however, was slightly superior to these materials in all tests. No deleterious effects upon resistance

to penetration by the cal. .45 Ball projectile were induced by lowering the testing temperature to -60°F. On the contrary the resistance of all materials showed a slight improvement.

10. Plastic sample R-141, equivalent in weight per unit area to .029" of steel, offered unusual resistance to penetration by the ball projectile in light of what would be expected of steel plate of equivalent weight. Whether this superiority carries over to tests with the fragment-simulating projectiles cannot be said in view of the lack of data on the effect of these projectiles on steel of such gauge. Further tests on samples of R-141 comparable in weight per unit area to .045" of steel may disclose a material superior to any of the steels tested thus far. However, it is possible that a diminution in the thickness of steel is more critical to that material's resistance to projectile penetration than a proportionate diminution in the thickness of the plastic and that when the steel thickness is about .045" the resistance of good steel and good plastic of equal weight is nearly the same.

11. From an observation of the character of failure of the plastic materials under attack by the various types of projectiles employed in these tests evolves the contention that against low velocity projectiles or against blunt or readily deformable projectiles this type of material will be highly resistant whereas against high velocity projectiles or against sharp projectiles their ballistic efficiency might be somewhat impaired.

12. It has been requested by the Air Corps that a body armor superior to that now in use be developed by the Ordnance Department. Hadfield manganese steel is the material now being used in body armor assemblies. If good quality steel of this type is now being utilized in these assemblies, no improvement of ballistic properties can be visualized by the substitution of any other material of equivalent weight per unit area, and, if improvement is mandatory, the only way of guaranteeing it is by increasing the weight allowance. Nevertheless, it must be recognized that there are definite limitations in the protection which any serviceable body armor can afford, and no feasible increase in weight allowance can be expected to produce protection against Flak fragments or armor piercing projectiles travelling at high velocities, but an increase of 25% in the allowable thickness of Hadfield manganese steel might well make considerable difference in the protection afforded by body armor from fragments or projectiles of lower velocity or smaller mass.

13. It is strongly suspected, however, that the Hadfield manganese steel now in use in body armor may not be of the best quality. Previous experience with helmet stock produced by the facilities now supplying body armor steel indicates that a large percentage of Hadfield manganese sheet steel produced by these facilities is badly decarburized. If plates of such steel are current components of body armor assemblies, the desire of the Air Corps for improved protection is quite understandable. The difference in the ballistic limits of Hadfield manganese of the best quality and that which is

decarburized may well be about 200 foot + seconds. All samples of the plastic material tested would afford better protection at the current weight tolerance than decarburized Hadfield steel.

14. The procurement of good quality Hadfield manganese steel could be assured, however, by the introduction of an adequate specification for the material to be used in the assemblies. Such a specification would necessarily embody an inspection device designed to discriminate between good quality Hadfield steel and that which is decarburized. Metallographic examination of samples selected on a sound statistical basis would accomplish this end, but the use of such a technique as an inspection device is impossible because of the lack of trained personnel. The bend test as specified in paragraph E-5e of Tentative Specification 1025 (Revision 2), if properly conducted and interpreted and strictly enforced, would differentiate between good and poor Hadfield steel as might also an Olsen cupping test. The examination, at this arsenal, of a large number of samples of Hadfield manganese steel has shown the magnetic test devised here to be a very reliable discriminator between good and bad steel of this type. Its simplicity recommends it as an ideal inspection tool. Its use, in accordance with a well-conceived specification, would undoubtedly improve the quality of acceptable steel components and, consequently, the protection afforded by the completed assemblies. However, it may be anticipated that the producers of body armor sheet steel will not react favorably to the suggestion that such a specification be inducted. It can readily be visualized that its introduction would affect the economies of the present production setups. It might even be argued that it would be economically unfeasible, in view of the low tonnage involved, to produce steel to meet such an adequate specification.

15. Nevertheless, without such a specification, real concern about the quality of steel used in body armor assemblies and the consequent protection afforded by armor is not amiss, and if such a specification cannot be introduced and adhered to strictly, serious consideration should be given to the use of a substitute material such as the plastic examined in this study. If psychology dictates the use of a steel component, the only prospect of improvement without the introduction of an adequate specification would be a substantial increase in the allowable weight of the assembly.

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TABLE I

Ballistic Limits of Various Samples of Experimental Body Armor Materials with Different Projectiles and at Different Temperatures - Fired at Watertown Arsenal

1 to 6 December 1943

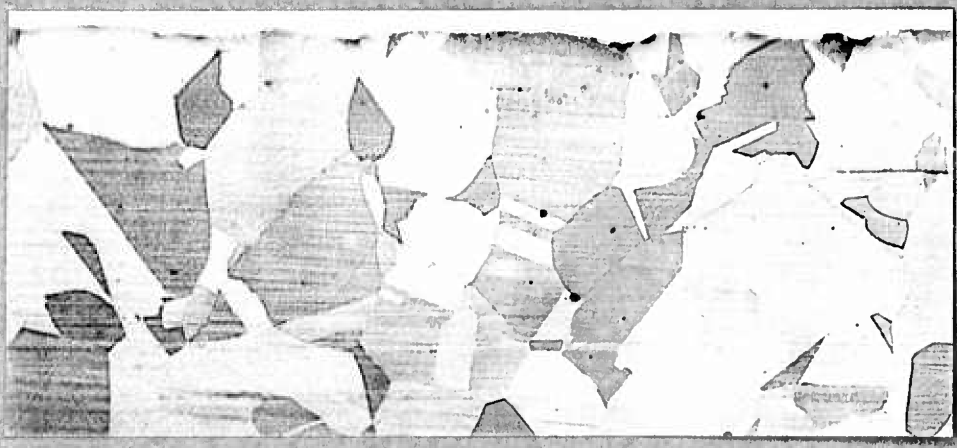
Identif.	Weight (Lbs.)	Dimensions (In.)	Gauge (In.)	Equiv. Steel Gauge (In.)	Hardness	Type	Ballistic Limits (Projectile or Piece Thereof thru) Cal. .45 (+50°F.)	Cal. .45 (-60°F.)	G-1-S (+65°F.)	G-1-A (+65°F.)
R-113	2.65	10 x 20	.20	.047	-	Plastic	1104	1118	998	445
R-116-1	2.60	10 x 20	.19	.046	-	"	1139	-	1075	515
R-116-2	1.85	12 x 12	.19	.045	-	"	1164	-	1055	480
R-117	1.76	12 x 12	.17	.043	-	"	1104	-	1030	483
R-120	1.88	12 x 12	.19	.046	-	"	1162	1173	1165	468
R-123	2.6	10 x 20	.19	.046	-	"	1098	1123	955	532
R-124	2.56	10 x 20	.19	.045	-	"	1117	1124	975	540
R-141	1.2	12 x 12	.13	.029	-	"	895	-	760	340
R-147	.79	8-1/8 x 8-1/8	.19	.042	-	"	>1060	-	1030	475
R-148	.78	8-1/8 x 8-1/8	.18	.041	-	"	1105	-	1009	495
R-150	1.38	11-1/4 x 10-3/16	.18	.042	-	"	-	-	1043	513
R-158	1.33	10-3/4 x 10-3/4	.17	.041	-	"	-	-	910	508
R-159	1.8	12 x 12	.18	.044	-	"	1105	-	955	453
O	-	-	-	.048	75 Rb	Mag. Steel	<745	<745	<890	425
D	-	-	-	.048	23 Rc	"	820	-	<870	453
B	-	-	-	.048	35 Rc	"	940	995	<880	413
F	-	-	-	.043	88 Rb	Had. Steel	1117	-	995	545
E	-	-	-	.043	30 Rc	"	848	-	943	418
A	-	-	-	.046	40 Rc	"	898	Cracked	995	<415
A-62	-	-	-	.044	92 Rb	"	1131	1175	1175	501
G-5	-	Helmet	-	.040	50 Rc	"	-	-	<920	-
G62	-	"	-	.040	90 Rb	"	-	-	985	-
H-5	-	"	-	.040	50 Rc	"	-	-	<[illegible]	-
H-2	-	"	-	.040	90 Rb	"	-	-	1010	-
24ST	-	12 x 12	.126	.045	-	Duralumin	913	-	885	475

Nital Etch X250

Item A - Full hard (Rockwell C 40) - .0013" decarburization. Slip lines indicative of cold working - Poor ballistic characteristics.

Nital Etch X250

Item E - Half hard (Rockwell C 30) - .0009" decarburization. Poor ballistic characteristics.



Nital Etch X250

Item F - Dead soft (Rockwell B 85) - No decarburization. Good quality steel - Good ballistic characteristics.

FIGURE 1

[redacted]

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Ballistic tests were conducted on various samples of experimental body armor materials. All plastic materials investigated which were of a weight comparable to steel of the current body armor gage exhibited substantially similar ballistic characteristics when subjected to any one of the ballistic tests conducted. It was concluded that the ballistic efficiency of the plastic materials was superior to that of the magnetic steel investigated and also superior to the decarburized samples of Hadfield manganese steel furnished. Room temperature tests with the cal. .45 Ball projectile M1911 and with the fragment-simulating projectiles G-1-A and G-1-S, and sub-zero (-65°F) test with the cal. .45 Ball projectile were conducted. Results of these tests are tabulated.

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