# WATERTOWN ARSENAL LABORATORY

## MEMORANDUM REPORT

NO. WAL 739/87



THE METALLURGICAL EXAMINATION OF A JAPANESE SAMURAI SWORD

BY
J. I. BLUHM
Materials Engineer





25 September 1946
DATE

WATERTOWN ARSENAL
WATERTOWN, MASS.



Form No. SPOBE-38
L 18 July 1944

Watertown Arsenal Laboratory
Memorandum Report No. WAL 739/7
Problem No. R-1.6 — 25 September 1946

# THE METALLURGICAL EXAMINATION OF A JAPANESE SAMURAI SWORD

## OBJECT

To conduct a metallurgical examination of the subject sword.


## SUMMARY

This sword was forged from poor quality 1.05 percent carbon steel, cooled in air from the forging temperature, locally hardened along the cutting edge and finally ground and/or polished. Several sections of the sword were examined microscopically and macroscopically and several transverse as well as a longitudinal hardness surveys were made. Tension tests of the "core" metal indicate a tensile strength of approximately [illegible]0,000 psi.


J. I. BLUHM
Materials Engineer

APPROVED:

H. C. MANN
Principal Materials Engineer
Chief, Mechanical Testing Branch

## INTRODUCTION

The subject Samurai Sword was examined in accordance with O.O. letter Nos. 386.3/1396 and 386.3/1406, dated 25 July 1946 and 30 July 1946, respectively. Copies of these letters are given in the Appendix to this report

## TEST PROCEDURE

After photographing the assembled sword and scabbard, (Fig. 1), the hilt covering was removed and the inscriptions found were photographed, (Fig. 2). A series of Rockwell "C" hardness readings were taken at approximately three (3) inch intervals near the back edge of the blade. Four half inch transverse sections were cut from the sword at Stations* 4, 13, 22 and 34.5 and examined microscopically. When micro examination had been completed, the specimens were repolished and transverse Vickers hardness surveys were made on the polished face. An additional specimen taken from the back edge of Station [illegible] was polished on a plane parallel to the longitudinal axis in order to examine the inclusion shape, size and distribution. Two Longitudinal sections of the blade taken from Station 0-3.5 and 8-12.5 were macro-etched and photographed. Chemical analyses were made of samples of the tool taken [illegible] the handle and the cutting edge of Station [illegible]-16. For comparative purposes, the cutting angle of the blade of Stations 4, 13 and 22 were measured. A simple protractor was used for this purpose. Two longitudinal tensile specimens were machined from the back edge of the sword near Station [illegible]2 and tested.

To check the heat treat three transverse 1/2 inch sections were heated to [illegible]°F. One specimen was air cooled and the others oil and water quenched. The hardness of these specimens was measured and compared with the original hardness.

## RESULTS AND DISCUSSION

The general appearance of the sword is shown in Figure 1. The blade was highly polished and had a sharp cutting edge (to the touch). In this connection, it is interesting to note that Japanese technical literature makes reference to swords having a cutting angle of 14 degrees whereas this particular sword had a corresponding included angle of 22 to 40 degrees as shown in Figure 3B for Station 4. The cutting power of the subject sword

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* Station numbers are shown in Fig. [illegible] and refer to the number of inches between any transverse section and the tip of the sword. For example Station 4 is four (4) inches from the tip.

Then is considerably less than might be attainable with a more acute cutting angle.

The steel scabbard was lined with a thin sheet of wood presumably to protect the blade. No attempt was made to analyze the secondary parts of the sword assembly.

When the hilt covering was removed, inscriptions were found stamped on both sides of the blade. These inscriptions are shown in Figure 2. No interpretation was possible.

Chemical and spectrographic analysis of chips removed from the hilt gave the following steel compositions:

| C | Mn | Si | S | P | Ni | Cr | Mo | Va | W |
|---|---|---|---|---|---|---|---|---|---|
| 1.05 | .50 | .17 | .053 | .060 | Trace | .06 | Nil | Nil | Nil |

An additional specimen removed from the cutting edge between Stations 13 and 16 checked the above carbon content. The high sulphur and phosphorous content are indicative of a poorer melting practice than is generally used in this country where SAE specifications call for maximum of .04 and .05 respectively.

The results of hardness surveys conducted are shown in Figure 3A and 3B. Rockwell "C" values measured near the back edge of the blade are shown in Figure 3A and indicate a fairly uniform hardness along the blade of [illegible] + 2.5 Rockwell "C" units with no definite trend. However, the hilt was definitely softer having a Rockwell "C" hardness value of 27 and 34 at Station 28, and 34 respectively. Results of transverse Vickers hardness surveys of sections cut at Stations 4, 13, 22 and 34.5 indicate a range of Vickers Hardness Numbers of 342 (Rockwell C = 35) at Station 36 to 519 (Rockwell C = 48) at Station 13. The values of hardness obtained at .05 inch intervals are shown in Figure 3B. From longitudinal tension specimens taken from the back of the blade at Station 22, the following data* were obtained:

| | |
|---|---|
| Tensile Strength | 191,000 psi. |
| Yield Strength | 121,000 psi. |
| Elongation | 7.5 - 12.5% |
| Reduction of Area | 31.4% |

The stress strain curve for one specimen was so curved that no attempt was made to determine the yield point, the value given.

* Two specimens were pulled in tension.

is the one obtained on the second specimen. This curvature in the elastic region of the stress strain diagram is characteristic of some normalized steels and indicates existance of internal stresses. Good metallurgical practice would have required a mild temper to relieve these stresses.

The microstructure of the sword is shown in Figures 4 and 5. For each section examined the cutting edge consisted of a tempered martensitic structure, the typical structure observed being shown in Figure 4A. Some spheroidized cementite can be seen. The back edges and hilt were predominantly mixtures of fine to very fine pearlite with occasional grains of course pearlite as evidenced in Figures 4B, C and D which show the unhardened structure at Stations 4, 22 and 34.5 respectively. In Figure 4C the quantity of spheroidized cementite is clearly evidenced.

The unetched structures of a typical section indicate that the steel is very "dirty", containing numerous small non metallic inclusions. Figures 5A and 5B a transverse and longitudinal section, clearly show the size and distribution of these inclusions.

Figures 6 and 7 show the macro-etched structure of two longitudinal sections taken from Stations 0-3.5 and 8-12.5. The dark region with the wavy boundary is the cutting edge of the blade and is characteristic of flame hardened edges; however this same effect could have been obtained by other methods. The dark band at the top of these Figures is due only to the lighting required to bring out the hardened region. The macrostructure revealed some randomly oriented medium fine dendrites indicating that a slight amount of additional forging might have been beneficial. Figure 7 is merely an enlargement of part of Figure 6. Etched transverse sections shown in Figure 8 at low magnification indicate the non-uniformity and depth of the hardened zone.

Three one-half inch specimens of the sword were heated to 1600°F and each cooled by one of the following medii - air, oil, water. Hardness values for each was as follows:

| | |
|---|---|
| Air Cooled (Normalized as from forging temp.) | Rc = 35 - 38 |
| Oil Quench | Rc = 64.5 - [illegible]4.0 |
| Water Quench | Rc = 64.0 - [illegible] |

These values compared with a hardness of Rc = [illegible] for the sword and in conjunction with the microstructure indicate clearly that the sword was air cooled from approximately 1600°F which is close to the limits of forging temperature.

It is concluded that the steel was forged, cooled in air from the "end of forging" temperature and finally the cutting edge was locally hardened and ground, and/or polished. Though it is definitely established that the structure indicates tempering, it is difficult to determine whether an independent tempering operation was used or whether the sword was only momentarily quenched during the hardening procedure and then withdrawn from the quenching medium allowing the retained heat in the relatively heavy back edge of the blade to flow toward the cutting edge thus effecting a tempering of the martensite. The excessive amount of non-metallics is considered unsatisfactory.

WATERTOW ARSENAL

SWORD, SAMURI, 36" INCLUDIN SCABBARD

6 AUG 1946

WTN.693-73

FIGURE I

WATERTOWN ARSENAL

INSCRIPTIONS FOUND ON UNDER HANDLE OF JAPANESE SAMURAI SWORD. A – LEFT SIDE, B – RIGHT SIDE
WTN.693-76
29 AUG 1946

FIGURE 2

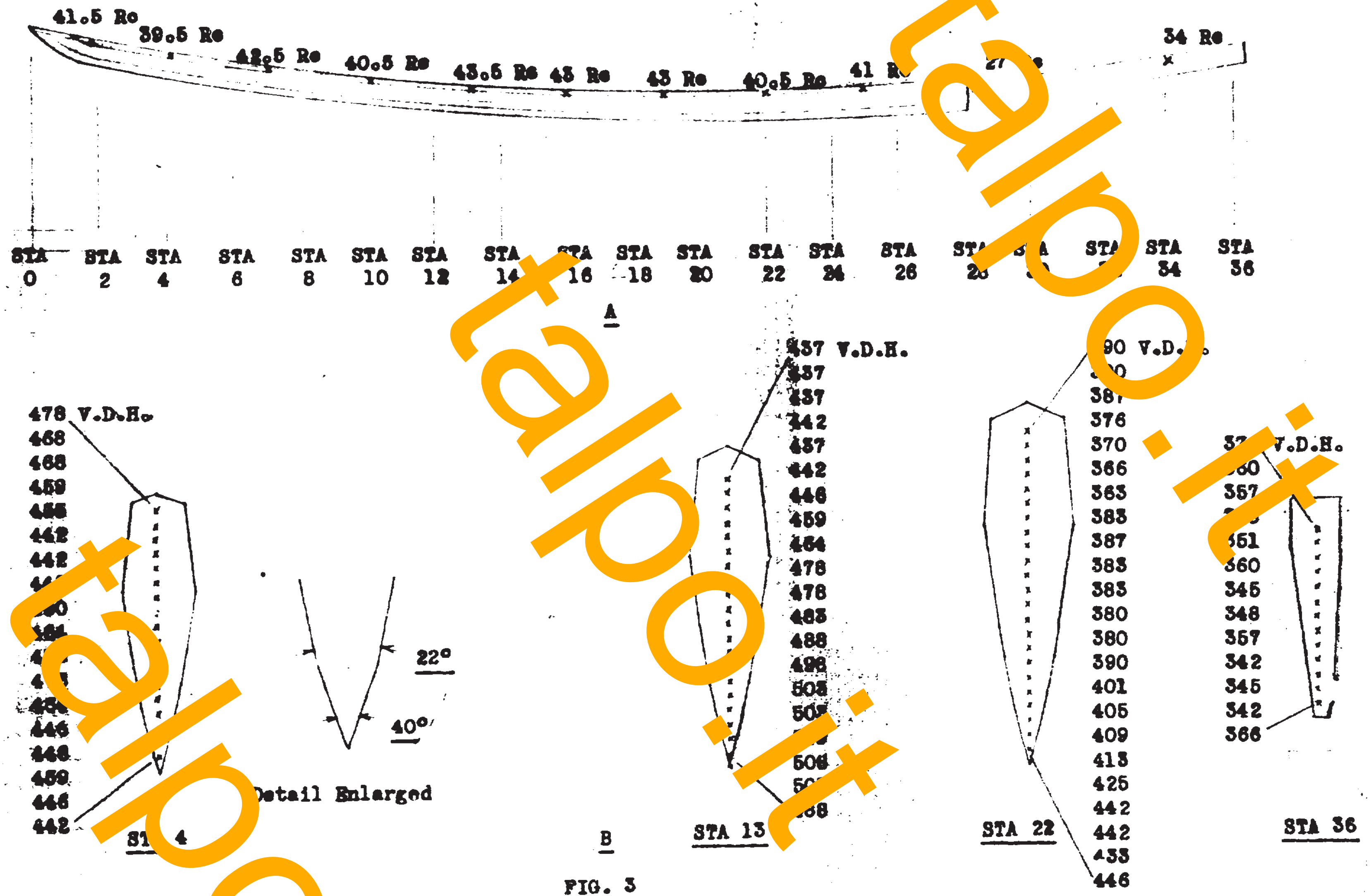
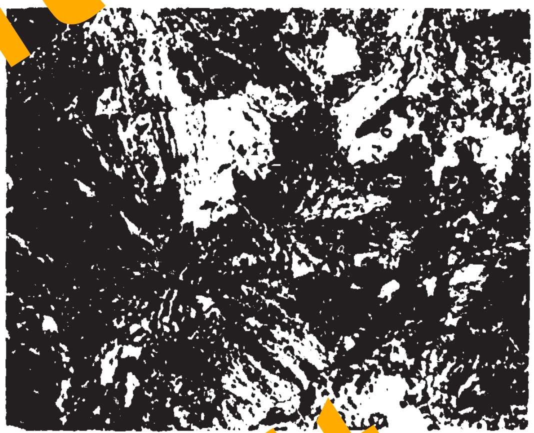



FIG. 3

HARDNESS SURVEYS ON JAPANESE SAMURAI SWORD

X1000 -A- Picral
Cutting Edge - Sta 4 - Tempered Martensite - Some Spheroidized Cementite.



X1000 - B - Picral
Back Edge - Sta 4 - Fine and Very Fine Pearlite.

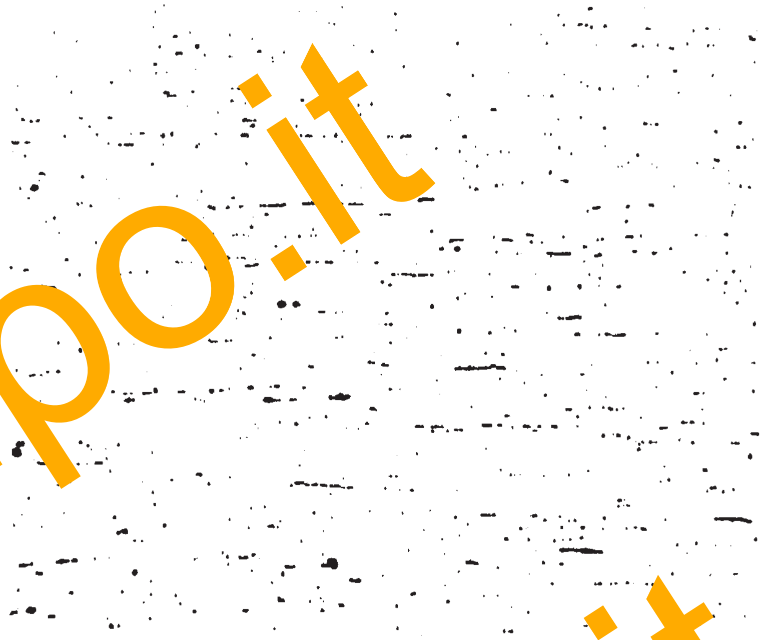
X1000 - C - Picral
Back Edge - Sta 22 - Spheroidized Cementite in Matrix of Fine and Very Fine Pearlite.

X1000 - D - Picral
Handle - Sta 34.5 - Fine and Very Fine Pearlite Grains Surrounded by Very Fine Membrane of Pro-Eutectoid Cementite.

FIGURE 4

MICRO-STRUCTURE OF JAPANESE SAMURAI SWORD

WTN.C39-8505



X100 - A - Etched
Longitudinal Section - Sta 22.

X100 - B - Etched
Transverse Section - Sta 22.

**FIGURE 5**

**PHOTOMICROGRAPHS OF JAPANESE SAMURAI SWORD**
**SHOWING SHAPE & DISTRIBUTION OF NON-METALLIC INCLUSIONS**

WTN.639-8506

WATERTOWN ARSENAL

SUMURAI SWORD - MACROETCHED SECTION SHOWING [redacted] HARDENED CUTTING EDGE
MAG. XI 22 AUG 1946 WTN.693-75

FIGURE 6

WATERTOWN ARSENAL

SUMURAI SWORD – LONGITUDINAL SECTION AT STA. 10 – MACROETCHED TO SHOW FLOW LINES
MAG. X2 22 AUG 1946 WTN.693-74

FIGURE 7

XI - Picral

Cross Section - Sta 4.

\- A -

XI - Picral

Cross Section - Sta 13.

\- B -

XI - Picral

Cross Section - Sta 22.

\- C -

FIGURE 8

JAPANESE SAMURAI SWORD - SHOWING DEPTH OF [redacted] HARDENED REGION.

THE NICKEL CASE AROUND THE SWORD WAS APPLIED BEFORE POLISHING THE SPECIMEN.

WTN.639-8507

# APPENDIX A

C
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73595

WAR DEPARTMENT
OFFICE OF THE CHIEF OF ORDNANCE
WASHINGTON, D. C.

Refer to:
O.O. No. 386.3/1406
Attention of
ORDTB F & T

30 July 1946

SUBJECT: Metallurgical Examination of Japanese Saber

TO : Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

1. At the suggestion of Major General G. M. Barnes, former Chief of the Research and Development Service, OCO and with the approval of Col S. B. Ritchie, Asst Chief, Research and Development Service, OCO, one Japanese saber is being shipped to Watertown Arsenal for metallurgical examination.

2. Of particular interest is the Japanese method of hardening and sharpening the blade so that it holds its cutting edge.

3. It is understood that the saber will be expended in the test.

BY ORDER OF THE CHIEF OF ORDNANCE:

/s/ H. A. Ellison

H. A. Ellison
Major, Ord Dept
Assistant

WTN 386.3/523

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Y

WAR DEPARTMENT
OFFICE OF THE CHIEF OF ORDNANCE
WASHINGTON, D. C.

Refer to:
O.O. No. 386.3/139[illegible]
Attention of
ORDTB

25 July 1946

SUBJECT: Analysis of Japanese Sword

TO: CO, Watertown Arsenal, Watertown 72, Massachusetts

1. There is being shipped your station from Aberdeen Ordnance Depot on Shipping Order No. 7-Z-23, dated 23 July 1946, a Japanese Samurai Sword.

2. It is requested that a study and analysis of the sword blade be accomplished with a view to determining the probable method of fabrication and the composition of the steel or steels from which the sword is made and that a report incorporating these findings be submitted to this office.

3. This study is requested in accordance with a suggestion made by General Barnes to Colonel Ritchie of this office in his letter of 3 July 1946, a copy of which is attached hereto.

4. Japanese swords manufactured by different craftsman at different times during the past [illegible]0 years vary in quality and method of fabrication. Those of more recent manufacture may show no particularly interesting features. Those which are some hundreds of years old may reveal interesting techniques utilized to secure an extremely hard cutting edge supported by a strong back. Unfortunately, this office has not seen the sword which has been shipped to you. If there are any markings stamped into the tang of the blade, under the handle, please include a carbon transfer of these markings for our use in determining the age of the sword.

BY ORDER OF THE CHIEF OF ORDNANCE:

/s/ G. F. Powell

G. F. POWELL
Colonel, Ordnance [illegible]
[illegible]istant

1 Incl
Copy of Ltr.

WTN 386.3/521

C
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Y

THE BUDD COMPANY

Railway Equipment Division
Philadelphia 32, Pa.

July 3, 1946

Colonel S. B. Ritchie, Chief,
Research and Development Service
Washington, D. C.

My dear Sam:

I received the notes on the German gas turbine development and wish to thank you very much for having this information gotten together for me.

You will remember Mr. Joe Winlock who was at Watertown Arsenal in the early days. As you probably know, Mr. Winlock is Metallurgist here at the Budd plant. He has been studying one of the Japanese officer swords. There seems to be some sort of a special hardening process or plating along the cutting edge. The sword which he has belongs to a friend and he cannot very well make the necessary tests to determine what the Japanese were doing.

I wonder whether this subject has been looked into by the Watertown Arsenal and whether the Japanese have used anything unusual in the manufacture of the sword. If not, I believe it would be worth while to have one of the swords sent up to Watertown Arsenal for a careful analysis. This might lead to something which we have previously overlooked.

If you think it worth while, I would appreciate very much knowing what you have found out.

With best personal regards,

Sincerely yours,

/s/ G. M. Barnes

G. M. Barnes,
Major General, U.S.A.

WTN 386.3/521

**DEPARTMENT OF THE ARMY**
**UNITED STATES ARMY RESEARCH LABORATORY**
**ABERDEEN PROVING GROUND, MARYLAND 21005-5066**

REPLY TO
THE ATTENTION OF

AMSRL-CS-IO-SC (380) 6 June 1997

MEMORANDUM FOR Defense Technical Information Center, 8725 John J. Kingman Road Suite 0944, Ft. Belvoir, VA 22060-6218

SUBJECT: Cancellation of Distribution Restrictions for Watertown Arsenal Laboratory Reports

1. References

a. AD-B962 843, Watertown Arsenal Laboratory Report No. WAL 320/[illegible], "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 [illegible], 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

P. Ann Brown
P. ANN BROWN
Chief, Security/CI Branch
ARL, APG