PHOTOGRAPH THIS SHEET

AD-A954 836

DTIC ACCESSION NUMBER

LEVEL

INVENTO[RY]

1

WAL 710/789

DOCUMENT IDENTIFICATION

30 OCT 1945

This document has been approved for public release and sale; its distribution is unlimited.

DISTRIBUTION STATEMENT

ACCESSION FOR		
NTIS	GRA&I	X
DTIC	TAB	☐
UNANNOUNCED		☐
JUSTIFICATION	per ltr	
BY		
DISTRIBUTION		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A-1		

DISTRIBUTION STAMP

DTIC ELECTE AUG 1 2 1985 S D E

DATE ACCESSIONED

DATE RETURNED

85 8 08 075

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED N[O.]

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDAC

Copy #2a

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/789

Metallurgical Examination of Sections from the Cast Armor Turret Made by Continental Foundry and Machine Company And Two Trunnion Pins from a Heavy Tank M6A2E1

BY

P. V. RIFFIN
T/5, Ord. Dept.

DATE 30 October 1945

WATERTOWN ARSENAL
WATERTOWN, MASS.

Watertown Arsenal Laboratory
Memorandum Report No. WAL 710/789
Final Report on Problem B-4.85 30 October 1945

METALLURGICAL EXAMINATION OF SECTIONS FROM THE CAST ARMOR TURRET MADE BY CONTINENTAL FOUNDRY AND MACHINE COMPANY AND TWO TRUNNION PINS FROM A HEAVY TANK M6A2E1

ABSTRACT

A metallurgical examination consisting of fracture, hardness, notched bar impact and microscopic tests has been conducted on two sections of cast armor of variable thickness (2" to 3-1/2" and 4-1/2" to 9") and a trunnion pin from the gun mount of the Heavy Tank M6A2E1. The 2" to 3-1/2" thick section, because of its high hardness (300 BHN) and temper embrittlement, possessed poor shock resistance. The 4-1/2" to 9" thick section, heat treated to a hardness of 248-269 BHN, possessed acceptable toughness.

The trunnion pins were heat treated to 300 BHN, a hardness which is considered too low for the application. An increase in hardness to 340 BHN can probably be attained without excessively impairing the toughness and this increase in strength would, no doubt, be sufficient to prevent the distortion which occurred in the subject pins during ballistic tests upon the tank.

1. According to a request from the Office, Chief of Ordnance-Detroit, through a letter from The Proving Center, Aberdeen, dated 30 August 1945 (APG 451.21/93-1(c)-Wtn. 400.112/3359(c)), a metallurgical examination has been conducted on the following items:

a. One sample M6-1, slightly curved, 3-1/2" to 2" thick from the gun shield for the M6A2E1 Turret.

b. One sample M6-2, curved 4-1/2" to 9" thick from the M6A2E1 Turret.

c. Two tubular trunnion pins 5" in diameter by 11-1/2" long. The results of the ballistic tests are reported in APG Armor Report No. APG 1028.

2. The turret casting which varied in thickness from 4-1/2" thick to 9" thick was heat treated to a hardness of 248-269 BHN, and possessed satisfactory surface toughness as required in the recently proposed specification for heavy cast armor. The 4-1/2" section was essentially fibrous, whereas, the 9" section possessed satisfactory surface notched bar impact properties although the center was quite brittle. Using this casting as a criterion, it is felt that heavy

castings of markedly variable thickness can be satisfactorily (according to our present toughness specification) heat treated to a hardness of 250 BHN.

3. The section from the gun shield casting, which was heat treated to a relatively high hardness of 290-310 BHN, exhibited inferior toughness as indicated by the fracture test and notched bar impact tests. Retempering tests revealed that the inferior toughness was attributable, for the most part, to temper embrittlement which is difficult to prevent in cast armor at the high hardness employed, since it may have been tempered at1100°F. or lower. Of course, it may be desirable to sacrifice some toughness if maintaining a high hardness enhances the resistance to penetration.

4. The trunnion pins were heat treated to a tensile strength of 150,000 psi., a value which was insufficient to prevent plastic deformation in these pins when the tank in which they were employed was subjected to ballistic tests. A compromise must be made between the strength and toughness of this part, but it is considered that the tensile strength can be increased to about 170,000 psi. (340 BHN) without an excessive sacrifice in toughness provided that the same design, composition, and quenching practice is employed. Of course, the use of a tempering temperature of less than1100°F. results in temper embrittlement in this steel, and so it is advisable to use as high a temperature and as short a holding time possible in obtaining the desired hardness.

5. The metallurgical examination consisted of the following tests:

a. Chemical analysis (trunnion pin only)

b. Hardness surveys.

c. Tensile Tests (trunnion pin only).

d. Fracture test (castings only).

e. V-notch Charpy Impact Tests.

f. Microscopic examination.

6. The results of the metallurgical examination are as follows:

Trunnion Pins

a. Chemical Analysis

The chemical analysis corresponds to WDX-4340 steel which is considered to have adequate hardenability for the given application although it is a steel which is quite susceptible to temper brittleness. The analysis is as follows:

	C	Mn	Si	S	P	Ni	Cr	Mo	Cu
Actual	.37	.74	.33	.029	.016	1.83	.68	.24	.10
Range for WDX-4340	.35 / .45	.60 / .90	.20 / .35	.04 Max.	.05 Max.	1.65 / 2.00	.60 / .90	.20 / .30	---

b. Visual Examination and Magnaflux Test for Cracks.

A dimension check of the two subject trunnion pins disclosed a maximum distortion of 1/16" in one and 1/32" in the other. Bending of the pins occurred at the change of section which would correspond to the point of maximum stress. The magnaflux test revealed no evidence of cracking as a result of the impact stresses to which the parts were subjected during the ballistic tests.

c. Physical Properties

The 1-1/2" thick hollow cylinder was found to possess a uniform hardness of 286-309 BHN. The results of tensile tests at the O.D. and the midwall are given in the following table:

Location	Yield Strength psi. (.1% Ext.)	Tensile Strength psi.	Elong. %	Reduction of Area %
O.D.	138,750	152,000	18.0	59.5
	131,250	150,000	19.0	59.5
Midwall	133,750	152,000	17.9	56.5
	138,750	155,000	17.9	58.5

The hardness test corroborated by the tensile test disclosed that the strength of the pins was insufficient to prevent deformation during the ballistic tests of the tank.

d. Impact Tests

Longitudinal V-notch Charpy impact tests were conducted at room temperature and -40°F. in an area adjacent to the outer diameter of one of the pins, and the results are as follows:

70°F.		-40°F.	
Ft.-Lbs.	Fracture	Ft.-Lbs.	Fracture
50.5	Fibrous	46.0	Fibrous
49.5	Fibrous	46.5	Fibrous

It is apparent that the toughness was satisfactory, being the maximum attainable in tempered martensite at the strength level to which the pins were heat treated. The hardness can probably be increased to approximately 340 BHN without seriously imparing the impact resistance.

However, an increase in tensile strength to greater than 170,000 psi. (340 BHN) would probably lower the impact strength below the toughness required to prevent brittle fracture.

e. Microscopic Examination

No undesirably large segregations of nonmetallic inclusions were observed in the specimens examined, indicating that the trunnion pins possessed satisfactory soundness. The trunnion pin examined possessed a tempered martensitic structure containing about 20% ferrite. Apparently the small quantity of nonmartensitic transformation products present were insufficient to lower the toughness appreciably.

Cast Armor Sections From the Turret and Gun Shield

a. Hardness Tests

The results of hardness surveys taken across the thickness of the castings are as follows:

	Brinell Hardness at Equal Intervals Across Section						
Gun Shield	302	293	302				
4-1/2" Section of Turret	262	255	262				
9" Section of Turret	269	262	255	248	255	262	269

The portion of the gun shield submitted extended about 6" from the edge of the casting. In this area it was impossible to keep away from edge effects, and it is very likely that the central area of the casting having the lowest hardness and poorest toughness was not available for examination. It was observed that the hardness at the centerline varied from 302 at the edge to 269 in the area examined farthest away from the edge.

The turret section showed a drop in hardness from surface to center which was more pronounced in the 9" than in the 4-1/2" cross section. The hardnesses of both sections are higher than that presently employed in most production heavy cast armor. This fact is encouraging because the penetration properties are improved by increasing the hardness providing the toughness is not decreased excessively.

b. Fracture Tests

Fracture test bars from the gun shield and the 4-1/2" thick section of the turret were flame notched on two sides and broken under the impact of a forge hammer. The fractured surface of the gun shield was about 75% crystalline while that of the turret section was essentially fibrous. The 9" section could not be broken without notching to a very small unnotched area, and so the toughness was evaluated by Charpy impact tests.

c. V-notch Charpy Impact Tests

The results of impact tests taken 1" below the surface and at the center of the two areas of the turret casting and 1" below the surface of the gun shield casting are given in Table I. A 1/2" x 3" x 4-1/2" section from the gun shield was retempered at 1150°F. for one hour and water quenched to prevent the occurrence of temper embrittlement during cooling. The results of V-notch Charpy impact tests on this small section are also included in Table I.

Considerable improvement in toughness resulted from the retempering treatment although the material still shows some drop in toughness from room temperature to -40°F. The retemper lowered the hardness about 10 points BHN and was employed on a relatively small section. Consequently the effect of water quenching a 3" section from the tempering temperature employed (especially if it were under 1100°F.) may result in the same embrittlement which was present in the gun shield after the manufacturer's heat treatment. However, raising the temperature of tempering without lowering the hardness more than 10-20 points Brinell would result in a considerable improvement in toughness in castings water quenched from the temper. Of course, if it is desirable to maintain a high hardness for resistance to penetration requirements, then it may be necessary to sacrifice shock resistance.

The turret sections exhibited satisfactory toughness according to the Charpy test requirements of the proposed specification for heavy cast armor. The surface values are greater than the 40 ft.-lbs. at 70°F. and 30 ft.-lbs. at -40°F. specified at a hardness of 240 BHN. The toughness at the center of the 9" section is very poor, but as yet it has not been possible to set up requirements at this location because of our present inability to obtain an appreciable toughness at the center of armor greater than 6" in thickness.

d. Microscopic Examination

The nonmetallic inclusions varied considerably in size and distribution in the two castings, but they were generally of the nonharmful globular variety. The castings were free, for the most part, of the eutectic type inclusions which result in interdendritic fractures and low impact strength.

The gun shield possessed a sorbitic (tempered martensitic) structure in which the carbides were fairly large.

The 4-1/2" thick area of the turret casting possessed a tempered martensitic structure with some acicular areas reminiscent of bainite. However, after being tempered to 260 BHN, the presence of bainite and its effect upon toughness is obscured.

The 9" thick area of the turret possessed a tempered martensitic structure with some acicular areas near the surface of the casting. About 40% ferrite was present at the center indicating that there was a large amount of nonmartensitic transformation products formed during the quench.

The metallurgical tests on the trunnion pin were conducted by A. Finocchio.

P. V. Riffin

P. V. RIFFIN
T/5, Ordnance Department

APPROVED:

E. L. Reed

E. L. REED
Research Metallurgist
Chief, Armor Section

TABLE I

V-NOTCH CHARPY IMPACT TESTS

Location	Tested at +70°F. Ft.-Lbs.	Fracture	Ave. Ft.-Lbs.	Tested at -40°F. Ft.-Lbs.	Fracture	Ave. Ft.-Lbs.
GUN SHIELD						
1" from surface of 3" section	41.0 40.5	Fctr Fctr	41.0	15.5 19.5	Cbf 1/2 Cbf 1/2	17.5
Retempered to eliminate temper-brittleness	44.0 37.5	F Fc 1/8	41.0	36.0 29.5	Fc 1/8 Fc 1/8	33.0
TURRET						
1" from surface of 4-1/2" section	54.0 47.0	F F	50.5	53.0 38.0	Cbf 1/8 Cbf 1/2	45.5
1" from surface of 9" section	53.5 56.5	F F	55.0	38.0 30.0	Cbf 1/2 Cbf 1/2	34.0
Center of 4-1/2" section	44.0 37.5	F Cbf 1/4	41.0	36.0 29.5	Cbf 1/2 Cbf 1/2	33.0
Center of 9" section	7.5 9.0	C C	8.5	3.0 2.0	C C	2.5

F = fibrous
Fctr = trace of crystallinity in a fibrous matrix.
Cbf = bright crystalline patch surrounded by fibrous border
C = crystalline
Fracture = amount of crystallinity