WATERTOWN ARSENAL LABORATORIES

Monograph Series

NUMBER 27

MICROSTRUCTURE of URANIUM STEELS

VACUUM MELTED URANIUM STEEL INGOT

by

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APRIL 1961

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ABSTRACT

Metallographic studies were conducted on small vacuum-melted steel ingots made from a 0.59% carbon ingot iron base to which uranium was added in the range of 1.33% to 2.37%. It was determined that uranium in excess of 1.33% resulted in an iron-uranium complex carbide segregation which persisted in the structure after austenitizing at 1500°F. An increase of uranium in the range studied failed to increase the hardenss of the annealed steels but produced a noticeable increase in hardness of the quenched series. Traces of fine peralite were present in some of the quenched uranium steels. An increase in carbon content of these steels may have contributed to the increase in hardness.

The mechanical properties of these high uranium steels would be impaired by the presence of these iron-uranium complex carbides in the grain boundaries.

INTRODUCTION

In connection with a thesis on "The Influence of Special Elements on the Carbon Content of the Euctectoid" prepared in 1930 at the Harvard University Engineering School by the author of this Monograph, recent studies were made of the microstructure and hardness of vacuum-melted iron-carbon alloys containing uranium.

MATERIALS

Base Metals

An ingot-iron base, containing 0.59 percent carbon, was used as melting stock. A container and screw cap, shown in Figure 1, was made of this iron-carbon alloy and weighed about 75 grams. The container was washed with ether after machining, to eliminate oil and grease, and weighed. The calculated amount of uranium metal was placed into the chamber shown in Figure 1 and sealed securely by screwing the cap tightly in place.

The chemical composition of the metals used in the melt was:

Metal	C	Mn	Si	S	F
Iron base	0.59	0.079	0.02	0.029	0.005
Uranium		purity 90.30%			

Melting Practice

Oxidation of the melts was prevented by melting in vacuum. Pronounced segregation of uranium was prevented by double melting.

An Arsen vacuum-melting furnace, capable of melting 70 to 100 grams of metal, was used for melting the alloys. The melt which was made in alumina crucibles was held at 2200°F for 10 minutes and cooled to black heat in 30 minutes. A typical vacuum melt is shown in Figure 2. This ingot was double melted by inverting the ingot after the first melt and remelting.

Preparation of Ingot for Study

The ingot was sectioned longitudinally, resulting in two sections of about the same weight. One section was examined in the as-cast condition while the other was annealed by packing it in cast iron chips heated to 1800°F, holding at this temperature for 1 hour and cooling to 122°F during a period of 60 hours.

TESTS AND RESULTS

Chemical Composition

The carbon-uranium composition of the heats are shown in Table I.

TABLE I

Chemical Composition

Heat	Carbon, Percent	Uranium Percent
435	0.52	-
527	0.48	1.30
531	0.56	1.77
568	0.69	2.36
513	0.74	2.37

Metallographic Examination

A. Cast and Annealed

Melt 435 (0.52% carbon, no uranium)

The central portions of the as-cast ingot sections and the central portions of the annealed ingot sections were examined. Figures 3A and 3B illustrate typical structures of a straight 0.52% carbon cast steel. After annealing, the cast structure of the casting has been refined, see Figure 3C. Figure 3D illustrates typical ferrite - fine pearlite structures resulting from annealing. Etching in boiling sodium picrate* shows that the cementite in the pearlite is darkened, see Figure 3E.

Melt 527 (0.48% carbon, 1.30% uranium)

Figures 4A and 4B illustrate typical structures of cast medium-carbon steels. No evidence of iron-uranium complex carbide was noted in these structures. After annealing, a medium coarse grain resulted, see Figure 4C. Under higher power, no iron-uranium complex carbide uranium was present in the grain boundaries, see Figure 4D.

**Sodium picrate (Kourbatoff's Reagent) - 2 g picric acid, 98 ml of 25% NaOH in water, used boiling 5 to 10 minutes. Etching in boiling sodium picrate darkens cementite and other types of carbides; ferrite is unattacked.*

After etching in picral or in boiling sodium picrate, see Figure 4E, only the cementite in the pearlite is blackened.

Melt 531 (0.56% carbon, 1.77% uranium)

This alloy, as-cast, has a coarse structure, Figure 5A. Under high power, evidence of iron-uranium complex carbide appears in the ferrite grain boundaries, Figure 5B. A medium-coarse grain is evident after annealing, Figure 5C, and under high power some iron-uranium complex carbide is evident in the structure, Figure 5D.

Melt 568 (0.69% carbon, 2.36% uranium)

The structure of this alloy consists of a cast structure with a large network of iron-uranium complex carbide present, see Figures 6A and 6B. After annealing, the iron-uranium complex carbide network is intensified, see Figures 6C and 6D.

Melt 513 (0.74% carbon, 2.37% uranium)

A pronounced iron-uranium complex carbide network was evident in the coarse as-cast structure, see Figures 7A and 7B. After annealing, this carbide network is quite pronounced, see Figures 7C and 7D. After etching in boiling sodium picrate, the carbide network is blackened as shown in Figures 7E and 7F. It is noted that this heavy carbide network does not always follow the austenitic grain boundaries, as shown by Figure 7E. The heavy carbide network passes through fine lamellar pearlite of the same orientation, see Figure 7F. The fine cementite plates of the pearlite are darkened by the sodium picrate etch.

B. Heat Treated Samples

In order to determine if the excessive carbide present in the annealed sections, containing 1.77%, 2.36% uranium, would be dissolved at an austenitizing temperature of 1500°F, the annealed sections of each ingot were heated 30 minutes at 1500°F followed by quenching in warm water and not tempered. The results were as follows:

Melt 435

Figure 8A illustrates a typical martensitic structure present.

Melt 527

A martensitic structure containing considerable fine pearlite with no excess carbide was present, see Figure 8B.

Melt 531

Grain boundary iron-uranium complex carbide was present in a martensitic matrix containing a small amount of fine pearlite, see Figure 8C.

Melt 568

Heavy grain boundary iron-uranium complex carbide was evident in a martensitic matrix. An occasional resemblence of a eutectic structure was observed in the carbide segregation, see Figure 8D.

Melt 513

A pronounced iron-uranium complex grain boundary network was present in a martensitic matrix containing a small amount of fine pearlite, see Figure 8E.

Brinell Hardness

Brinell hardness determinations were made on sections of the as-cast ingots, annealed ingots, and quenched ingots. The results are given in Table II.

TABLE II

Brinell Hardness

Melt	%C	%U	As-Cast	Annealed	Quenched
435	0.52	-	163	149	590*
527	0.48	1.30	192	134	538*
531	0.56	1.77	197	143	640*
568	0.69	2.36	152	149	668*
513	0.74	2.37	241	170	682*

*Brinell hardness values (converted from Rockwell C hardness determinations) were determined on the annealed samples after austenitizing at 1500°F for 30 minutes and quenching in warm water.

The additions of uranium in the range of 1.30% to 2.37% to the medium carbon steel did not increase the hardness appreciably in the annealed condition. The relatively high carbon content in Melt 513 may contribute to the increase in hardness in this particular annealed steel.

It was noted that the addition of 1.33% uranium to medium carbon quenched steel did not increase its hardness. In fact, there was a slight decrease in hardness reported. This may have been due to the presence of considerable fine pearlite in the structure, see Figure 8B. Increasing the uranium content within the range of 1.77% to 2.36%, an increase of some 50 to 78 points Brinell was obtained over the plain medium carbon quenched steel. The increase in carbon content of the steels shown in Table I may be a contributing factor in increasing the hardness of these quenched steels.

DISCUSSION

Uranium, which is a carbide former, belongs to the same group as tungsten, chromium and molybdenum. In this investigation, additions of uranium in excess of 1.33% to a medium carbon steel base produced a iron-uranium complex carbide which was located in most cases in the grain boundaries. In several cases these carbide membranes passed through the grains. An alloy steel containing 0.48% carbon and 1.33% uranium contained no excessive carbide segregation.

No marked increase in hardness was obtained by an increase in uranium from 1.33% to 2.37% in the annealed series. In the quenched steels, the effect of an increase in uranium and the combined effect of an increase in carbon content resulted in a substantical increase in hardness. The presence of these complex carbides, which were not dissolved during an austenitizing treatment at 1500°F before quenching, may have contributed to this increase in hardness.

Several of the high uranium steels contained small areas of fine pearlite.

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SUMMARY

It is doubtful if the high uranium medium carbon steels, in excess of 1.33% uranium, would be of value in industry since the mechanical properties would be diminished by the presence of the complex uranium carbide in the grain boundaries.

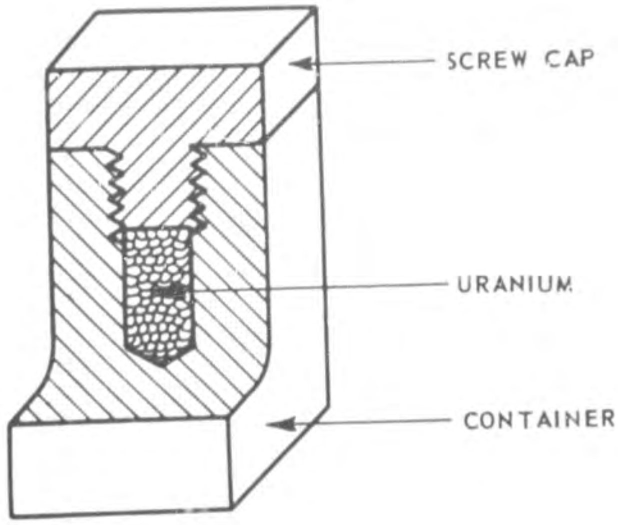


Figure 1

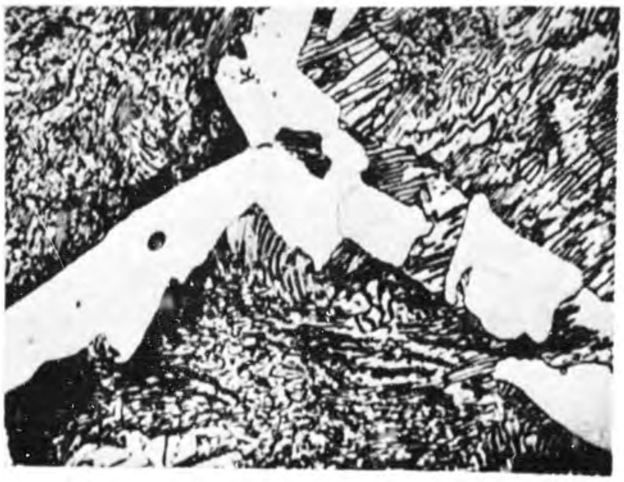
Cross Section of Metal Container in which Uranium was Sealed for Melting

Figure 2

Typical Vacuum Melted Ingot

Melt No. 435 - 0.52% Carbon. No Uranium

Etch; Picral-HCl Figure 3A X100
As Cast - Medium Coarse Grain
Ferrite & Pearlite



Etch; Picral-HCl Figure 3B As Cast X1000
Ferrite & Very Fine Lamellar
Pearlite

Etch; Icral-HCl Figure 3C X100
Annealed - Fine Grain - Ferrite &
Pearlite

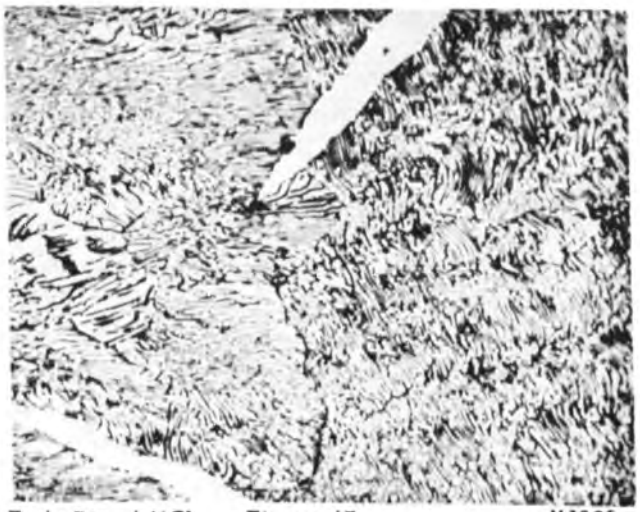
Etch; Picral-HCl Figure 3D X1000
Annealed - Ferrite & Fine Lamellar
Pearlite

Figure 3E Annealed X1000
Etch; Boiling Sodium Picrate
Cementite in Pearlite Etched Black

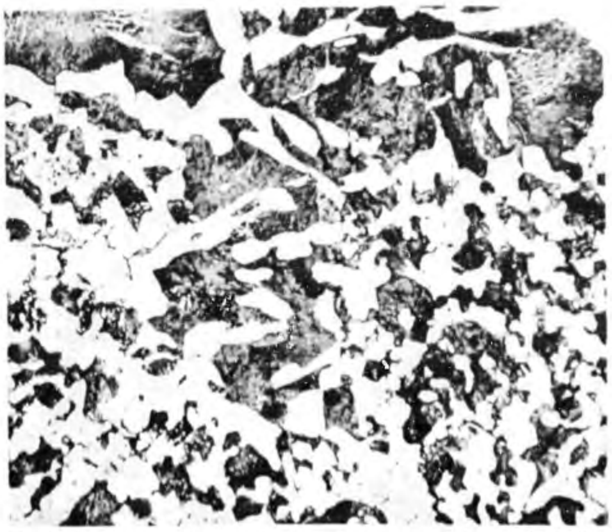
Figures 3A, B, C, D, E

Microstructure
Melt No. 527 - 0.48% Carbon 1.30% Uranium

Etch; Picral-HCl   Figure 4A   X 100
As Cast - Coarse Grain
Ferrite & Pearlite



Etch; Picral-HCl   Figure 4B   X 1000
As Cast
Ferrite & Very Fine Lamellar Pearlite



Etch; Picral-HCl   Figure 4C   Annealed X 100
Medium Coarse Grain
Ferrite & Pearlite

Etch; Picral-HCL   Figure 4D   Annealed X 1000
Ferrite & Fine Lamellar Pearlite

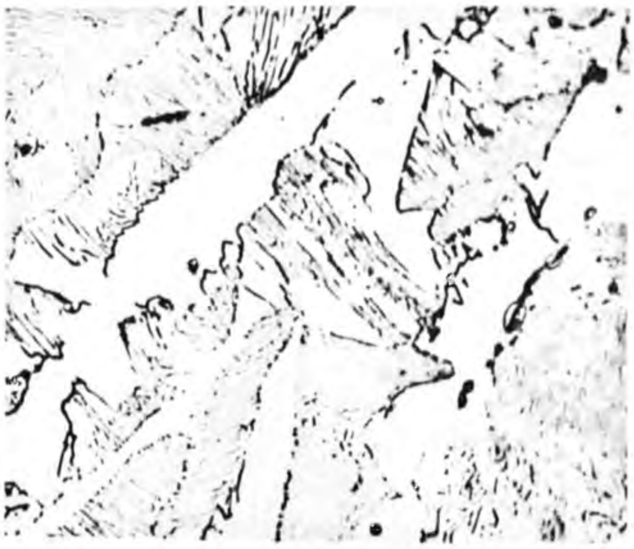


Figure 4E   Annealed X 1000
Etch; Boiling Sodium Picrate
Cementite in Pearlite
Etched Dark

Figures 4A, B, C, D, E

Microstructure

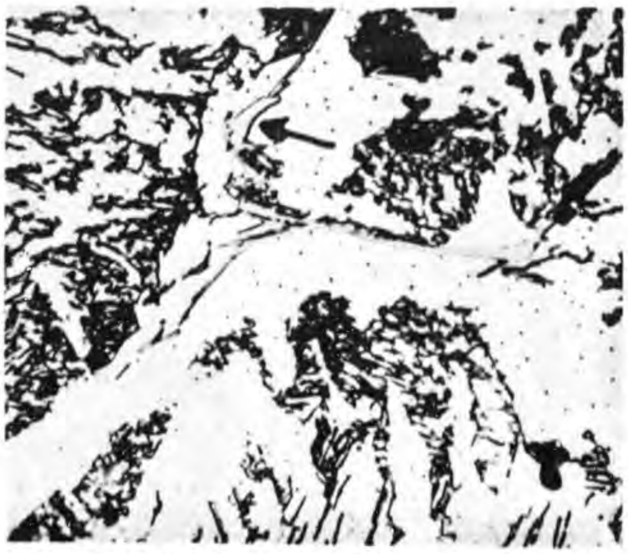
Melt No. 531 - 0.56% Carbon, 1.77% Uranium

Etch; Picral HCl Figure 5A X100

As Cast

Coarse Grain

Ferrite & Pearlite



Etch; Picral HCl Figure 5B X1000

As Cast

Iron - Uranium Complex Carbide

in Ferrite, (Arrow) very fine

Pearlite

Etch; Picral HCl Figure 5C Annealed X100

Medium Coarse Grain

Ferrite & Pearlite

Etch; Picral HCl Figure 5D Annealed X1000

Iron - Uranium Complex Carbide

in Ferrite - Pearlite Matrix

(Arrow)

Figures 5A, B, C, D

Microstructure
Melt No. 568 - 0.69% Carbon, 2.36% Uranium

Etch; Picral HCl Figure 6A X100

As Cast

Iron - Uranium Complex Carbide

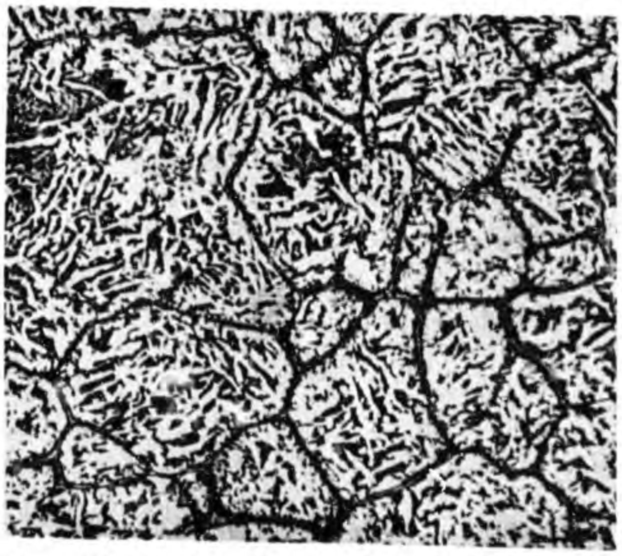
in Ferrite Pearlite Matrix

Etch; Picral HCl Figure 6B X1000

As Cast

Iron - Uranium Complex Carbide

in Ferrite Pearlite Matrix

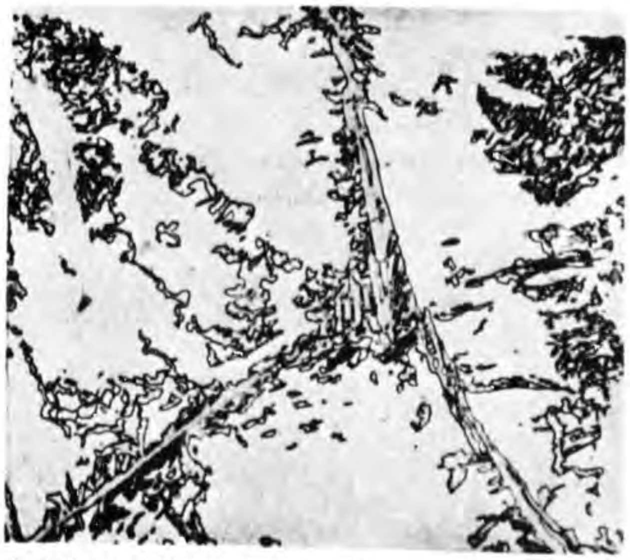


Etch; Picral HCl Figure 6C X100

Annealed

Iron - Uranium Complex Carbide

in Ferrite Pearlite Matrix



Etch; Picral HCl Figure 6D X1000

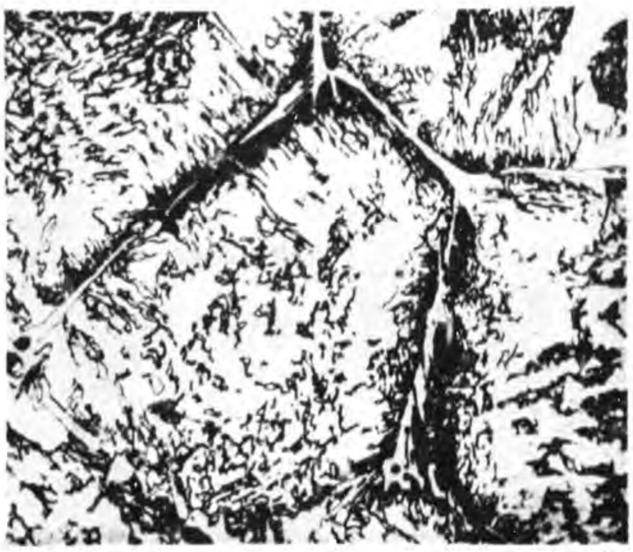
Annealed

Iron - Uranium Complex Carbide

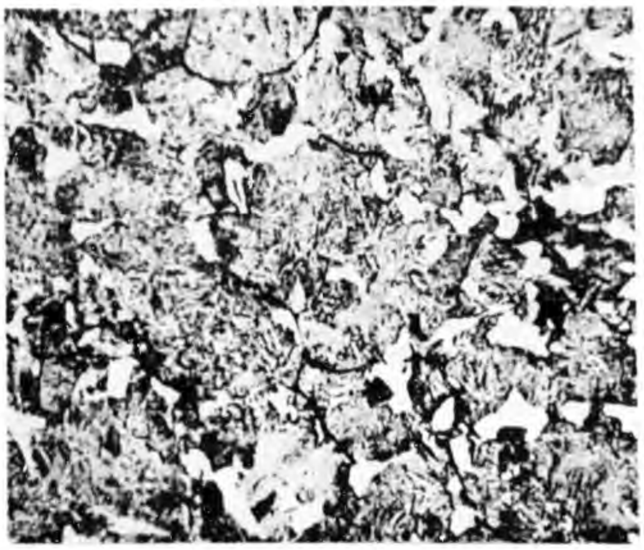
in Ferrite Pearlite Matrix

Microstructure
Melt No. 513 - 0.74% Carbon, 2.37% Uranium

Etch; Picral HCl Figure 7A As Cast X100
Iron - Uranium Complex Carbide
in Ferrite - Pearlite Matrix



Etch; Picral-HCl Figure 7B As Cast X1000
Iron - Uranium Complex Carbide
in Ferrite - Pearlite Matrix



Etch; Picral-HCl Figure 7C Annealed X100
Iron - Uranium Complex Carbide
in Ferrite-Pearlite Matrix

Etch; Picral-HCl Figure 7D Annealed X1000
Iron - Uranium Complex Carbide
in Ferrite-Pearlite Matrix

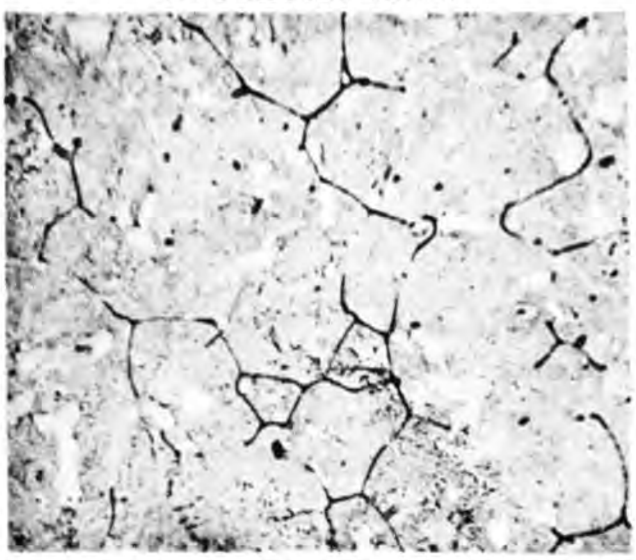


Figure 7E Annealed X100
Etch; Boiling Sodium Picrate
Iron-Uranium Complex Carbide
Etched Black

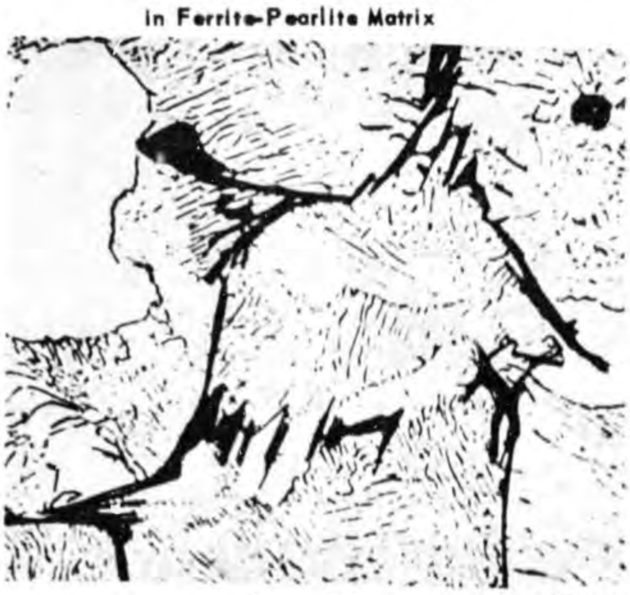
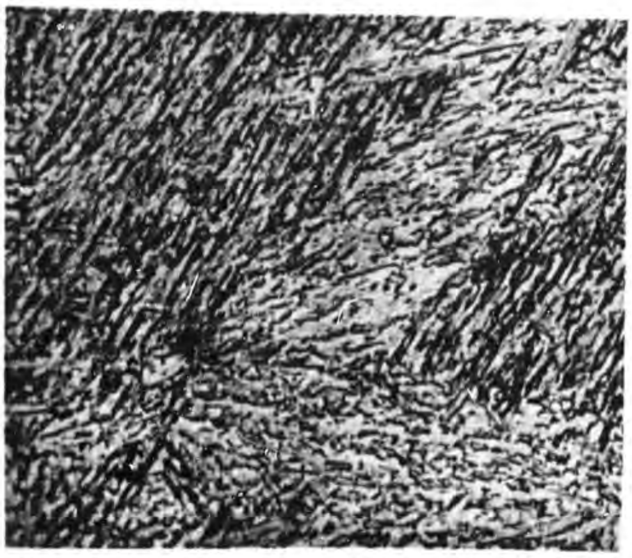
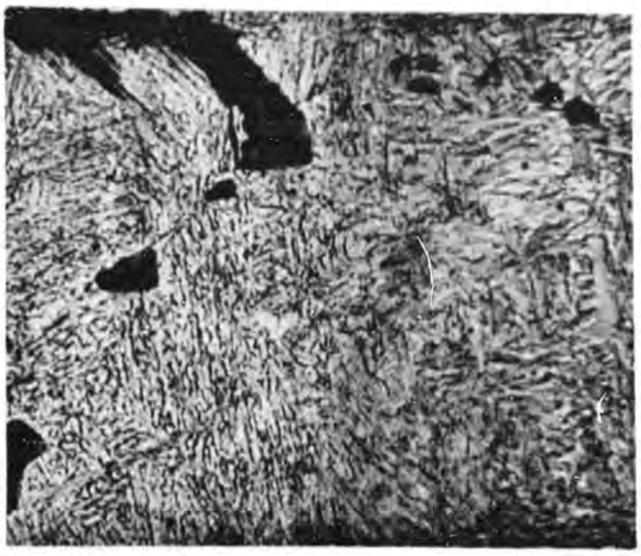


Figure 7F Annealed X1000
Etch; Boiling Sodium Picrate
Iron-Uranium Complex Carbide & Pearlite Cemetite
Etched Black

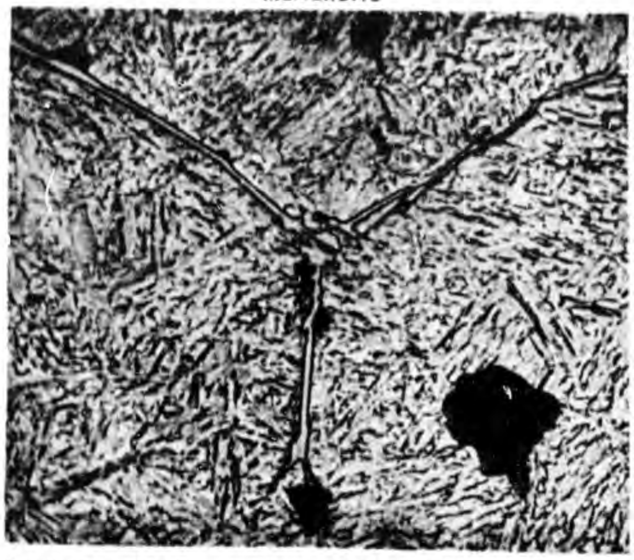
Microstructure
Quenched Steels



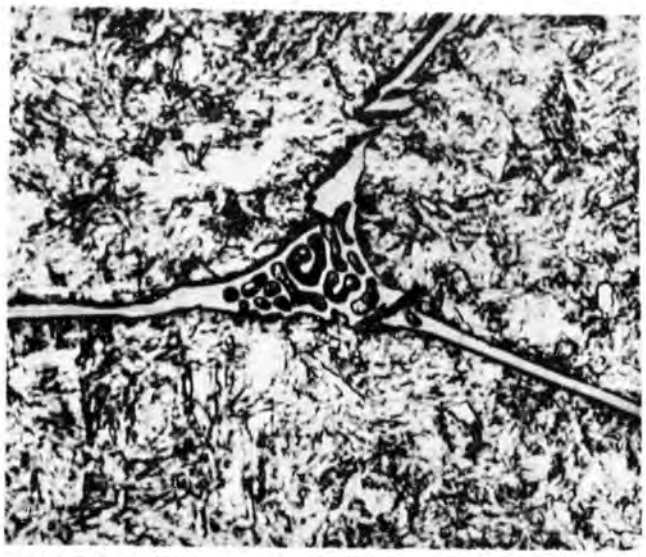
Etch; Picral - HCl Figure 8A Melt No. 435 X1000
0.52% Carbon No Uranium
Martensite



Etch; Picral-HCl Figure 8B Melt No. 527 X1000
0.48% Carbon, 1.33% Uranium
Martensite & Fine Pearlite



Etch; Picral-HCl Figure 8C Melt No. 531 X1000
0.56% Carbon, 177% Uranium
Iron-Uranium Complex Carbide in Matrix
of Martensite & Fine Pearlite



Etch; Picral-HC1 Figure 8D Melt No. 568 X1000
0.69% Carbon, 2.36% Uranium
Iron-Uranium Complex Carbide in Matrix
of Martensite. Note: Eutectic Type Structure

Etch; Picral-HCl Figure 8E Melt No. 513 X1000
0.74% Carbon, 2.37% Uranium
Iron - Uranium Complex Carbide in Martensite
& Fine Pearlite

Figures 8A, B, C, D, E