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SHORT-TERM HOT-HARDNESS CHARACTERISTICS OF FIVE CASE HARDENED STEELS

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16. Abstract

Short-term hot-hardness studies were performed with carburized and hardened AISI 8620, CBS 1000, CBS 1000M, CBS 600, and Vasco X-2 steels. Case and core hardness measurements were made at temperatures from 294 to 811 K (70° to 1000° F). The data were compared with data for high-speed tool steels and AISI 52100. The materials tested can be ranked as follows in order of decreasing hot-hardness retention: (1) Vasco X-2; equivalent to through-hardened tool steels up to 644 K (700° F) above which Vasco X-2 is inferior; (2) CBS 1000, (3) CBS 1000M; (4) CBS 600; better hardness retention at elevated temperatures than through-hardened AISI 52100; and (5) AISI 8620. For the carburized steels, the change in hardness with temperature of the case and core are similar for a given material. The short-term hot hardness of these materials can be predicted within ±1 point Rockwell C.

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SUMMARY

Short-term hot-hardness studies were performed with carburized and hardened AISI 8620, CBS 600, CBS 1000, CBS 1000M, and Vasco X-2 steels. The materials were tested for hardness from room temperature to 811 K (1000° F). Measurements were obtained with a standard indentation hardness tester fitted with a low-oxygen environment electric furnace. The results were compared with data obtained for through-hardened high-speed tool steels and AISI 52100 obtained in a previous investigation.

The materials tested can be ranked as follows in order of decreasing hot-hardness retention: (1) Vasco X-2 (approximately equivalent to through-hardened tool steels up to 644 K (700° F) above which Vasco X-2 is inferior); (2) CBS 1000; (3) CBS 1000M; (4) CBS 600 (better hardness retention at elevated temperatures than through-hardened AISI 52100); and (5) AISI 8620.

For the carburized steels, the change in hardness with temperature of the case and core are similar for a given material.

The short-term Rockwell C hardness at temperature for the materials studied can be determined within ±1 point Rockwell C (Rc) hardness from the following equation:

$$(Rc)_T = (Rc)_{RT} - \alpha \, \Delta T^{\beta}$$

where

$(Rc)_T$	Rockwell C hardness at operating temperature
$(Rc)_{RT}$	Rockwell C hardness at room temperature
ΔT	change in temperature, $T_T - T_{RT}$
T_T	operating temperature, K; °F
T_{RT}	room temperature, K, °F
α	temperature proportionality factor, $(K)^{-\beta}$; $(^{\circ}F)^{-\beta}$
β	exponent

This equation is valid for AISI 8620 and CBS 600 from 294 to 589 K (70° to 600° F) and for Vasco X-2, CBS 1000, and CBS 1000M, from 294 to 811 K (70° to 1000° F).

INTRODUCTION

Carburized steels have found extensive use as gear and bearing materials where both surface hardness and bending strength are required. The range of material core hardness required for maximum bending strength in gears is Rockwell C 30 to 40 (ref. 1). The surface hardness, however, must be greater than Rockwell C 58 to prevent surface brinelling and to provide acceptable fatigue life (ref. 2).

The selection of the proper heat treatment for a carburized steel is complicated by the fact that the carbon content varies from a high level at the surface to a low level at the core. During carburization, carbon is diffused into the surface of an initially low carbon steel. The carbon content of the surface area increases up to 1.2 percent (ref. 3). The depth of penetration of the carbon is controlled by the carburizing temperature, time, and carburizing medium. A successful heat treatment results in a component with high surface hardness and good bending strength.

The mechanism of hardening in these steels is similar to that found in high-carbon tool steels. During heat treatment, the carbon combines with alloying elements to form carbides such as $Fe_{2.4}C$, W_2C, or Mo_2C. These carbides not only serve to harden the steel but also aid retention of hardness at elevated temperatures.

Case hardened gears and rolling-element components are required to operate at elevated temperatures. Surface hardness is known to have a direct relation to rolling-element or pitting fatigue life (ref. 2). Thus, the hot-hardness characteristics of case hardened gear and bearing steels must be known for accurate system life prediction. These data are not generally available in the open literature.

The objectives of the research reported herein were (1) to determine the hot-hardness properties of AISI 8620, Vasco X-2, CBS 1000, CBS 1000M, and CBS 600 case-hardened steels and (2) to compare the hardness characteristics of these steels with those of through-hardened high-speed tool steels and through-hardened AISI 52100. These objectives were accomplished by testing samples of the case and core of each material for hardness from room temperature to 811 K (1000° F). Measurements were obtained with a standard indentation hardness tester fitted with a low-oxygen environment electric furnace. All specimens for each material were made from a single ingot. Comparisons were made of these results with those obtained with through-hardened high-speed tool steels and AISI 52100 reported in references 4 and 5. All material was supplied by The Timken Company with specimen preparation and heat treatment performed by Chester F. Jatczak, Section Chief, Physical Metallurgy Research and Jesse A. Burnett, Research Metallurgist, The Timken Company.

TEST SPECIMENS

The materials used in this investigation were carburized, heat-treated, and tempered AISI 8620, Vasco X-2, CBS 600, CBS 1000, and CBS 1000M steels. The chemical compositions of these materials are presented in table I. AISI 8620 is typical of the carburized steels used in the bearing and gearing industry today. Vasco X-2, CBS 1000, CBS 1000M, and CBS 600 are experimental steel alloys currently being developed for high-temperature bearing and gearing applications. Material heat treatments and retained austenite values are given in table II. Photomicrographs of the case and core of each of the materials tested in this investigation are shown in figure 1.

Specimens approximately 7.62 millimeters (0.300 in.) thick and 38.1 millimeters (1.5 in.) in diameter or 38.1 millimeters (1.5 in.) square were carburized and hardened so that a uniform case was formed on all surfaces of the specimen. A test surface free of the massive carbides that occur during heat treatment was formed by grinding 0.381 millimeters (0.015 in.) of material from the hardened surface. One specimen of each material was then sectioned into smaller pieces with a cutoff wheel. A copious supply of coolant was supplied during this operation to prevent specimen overheating. One of these smaller specimens was used as the case test specimen.

Another specimen was used in the determination of the hardness gradient of the material. The hardness gradient was established from a series of Knoop hardness measurements made across a section at the center of the specimen. The results of these measurements are shown in figure 2 as Rockwell C equivalents converted from Knoop hardness numbers as a function of depth below the specimen surface.

The core of the specimen was defined to be the region of minimum hardness shown in figure 2. With the hardness gradient established, material was ground from another of the sectioned samples until the core surface was exposed (as indicated in fig. 2).

APPARATUS AND PROCEDURE

Elevated temperature hardness measurements were made with a motorized Rockwell hardness tester fitted with an electric resistance furnace (shown in fig. 3). Errors due to major load dwell time were minimized by the automatic cycling operation of the motorized tester. A nitrogen cover gas was used within the furnace to inhibit surface oxidation and decarburization of the test specimens. A large size dial indicator was fitted to the tester so that readings to the nearest tenth of a point Rockwell "A" could be made.

All elevated temperature hardness measurements were made using the Rockwell "A" scale, 60 kilogram weight with a Rockwell C diamond indenter. These measurements were converted to their Rockwell C equivalents. Use of the Rockwell "A" scale for testing case hardened materials is necessary to minimize indenter depth of penetration. Maximum indenter penetration was 0.075 millimeter (0.003 in.) in the case and 0.102 millimeter (0.004 in.) in the core. Standard testing procedure requires homogeneous material below the tested surface to a depth of ten times the indenter penetration depth (ref. 6). All specimens tested met this requirement.

Specimen temperatures were measured by means of a thermocouple welded to the surface of the specimens. The specimens were stabilized for approximately 15 minutes at the test temperature before any measurements were taken. A minimum of three hardness measurements were made at each temperature.

RESULTS AND DISCUSSION

Hot-hardness measurements were made on the case and core areas of five case hardened bearing and gear steels; AISI 8620, Vasco X-2, CBS 1000, CBS 1000M, and CBS 600. The results of these measurements are shown in figure 4 as plots of hardness against specimen temperature for each material. To eliminate room temperature hardness differences, the data of figure 4 was normalized in figure 5. Figure 5 is a plot of the change in hardness from room temperature hardness as a function of specimen temperature. These data indicate the similarity between changes in case and core hardness with temperature.

The individual normalized short-term hot-hardness curves for the case from figure 5 are combined for comparison in figure 6(a). Two general trends are apparent from the data of figure 6(a). Both AISI 8620 and CBS 600 steels (fig. 6(a)) experienced a relatively rapid decrease in material hardness with temperature. The group of materials comprising CBS 1000, CBS 1000M, and Vasco X-2 had a more gradual decrease in material hardness with temperature up to 811 K (1000° F). These trends are consistent with the tempering characteristics of these two groups of steels.

All of the steels tested in this study are similar in that they are precipitation hardening alloys. However, they differ in their type of precipitation hardening phase. As the temperature of these materials is increased, they begin to overage and soften. When the operating temperature nears the tempering temperature, this process is accelerated and the hardness begins to decrease more rapidly. As the test temperature is raised beyond the tempering temperature, the precipitation hardening precipitate particles increase in size and decrease in number. The material begins to spheroidize. At this point, the greatest decrease in hardness occurs and the material hardness tends to decrease toward the fully annealed condition. The AISI 8620 and CBS 600 steels have tempering temperatures of 455 K (360° F) and 622 K (660° F), respectively, where the large decrease in material hardness was found to occur. The tempering temperatures of CBS 1000, CBS 1000M, and Vasco X-2 were 838 K (1050° F), 838 K (1050° F), and 810 K (1000° F), respectively.

The difference in tempering temperature and thus hot-hardness capability can be explained by the differences in the precipitation hardening phase of these steels. The precipitate in AISI 8620 and CBS 600 is an iron carbide, $Fe_{2.4}C$ called epsilon carbide, whereas molybdenum carbide, Mo_2C, and tungsten carbide, W_2C, are the precipitates in CBS 1000, CBS 1000M, and Vasco X-2 steels. These precipitates occur in both the case of the material and to a lesser degree in the core due to the lower carbon content in the core.

In figures 6(b) and (c) the data of this study are compared to data from references 4 and 5. The case hardened CBS 1000, CBS 1000M, and Vasco X-2 (fig. 6(b)) are compared to a hot-hardness curve representing a large number of through-hardened high-speed tool steels. These tool steels are also precipitation hardening alloys and have the same precipitates as this group of steels. From figure 6(b) it is evident that the Vasco X-2 steel has hot-hardness characteristics similar to the through-hardened high-speed tool steels up to 644 K (700° F) above which Vasco X-2 is inferior. CBS 1000 and CBS 1000M, however, lose hardness with temperature at a greater rate than do the tool steels.

Case hardened AISI 8620 and CBS 600 are compared to through-hardened AISI 52100 in figure 6(c). AISI 52100 is a precipitation hardening bearing steel whose precipitate is epsilon carbide. The data for CBS 600 indicate better hardness retention at elevated temperature than that for AISI 52100. The data for AISI 8620 show a greater loss in material hardness at temperature than AISI 52100.

The changes in hardness as a function of temperature for these materials satisfy the equation developed in reference 4 for the prediction of hardness with change in temperature

$$(Rc)_T = (Rc)_{RT} - \alpha \, \Delta T^{\beta}$$

where

$(Rc)_T$	Rockwell C hardness at temperature
$(Rc)_{RT}$	Rockwell C hardness at room temperature
ΔT	change in temperature, $T_T - T_{RT}$
T_T	operating temperature, K; °F
T_{RT}	room temperature, K; °F
α	temperature proportionality factor, $(K)^{-\beta}$; $(^{\circ}F)^{-\beta}$
β	exponent

The values for α and β for the individual materials studied are summarized in table III. The equation is valid for AISI 8620 and CBS 600 from 298 to 589 K (70° to 600° F) and for Vasco X-2, CBS 1000, and CBS 1000M from 294 to 811 K (70° to 1000° F).

SUMMARY OF RESULTS

Short-term hot-hardness studies were performed with carburized and hardened AISI 8620, CBS 600, CBS 1000, CBS 1000M, and Vasco X-2 steels. Both case and core hardness measurements were made in an electric furnace with a low-oxygen environment at temperatures from 294 to 811 K (70° to 1000° F). The data were compared with data for through-hardened high-speed tool steels and AISI 52100 obtained in a previous investigation. The following results were obtained:

1. The materials tested can be ranked as follows in order of decreasing hot-hardness retention:
   - (a) Vasco X-2; approximately equivalent to through-hardened high-speed tool steels up to 644 K (700° F) above which Vasco X-2 is inferior
   - (b) CBS 1000
   - (c) CBS 1000M
   - (d) CBS 600; better hardness retention at elevated temperatures than through-hardened AISI 52100
   - (e) AISI 8620

2. For the carburized steels studied, the change in hardness with temperature of the case and core are similar for a given material.

3. The short-term Rockwell C hardness at a given temperature can be predicted within ±1 point Rockwell C hardness by the following equation for the materials studied:

$$(Rc)_T = (Rc)_{RT} - \alpha \, \Delta T^\beta$$

The equation is valid for AISI 8620 and CBS 600 from 298 to 589 K (70° to 600° F) and for Vasco X-2, CBS 1000, and CBS 1000M from 294 to 811 K (70° to 1000° F).

Lewis Research Center,
National Aeronautics and Space Administration,
and
U. S. Army Air Mobility R&D Laboratory,
Cleveland, Ohio, April 10, 1975,
505-04.

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TABLE I. - CHEMICAL COMPOSITIONS OF

CARBURIZED STEEL SPECIMENS

Material	Alloying element, percent by weight (balance Fe)								
	C	Si	Mn	W	Cr	V	Mo	Ni	Al
AISI 8620	0.21	0.23	0.76	----	0.47	----	0.23	0.61	0.035
CBS 600	0.23	1.08	0.65	----	1.58	----	0.96	0.15	0.04
CBS 1000	0.21	0.40	0.49	----	1.01	0.85	4.7	0.05	0.04
CBS 1000M	0.14	0.36	0.49	----	1.09	0.32	4.5	2.98	-----
Vasco X-2	0.24	0.88	0.30	1.44	4.87	0.54	1.37	----	0.04

TABLE II. - HEAT TREATMENTS OF CASE HARDENED SPECIMENS

Material	Heat treatment[a]					Retained austenite, percent
	Preheat	Condition	Austenitize	Quench	Temper	
AISI 8620	---------	--------	1102 K (1525° F) for 30 min in salt	Oil	455 K (360° F) for 1 hr	29.0
Vasco X-2	1060 K (1450° F) for 15 min	--------	1338 K (1950° F) for 10 min in salt	Oil	Triple tempered at 810 K (1000° F) for 2 + 2 + 2 hr	17.1
CBS 600	---------	866 K (1100° F) for 5 hr	1102 K (1525° F) for 30 min in salt	Oil	Double tempered at 622 K (660° F) for 1 + 1 hr	11.2
CBS 1000	[b]1117 K (1550° F) for 15 min	-------	[b]1395 K (2050° F) for 10 min	Oil[b]	Double tempered at 839 K (1050° F) for 2 + 2 hr	0
CBS 1000M	[b]1117 K (1550° F) for 15 min	--------	[b]1381 K (2025° F) for 10 min	Oil[b] Deep freeze at 321 K (-120° F) for 1 hr	Triple tempered at 810 K (1000° F) for 2 + 2 + 2 hr	5 to 7

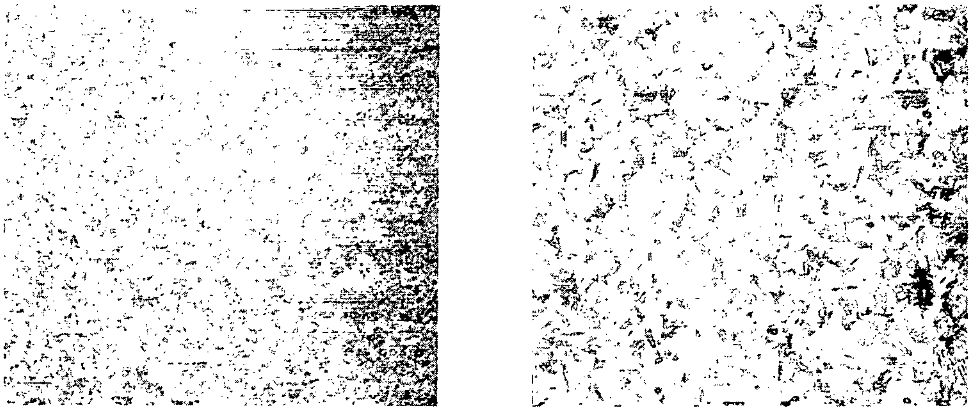
[a]Heat treatment performed in air furnace except where noted.
[b]Vacuum furnace.

TABLE III. - TEMPERATURE PROPORTIONALITY FACTORS α

AND EXPONENTS β FOR FIVE CASE HARDENED STEELS

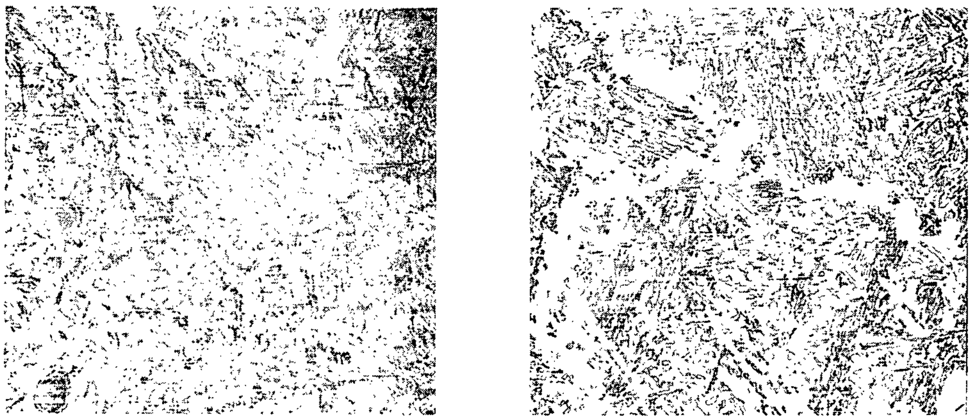
$$[(Rc)_T = (Rc)_{RT} - \alpha \Delta T^{\beta}.]$$

Material	Temperature range		α		β	
	K	°F	K	°F	K	°F
AISI 8620	294 to 589	70 to 600	73×10^{-5}	26×10^{-5}	1.7	1.7
CBS 600	294 to 589	70 to 600	0.75×10^{-5}	0.18×10^{-5}	2.4	2.4
Vasco X-2	294 to 811	70 to 1000	1.4×10^{-5}	0.38×10^{-5}	2.2	2.2
CBS 1000	294 to 811	70 to 1000	93×10^{-5}	38×10^{-5}	1.5	1.5
CBS 1000M	294 to 811	70 to 1000	340×10^{-5}	160×10^{-5}	1.3	1.3



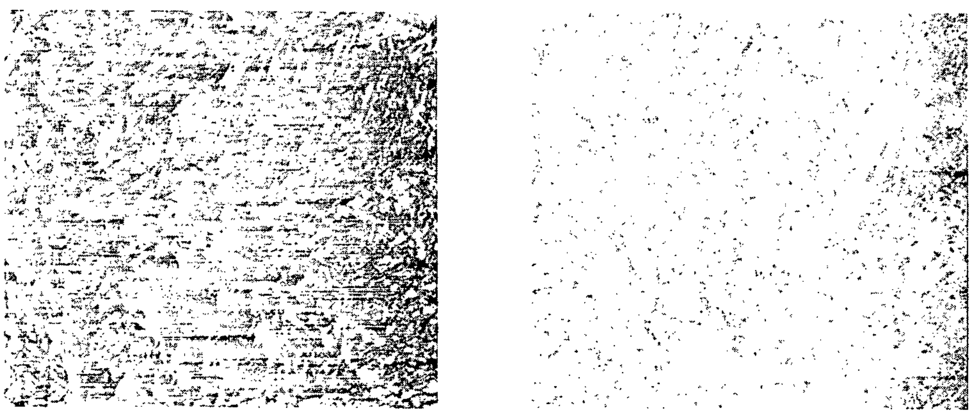
Case Core

(a) AISI 8620; ×410.



Case Core

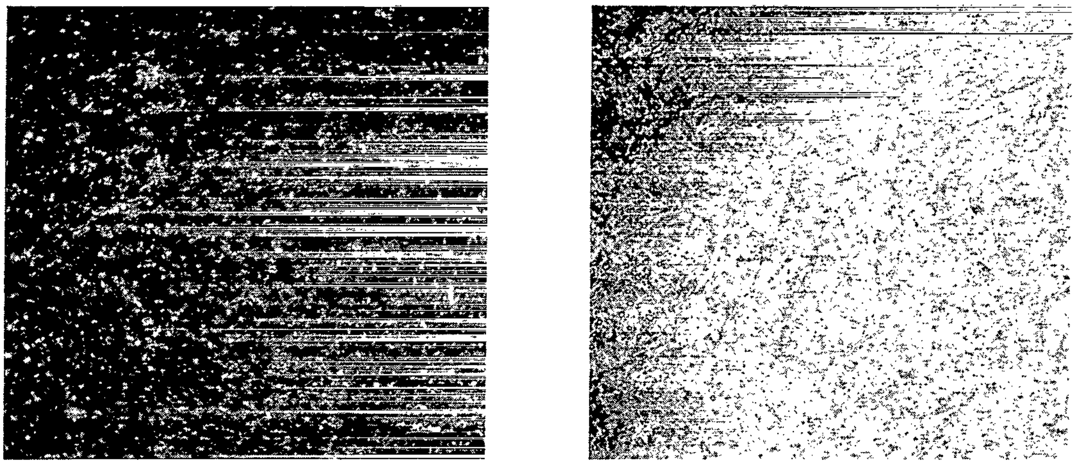
(b) CBS 600; ×410.



Case Core

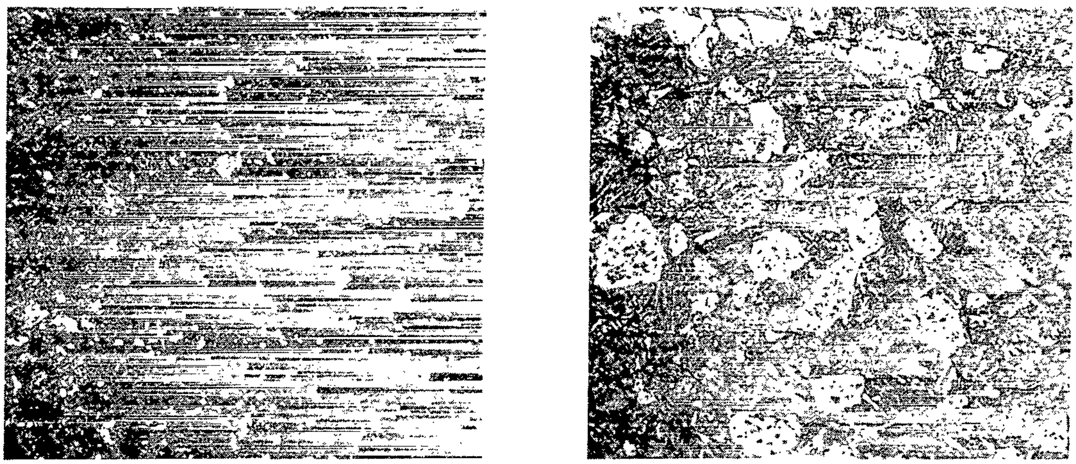
(c) Vasco X-2; ×410.

Figure 1. - Photomicrographs of case and core of five case hardened steels.



Case | Core

(d) CBS 1000; ×500.



Case | Core

(e) CBS 1000M; ×500.

Figure 1. - Concluded.

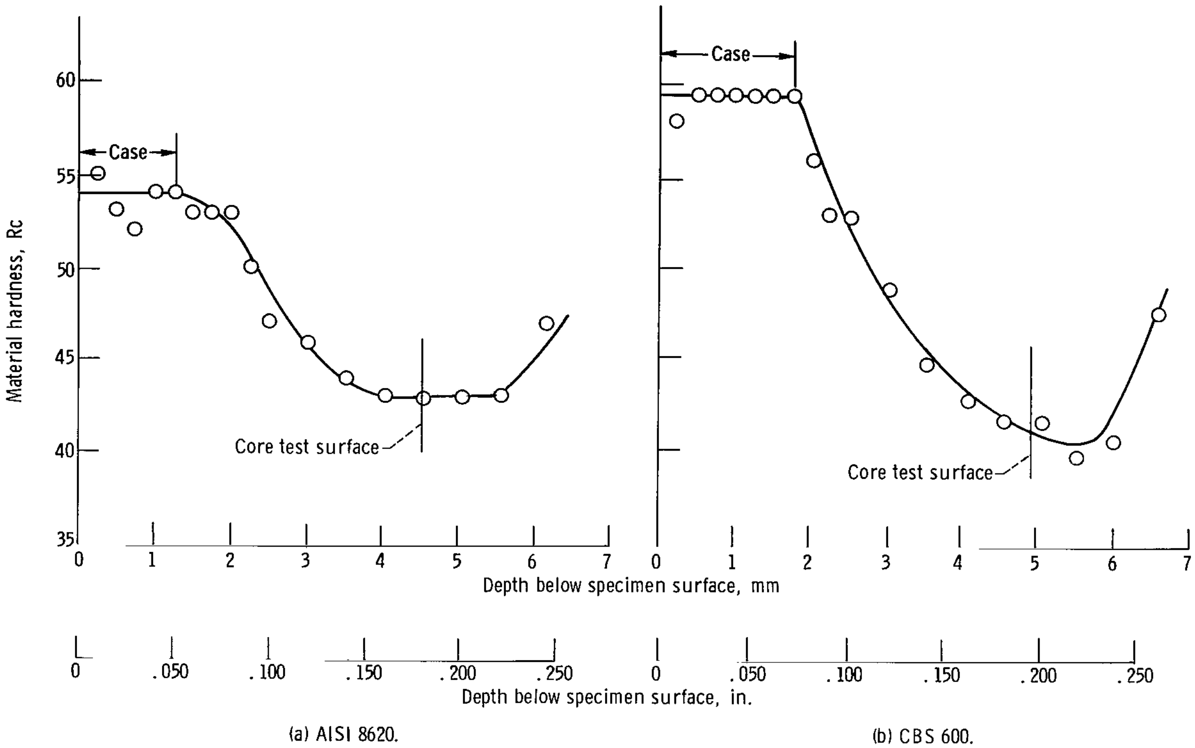
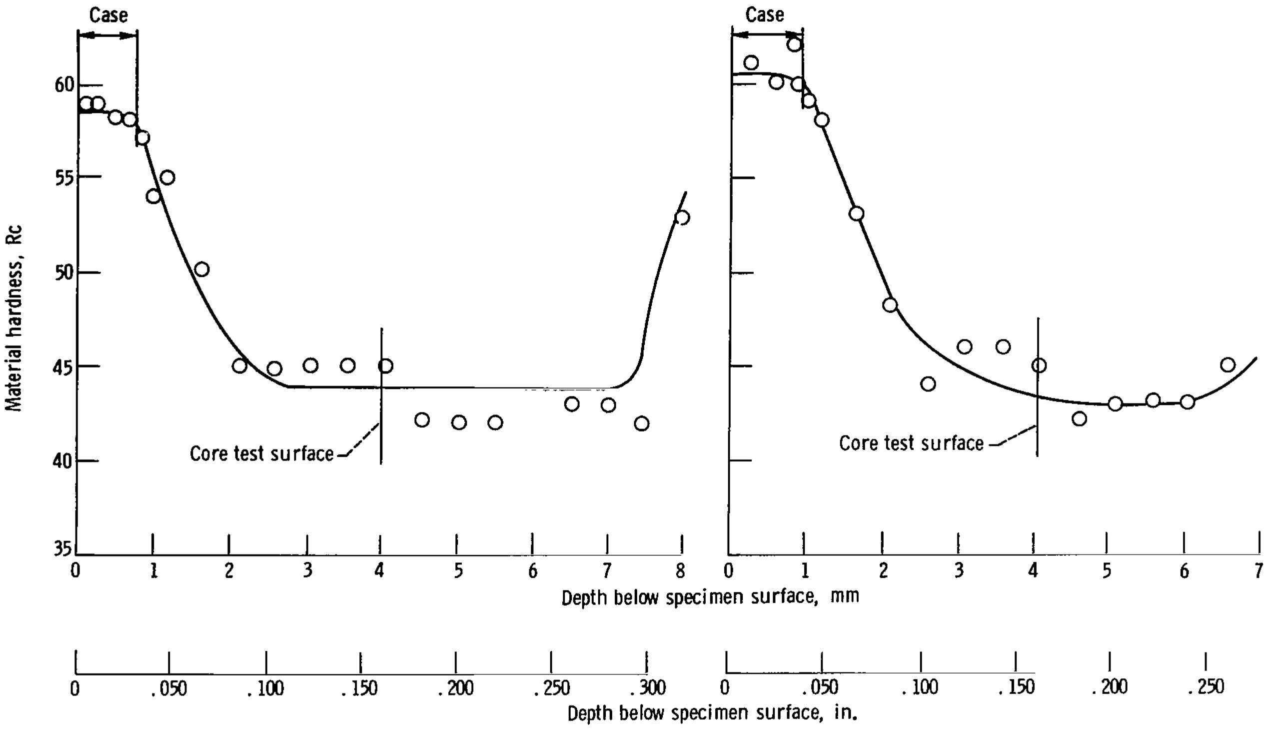
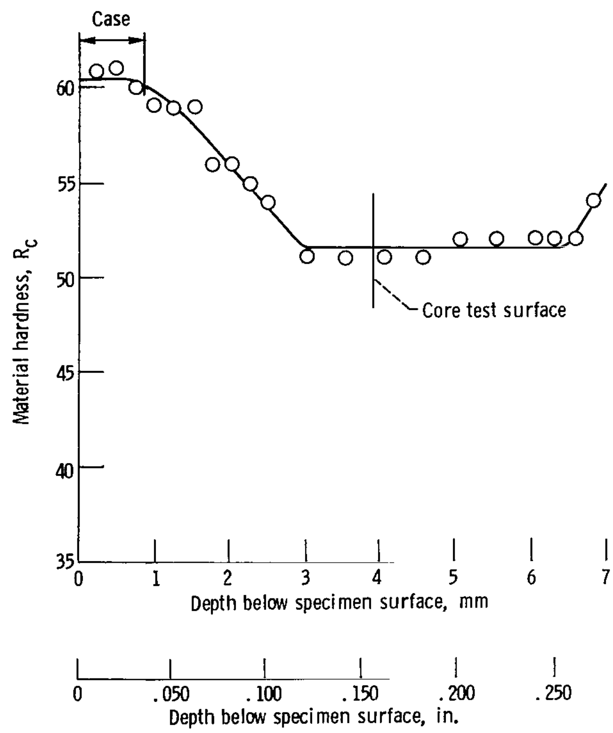


Figure 2. - Specimen microhardness gradients (room temperature Knoop hardness measurements converted to Rockwell C equivalents).



(c) CBS 1000.

(d) CBS 1000M.



(e) Vasco X-2.

Figure 2. - Concluded.

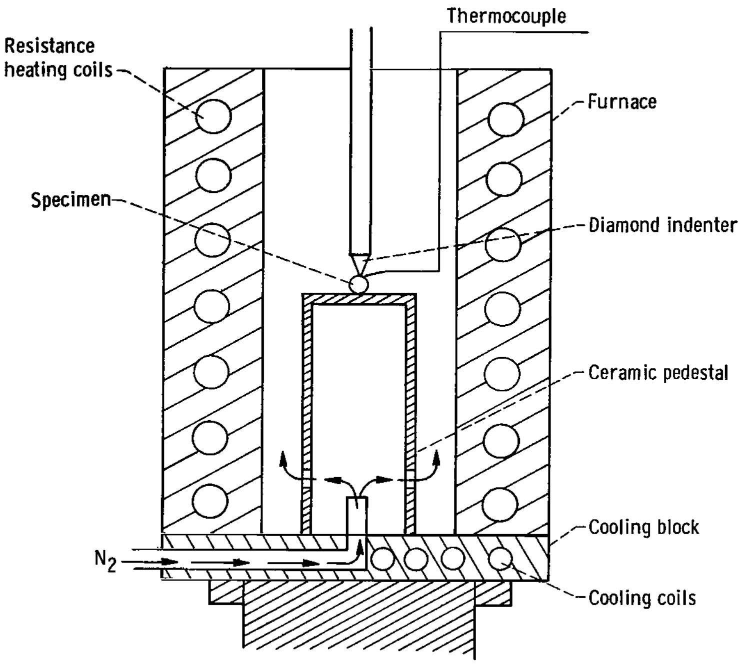
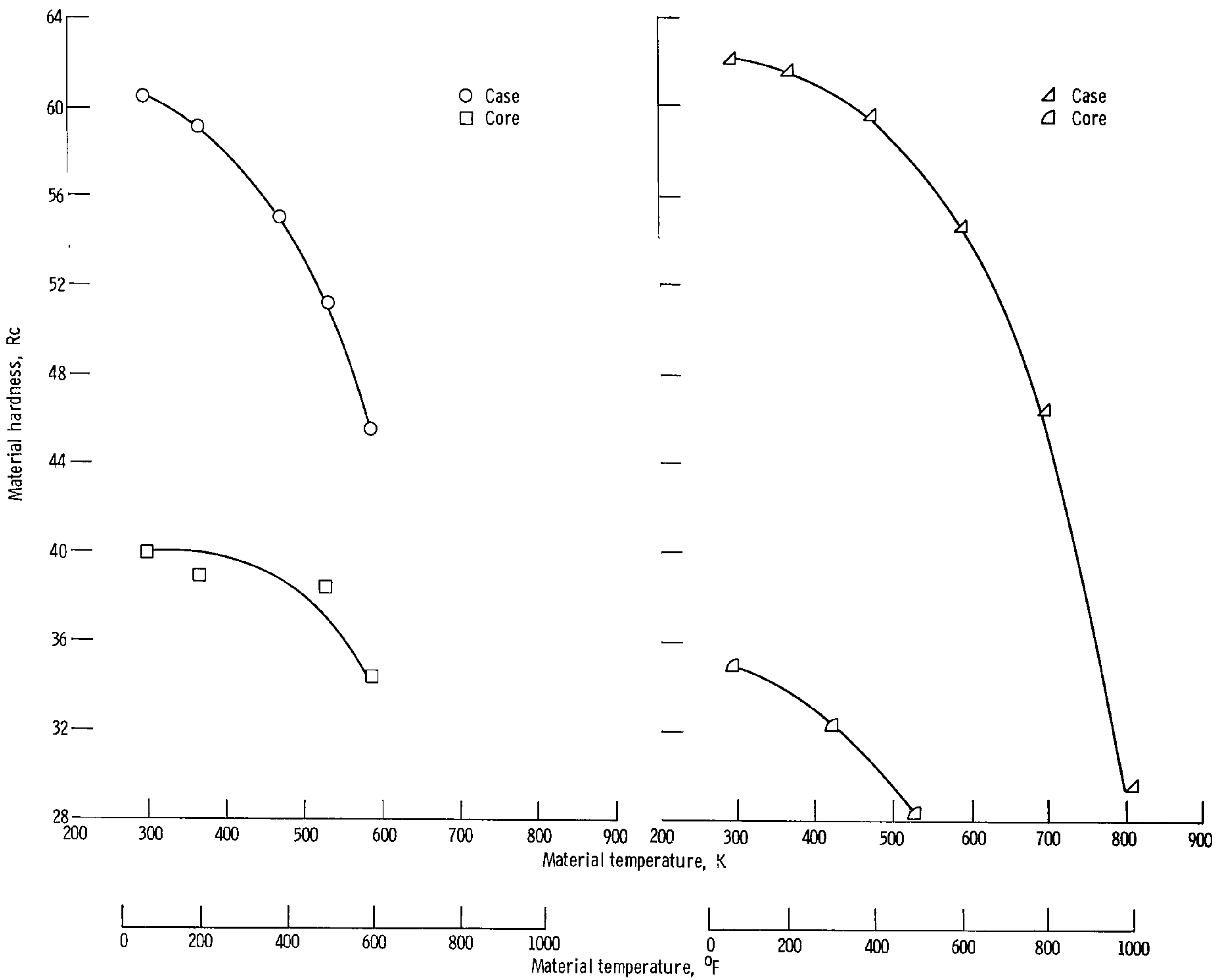


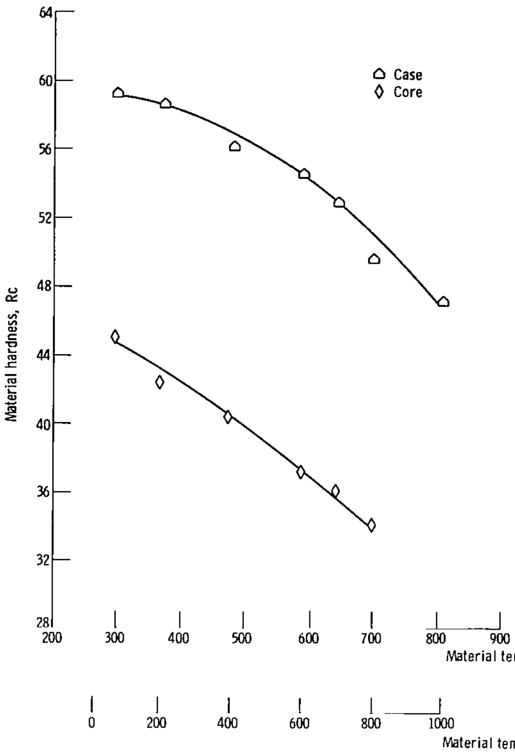
Figure 3. - Cross section of hot-hardness tester.



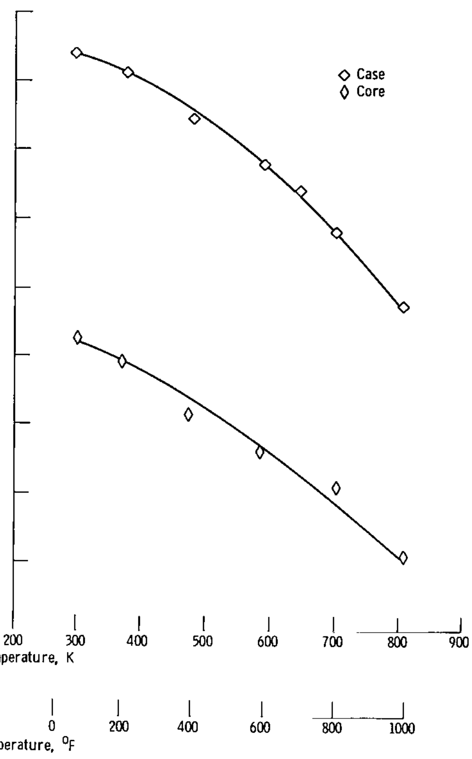
(a) AISI 8620.

(b) CBS 600.

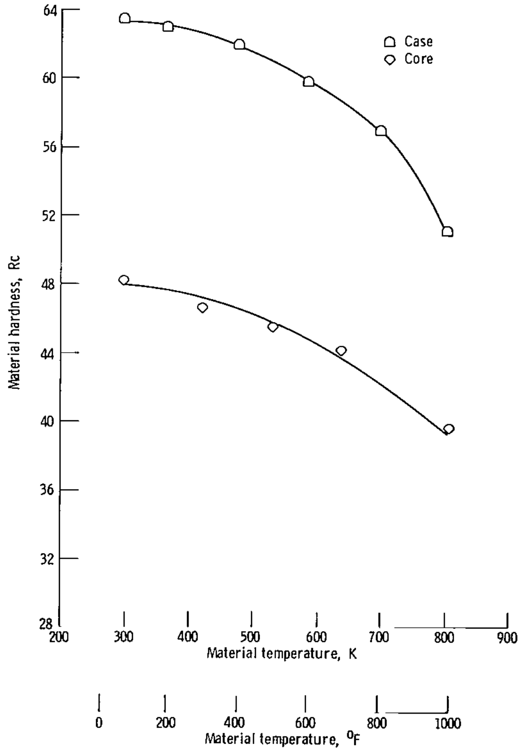
Figure 4. - Short-term hot-hardness characteristics of five case hardened steels.



(c) CBS 1000.



(d) CBS 1000M.



(e) Vasco X-2.

Figure 4. - Concluded.

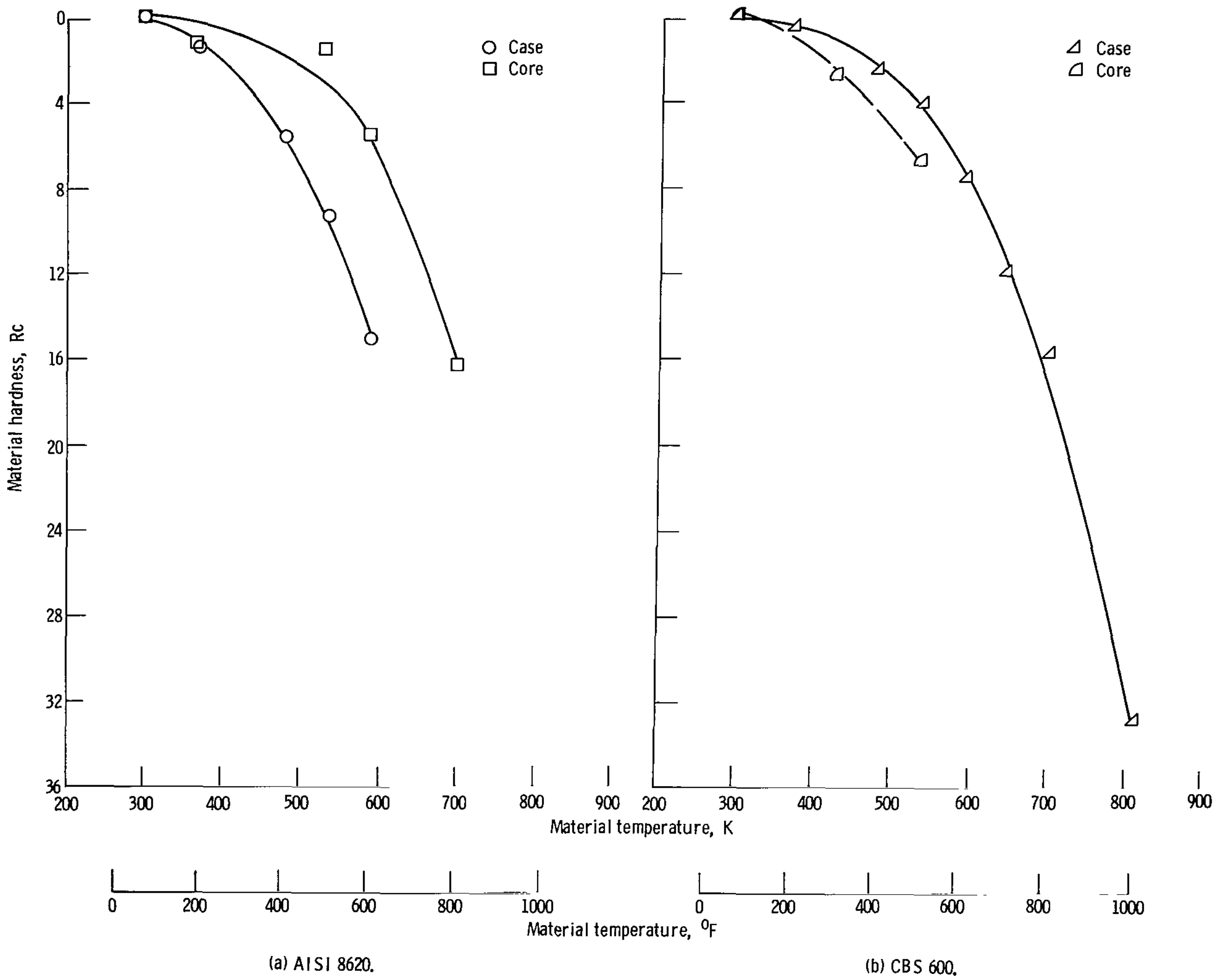
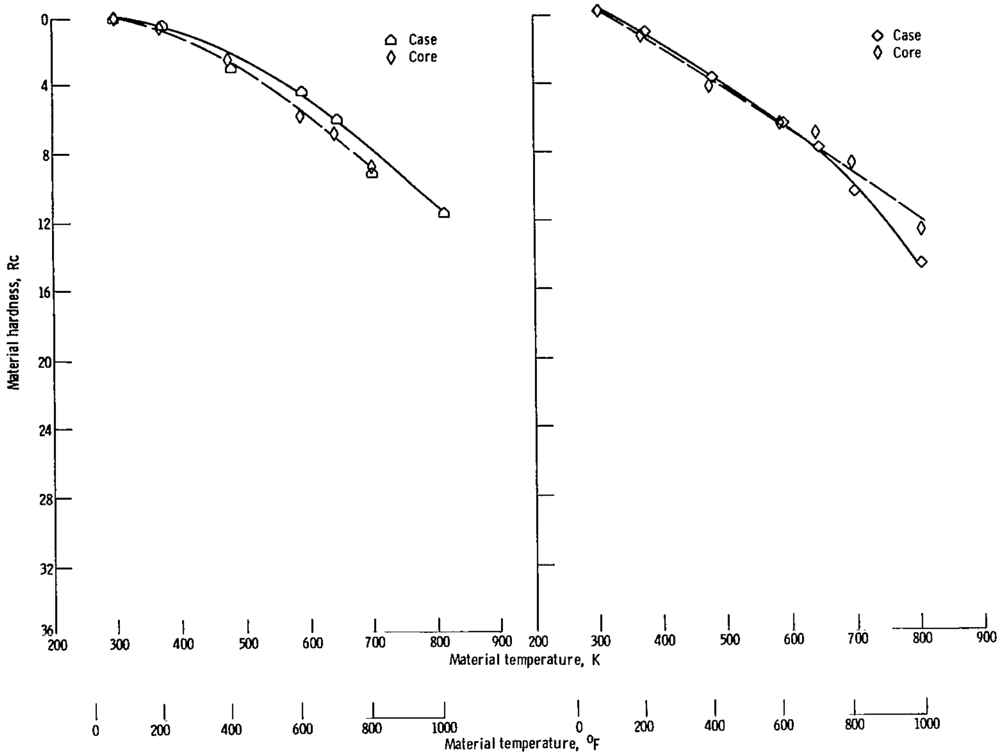
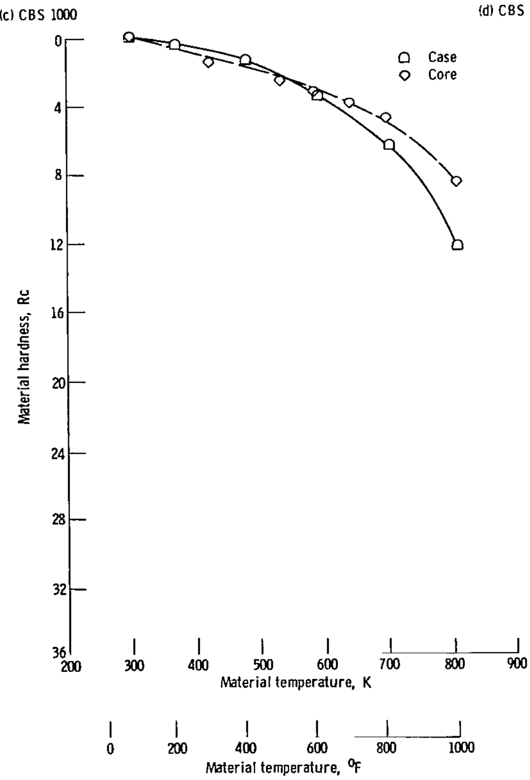


Figure 5. - Normalized short-term hot-hardness data for five case hardened steels.



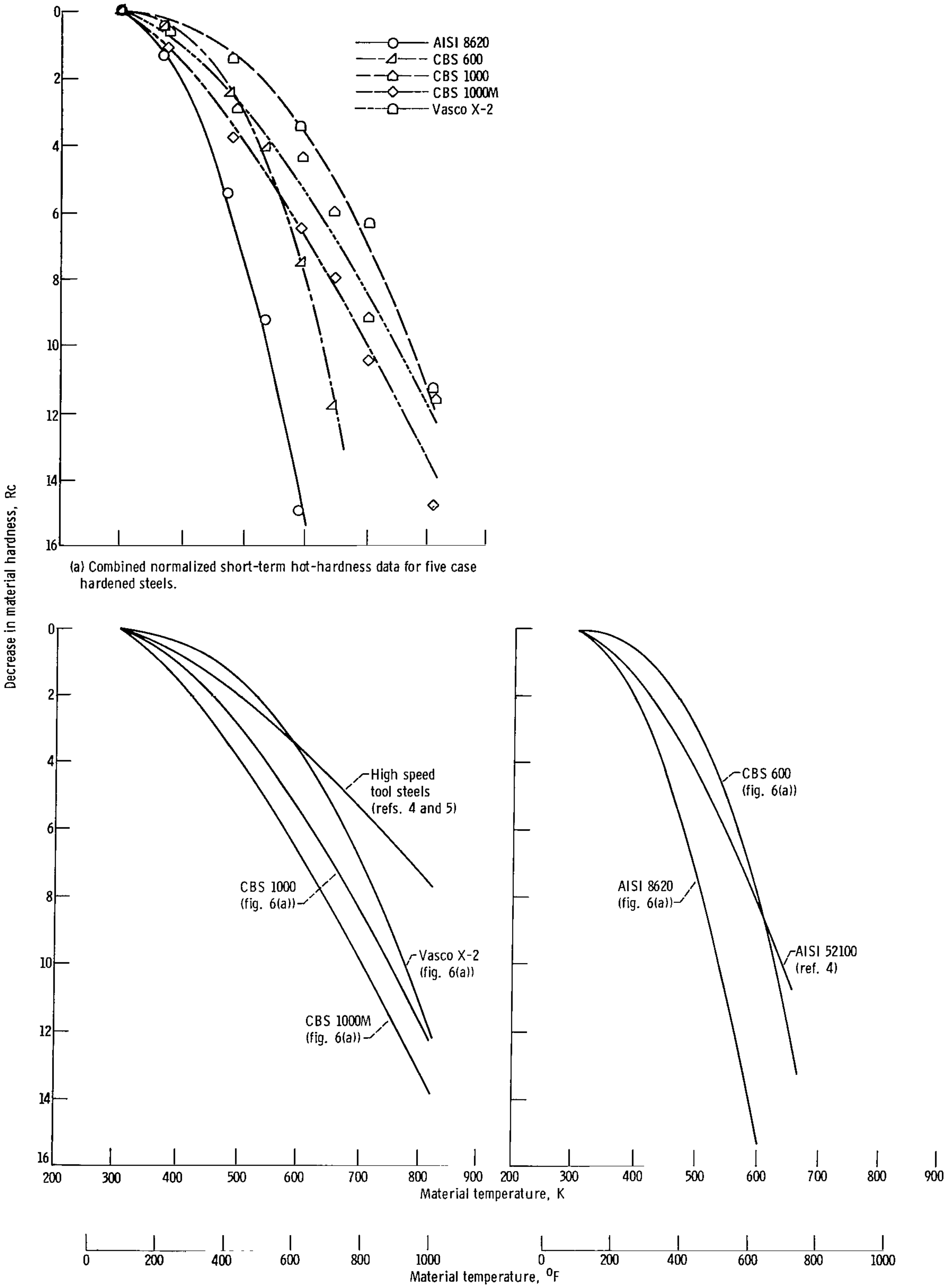
(c) CBS 1000

(d) CBS 1000M.



(e) Vasco X-2.

Figure 5. - Concluded.



(b) Comparison of CBS 1000, CBS 1000M, and Vasco X-2 with through-hardened high-speed tool steels.

(c) Comparison of AISI 8620 and CBS 600 with AISI 52100.

Figure 6. - Summary of case hardened steel short-term hot-hardness data and comparison with through-hardened high-speed tool steels and AISI 52100.

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