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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO WAL 810/760

Metallurgical examination of 1" and 3" Plate Test Armor Used For the Development of Effective Armor for Projectile Shock Tests

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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 710/760

First Partial Report on Problem B-4.78

28 June 1945

Metallurgical Examination of 1" and 2" Thick Cast Armor Used for the Development of 57 MM and 105 MM Proof Projectile Shock Tests

Abstract

Except for a few cases, the ballistic performance of 1" and 2" thick cast armor shock tested at velocities of 1000 and 1100 ft./sec. with 57 mm. and 105 mm. proof projectiles respectively does not correlate with the shock properties of the armor as revealed by metallurgical tests. There is evidence that low hardness is the factor responsible for the failure of 1" thick plates during the shock test. In general, the ballistic failures resulted from complete penetrations (Army criterion) rather than from breakage or excessive cracking. Complete penetrations are not considered reliable indices of the shock resistance of armor. As presently conducted, the subject ballistic shock tests are not considered satisfactory for inclusion in Specification AXS-492-5.

1. At the request of the Ordnance Research Center, Aberdeen[1], a metallurgical examination of seventeen 1" and eleven 2" thick cast armor plates has been completed. These plates had been shock tested with 57 mm. and 105 mm. proof projectiles respectively in an attempt to establish required velocities for these tests for incorporation in Specification AXS-492-5.

2. Metallurgical examination and an evaluation of the results of the ballistic tests lead to the following observations and conclusions.

a. The 57 mm. proof projectile shock tests at velocities of 1000 ft./sec. and 1100 ft./sec. are not considered satisfactory as criteria of the shock resistance of 1" thick cast armor since metallurgical tests show, in general, no difference in shock properties between plates which

1. APG. 470.5/1476 - Wtm. 470.5/8735 dated 25 April 1945.

passed and plates which failed the test. Furthermore, plates generally failed the test because of complete penetrations (Army criterion) rather than cracking or breaking. Complete penetrations are not satisfactory indices of poor shock resistance.

b. The ballistic behavior of 2" thick cast armor shock tested at a velocity of 1000 ft./sec. with 105 mm. proof projectiles does correlate somewhat more satisfactorily with the shock properties as revealed by metallurgical tests. Complete penetrations (Army criterion) occurred, however, in some of the failing plates. The philosophy of failing plates as the result of complete penetrations during shock testing is open to severe criticism.

3. The metallurgical examination included the following tests:

a. Fibre fracture test.

b. Cross-sectional Brinell hardness survey.

c. V-notch Charpy impact tests.

The 6"x12"x2" and 4"x8"x1" sections were notched by flame cutting in from the middle of the two longer sides and were fractured under the impact of a steam forge hammer. One-half inch thick sections cut from the middle of one of the fractured halves were surface ground. Brinell hardness surveys were made on the cross-sectional surfaces, after which two V-notch Charpy impact specimens were machined from each section, from positions halfway between the surface and the center in the case of the 1" thick plates and from near the center of the 2" thick plates. One impact specimen from each plate was tested at +70°F. and the other at -40°F.

4. The details regarding the ballistic performance, hardness, fibre fracture rating, and notched bar impact values of the 1" and 2" thick plates are tabulated in Tables I and II respectively.

5. According to the ballistic data forwarded to this arsenal with the 2nd indorsement to the basic letter[1], all but a very few of the plates which failed the shock test at the various velocities failed because of complete penetrations (Army criterion). The fact that failure occurred through complete penetration rather than as a result of breakage or cracking of the test plates casts immediate doubt upon the success of 57 mm. and 105 mm. proof projectiles employed to shock test 1" and 2" thick cast armor respectively. A complete penetration cannot in itself be considered an adequate proof of poor shock properties. The one 1" thick plate, Ordnance Steel Foundry plate 2, heat B142, which did break up under the impact of a 57 mm. proof projectile was found to possess extremely poor impact properties, having an impact energy of 7.9 ft.lbs. at +70°F. and 4.1 ft.lbs. at -40°F. Likewise, two 2" thick plates which cracked in excess of 8½", Symington-Gould, heat

1. See reference on preceding page.

4422 and Union Steel, heat 401A, possessed relatively poor low temperature impact properties. Except for these three isolated cases, however, no correlation can be established between the ballistic performance and the shock properties as determined by metallurgical tests.

6. In order to more clearly demonstrate the lack of correlation between the results of the ballistic and the metallurgical shock tests, the data were rearranged as shown in Tables III and IV. The hardnesses, impact properties, and fibre fracture ratings of the plates which passed and those which failed the shock tests at velocities of both 1000 ± 15 ft./sec. and 1100 ft./sec. are arranged for purposes of comparison. The data in Table III indicate that at a velocity of 1100 ± 15 ft./sec., hardness rather than shock resistance determines whether plates pass or fail the 57 mm. proof projectile test. The hardness of the passing plates averages 340 ± 10 BHN and that of the failing plates 320 ± 7 BHN, whereas the impact energy of the passing plates at -40°F. averages 16.3 ± 5.8 ft.lbs. and that of the failing plates 17.2 ± 3.5 ft.lbs. No correlation whatsoever exists between the ballistic and metallurgical shock tests of the 1" thick plates tested at 1000 ± 15 ft./sec., except in the case of the previously described Ordnance Steel Foundry plate of extremely poor shock properties.

7. A further criticism of the 57 mm. proof projectile shock test arises from the fact that some 1" thick cast plates, which upon the basis of metallurgical tests would be considered of inferior quality, passed the shock test at striking velocities of both 1000 and 1100 ft./sec. American Radiator heat J160 and Symington Gould heat 4375 possess poor shock properties as measured by notched bar impact tests, yet these plates passed the shock test at both striking velocities.

8. The 105 mm. proof projectile shock test of 2" thick cast armor at a velocity of 1000 ± 15 ft./sec. does correlate somewhat better with the metallurgical shock tests in that the passing plates have an average impact energy at -40°F. of 38.2 ± 4.7 ft.lbs. whereas the failing plates average average 23.5 ± 2.1 ft.lbs., see Table IV. No similar correlation was found, however, at a velocity of 1100 ± 15 ft./sec. Of the three plates failing, one has the relatively low impact energy of 26.5 ft.lbs. but the other two failing plates have impact energies higher than those of some of the passing plates.

9. The results of the metallurgical examination show, in general, a very imperfect relation between the ballistic performance of the subject plates and their shock properties. The poor correlation between the ballistic and metallurgical shock tests in combination with the fact that ballistic failures for the most part resulted from Army complete penetrations, demonstrate beyond doubt that the 57 mm. proof projectile shock test for 1" thick cast armor and the 105 mm. proof projectile shock test for 2" thick cast armor as conducted at the Ordnance Research Center do not qualify as bona fide shock tests.

It is possible that these projectiles may yield more satisfactory results at an obliquity where the force of the impact would be spread over a larger area than at normal obliquity.

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TABLE I

1" Thick Plates Tested with 57 MM Proof Projectiles

Company	Heat No.	Ave. BHN*	57 MM Proof Projectile Velocity Ft./Sec. 900 ± 15	1000 ± 15	1100 ± 15	Fibre Fracture Rating**	V-Notch Charpy Data Ft.Lbs. at +70°F.	Ft.Lbs. at -40°F.
American Radiator	J43	334		Passed	Passed	F (shrinkage)	26.5	23.0
" "	J160	359		Passed	Passed	Cbf 1/2	22.9	10.6
Ordnance Steel Fdry.	B142	341		Failed***		Fc 1/4	7.9	4.1
Pratt & Letchworth	E154	334		Passed	Failed	Fc(tr shrinkage)	34.2	15.5
" " "	E157	324		Passed	Failed	F (shrinkage)	24.7	18.1
" " "	E138	311		Passed	Failed	Fc 1/8	26.5	17.4
" " "	E162	328		Passed	Failed	F (shrinkage)	45.8	15.8
" " "	E167	328		Passed	Failed	F	17.4	12.1
" " "	E170	318		Passed	Failed	F	43.6	22.5
" " "	E183	334	Passed	Failed		Fc 1/8	23.2	13.3
" " "	E186	334		Passed	Passed	F (shrinkage)	29.5	13.0
" " "	E188	315		Passed	Failed	Cbf 1/4	28.0	10.6
Symington-Gould(D)	3719	324		Passed	Failed	Fc 1/8	28.0	15.1
" "	4375	331		Passed	Passed	Fc trace	16.4	13.6
" "	4380	301		Passed	Failed	F (shrinkage)	20.8	16.8
" "	3741	299	Passed	Failed		F (shrinkage)	28.8	18.4
Symington-Gould(R)	B4576	321		Passed	Failed	F	35.8	28.0

*Average of 3 cross-sectional readings.
**F = fibrous, Fc = fibrous matrix with spots of crystallinity, Cbf = bright crystalline patch surrounded by fibrous border. Fractions represent portion of crystalline area.
***This plate broke in 3 pieces. All other plates failed because of Army complete penetrations, none had cracking greater than 4½".

TABLE II

2" Thick Plates Tested with 105 MM Proof Projectiles

Company	Heat No.	Ave. BHN*	105 MM Proof Projectile Velocity Ft./Sec. 900 ± 15	1000 ± 15	1100 ± 15	Fibre Fracture Rating**	V-Notch Charpy Data Ft.Lbs. at +70°F.	Ft.Lbs. at -40°F.
Continental (W)	1367 (Sq. 183)	264		Passed	Passed	Fc 1/8	32.6	35.0
" "	2508 (Sq. 178)	264		Passed	Failed	Fc 1/4	56.8	37.4
Continental (C)	5928	253		Passed	Passed	Fc trace	50.1	42.4
" "	5951	255		Passed	Failed	Fc 1/4	40.7	26.5
Symington-Gould (D)	3705	250		Passed	Failed	Fc tr (shrinkage)	41.1	42.0
" " "	3719	264		Passed	Passed	Fc trace	29.5	37.4
" " "	3746	253	Passed	Failed		Fc 1/4	24.7	28.0
" " "	4397	248		Passed	Passed	F (shrinkage)	38.2	46.6
" " "	4422	253	Passed	Failed***		Fc 1/10	23.6	23.6
Union Steel	373A	285	Passed	Failed		Fc 1/2	34.2	20.1
" "	401A	272	Failed*** (cracking in excess of $8\frac{1}{2}$")	Failed***		Fc 1/4 (slight conchoidal)	47.5	22.2

*BHN determined at Watertown Arsenal.
**F = fibrous, Fc = fibrous matrix with spots of crystallinity. Fractions represent portion of crystalline area.
***Cracking in excess of $8\frac{1}{2}$" occurred on these plates as well as Army complete penetrations. All other failing plates failed on Army complete penetrations only.

TABLE III

Correlation Between Ballistic and Metallurgical Properties

of 1" Thick Cast Armor Shock Tested with 57 MM Proof Projectiles

Required Velocity - 1000 ± 15 ft./sec.

Hardness of Plates Passing the Test	Hardness of Plates Failing the Test
334	341
359	334
334	299
324	Ave. - 325 ± 13 BHN
311	
328	
328	
318	
334	
315	
324	
331	
301	
321	
Ave. - 326 ± 10 BHN	

Required Velocity - 1100 ± 15 ft./sec.

Hardness of Plates Passing the Test	Hardness of Plates Failing the Test
334	334
359	324
334	311
331	328
Ave. - 340 ± 10 BHN	328
	318
	315
	324
	301
	321
	Ave. - 320 ± 7 BHN

TABLE III (Cont'd)

Required Velocity - 1000 ± 15 ft./sec.

V-Notch Charpy Impact at -40°F. of Plates Passing the Test - Ft.Lbs.	V-Notch Charpy Impact at -40°F. of Plates Failing the Test - Ft.Lbs.
28.0	4.1*
10.6	13.3
15.5	18.4
18.1	Ave. - 11.9 ± 4.7 ft.lbs.
17.4	
15.8	
12.1	*Plate broke in 3 pieces.
22.5	
13.0	
10.6	
15.1	
13.6	
16.8	
28.0	
Ave. - 16.9 ± 4.1 ft.lbs.	

Required Velocity - 1100 ± 15 ft./sec.

V-Notch Charpy Impact at -40°F. of Plates Passing the Test - Ft.Lbs.	V-Notch Charpy Impact at -40°F. of Plates Failing the Test - Ft.Lbs.
28.0	15.5
10.6	18.1
13.0	17.4
13.6	15.8
Ave. - 16.3 ± 5.8 ft.lbs.	12.1
	22.5
	10.6
	15.1
	16.8
	28.0
	17.2 ± 3.5 ft.lbs.

TABLE III (Cont'd)

Required Velocity - 1000 ± 15 ft./sec.		Required Velocity - 1100 ± 15 ft./sec.	
Fibre Fracture Rating* of Plates Passing the Test	Fibre Fracture Rating of Plates Failing the Test	Fibre Fracture Rating of Plates Passing the Test	Fibre Fracture Rating of Plates Failing the Test
F (shrinkage)	Fc 1/4	F (shrinkage)	Fc trace
Cbf 1/2	Fc 1/8	Cbf 1/2	F (shrinkage)
Fc trace	F (shrinkage)	F (shrinkage)	Fc 1/8
F (shrinkage)		Fc trace	F (shrinkage)
Fc 1/8			F
F (shrinkage)			F
F			Cbf 1/4
F			Fc 1/8
F (shrinkage)			F (shrinkage)
Cbf 1/4			
Fc 1/8			
Fc trace			
F (shrinkage)			
F			

*F = fibrous.
Fc = fibrous matrix with scattered crystalline patches.
Cbf = Crystalline matrix with fibrous edges.
Fractions after rating refer to the amount of the fractured surface which is crystalline.

TABLE IV

Correlation between Ballistic and Metallurgical Properties

of 2" Thick Cast Armor Shock Tested with 105 MM Proof Projectiles

Required Velocity - 1000 ± 15 ft./sec.

Hardness of Plates Passing the Test	Hardness of Plates Failing the Test
264	253
264	253
253	285
255	272
250	Ave. - 266 ± 13 BHN
264	
248	
Ave.- 257 ± 6 BHN	

V-Notch Charpy Impact at -40°F. of Plates Passing the Test - Ft.Lbs.	V-Notch Charpy Impact at -40°F. of Plates Failing the Test - Ft.Lbs.
35.0	26.0
37.4	23.6
42.4	20.1
26.5	22.2
42.0	Ave. - 23.5 ± 2.1 ft.lbs.
37.4	
46.6	
Ave. - 38.2 ± 4.7 ft.lbs.	

Required Velocity - 1100 ± 15 ft./sec.

Hardness of Plates Passing the Test	Hardness of Plates Failing the Test
264	264
253	255
264	250
248	Ave. - 256 ± 5 BHN
Ave. - 257 ± 7 BHN	

V-Notch Charpy Impact at -40°F. of Plates Passing the Test - Ft.Lbs.	V-Notch Charpy Impact at -40°F. of Plates Failing the Test - Ft.Lbs.
35.0	37.4
42.4	26.5
37.4	42.0
46.6	Ave. - 35.3 ± 5.9 ft.lbs.
Ave- 40.4 ± 4.2 ft.lbs.	

TABLE IV (CONT'D)

Required Velocity - 1000 ± 15 ft./sec.

Fibre Fracture Rating of Plates Passing the Test	Fibre Fracture Rating of Plates Failing the Test
Fc 1/8	Fc 1/4
Fc 1/4	Fc 1/10
Fc trace	Fc 1/2
Fc 1/4	Fc 1/4 (slightly conchoidal)
Fc trace (shrinkage)	
Fc trace	
F (shrinkage)	

Required Velocity - 1100 ± 15 ft./sec.

Fibre Fracture Rating of Plates Passing the Test	Fibre Fracture Rating of Plates Failing the Test
Fc 1/8	Fc 1/4
Fc trace	Fc 1/4
Fc trace	Fc trace (shrinkage)
F (shrinkage)	