File.

FILE COPY

OTTAWA June 1st, 1943.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1422.

Austempering of SAE 1060 Armour Plate
to Rockwell 'C' Hardness of 50.

(Copy No. 18.)

Bureau of Mines
Division of Metallic
Minerals
-
Ore Dressing
and Metallurgical
Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

O T T A W A   June 1st, 1943.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1422.

Austempering of SAE 1060 Armour Plate
to Rockwell 'C' Hardness of 50.

Origin of Request and Object of Investigation:

At the request of A/Lt. Commander J. R. Millard, Senior Technician Technical Development, Department of National Defence, Naval Services, Ottawa, Ontario, work was begun in the Laboratories to ascertain whether a steel of analysis similar to SAE 1060 could be austempered to a hardness suitable for use in armour plate.

Material Used:

Steel plate 0.375 inch thick was used for the experimental work. This steel had the following analysis:

		Per cent
Carbon	-	0.64
Manganese	-	0.71
Silicon	-	0.23
Sulphur	-	0.029
Phosphorus	-	0.022
Chromium	-	Not detected.
Nickel	-	" "
Molybdenum	-	" "

Description of Experimental Work:

In order to avoid the precipitation of ferrite during the quenching of this class and thickness of steel (presence of ferrite lowers the ballistic properties of armour plate), it must be quenched below 900° F. in less than half a second.

The usual method of 'austempering' is to quench the steel into a bath (salt, lead, etc.) held at the temperature at which it is desired to isothermally transform. The steel is held at this constant temperature until transformation is complete. This conventional treatment was not satisfactory for this class and thickness of steel, due to the fact that the quenching bath (salt in this case) did not produce a rapid enough quench to avoid the precipitation of ferrite. The photomicrograph in Figure 2 shows the structure produced by quenching into 600° F. salt and permitting the steel to transform isothermally for 30 minutes. The light areas are ferrite. This heat treatment indicated that an immediate quench into the medium in which the steel would isothermally transform was not rapid enough to avoid the precipitation of ferrite.

Consequently, a timed water-quench was resorted to. This involved quenching the steel into water for a time long

(Description of Experimental Work, cont'd) -

enough to bring the temperature of the steel down to the temperature at which it will be isothermally transformed but avoiding the formation of both ferrite and martensite.

It was determined, after repeated experiments with various water quenching times and various salt bath temperatures (salt was the medium used in which to isothermally transform), that a water quench from 1525° F. for 5 seconds and an isothermal transformation for 30 minutes in a 600° F. salt bath gave the desired hardness of 50 Rockwell 'C' and the desired microstructure (bainite).

Now that the desired microstructure and hardness were obtained, it was necessary to compare the physical properties of steel heat-treated by the above method (austempered) with those of conventionally heat-treated material (quenched and drawn).

Bend tests and Izod impact tests only were conducted for the austempered and the quenched-and-drawn material, since the physical properties of material heat-treated in these two ways vary significantly in yield strength and Izod impact strength.

A specimen 1 inch wide and 7 inches long was austempered as described above, and from this a bend test piece (dimensions, 0.349 x 0.388 x 7 inches long) and an Izod impact test piece (0.361 x 0.361; below standard size) were machined. The hardness of these test pieces was Rockwell 'C' 50 for each.

A specimen of the same size was water-quenched and drawn to the same hardness as the austempered piece. It was subsequently found that the hardness of this specimen was Rockwell 'C' 49. From this specimen bend and impact test

(Description of Experimental Work, cont'd) -

pieces were machined, of exactly the same dimensions as those from the austempered specimen.

The bend tests were performed using 3-inch centres and the load was applied in the centre of the test piece by a 1½-inch-diameter cylinder. The impact specimens were broken on a 120 foot pound Izod impact machine. The results of the bend tests are shown in Figure 1.

Results of impact tests are shown in Table I below:

Table I. - Results of Impact Tests.

		Ft.lb.
Quenched and drawn	-	9
Austempered	-	136

(Average of 3 tests).

Figures 3 and 4 are photomicrographs, at X2000, of specimens cut from each bend test piece.

Discussion of Results; Conclusions:

Reference to Figure 1 indicates that the austempered material has a lower yield point and a higher impact strength than the quenched-and-drawn material. Reference to Figures 3 and 4 indicates the difference in microstructure between the austempered material and the quenched-and-drawn material. Figure 3 shows a finer, more feathery structure, typical of austempered structures. Figure 4 shows the structure of tempered martensite.

It is concluded that by resorting to a "timed" water quench this thickness and quality of steel can be austempered.

Report of Investigation No. 1021, issued from these

(Discussion of Results; Conclusions, cont'd) -

Laboratories on May 28th, 1941, discussed in detail the differences between austempered steel and quenched-and drawn steel. This report stated:

"The significant difference between austempered and conventionally heat-treated steel at around Rockwell 'C' 50 is that the former yields at a lower load and ruptures at a much higher load (p.s.i.), thus a longer period of distortion is obtained before failure. The conditions which exist during the time a shell is penetrating a plate are not directly related to the physical properties as measured at slow speeds. However, recent evidence has shown that some relation does exist. Therefore, the longer period of distortion (i.e., greater area distorted, consequently lower unit stress) obtained with austempered products should relate to the amount of energy absorbed by an austempered plate in resisting the progress of a projectile through it."

Quoting further from Report of Investigation No. 1021:

"Yielding properties are of great significance in armour plate........... It is logical to assume, therefore, that the superiority of austempered armour plate lies in its lower elastic limit, which allows it to cushion the shock and distribute the stresses farther through the plate. It was observed that austempering produced a steel with a lower elastic limit (for the same ultimate) and that in the plastic range of deformation the load-to-deformation ratio was higher for austempered products."

From Figure 1 the following chart was compiled:

YIELD CHARACTERISTICS.

Material	A Load for 0.020 inch permanent set, in pounds	B Load for 0.080 inch permanent set, in pounds	Load required to increase from A to B, in pounds
Quenched and drawn	5,450	6,200	750
Austempered	4,800	5,600	800

The above table indicates that the load-to-deformation ratio is greater in the austempered material.

It may be seen, therefore, that although the specimens

(Discussion of Results; Conclusions, cont'd) -

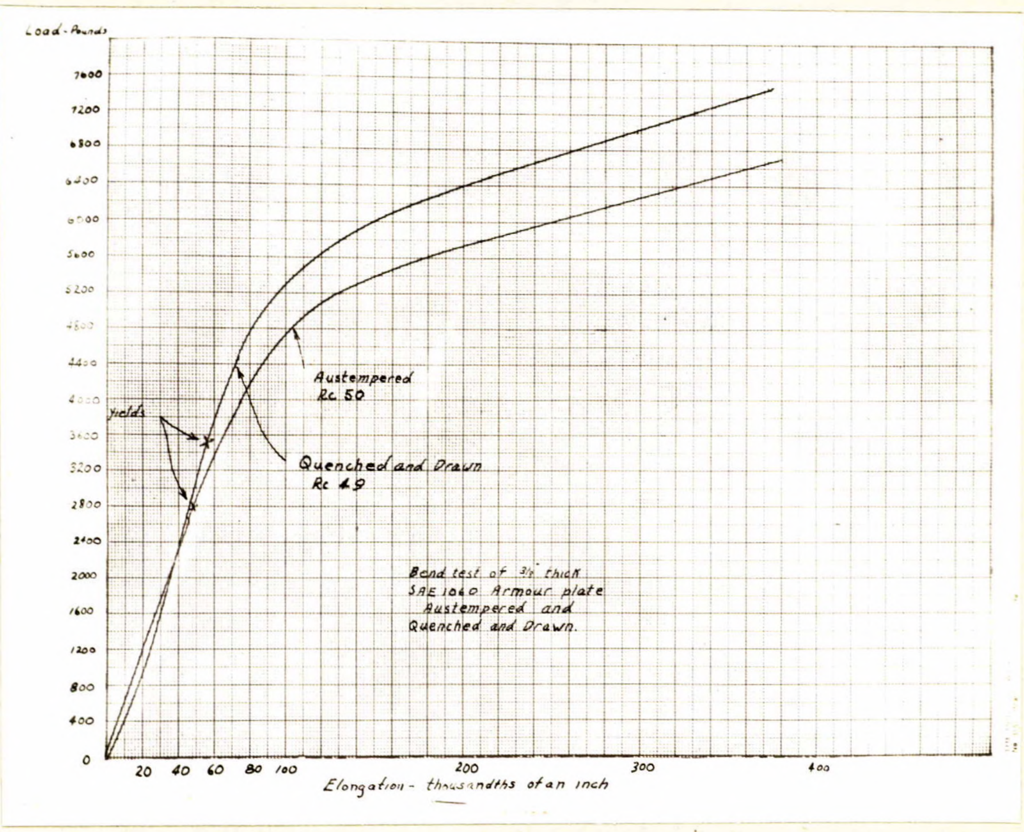
were heat treated in two different ways to approximately the same hardness, their yield and impact properties are markedly different.

Further work will be undertaken to austemper and quench-and-draw large sections of this plate and subject them to ballistic tests for comparison.

ooooooooooooooo
ooooooooo
ooo

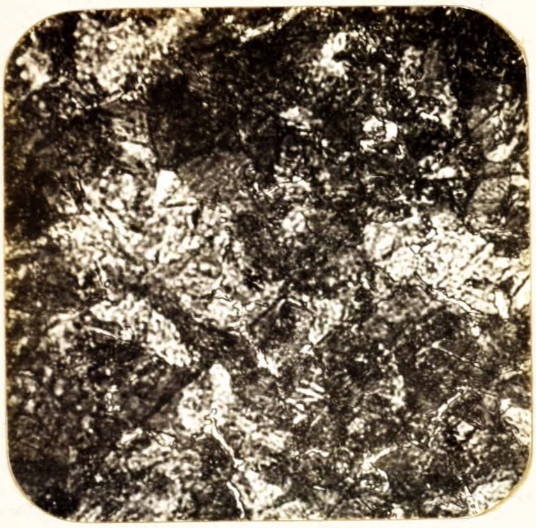
HLL:GHB.

Figure 1.



Load-Pounds
7600
7200
6800
6400
6000
5600
5200
4800
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
20 40 60 80 100 200 300 400
Elongation - thousandths of an inch
yields
Austempered
Rc 50
Quenched and Drawn
Rc 49
Bend test of 3/8" thick
SAE 1060 Armour plate
Austempered and
Quenched and Drawn.

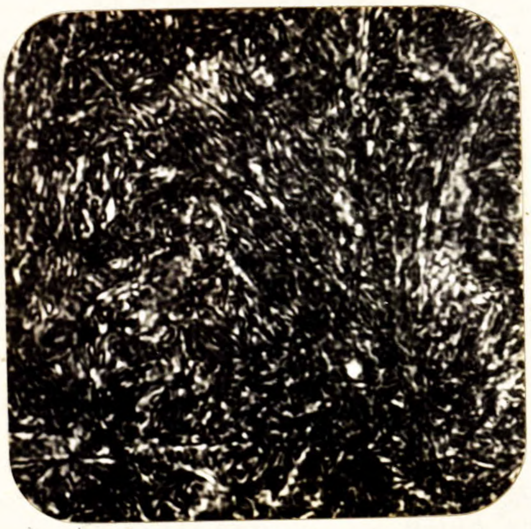
Figure 2.



X500, nital etch.

QUENCHED IN 600° F. SALT
FOR 30 MINUTES.

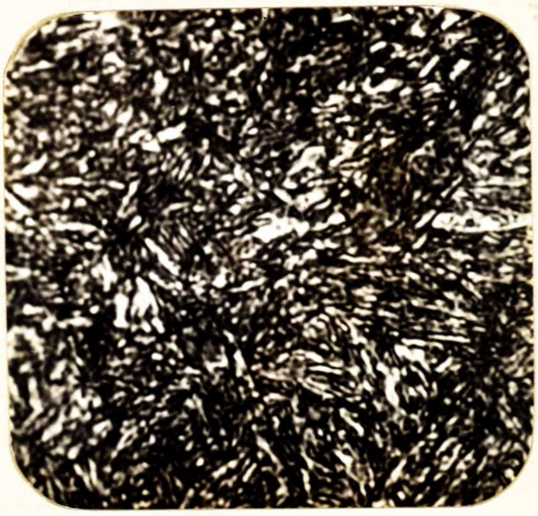
Figure 3.



X2000, nital etch.

AUSTEMPERED.

Figure 4.



X2000, nital etch.

QUENCHED AND DRAWN.

HLL:GHB.