

13
OCT - 6 1967

NATIONAL BUREAU OF STANDARDS REPORT

9614

EFFECT OF SOME HARDENING VARIABLES ON THE MECHANICAL
PROPERTIES OF TYPE 431 STAINLESS STEEL

By

I. J. Feinberg
Engineering Metallurgy Section

To

Materials Division
Air Systems Command
Department of the Navy



U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards¹ provides measurement and technical information services essential to the efficiency and effectiveness of the work of the Nation's scientists and engineers. The Bureau serves also as a focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To accomplish this mission, the Bureau is organized into three institutes covering broad program areas of research and services:

THE INSTITUTE FOR BASIC STANDARDS . . . provides the central basis within the United States for a complete and consistent system of physical measurements, coordinates that system with the measurement systems of other nations, and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. This Institute comprises a series of divisions, each serving a classical subject matter area:

—Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic Physics—Physical Chemistry—Radiation Physics—Laboratory Astrophysics²—Radio Standards Laboratory,² which includes Radio Standards Physics and Radio Standards Engineering—Office of Standard Reference Data.

THE INSTITUTE FOR MATERIALS RESEARCH . . . conducts materials research and provides associated materials services including mainly reference materials and data on the properties of materials. Beyond its direct interest to the Nation's scientists and engineers, this Institute yields services which are essential to the advancement of technology in industry and commerce. This Institute is organized primarily by technical fields:

—Analytical Chemistry—Metallurgy—Reactor Radiations—Polymers—Inorganic Materials—Cryogenics²—Office of Standard Reference Materials.

THE INSTITUTE FOR APPLIED TECHNOLOGY . . . provides technical services to promote the use of available technology and to facilitate technological innovation in industry and government. The principal elements of this Institute are:

—Building Research—Electronic Instrumentation—Technical Analysis—Center for Computer Sciences and Technology—Textile and Apparel Technology Center—Office of Weights and Measures—Office of Engineering Standards Services—Office of Invention and Innovation—Office of Vehicle Systems Research—Clearinghouse for Federal Scientific and Technical Information³—Materials Evaluation Laboratory—NBS/GSA Testing Laboratory.

¹ Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C., 20234.

² Located at Boulder, Colorado, 80302.

³ Located at 5285 Port Royal Road, Springfield, Virginia 22151.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

DET - 6 1967

NBS REPORT

3120410

9614

EFFECT OF SOME HARDENING VARIABLES ON THE MECHANICAL
PROPERTIES OF TYPE 431 STAINLESS STEEL

By

I. J. Feinberg
Engineering Metallurgy Section

Sponsor

Materials Division
Air Systems Command
Department of the Navy

IMPORTANT NOTICE

NATIONAL BUREAU OF STANDARDS
for use within the Government. Before being
and review. For this reason, the report
whole or in part, is not authorized for
Bureau of Standards, Washington, D.C.
the Report has been specifically prepared

Approved for public release by the
director of the National Institute of
Standards and Technology (NIST)
on October 9, 2015

accounting documents intended
subjected to additional evaluation
listing of this Report, either in
Office of the Director, National
Government agency for which
ies for its own use.



U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Effect of Some Hardening Variables on the Mechanical Properties of Type 431 Stainless Steel

Introduction: Type 431 stainless steel is a complex alloy that requires exacting care from the melting stage through the final clean-up of part surfaces to attain the properties of which the alloy is capable. When fully hardened to 200,000 psi minimum tensile strength it offers the best corrosion resistance of all the hardenable stainless steels. However, when improperly processed it may be extremely brittle and susceptible to intergranular corrosion.

Angstadt and Gassner, who have worked extensively with this alloy, have traced some difficulties to faults in the hardening practice.⁽¹⁾ The Naval Air Systems Command suspects that part failures it has experienced stem from this source. At the request of that agency studies have been conducted to determine the effects of air quenching, oil quenching and refrigeration and the effects of different types of atmospheres and of delays before quenching on the mechanical properties of type 431 stainless steel. These studies were concerned exclusively with material of small diameter, heat treated to 200 Ksi minimum ultimate tensile strength.

Material: The test material obtained for this investigation was 0.625 inch diameter bar stock. This size was used inasmuch as many of the hardening problems that have been encountered are in components that have a section diameter of 0.50 inch or less.

All of the bar stock originated from a single heat. The chemical composition in weight percent as determined by the Analytical Chemistry Division of the National Bureau of Standards for elements other than iron was as follows: 0.152 carbon, 0.7 manganese, 0.5 silicon, 0.018 phosphorus, 0.019 sulfur, 2.3 nickel, 15.5 chromium, 0.2 molybdenum and 0.044 nitrogen. The chemical composition of the steel complied with that specified for type 431 in Mil-S-18732 C. This document specifies a range of 15.50 - 17.00 percent chromium for 431. The chromium content of the test material used in these investigations is the lower limit of this range. The hardness of the material as-received averaged 235 Brinell (\approx Rockwell B 99).

Samples of the test steel in the as-received condition were examined metallographically. The microstructures are shown in figures 1 and 2. The inclusion content, figure 1, appears to be greater than that expected in steel of aircraft quality. The as-received annealed microstructure shown in figure 2 consists of ferrite, decomposition products of austenite and some austenite.

(1) C. C. Angstadt and R. H. Gassner, Douglas Materials and Process Engineering Report, E.S.R. 50514, May 14, 1955.

Section 1. Effects of Quenching Media and Refrigeration

Objectives: Air quenching is a slow quench and oil quenching a moderately fast one. Equivalent hardnesses have been obtained in hardening type 431 stainless steel parts by either quench method. Refrigeration is introduced into type 431 heat treating cycles to reduce residual austenite contents. The lowered retained austenite is thought desirable to limit the possibilities of embrittlement and unacceptable dimensional changes resulting from temperature fluctuations in service. Questions as to the suitability of an air quench and the refrigeration treatment in heat treating small type 431 parts to a tensile strength of 200 Ksi have led to this investigation in which properties obtained by air quenching and oil quenching, both with and without refrigeration in the heat treating cycle, are compared.

Specimens and Procedure: Tensile and impact test specimens for the study of air and oil hardening and refrigeration effects were machined 0.040 inch oversize before heat treatment. The specimens were divided into four groups for heat treatments, designated as A, B, C and D. The heat treatment sequence for each group is given in figure 3. After heat treatment specimens were ground to finished dimensions and then tested.

Results and Discussion: Tensile and Charpy V-notch impact properties obtained after subjecting the test material to heat treatments A, B, C and D are presented in figure 4. It is evident from these data that although type 431 can be heat treated to a tensile strength of 200 Ksi by a heat treatment involving either an air quench or an oil quench generally higher mechanical properties are obtained through oil quenching than through air quenching. The variations in the heat treatments had little effect on hardness. Refrigeration reduced the yield strength of both air quenched and oil quenched material and conversely increased the ultimate tensile strength. Through elimination of refrigeration the ratio of yield strength to ultimate tensile strength was increased. The removal of refrigeration from heat treating sequences employing either an air quench or an oil quench slightly improved ductility (percent elongation and reduction of area) and markedly improved Charpy V-notch impact properties at both room temperature and -40° F.

Heat treatment of the 431 test material by sequence D, involving a stabilization treatment, austenitizing in air, quenching in oil and a double temper yielded the best combination of tensile properties and Charpy V-notch impact strength. The superior ductility and V-notch impact properties of this material were evidently imparted by a relatively high residual austenite content. Through X-ray determinations retained austenite contents were found to be as follows:

<u>Sequence</u>	<u>Retained Austenite, volume %</u>
A	< 3
B	18
C	< 3
D	10

Retained austenite or ferrite banding was not observed in the structure of the sequence D material or in the structure of the other test materials. Changes in microstructure resulting from the variations in the heat treatment employed are subtle and not readily revealed with an optical microscope. Consequently, the quenched and tempered martensitic structures obtained after the four heat treatments are all similar in appearance, figure 5.

Conclusions: Higher tensile and notch impact properties are obtained by quenching type 431 stainless steel in oil than by air quenching. In this investigation a type 431 heat treating sequence that included a stabilization heat treatment, austenitizing in air, quenching in oil and a double temper yielded the best combination of tensile properties and notch toughness. This heat treating sequence, basically, was used in the other studies herein reported.

A residual austenite content of 10% obtained in a heat treatment involving oil quenching and tempering (minus refrigeration) is not excessive and is beneficial to this steel. Refrigeration to reduce retained austenite contents lowered the ductility (percent elongation and reduction of area) of the material slightly. It reduced notch toughness markedly. Refrigeration is definitely not recommended for this steel.

Section II. Effects of Heat-Treating Atmospheres

Objectives: Austenitizing atmospheres vary in their capacity to prevent minimize or control changes on the surface of work being hardened. Surface condition has an effect on some of the mechanical properties of metals. This study was conducted to determine the changes effected by air, argon, dissociated ammonia, endothermic gas, exothermic gas, hydrogen, nitrogen and vacuum on the surface of type 431 stainless steel in hardening and the effects on tensile and V-notch Charpy impact properties resulting from these changes.

Specimens and Procedure: 0.5 inch diameter by 4.0 inch specimens were used in determining the effects of atmospheres on material surfaces. The specimens were austenitized in these atmospheres and oil quenched. The carbon, nitrogen, oxygen and hydrogen contents of a surface layer 0.03 inch deep on the specimens were then determined. Carbon was determined by the combination-gravimetric method; nitrogen, oxygen and hydrogen by the vacuum-fusion method. The hardness of the 0.03 inch deep surface layer and the hardness of the core of the specimens were also ascertained.

ASTM standard longitudinal tensile test specimens with a 1.0 inch gage length and 0.252 inch diameter in the reduced section and standard Charpy V-notched impact test specimens were used in determining the effects of austenitizing atmospheres on mechanical properties. These specimens were

ground to size before heat treatment so that the affected surface layer would not be removed by a post heat treatment finish machining. The following heat treating sequence was employed:

Heat Treating Sequence used in Study of Effects of Atmospheres

Stress relieve 1/2 hour at 1200° F;
air cool.

Austenitize in subject atmospheres, 1/2 hour
at 1900° F.

Quench rapidly in oil at 100 - 105° F. Then
cool to room temperature in cold water.

Temper twice for 2 hours, each temper at 550° F;
air cool.

The mechanical test specimens were tested with the heat treated surfaces intact.

Austenitization in exothermic gas was effected at a dew point of 100° F, the optimum temperature employed by a commercial vendor. Austenitization in the other gaseous media was effected at the highest dew point temperature and at the lowest dew point temperature consistent with a given atmosphere and available equipment. The austenitizing media used and their dew points are included in table 1.

Results and Discussion: All of the hardening treatments (austenitizing and oil quenching) produced a discolored film or even mild scaling effect on material surfaces. Characterized as to product, the film or scale ranged from the light yellowish tarnish produced by hydrogen dew point temperature (D.P. -17° F) to a blue-black deposit produced by hydrogen (D.P. -87° F). All surface effects were thin and adherent.

Table 1 gives the interstitial contents of the 0.030 inch surface layer on specimens after hardening. It shows the extent to which interstitial changes to a depth of 0.030 inch beneath the surface varied with the atmosphere and the atmosphere dew point temperature employed in hardening. Argon (D.P. -76° F) controlled the alteration of surface interstitial contents best, as shown by the only very slight changes in interstitial content after treatment. Good control was also obtained with endothermic gas (D.P. 72° F), air (D.P. -30° F) and nitrogen (D.P. -80° F). It is

noteworthy that better results were obtained when argon, air and nitrogen were dry rather than wet. Poor control of surface interstitial contents resulted from the use of dissociated ammonia (wet or dry), endothermic gas (D.P. 13° F), exothermic gas (D.P. 100° F), hydrogen (wet or dry) and vacuum.

Figures 6 through 13 show the microstructures of type 431 adjacent to the surface after the various hardening treatments. Some peripheral areas appear unaffected while cases present in others are evidence that metallurgical changes have occurred. Dissociated ammonia (D.P. -59° F) and hydrogen (D.P. -87° F and -17° F) produced decarburized cases. Endothermic gas (D.P. 13° F) and the vacuum-oil quench treatment produced carburized cases. The cases were probably formed through the reaction of the gaseous media with the material surfaces during austenitization. The thin case formed on the vacuum treated material is believed to be due to the reaction of the hot metal surface with the oil during the quench.

Changes in hardness revealed by hardness traverses confirmed that some metallurgical change occurred adjacent to the surface of all of the austenitized material, table 2. Low hardnesses found to a depth of 0.0015 inch are probably associated with the reduced total of carbon plus nitrogen found in all but one of the samples.

The tensile properties of the finish machined type 431 test material, austenitized in the various media and fully heat treated are given in figures 14 and 15. Charpy V-notch impact properties are given in figure 16. These data indicate that austenitizing atmospheres varied little in their effects on tensile strength, yield strength, percent elongation and reduction of area. Effects on tensile properties were found to be inconclusive. This is probably due to the insensitivity of these properties to subtle changes in surface conditions. However, notch toughness at both room temperature and at -40° F are greatly influenced by the austenitizing atmosphere employed. There is a correlation between the capacity of an atmosphere to control surface alteration during austenitization and notch toughness properties obtained. Generally, good notch toughness properties were linked with a low alteration of surface interstitial contents. Good combinations of tensile and notch toughness properties were obtained from material austenitized in air and in argon which afforded good control. Inferior combinations of these properties were obtained from material austenitized in dissociated ammonia, endothermic gas, hydrogen and nitrogen which rendered relatively poor control. A good combination of properties was obtained after austenitization in vacuum. The case formed in the vacuum austenitizing treatment apparently had little effect on tensile properties or notch toughness.

High yield strengths and ultimate tensile strengths were obtained by austenitizing in dissociated ammonia, endothermic gas, hydrogen and nitrogen. However, notch toughness obtained in these treatments was generally low. No appreciable improvement in notch toughness resulted from austenitization in dry dissociated ammonia or in dry endothermic gas.

Austenitization in dry hydrogen and in dry nitrogen resulted in very low -40°F notch impact values. On the other hand austenitization in dry air and in dry argon improved low temperature notch toughness.

Conclusions: Protection of the surface of type 431 stainless steel from alteration of its original interstitial contents is necessary to avoid poor ductility and toughness. No over-all improvement in properties is obtained by austenitizing in dry dissociated ammonia, dry hydrogen or dry nitrogen, but better properties are obtained after austenitizing in dry air and in dry argon. Considering combined effects on tensile properties and notch toughness the atmospheres investigated are rated as follows:

<u>Good</u>	<u>Fair</u>	<u>Poor</u>
Air (D.P. -30°F)	Argon (D.P. -38°F)	Air (D.P. 70°F)
Argon (D.P. -76°F)	Exothermic gas (D.P. 100°F)	Dissociated ammonia (D.P. -59°F)
Vacuum	Hydrogen (D.P. -17°F)	Dissociated ammonia (D.P. 24°F)
	Nitrogen (D.P. -18°F)	Endothermic gas (D.P. 13°F)
		Endothermic gas (D.P. 72°F)
		Hydrogen (D.P. -87°F)
		Nitrogen (D.P. -80°F)

Section III. Effects of Delays Before Quenching

Objectives: Delays or variations in the interval between austenitizing and quenching can occur in all steel hardening operations from mechanical deficiencies and from negligence on the part of heat treaters. There is scant information on the effects of delays before quenching on type 431 stainless steel. This study was conducted to determine the effects of delays of up to one minute between removal from the furnace and quenching on the microstructure, tensile and Charpy V-notch impact properties of this alloy.

Specimens and Procedure: Specimens 0.187 inch and 0.50 inch in diameter and 1.00 inch in length were used to obtain cooling rate data for the study of the effects of delays before quenching. Holes 0.375 inch deep were drilled in one end of these specimens to accommodate a sheathed AWS 30 gage chromel-alumel thermocouple. The couple was monitored by a potentiometer recorder for temperature-time measurement. The delay time established was the time elapsed in transferring specimens from the furnace mouth to an oil bath.

Tensile and impact test specimens for this study were machined 0.040 inch oversize before heat treatment. After stress relief and austenitization these specimens were subjected to 1, 9, 15, 30 and 60 second delays before quenching. The full heat treatment given was one that yielded a good combination of mechanical properties in a related investigation. The full heat treatment was as follows:

Heat Treating Sequence Used in Study of Effects of Delays Before Quenching

Stress relieve 1/2 hour at 1200° F; air cool.

Austenitize in air, 1/2 hour at 1900° F

Quench in oil at 100 - 105° F after delays. Then cool to room temperature in cold water.

Temper twice for two hours, each temper at 550° F; air cool.

After heat treatment, the tensile and impact test specimens were ground to finished dimensions and then tested.

Results and Discussion: When cooling rate study specimens were drawn to the furnace mouth, where they were delayed before quenching, there were immediate drops from the austenitizing temperature (1900° F) to the temperatures shown at zero time, figure 17. The 0.187 inch diameter specimens cooled to lower temperatures than the 0.50 inch diameter specimens. Delay intervals resulted in corresponding increases in the time occupied in an ensuing slow cooling stage for both sizes. During the delays the larger specimens cooled much more slowly than the smaller. On quenching, specimens of both sizes cooled to 1000° F at fast and surprisingly similar rates, figures 18 and 19.

The effects of mass in causing the smaller specimens to cool to lower temperatures at zero delay time are obvious. However, the much slower cooling of the larger specimens during respective quench delays cannot be attributed to mass alone. The greater amount of heat liberated on the precipitation of non-martensitic products in the high temperature transformation of austenite during quench delays contributed to the slower cooling of the larger specimens. It is apparent from these data that quench delays retard the cooling rate and prolong the precipitation of the non-martensitic products.

According to Angstadt and Gassner⁽²⁾ carbides are precipitated from austenite in type 431 at 1400° F after 12 seconds at that temperature. Using this reaction temperature and the cooling rates in table 3 as criteria it would seem quench delays as long as 60 seconds could be tolerated in hardening 0.187 inch diameter material before carbide precipitation occurred; but delays should be limited to about 7 seconds to avoid carbide precipitation in 0.50 inch diameter material.

In examining microstructures it was found that appreciable carbide precipitation resulted from a 12 second delay before quenching in both sizes, figures 20 and 21. From this it is apparent that the condition of the material prior to hardening may also influence carbide precipitation. Or it is possible that some of the carbides in the microstructure of specimens subjected to short quench delays are the residue of a prior heat treatment, not having been completely dissolved in austenitization for these tests. It is very difficult to obtain a type 431 quenched and tempered martensitic structure free of carbides. Nevertheless, it is apparent from this investigation that carbide precipitation in type 431 is influenced to a large degree by quench delays; and that quench delays should be as short as possible for carbide control.

Banding of carbides such as that obtained after 60 second quench delays is particularly detrimental to material properties. Carbides thus formed

(2) From isothermal transformation diagram, page 22, reference (i).

usually have a high chromium content (Cr_{26}C_6). They induce brittleness and because they deplete the chromium content in surrounding areas in the structure they may reduce corrosion resistance.

Interestingly, varying quench delays had little effect on the quenched and tempered martensitic structures obtained in heat treatment. The structures revealed by etching and observed microscopically after quench delays of from 1 to 60 seconds, were similar in appearance, figures 22 and 23. Ferrite was not observed to any appreciable extent.

Hardness: Hardness obtained at the periphery, mid-radius and center of specimens subjected to quench delays are given in table 4. The Rockwell C values listed are approximate equivalent conversions from Superficial Rockwell 45 N. Low hardness values found at the periphery of some of the test material is attributed to decarburization. At mid-radius and center hardness ranged from 42 to 46 Rockwell C. The higher hardnesses, 45 and 46 Rockwell C, obtained at mid-radius and at the center of the 30 and 60 second delay specimens are attributed to the precipitation of the carbides previously noted. Neglecting instances of low peripheral hardness, the data in table 4 generally show through hardening regardless of the delay interval.

Mechanical Properties: Tensile property data given in table 5 indicate that yield strength and ultimate tensile strength are similar after quench delays of up to 30 seconds and only a small decrease in these properties occurs when the material is subjected to a 60 second quench delay. Percent elongation and reduction of area generally increased slightly as the delay interval was increased. The similarity in tensile properties is not surprising in view of the likeness in microstructure obtained throughout the delay spectrum.

Charpy V-notch impact data given in table 6 indicate there is no appreciable effect on fracture toughness at ambient temperature from quench delays of up to 15 seconds; but delays of 30 and 60 seconds result in slightly higher fracture toughness at these temperatures. Conditioning of specimens at -40°F to induce brittleness reduced the notch toughness of all quench delay material. The greatest reduction occurred in specimens quenched after 30 and 60 second delays.

Conclusions: Detrimental carbide precipitation in type 431 stainless steel will result from extended delays before quenching. Quench delays appear to have a greater effect than mass in retarding the rate of cooling of material of small size. They should be as short as possible to minimize the possibility of serious carbide precipitation.

Hardness and tensile property tests alone may be misleading in determining the quality of type 431 after heat treatment since harmful carbide precipitation will not show up in these tests. Charpy V-notch impact tests at -40°F and specific metallographic examination are suggested to detect this condition.

Table 1. Interstitial Contents of Surface Layers on Type 431
Stainless Steel Specimens Hardened from Various
Austenitizing Media (Depth of Surface
Layer 0.030 Inch)

Specimen	Austenitizing Medium	Dew Point Temp. F	Carbon %	Nitrogen %	Oxygen %	Hydrogen %	Carbon + Nitrogen %
As-Received Material	-	-	0.152	0.044	0.011	0.0003	0.196
D-10	Air	- 30	0.155	0.026	0.015	0.0004	.181
D-11	Air	- 70	0.150	0.021	0.015	0.0004	.171
D-12	Argon	- 76	0.149	0.045	0.014	0.0003	.194
D-13	Argon	- 38	0.148	0.032	0.018	0.0004	.180
D-20	Dissociated ammonia	- 59	0.127	0.049	0.013	0.00035	.176
E-19	Dissociated ammonia	24	0.138	0.043	0.021	0.0035	.181
D-17	Endothermic gas	13	0.224	0.045	0.023	0.0003	.269
D-16	Endothermic gas	72	0.150	0.042	0.017	0.0003	.192
D-6	Exothermic gas	100	0.132	0.029	0.053	0.00055	.161
E-20	Hydrogen	- 87	0.135	0.043	0.011	0.0005	.178
D-3	Hydrogen	- 17	0.126	0.025	0.015	0.00045	.151
D-14	Nitrogen	- 80	0.153	0.037	0.015	0.0003	.190
D-15	Nitrogen	- 18	0.147	0.033	0.013	0.0003	.180
D-8	Vacuum ¹	-	0.165	0.025	0.011	0.00035	.190

¹ 190 microns for 1/2 hour at 1900° F.

Table 2. Rockwell C Hardness of Type 431 Stainless Steel¹ Specimens After Various Austenitizing Treatments.

Austenitizing Medium	Dew Point Temp.	Approximate Rockwell C Hardness of Surface Layer at Various Depths				
		0.0 - 0.0015"	0.0015 - 0.01"	0.01 - 0.02"	0.02 - 0.03"	Center
F						
Air	- 30	44	48	48	47	45
Air	70	41	47	47	46	46
Argon	- 76	42	46	47	45	45
Argon	- 38	42	46	46	46	46
Dissociated ammonia	- 59	43	47	46	44	42
Dissociated ammonia	24	42	47	45	46	44
Endothermic gas	13	43	45	43	44	45
Endothermic gas	72	44	47	47	47	44
Exothermic gas	100	42	47	46	46	44
Hydrogen	- 87	37	47	48	48	46
Hydrogen	- 17	42	45	48	48	52
Nitrogen	- 80	39	47	46	46	48
Nitrogen	- 18	43	47	45	45	44
Vacuum	-	35	45	45	46	46

¹ Rockwell C hardnesses are approximate equivalent conversions from Knoop values obtained with a 500 gram load.

Table 3. Cooling Rates from 1900° F to 1400° F
of Type 431 Test Material Subjected
to Intervening Quench Delays

<u>Quench Delay, Sec.</u>	<u>Cooling Rate, Deg. F/Sec.</u>	
	<u>0.187 in. Dia.</u>	<u>0.50 in. Dia.</u>
1	272	93
4	104	65
6	71	51
9	59	39
12	50	32
15	45	29
30	45	17
60	45	17

Table 4. Hardness of Fully Heat Treated Specimens
Quenched after Various Delays

Quench Delay, Sec.	Rockwell C Hardness ¹					
	0.187 in. Dia.			0.50 in. Dia.		
	P ²	MR ³	C ⁴	P	MR	C
1	40	45	44	44	44	44
4	44	43	44	43	45	44
9	39	42	43	43	45	43
15	44	44	45	37	45	44
30	43	45	45	41	45	46
60	45	45	46	38	46	45

¹ Rockwell C values are approximate equivalent conversions from Rockwell 45 N.

² Periphery

³ Mid-radius

⁴ Center

Table 5. Tensile Properties of Fully Heat Treated Type 431 Test Material Subjected to Intervening Quench Delays. Results from Longitudinal Test Specimens Heat Treated and then Ground to Finished Dimensions Before Testing.
(Average of 4 Specimens)

Quench Delay, Sec.	0.2% Yield Strength, Ksi	Ultimate Tensile Strength, Ksi	Elongation in 1 Inch, Percent	Reduction of Area, Percent
1	143.25	203.25	17.7	52.7
9	142.75	204.25	18.1	55.3
15	144.50	204.75	18.3	58.3
30	142.50	204.25	18.3	59.3
60	139.50	202.75	19.1	59.0

Table 6. Charpy V-Notch Properties of Fully Heat Treated Type 431 Test Material Subjected to Intervening Quench Delays. Results from Longitudinal Test Specimens Heat Treated and Then Ground to Finished Dimensions Before Testing (Average of 2 Specimens)

Quench Delay, Sec.	Charpy V-Notch, Ft.lbs	
	Room Temperature	- 40° F
1	46.7	28.3
9	46.5	29.3
15	47.3	29.0
30	49.0	26.5
60	49.3	25.3

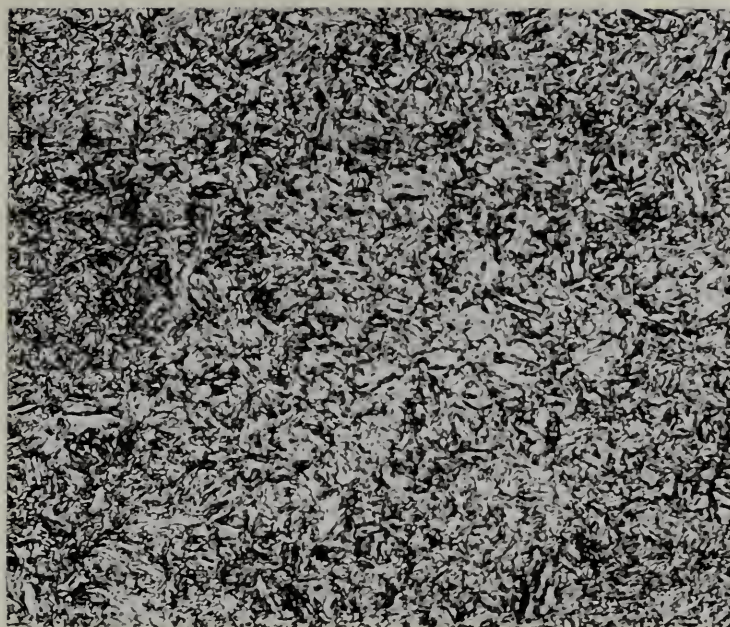


Longitudinal

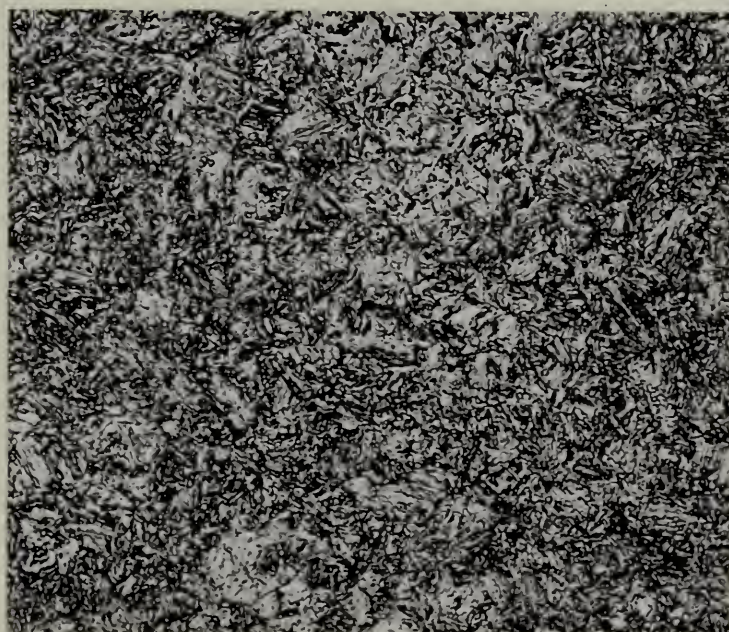


Transverse

Figure 1. Inclusion content of the test steel.
Unetched. X 500



Longitudinal

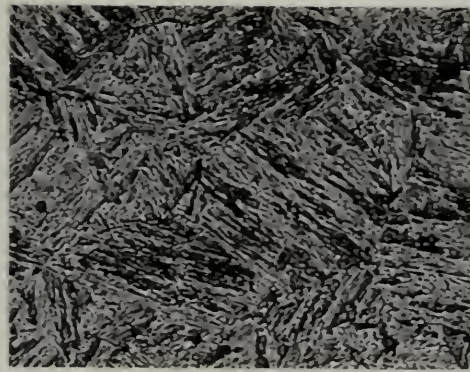
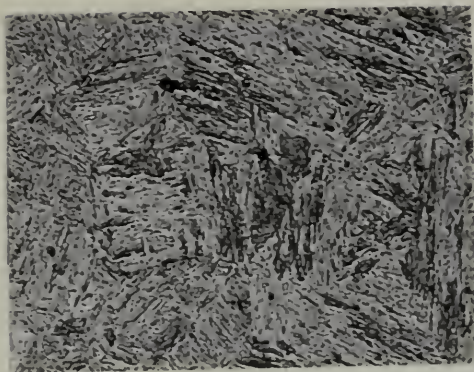


Transverse

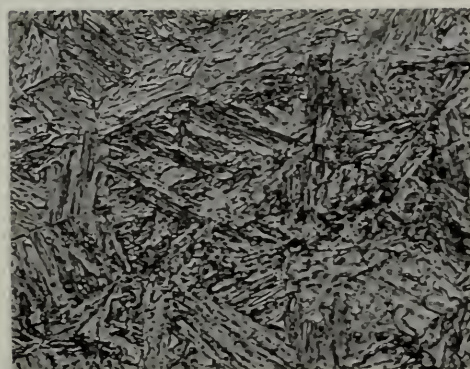
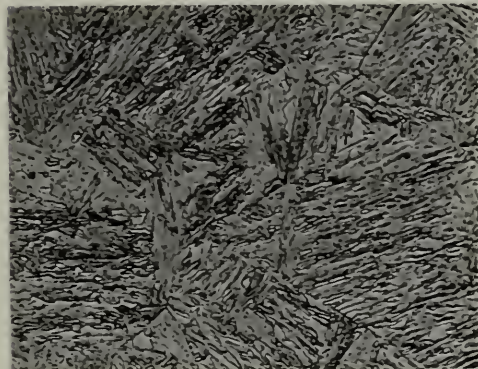
Figure 2. Microstructure of the test steel in the as-received annealed condition. Structure consists of ferrite, decomposition products of austenite and some austenite. Etched with Vilella's reagent. X 500

Longitudinal

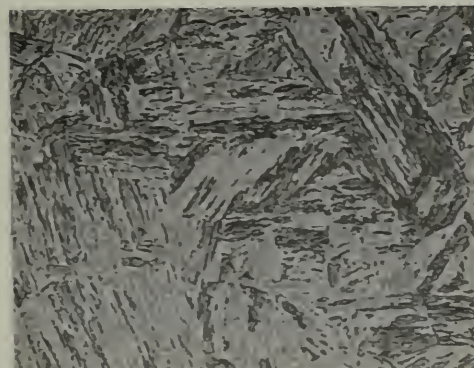
Transverse



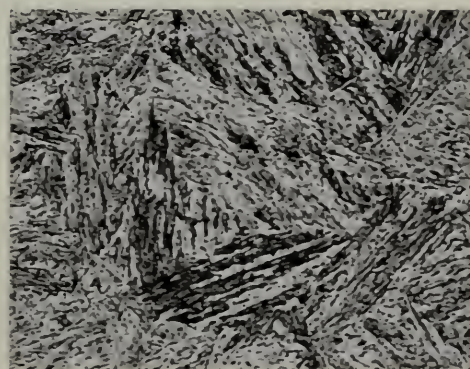
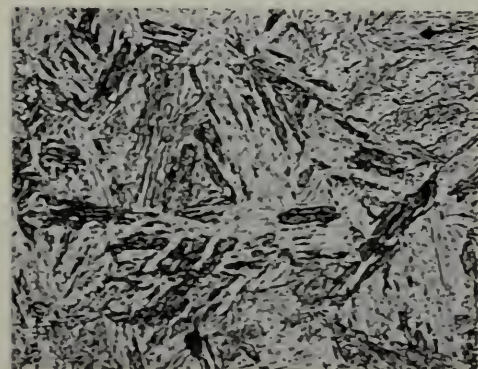
Air Hardened, Air Quenched, Refrigerated, Tempered



Air Hardened, Air Quenched, Tempered



Air Hardened, Oil Quenched, Refrigerated, Tempered



Air Hardened, Oil Quenched, Tempered

Figure 5. Microstructures of the test steel diversely heat treated to obtain a tensile strength of 200 Ksi. Etched with Vilella's reagent. X 500

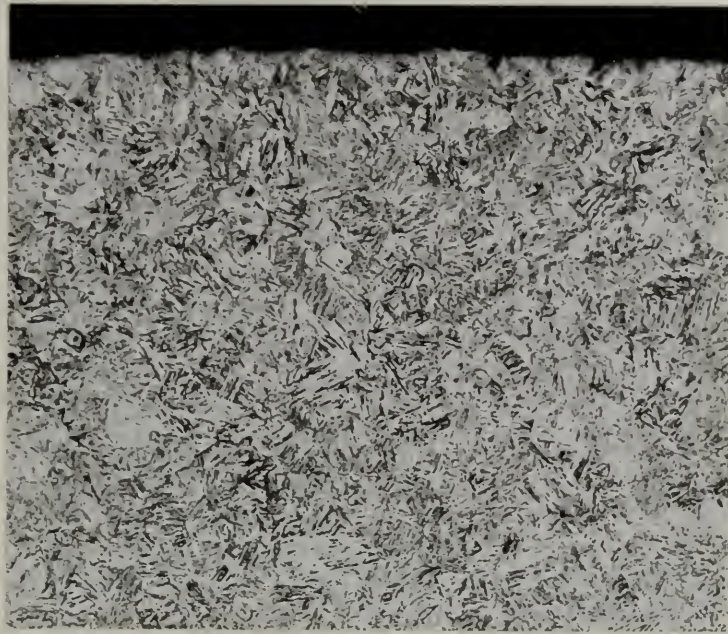


Air, Dew Point -30°F



Air, Dew Point 70°F

Figure 6. Microstructures adjacent to surface of test steel hardened from air, dew points -30°F and 70°F . Transverse sections. Etched with Vilella's reagent. X 100



Argon, Dew Point -76° F



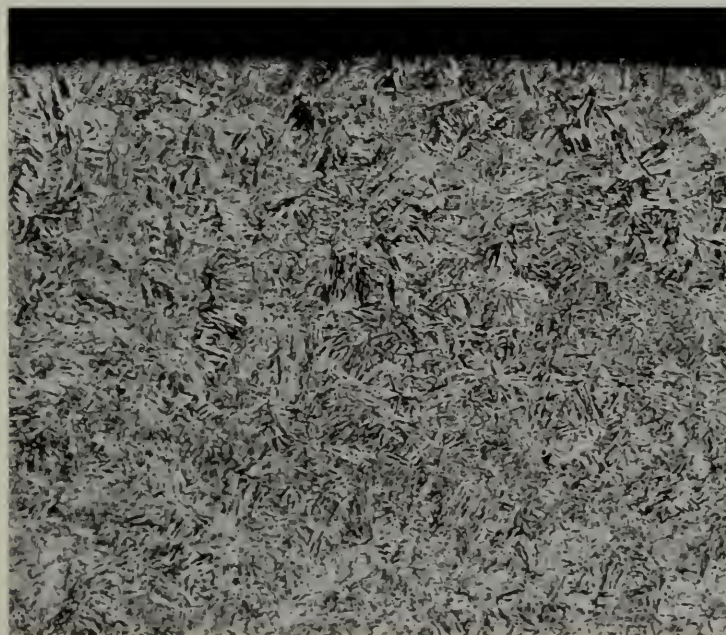
Argon, Dew Point -38° F

Figure 7. Microstructures adjacent to surface of test steel hardened from argon, dew points -76° F and -38° F Transverse sections. Etched with Vilella's reagent. X 100



0.0001"
Apparent case

Dissociated Ammonia, Dew Point -59° F



Dissociated Ammonia, Dew Point 24° F

Figure 8. Microstructures adjacent to surface of test steel hardened from dissociated ammonia, dew points -59° F and 24° F. Transverse sections. Etched with Vilella's reagent. X 100



0.0125"

Apparent case



Endothermic Atmosphere, Dew Point 13° F



Endothermic Atmosphere, Dew Point 72° F

Figure 9. Microstructures adjacent to surface of test steel hardened from endothermic atmosphere, dew points 13° F and 72° F. Transverse sections. Etched with Vilella's reagent. X 100

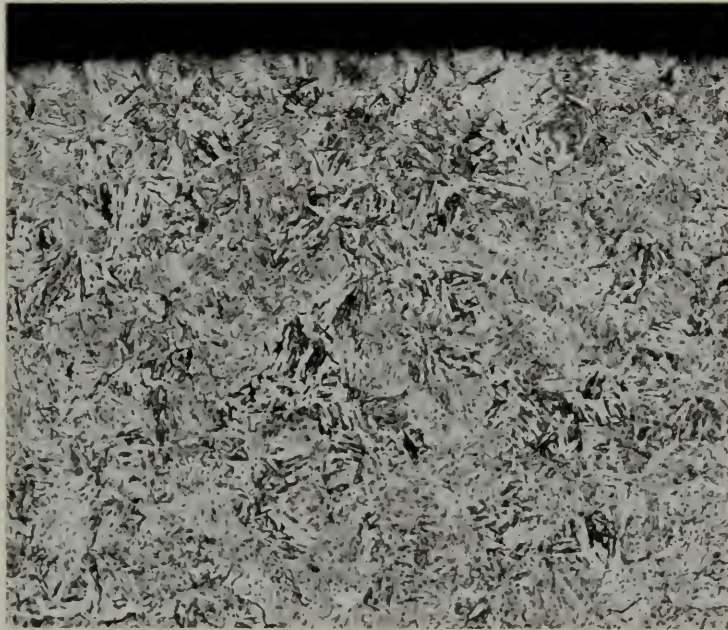


Figure 10. Microstructure adjacent to surface of test steel hardened from exothermic atmosphere, dew point 100° F. Transverse section. Etched with Vilella's reagent. X 100



0.01"

Apparent case



Hydrogen, Dew Point -87°F



0.0025"

Apparent case

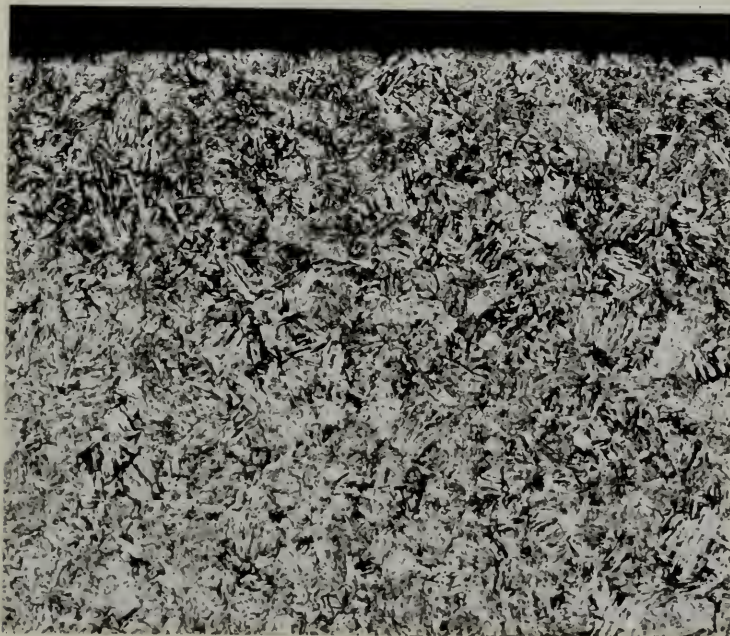


Hydrogen, Dew Point -17°F

Figure 11. Microstructures adjacent to surface of test steel hardened from hydrogen, dew points -87°F and -17°F . Transverse sections. Etched with Vilella's reagent. X 100



Nitrogen, Dew Point -80°F



Nitrogen, Dew Point -18°F

Figure 12. Microstructures adjacent to surface of test steel hardened from nitrogen, dew points -80°F and -18°F . Transverse sections. Etched with Vilella's reagent. X 100



0.0003"
Apparent case

Figure 13. Microstructure adjacent to surface of test steel hardened from vacuum. Transverse section. Etched with Vilella's reagent. X 100

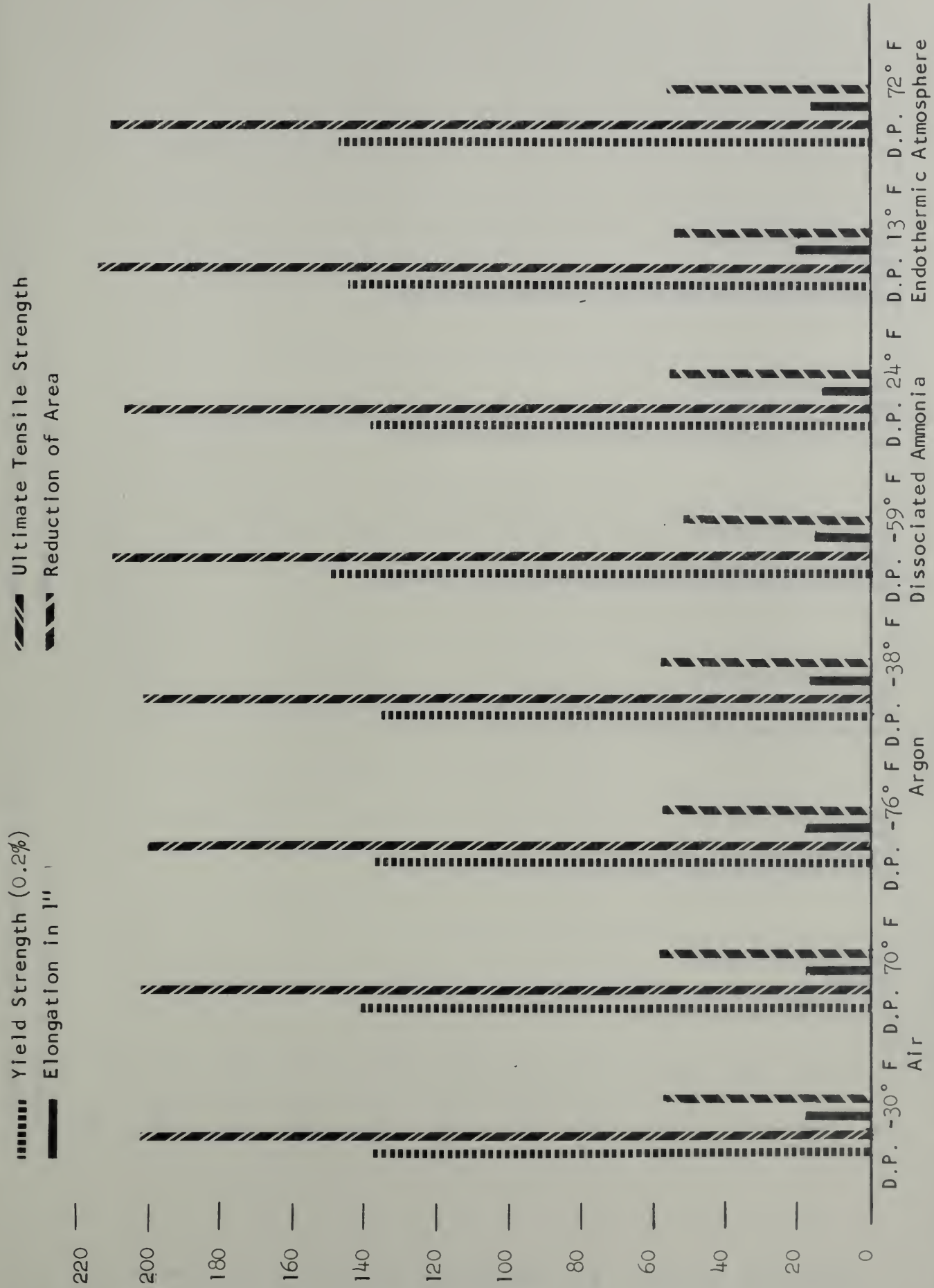


Figure 14. Mechanical properties of type 431 steel finish machined and austenitized in various media. Stress relieved 1/2 hr at 1200° F, austenitized - 30 min. at 1900° F, oil quenched, double tempered 2 hours at 550° F.

1. The first part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

2. The second part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

3. The third part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

4. The fourth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

5. The fifth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

6. The sixth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

7. The seventh part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

8. The eighth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

9. The ninth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

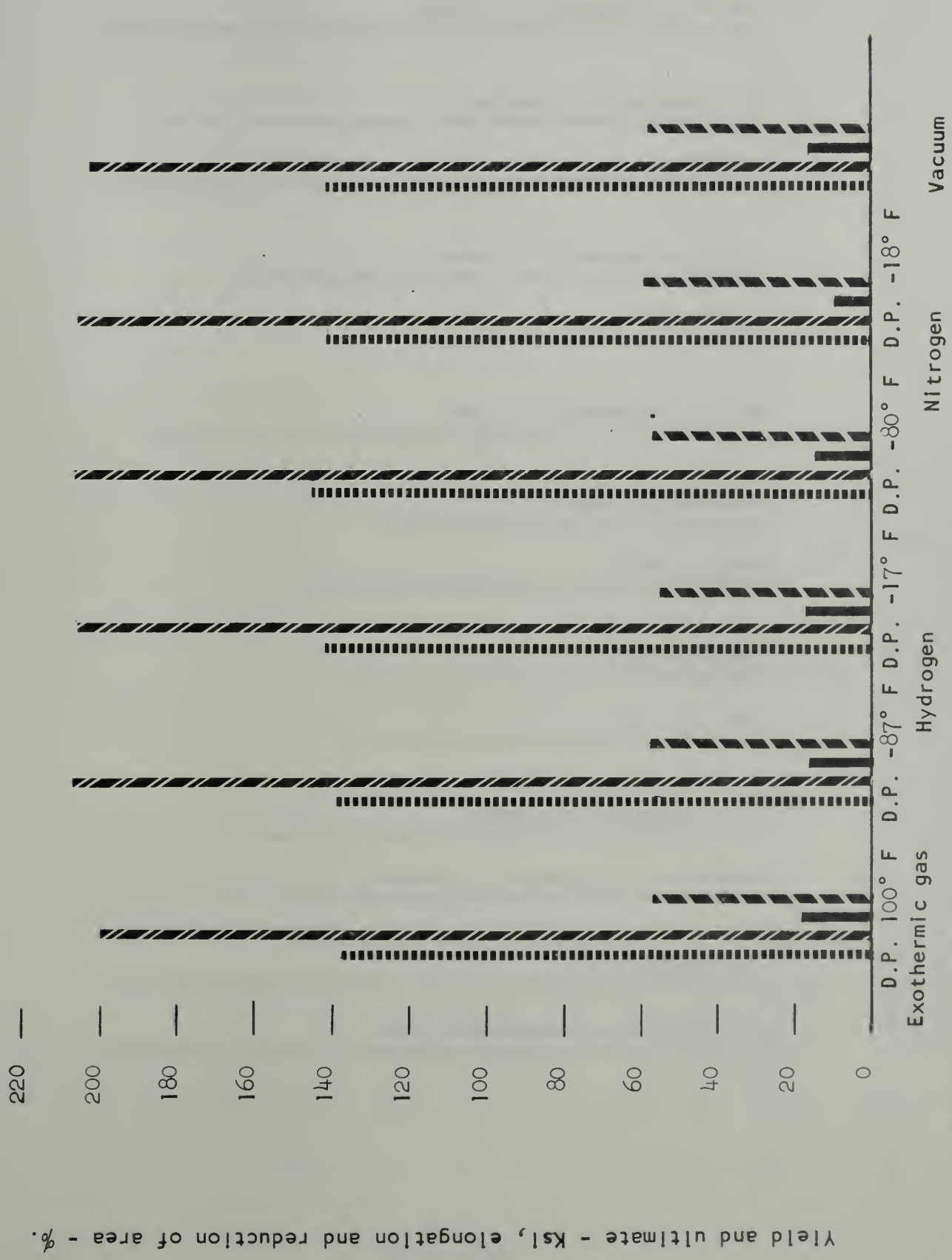


Figure 15. Mechanical properties of type 431 steel finish machined and austenitized in various media. Stress relieved 1/2 hr at 1200° F, austenitized - 30 min. at 1900° F, oil quenched, double tempered 2 hours at 550° F.

1. The first part of the document is a list of the names of the persons who have been appointed to the various offices of the corporation.

2. The second part of the document is a list of the names of the persons who have been appointed to the various offices of the corporation.

3. The third part of the document is a list of the names of the persons who have been appointed to the various offices of the corporation.

4. The fourth part of the document is a list of the names of the persons who have been appointed to the various offices of the corporation.

5. The fifth part of the document is a list of the names of the persons who have been appointed to the various offices of the corporation.

6. The sixth part of the document is a list of the names of the persons who have been appointed to the various offices of the corporation.

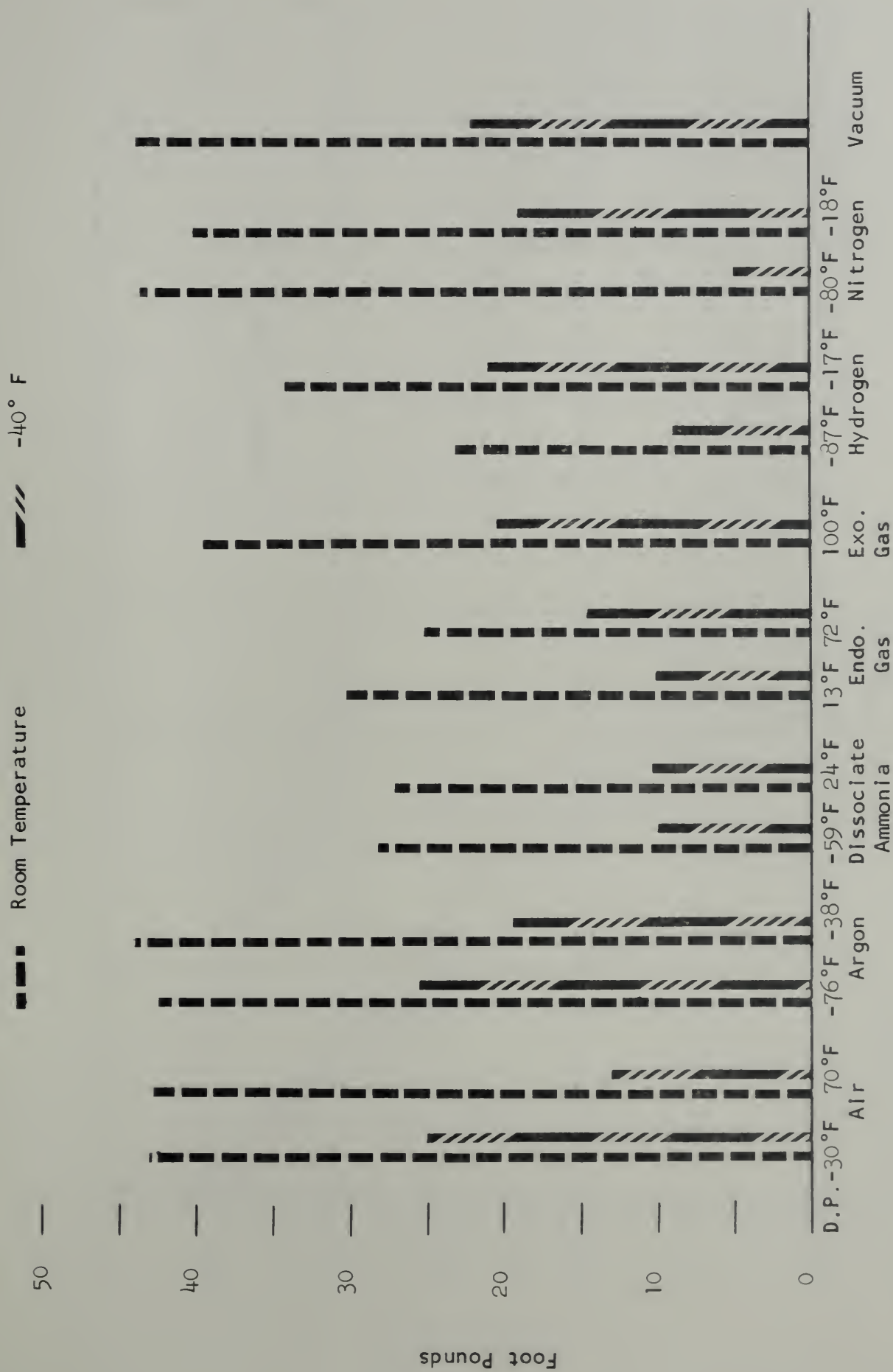


Figure 16. Charpy V-notch impact properties of type 431 steel finish machined and austenitized in various media. Stress relieved 1/2 hr at 1200° F, austenitized 30 min. at 1900° F, oil quenched, double tempered 2 hours at 550° F.

THE UNIVERSITY OF CHICAGO

DEPARTMENT OF THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

THE HISTORY OF ARTS

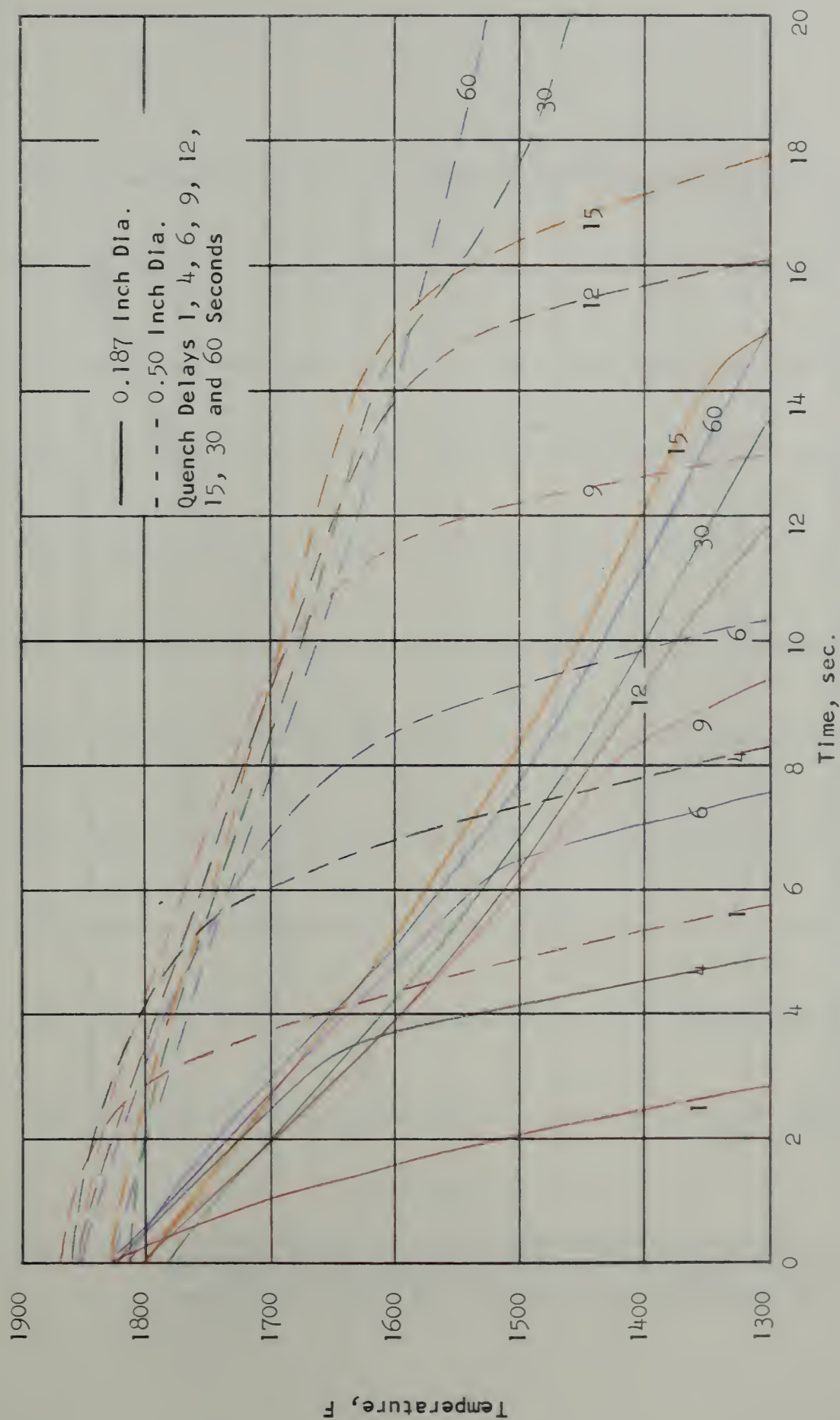
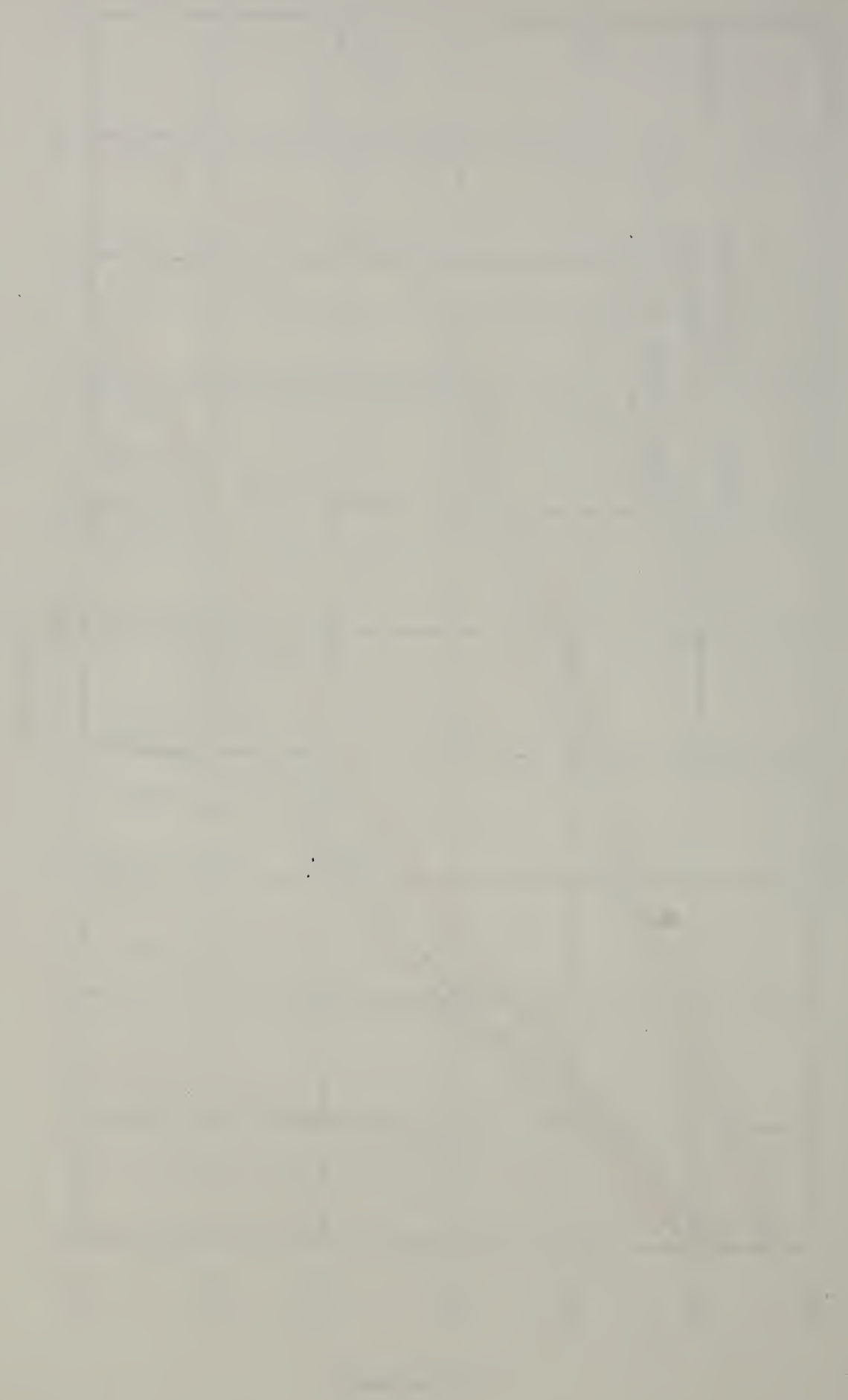


Figure 17. Characteristics of 0.187 inch and 0.050 inch diameter type 431 stainless steel specimens cooling from austenitizing temperature (1900° F), with intervening quench delays, to 1300° F.



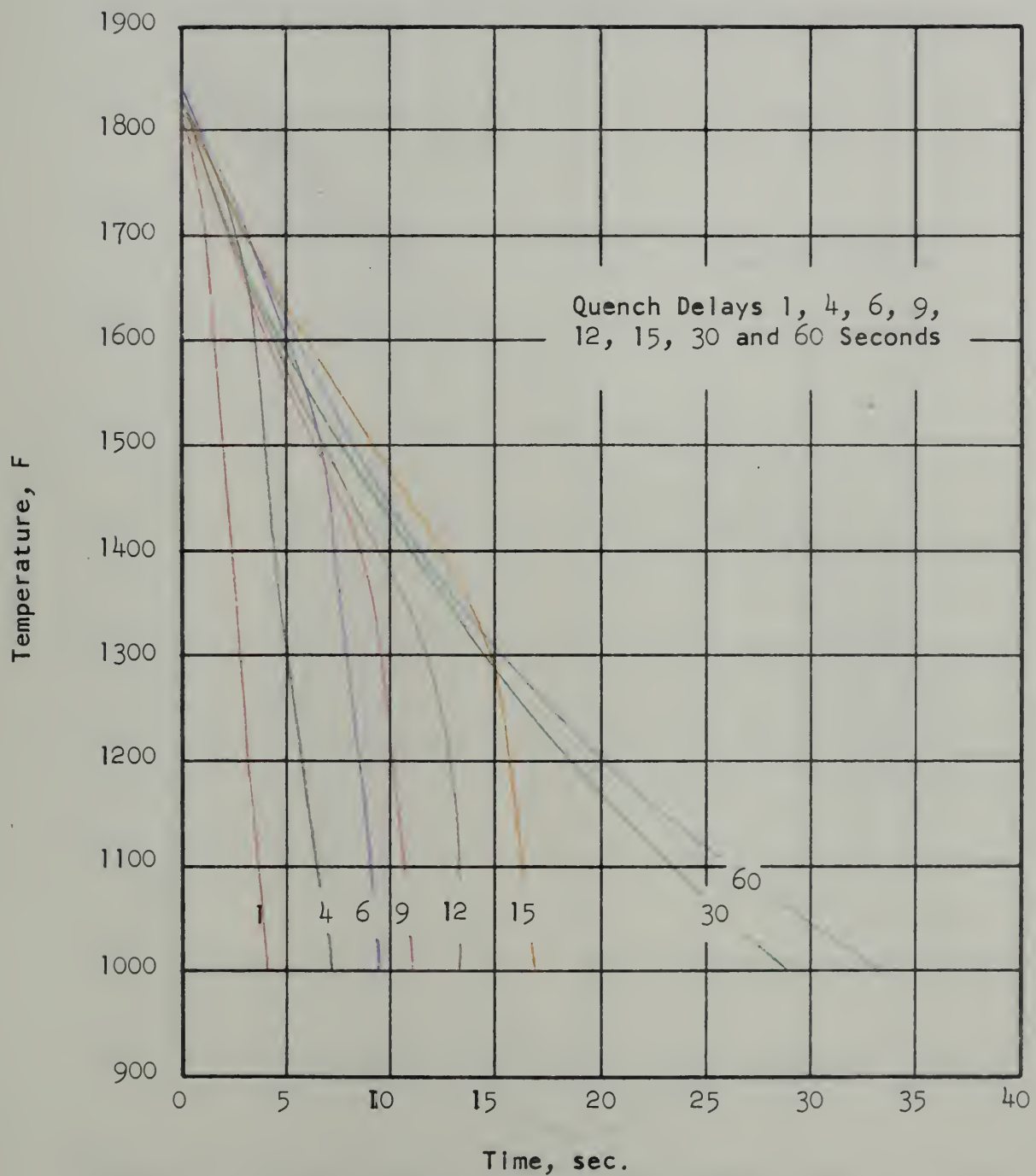


Figure 18. Characteristics of 0.187 inch diameter type 431 stainless steel specimens cooling from austenitizing temperature (1900° F), with intervening delays, to 1000° F.

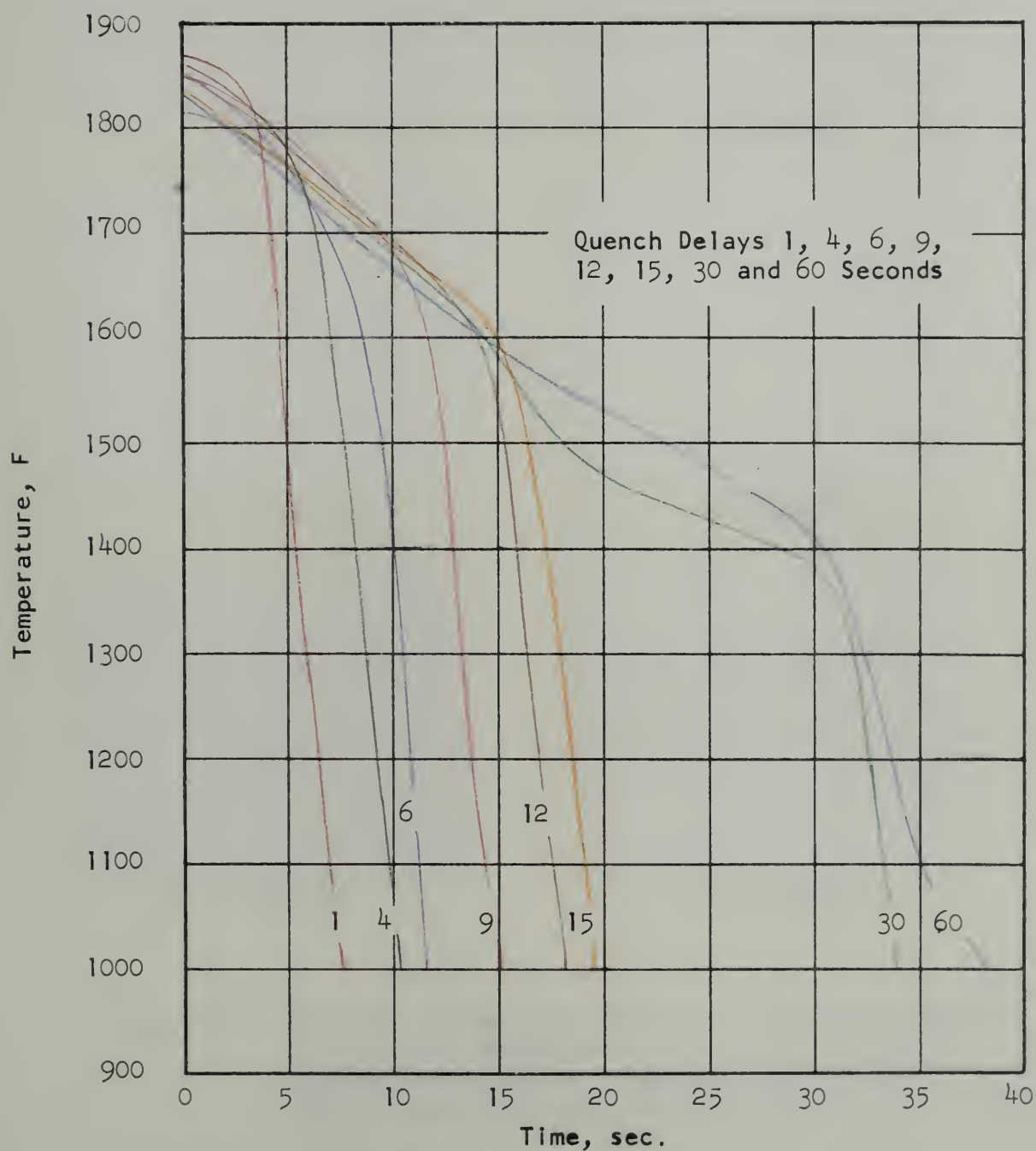
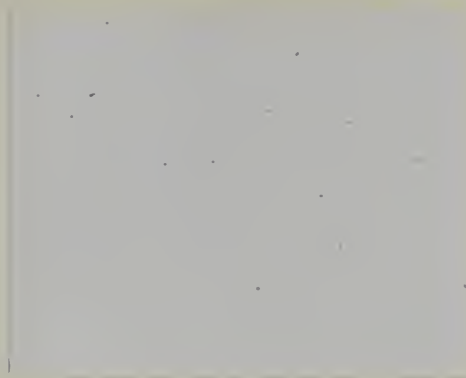
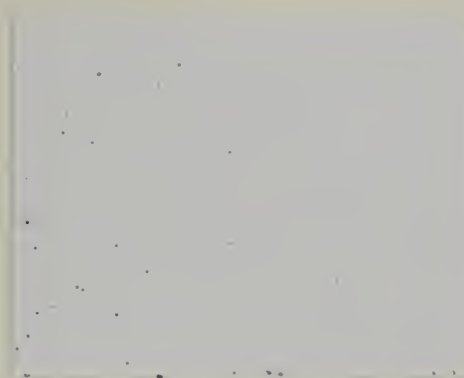


Figure 19. Characteristics of 0.50 inch diameter type 431 stainless steel specimens cooling from austenitizing temperature (1900° F), with intervening delays, to 1000° F.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489	1490	1491	1492	1493	1494	1495	1
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	---



1 second



4 seconds



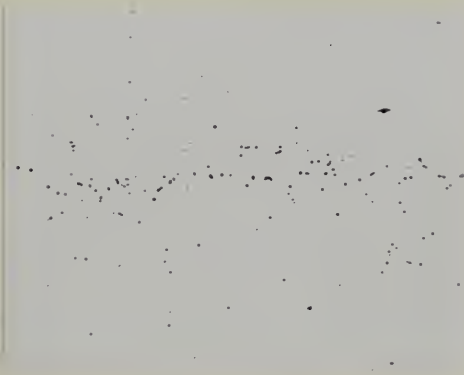
9 seconds



12 seconds



30 seconds

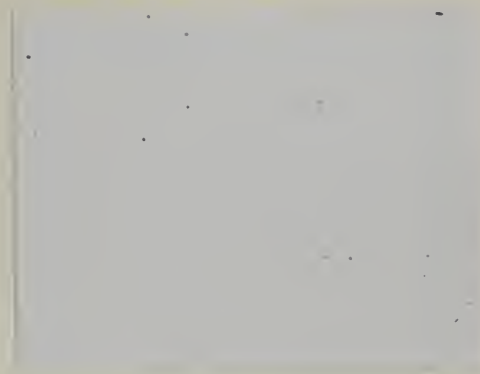


60 seconds

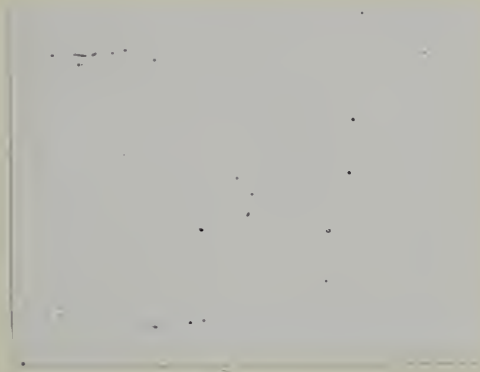
Figure 20. Carbides in the test steel; air hardened, quenched in oil after delays of 1, 4, 9, 12, 30 and 60 seconds and tempered. Section diameter 0.187 inch. Etched electrolytically with sodium cyanide. X 500



1 second



4 seconds



9 seconds



12 seconds



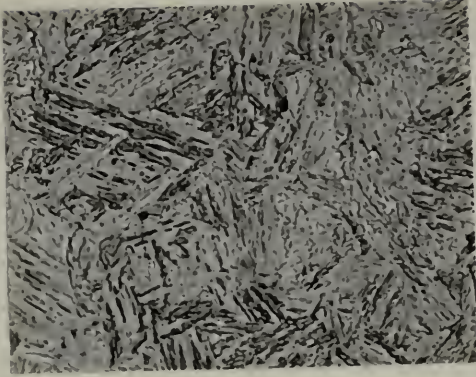
30 seconds



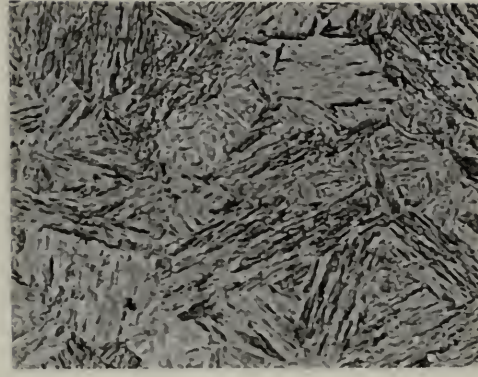
60 seconds

Figure 21. Carbides in the test steel; air hardened, quenched in oil after delays of 1, 4, 9, 12, 30 and 60 seconds and tempered. Section diameter 0.50 inch. Etched electrolytically with sodium cyanide.
X 500

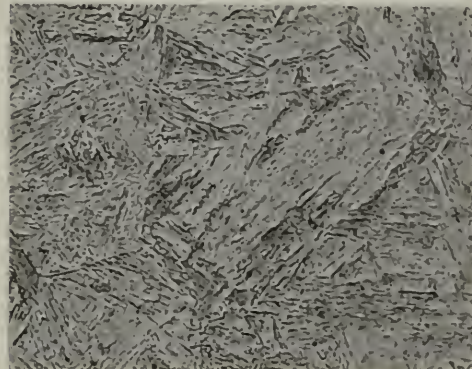
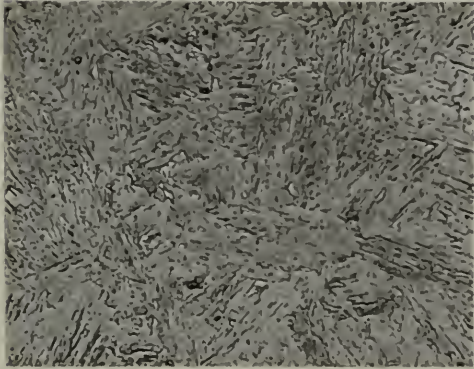
Longitudinal



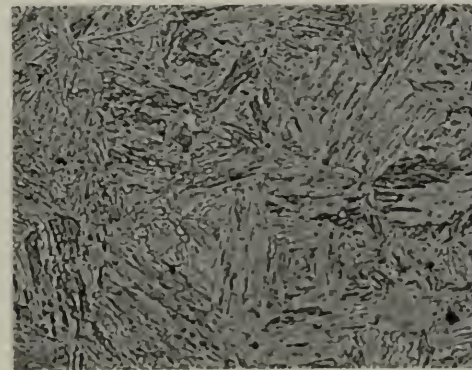
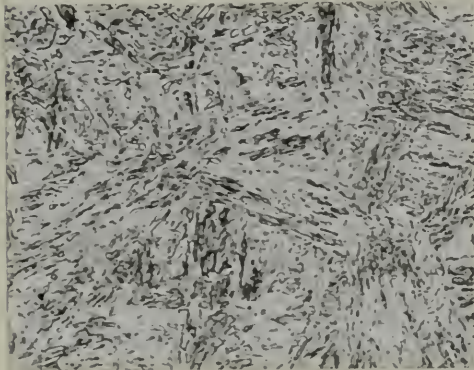
Transverse



1 Second Delay



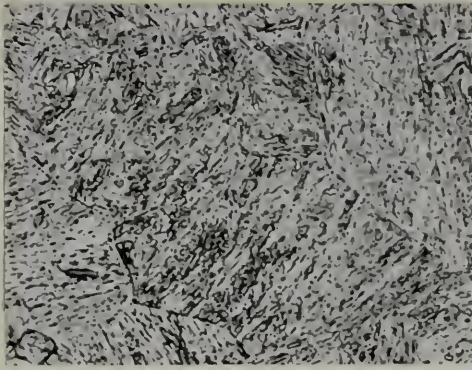
4 Second Delay



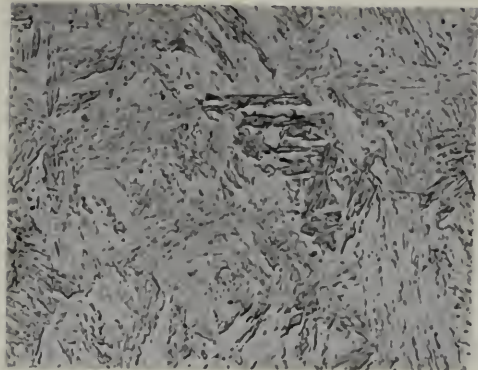
9 Second Delay

Figure 22. Microstructures of the test steel; air hardened, quenched in oil after delays of 1, 4 and 9 seconds and tempered. Section diameter 0.50 inch. Etched with Vilella's reagent. X 500

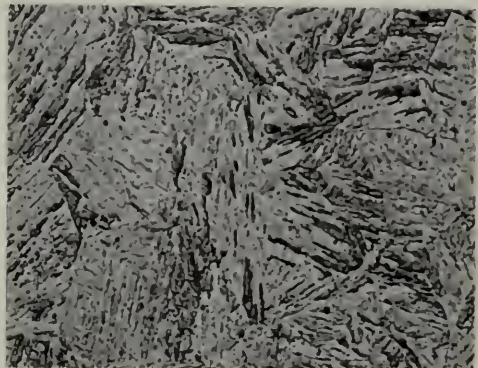
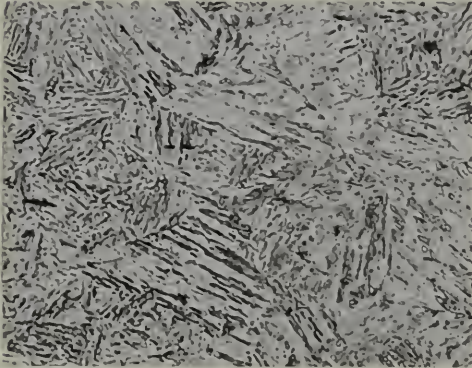
Longitudinal



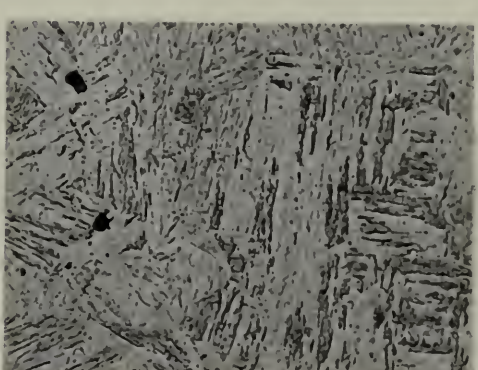
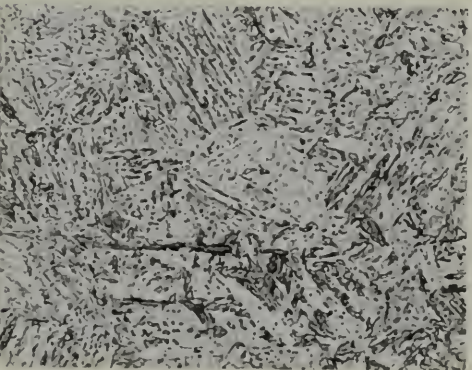
Transverse



12 Second Delay



30 Second Delay



60 Second Delay

Figure 23. Microstructures of the test steel; air hardened, quenched in oil after delays of 12, 30 and 60 seconds and tempered. Section diameter 0.50 inch. Etched with Vilella's reagent. X 500

