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Watertown Arsenal Laboratory
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19 January 1944

BAYONET BLADES

Investigation of WD-1080 Steel for Use in Bayonet Blades

OBJECT

To determine the requisite metallurgical characteristics to produce the optimum hardness and ductility in WD-1080 steel for bayonet use.

CONCLUSIONS

1. The metallurgical characteristics necessary to produce optimum hardness and ductility in WD-1080 steel for bayonet use result from a substantially homogeneous microstructure consisting of tempered martensite of Rockwell "C" hardness 46-52.

2. Increased impact strength at a Rockwell "C" hardness of 55-57 may be obtained with an inhomogeneous microstructure resulting from a low hardening temperature; however, this increase is not considered sufficient to offset the pratical disadvantages involved in applying such a heat treatment to the production hardening of WD-1080 bayonet blades.

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87-9-24-348

INTRODUCTION AND TEST PROCEDURE

At the request of the Office, Chief of Ordnance,* an investigation was carried out to determine the requisite metallurgical characteristics to produce the optimum hardness and ductility in WD-1080 steel for bayonet use. Ductility as used in this connection was interpreted to mean impact strength or resistance to breakage by shock loads. Because an investigation had already been carried out by Springfield Armory** to determine the properties imparted to WD-1080 steel bayonet by the austempering process, the present investigation was confined to determining the potentialities of the conventional quench and draw treatment. Two major variables were considered important in this investigation from the standpoint of controlling the metallurgical characteristics of WD-1080 steel; (1) extent of carbide solution on heating for hardening, and (2) degree of tempering of the hardened structure. As criteria for the evaluation of the effect of these variables on the probable performance of WD-1080 steel bayonet blades, reliance was placed on hardness, impact, and bend tests. These tests were supplemented by microexamination to determine the effect of variations in heat treatment on the metallographic structure of WD-1080 steel.

The commercial hardening of WD-1080 steel bayonet blades is at present carried out by heating in either a salt or lead bath followed by quenching in oil. In this investigation, heating for hardening was accomplished in a lead bath. Quenching was done both in oil (Houghton No. 2) and in water.

RESULTS AND DISCUSSION

A. Chemical Composition

The chemical compositions of the materials used in this investigation are given in Table I.

TABLE I - CHEMICAL COMPOSITION

Steel Designation	Condition	C	Mn	Si	S	P	Cr
WD-1080-A	Bar form (0.2" x 0.8" x 2")	.80	.68	.25	.029	.008	.05
WD-1080-B	M1905 Bayonet Blades	.81	.79	.26	.040	.025	.10

* O.O. 470.1/16624 - W.A. 470.1/6316
** Springfield Armory Report - July 1943 Sub-Item 21 (3)

B. Effect of Hardening Treatment

1. Hardness Tests

The effect of hardening temperature on the surface hardness of specimens (0.2" x 0.8" x 2") quenched in oil is shown in Table II. These specimens were quenched after heating in a lead bath for 6 minutes at temperatures in the range 1350°F to 1600°F.

TABLE II - SURFACE HARDNESS OF SPECIMENS OIL QUENCHED FROM 1350°F - 1600°F.

Quenching Temperature °F.	1350	1375	1450	1525	1600
Rockwell "C" Hardness	15	65	65.5	65.5	66.0

Table II reveals that a minimum hardening temperature of 1375°F is necessary to produce maximum hardness (Rockwell "C" 65-66) at the surface after oil quenching.

The effect of time of heating in a lead bath at 1400°F on the surface hardness of specimens (0.2" x 0.8" x 2") quenched in water is shown in Table III.

TABLE III - SURFACE HARDNESS OF SPECIMENS WATER QUENCHED FROM 1400°F

Time of Heating in Lead Bath, Minutes	1/4	1/2	3/4	1	2	4	8
Rockwell "C" Hardness	13-47	65.5	66	66	66	65.5	66

These results indicate that 1/2 minute of heating in a lead bath at 1400°F is necessary to produce maximum hardness (Rockwell "C" 65-66) at the surface after water quenching.

2. Microexamination

The microstructure of specimens annealed by heating for one hour at 1450°F and furnace cooling consists entirely of pearlite (Fig. 1-A).

The microstructures at the center of specimens quenched in oil from 1375, 1450, and 1525°F are shown in Figures 1-B-, -C-, and -D-. These structures reveal that it is necessary to harden from 1525°F to obtain substantially complete solution of carbides, and a structure free from primary troostite areas.

The microstructures at the centers of specimens heated for 1/2, 2, and 8 minutes in a lead bath at 1400°F, water quenched, and drawn at 400°F for 2 hours, are shown in Figures 1 -E-, -F-, and -G-. These structures reveal that 1/2 minute of heating time is insufficient to complete the transformation of all the original pearlite to austenite even though maximum hardness is obtained at the surface. After two minutes of heating time, all of the original pearlite was transformed, although pearlite configurations (cementite concentrations in solid solution) still exist. These configurations are less evident after 8 minutes of heating.

On the basis of the results of microexamination, it was decided to limit further tests to specimens treated to produce two conditions: (1) substantially complete carbide solution and (2) sufficient carbide solution to obtain maximum hardness (Rockwell "C" 65-66). Heating for 6 minutes in lead at 1525°F and oil quenching was used to attain the first condition, whereas heating for 1/2 minute in lead at 1400°F and water quenching was used to obtain the second condition. It was also believed that the condition resulting from the latter treatment might have the effect of increasing impact strength at high hardness levels.

C. Effect of Tempering Treatment

1. Hardness Tests

The effect of tempering temperature on the surface hardness is shown in Table IV.

TABLE IV - SURFACE HARDNESS OF QUENCHED AND TEMPERED SPECIMENS

Tempering Temperature	300°F	400°F	500°F	600°F	700°F	800°F	900°F
			Rockwell "C" Hardness				
Lead Bath 1525°F - 6 min. oil quenched	64.5	60.5	56.5	52	48.5	42.5	37.5
Lead Bath 1400°F - ½ min. water quenched	63.5	59	57	51	48	43	35.5

Note 1 - Tempering time was 2 hours in all cases.

As shown in Table IV, the tempering characteristics of WD-1080 steel given a hardening treatment at 1520°F to result in substantially complete carbide solution are quite similar to those of WD-1080 steel given a hardening treatment at 1400°F to result in partial carbide solution.

2. Impact Tests

A. Specimens Oil Quenched from 1525°F

The results of Charpy impact tests at temperatures of from +70°F to -70°F specimens (0.2" x 0.8" x 2.0") oil quenched from 1525°F and tempered in the range of 400°F to 850°F are given in Table V. A plot of room temperature impact strength vs. draw temperature and hardness is shown in Figure 2. The specimens were unnotched and were tested by striking the 0.8" x 2.0" face in a direction perpendicular to the 2.0" dimension.

The results show that in the hardness range of Rockwell "C" 43 to 61, impact strength increases with decreased hardness with a sharp change of impact strength occurring at a hardness of about Rockwell "C" 54. The testing temperature has no apparent effect on impact strength in the temperature range investigated. Likewise, the time the specimens were heated in the lead bath (3 to 12 minutes) does not appear to be significant.

B. Specimens Water Quenched from 1400°F

The results of Charpy impact tests of specimens water quenched after heating in lead for times varying from 1/2 to 8 minutes and drawn in the range of 400 to 650°F are given in Table VI. All tests were conducted at room temperature (70°F). Table VI reveals that impact strength increases with tempering temperature and that a heating time of at least 3/4 minute is necessary for full hardening and high impact values. It is also shown that at a hardness of Rockwell "C" 55-57, maximum impact strength (43-49 ft. - lbs.) results from heating for 3/4 to 1½ minutes. As compared with the impact strength (20 ft. - lbs. at 70°F) of specimens quenched from 1525°F and drawn to the same hardness, this represents an increase of over 100%. In view of the fact that the same increase can be obtained by lowering the hardness of specimens quenched from 1525°F by approximately 2 or 3 points Rockwell "C", it is believed that the use of the 1400°F treatment does not possess a significant advantage. Furthermore, from the point of view of production hardening of bayonet blades, the 1400°F treatment would probably be more critical from the standpoint of temperature and time control especially if different heats of WD-1080 steel varied in the rate of carbide solution. Also, the need for water quenching to offset the tendency for the formation of soft spots because of lowered hardenability imparted by the 1400°F treatment would increase the danger of distortion. For these reasons, no further investigation of the effect of the 1400°F treatment on other properties of WD-1080 steel was made.

3. Transverse Bend Tests

The results of transverse bend tests of specimens (0.2" x 0.8" x 6") are given in Table VII. These specimens were oil quenched after 6 minutes heating in a lead pot at 1525°F and tempered to hardnesses of Rockwell "C" 41-60. The results show that the proportional limit increases with increased hardness whereas the modulus of rupture reaches a maximum value at Rockwell "C" hardness 55-56. Although a purely empirical value, the modulus of rupture is generally considered a criterion of material toughness.

D. Tests of WD-1080-B Steel Bayonets

1. Specification Bend Tests

Bend tests of the bayonets were carried out in accordance with U.S. Army Specification No. 52-4-13. These blades were heat treated* by heating for 6 minutes in a lead pot operating at 1525°F, quenching in oil, and drawing to obtain various hardnesses from Rockwell "C" 37 to 55. The specification bend test consists of bending a bayonet blade on both sides over a curved surface having a radius of eighteen inches. Blades taking a set of 1/16" in either direction are considered rejectable.

The results of the specification bend tests are given in Table VIII. Only those blades possessing a hardness of Rockwell "C" 46 and above successfully passed the bend test.

2. Microexamination

The microstructure of a bayonet blade oil quenched from 1525°F and tempered at 650°F is shown in Figure 1 -H- and consists of tempered martensite with little evidence of excess carbides. This microstructure corresponds to that of blades tempered to hardnesses in the range of Rockwell "C" 46-52.

E. General Considerations

The results of this investigation indicate that WD-1080 steel bayonet blades should be given a hardening treatment to result in a substantially homogeneous structure. The desirable hardness range for these blades is considered to be Rockwell "C" 46 to 52 after tempering. The corresponding tempering and impact strength ranges are indicated in Figure 2. The lower limit of the desirable hardness range is set by the yield strength required by WD-1080 steel in order to comply with the bend test requirements of U.S. Army Specification No. 52-4-13. The upper limit was established from considerations of impact

* Heat treatment of the experimental WD-1080-B bayonet blade was carried out by the Utica Cutlery Company, Utica, New York

strength although from the point of view of bend strength and keenness of cutting edge, a hardness of Rockwell "C" 56-57 would be more desirable. It is possible to improve impact strength somewhat at this hardness level by heating for a short time at a low hardening temperature; however, the improvement obtained does not appear sufficient to justify the use of such a heat treatment in regular production.

TABLE V

RESULTS OF IMPACT TESTS OF QUENCHED AND TEMPERED WD-1080-A STEEL SPECIMENS

Time In Lead Bath At 1525°F Minutes	Tempering Temperature, °F	Impact Energy, Ft. - Lbs. At Various Testing Temperatures 70°F	35°F	0°F	-35°F	-70°F	Rockwell "C" Hardness
3	400	10	9	10	8	8	60-61
3	550	21	22	15	13	21	55-56
3	650	60	70	62	59	68	51-52
3	750	92	85	81	97	102	47-48
3	850	103	93	99	90	92	43-44
6	400	9	9	14	8	8	60-61
6	550	20	14	11	13	12	56-57
6	650	58	72	75	76	66	52-53
6	750	83	77	78	83	79	48-49
6	850	101	101	102	100	86	43-44
12	400	8	8	8	8	8	60-61
12	550	16	16	13	14	13	56-57
12	650	73	60	64	68	50	52-53
12	750	82	84	61	81	81	48-49
12	850	98	99	102	98	99	42-43

Note - All specimens were tempered for 2 hours.

TABLE VI

RESULTS OF IMPACT TESTS OF QUENCHED AND TEMPERED WD-1080-A STEEL SPECIMENS

Tempering Temperature °F	1/2 Min.	3/4 Min.	1 Min.	1½ Min.	2 Min.	4 Min.	8 Min.	Rockwell "C" Hardness
	Time of Heating in Lead Bath at 1400°F							
	Impact Energy, Ft. - Lbs.							
400	17.2*	20	15	16.0	14.2	17.0	12.1	59-61
550	23.1*	49.6	43.5	47.1	35.1	30.4	21.1	55-57
650	30.8*	67.9	61.9	61.1	61.7	59.3	57.8	50-52

Note - All specimens were tempered for 2 hours.

* Fractures of these specimens were partially crystalline and indicated incomplete hardening. All other fractures were completely fibrous indicating full hardening.

TABLE VII

RESULTS OF TRANSVERSE BEND TESTS OF QUENCHED AND TEMPERED WD-1080-A STEEL SPECIMENS

Tempering Temperature °F	Proportional Limit PSI.	Modulus of Rupture PSI.	Rockwell "C" Hardness
400	358,000	358,000	59-60
550	337,000	540,000	55-56
650	304,000	481,000	51-52
750	238,000	412,000*	45-46
850	211,000	391,000*-452,000*	41-42

* Maximum specimen did not fracture.

Note - All specimens were oil quenched after 6 minutes at 1525°F and tempered for 2 hours.

Values of proportional limit and modulus of rupture represent average of two tests.

TABLE VIII

RESULTS OF SPECIFICATION BEND TESTS OF HEAT TREATED WD-1080-B STEEL BAYONET BLADES

Bayonet Designation	Rockwell "C" Hardness	Amount of Permanent Set - First Bend	Compliance with U.S. Army Specification 52-4-1B
A-1	55-56	1/32"	Satisfactory
A-2	54-55	None	Satisfactory
B-1	51-52	1/32"	Satisfactory
B-2	51-52	1/32"	Satisfactory
C-1	49-50	1/32"	Satisfactory
C-2	49-50	1/16"	Satisfactory
D-1	47-48	1/16"	Satisfactory
D-2	46-47	1/16"	Satisfactory
E-1	44-45	3/32"	Unsatisfactory
E-2	44-45	1/8"	Unsatisfactory
F-1	37-38	3/16"	Unsatisfactory
F-2	37-38	3/16"	Unsatisfactory

PICRAL —A— X1500
ANNEALED AT 1450°F.
PEARLITE STRUCTURE.

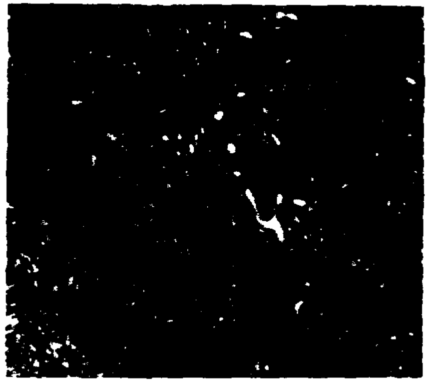
PICRAL —B— X1500
OIL QUENCHED AFTER 6 MINUTES IN LEAD AT 1375°F. UNDISSOLVED CARBIDES, PRIMARY TROOSTITE AREAS, AND MARTENSITE MATRIX.

PICRAL —C— X1500
OIL QUENCHED AFTER 6 MINUTES IN LEAD AT 1450°F. UNDISSOLVED CARBIDES, PRIMARY TROOSTITE AREAS, AND MARTENSITE MATRIX.

PICRAL —D— X1500
OIL QUENCHED AFTER 6 MINUTES IN LEAD AT 1525°F. MARTENSITE STRUCTURE. SUBSTANTIALLY COMPLETE SOLUTION OF CARBIDES OCCURRED.

PICRAL —E— X1500
WATER QUENCHED AFTER 1/2 MINUTE IN LEAD AT 1400°F AND DRAWN AT 400°F. AREAS OF PEARLITE PRESENT.

PICRAL —F— X1500
WATER QUENCHED AFTER 2 MINUTES IN LEAD AT 1[illegible]0°F AND DRAWN AT 400°F. UNDISSOLVES CARBIDES PEARLITIC CONFIGURATIONS, AND TEMPERED MARTENSITE.



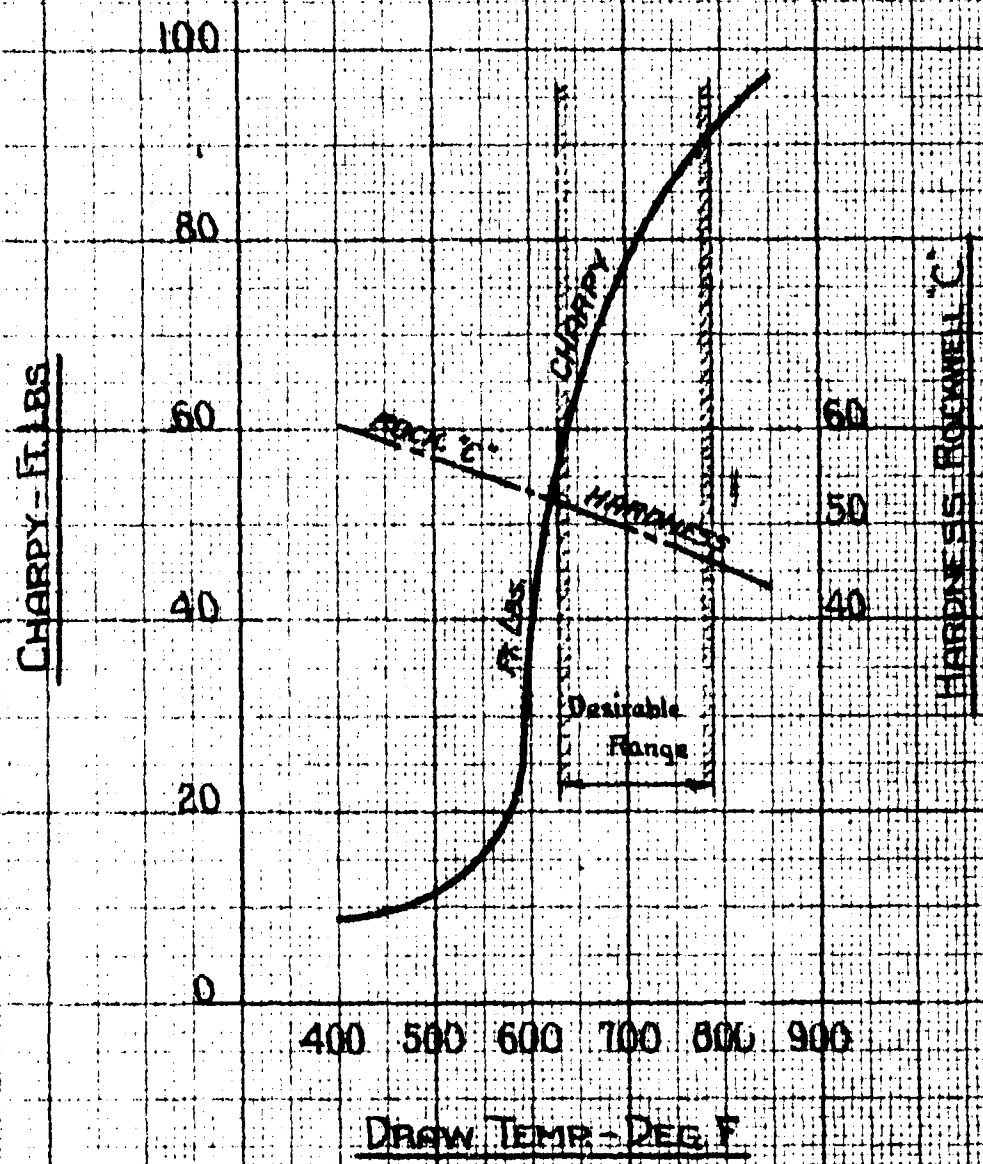
PICRAL —G— X1500
WATER QUENCHED AFTER 8 MINUTES IN LEAD AT 1400°F AND DRAWN AT 400°F. UNDISSOLVED CARBIDES AND TEMPERED MARTENSITE.

PICRAL —H— X1500
OIL QUENCHED AFTER 6 MINUTES IN LEAD AT 1525°F AND DRAWN AT 650°F. TEMPERED MARTENSITE

FIGURE 1. PHOTOMICROGRAPHS AT CENTERS OF 0.2" THICK WD-1080 STEEL SPECIMENS.

WTN.639-6207

FIG. 1



IMPACT STRENGTH
VS.
DRAW TEMP. AND HARDNESS

FIG. 2

DEPARTMENT OF THE ARMY
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SUBJECT: Cancellation of Distribution Restrictions for Watertown Arsenal Laboratory Reports

1. References:

a. AD-B962 843, Watertown Arsenal Laboratory Report No. WAL 320/29, "Bayonet Blades, Investigation of WD 10-80 Steel for Use in Bayonet Blades", 19 January 1944.

b. AD-B962 712, Watertown Arsenal Laboratory Memorandum Report No. WAL, 739/87, "The Metallurgical Examination of a Japanese Samurai Sword", by J. I. Blum, 25 September 1946.

c. AD-B962 710, Watertown Arsenal Laboratory Report No. WAL 739/47, "Bayonets, Metallurgical Examination of Six Lots of T2 Bayonets", 2 August 1944.

d. AD-B962 687, Watertown Arsenal Laboratory Report No. WAL 739/48, "Bayonets, Metallurgical Examinaton of Eight M1 Bayonets Submitted by Springfield Armory", 8 August 1944.

e. AD-B962 689, Watertown Arsenal Laboratory Report No. WAL 739/37, "Bayonets, Metallurgical Examination of Bayonets of Commercial and Springfield Armory Manufacture", 5 April 1944.

2. Our Laboratory has reviewed the reference reports and has approved them for public release; distribution is unlimited. Request that you annotate your records and mark the documents with distribution statement A in accordance with DOD Directive 5230.24.

3. Our action officer is Mr. Douglas J. Kingsley, telephone 410-278-6960

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