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REPORT NO. 710/382

RESTRICTED

A PRELIMINARY STUDY ON THE  
HEAT TREATMENT OF CHROMIUM-MOLYBDENUM CAST ARMOR PLATE

By

E. L. Reed  
Research Metallurgist

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August 26, 1941  
WATERTOWN ARSENAL  
WATERTOWN, MASS.

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A Preliminary Study on the  
Heat Treatment of Chromium-Molybdenum Cast Armor Plate

Purpose

The purpose of this investigation was to compare the effect of various homogenizing cycles on the macro and microstructure of chromium-molybdenum cast armor plate.

Introduction

On June 14, 1941, Mr. W. C. Hamilton, Director of Research, American Steel Foundries, East Chicago, Indiana, discussed with representatives of this Arsenal, a cooperative program on the homogenizing of cast armor. Such a program was to cover the effect on the refinement of the structure of Cr-Mo cast armor by homogenizing at 2100°F and also at 1825°F for certain periods of time. Studies were contemplated on further refinement of structure by the subsequent single and double normalize. Accordingly, Mr. Hamilton submitted with his letter of July 2, 1941 several 10"x10"x3" cast armor plates of the chromium-molybdenum type for this investigation.

Conclusions

The following conclusions are based upon the results of tests made in this investigation.

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1. Homogenizing at 2100°F for 12 hours followed by a single normalize at 1700°F for 5 hours was more effective in refining the structure of the Cr-Mo cast armor composition than homogenizing at 1825°F for the same period of time followed by the identical normalizing cycle (see Figures 11b and 10b).

2. Following the homogenizing treatment at 2100°F for 12 hours, the single normalize at 1700°F for 5 hours was slightly more effective on refining the structure than the double normalize (1700°F - 4 hours, air cool followed by 1675°F - 1 hr. air cool). (See Figures 9b and 11b).

3. An increase in time at the standard homogenizing temperature of 1825°F followed by either the single or double normalize failed to produce any progressive increase in grain refinement, (see Figures 8 and 10).

4. Homogenizing at 2100°F for 16 hours failed to promote greater grain refinement than at the same temperature for 12 hours. (See Figures 11b and 11c.)

5. There were some indications that homogenizing at 2100°F promoted slightly greater diffusion of dendritic segregation than homogenizing at the standard temperature, 1825°F. (See Figures 6 and 7.)

### Results

#### 1. Chemical Analysis

The chemical analysis of the material is given below:

<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Cr</u>	<u>Mo</u>	<u>V</u>
.32	.63	.025	.035	.40	3.00	.39	.21

2. Macroscopic Examination

a. Deep Etch

Generally speaking, the deep etch did not indicate very clearly the effect of homogenizing and subsequent normalizing treatments on the diffusion of the dendritic segregation present. (See Figures 2, 3, 4, and 5.)

b. Oberhoffer s Etch

There was some indication that homogenizing at 2100°F produced a slightly greater degree of diffusion of the dendritic segregation than homogenizing at 1825°F. (See Figures 6 and 7.)

3. Microscopic Examination

The results of the microscopic examination indicated that the heat treatments which promoted the maximum grain refinement consisted of normalizing at 2100°F for 12 and 16 hours, and renormalizing at 1700°F for 5 hours. Table I indicates the A.S.T.M. grain size determined on the surface of a section cut from the center of a heat treated 3 inch cube, see Figure 1.



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Table I  
Grain Size Determinations  
A.S.T.M. Ratings

Location on Surface of Section Cut from the Center of Cube

<u>Spec. No.</u>	<u>Outer Third</u>	<u>Middle Third</u>	<u>Outer Third</u>
NI-18-8	4	3-4	4
NI-18-12	4-5	4	4
NI-18-16	4-5	4-5	4
NI-21-8	4	3-4	4
NI-21-12	5	4-5	4-5
NI-21-16	4-5	5	5
NII-18-8	4-5	4	4
NII-18-12	4-5	4-5	4-5
NII-18-16	3-4	3-4	3-4
NII-21-8	6	6 (Occasional coarse grains up to #1)	6
NII-21-12	5-6	6	6
NII-21-16	5-6	5-6	5-6

Note:

Series NI and NII - Normalized at 1825°F for 8, 12, 16 hrs.  
 " " 2100°F for 8, 12, 16 hrs.  
 Cooled to black, reheated to 1250°F for  
 4 hrs., air cooled.

Series NI - Normalized at 1700°F for 4 hrs., air cooled.  
 " " 1675°F for 1 hr., air cooled.  
 Drawn " 1050°F for 6 hrs., air cooled.

Series NII - Normalized at 1700°F for 5 hrs., air cooled.  
 Drawn " 1050°F for 6 hrs., air cooled.

Table II

Heat Treatment

Sample#	Homogenizing Treatment	Low Temperature Anneal	Normalizing Treatment	Draw
NI-18-8	1825°F - 8 hrs. cooled to black.	1250°F - 4 hrs. air cooled.	1700°F - 4 hrs. 1675°F - 1 hr.	1050°F, air cooled.
NI-18-12	1825°F - 12 hrs.	"	1700°F - 4 hrs. 1675°F - 1 hr.	"
NI-18-16	1825°F - 16 hrs.	"	1700°F - 4 hrs. 1675°F - 1 hr.	"
NI-21-8	2100°F - 8 hrs.	"	1700°F - 4 hrs. 1675°F - 1 hr.	"
NI-21-12	2100°F - 12 hrs.	"	1700°F - 4 hrs. 1675°F - 1 hr.	"
NI-21-16	2100°F - 16 hrs.	"	1700°F - 4 hrs. 1675°F - 1 hr.	"
NII-18-8	1825°F - 8 hrs.	"	1700°F - 5 hrs.	"
NII-18-12	1825°F - 12 hrs.	"	1700°F - 5 hrs.	"
NII-18-16	1825°F - 16 hrs.	"	1700°F - 5 hrs.	"
NII-21-8	2100°F - 8 hrs.	"	1700°F - 5 hrs.	"
NII-21-12	2100°F - 12 hrs.	"	1700°F - 5 hrs.	"
NII-21-16	2100°F - 16 hrs.	"	1700°F - 5 hrs.	"

### Test Procedure and Materials

Two 10x10x3" cast armor plates of the chromium-molybdenum type which were submitted for preliminary heat treatment were originally shaken out of the mould at approximately 1200°F and reheated immediately to 1650°F for 6 hours. The plates were then cooled in the furnace to 1200°F at which temperature the burning of the gates and risers was started. After burning the plates were reheated to 1200°F for two hours, followed by cooling in the furnace to 900°F and then in still air.

The above plates were cut into 3 inch cubes and subjected to the heat treatments noted in Table II.

Since considerable interest was indicated on the effect of a high homogenizing temperature (2100°F) on the macro and microstructure of cast armor of this composition, comparative tests were made on samples homogenized at the standard temperature, 1825°F. The effect of the single and double normalize on the above homogenized series was also investigated.

Macroscopic and microscopic examinations including a grain size study were made on the surface of a section cut from the center of each heat treated cube. This section was cut into thirds and the microstructure was studied on the two outer thirds and also on the middle third, see Figure 1. The microstructure was revealed by a light etch, in a 1% Nital solution.

### Discussion

Homogenizing this particular composition at 2100°F for 12 hours followed by a single normalize at 1700°F for 5 hours is effective in producing an A.S.T.M. grain size of 5-6, see Figure 11b. An increase



in time at this same cycle of heat treatment failed to further refine the structure, see Figure 11c. Homogenizing for 8 hrs. at 2100°F followed by the single normalize practically refines the grain. This heat-treated section had a grain size of A.S.T.M. No. 6 with an occasional large grain (up to A.S.T.M. No. 1).

The single normalize at 1700°F for 5 hours following the high homogenizing treatment at 2100°F for 12 hours produced a slightly greater refinement of grain (A.S.T.M. No. 6) than the double normalize (1700°F - 4 hours/1675°F - 1 hour, resulting in an A.S.T.M. grain size of 4-5), see Figures 11b and 9b). An increase in time at the homogenizing temperature of 1825°F followed by either a single or double normalize is not effective in producing a progressive increase in grain refinement (Figures 8 and 10). A.S.T.M. 3 to 4 grain sizes result from this series of heat treatments.

A complete series of photomicrographs illustrating the various microstructures of the heat-treated sections are shown in Figures 8, 9, 10, and 11.

The high temperature homogenizing treatment was slightly more effective in the diffusion of the dendritic segregation than the standard homogenizing treatment, see Figures 6 and 7.

It is believed that a similar series of homogenizing tests at 1900°F and 2000°F should be conducted.

Respectfully submitted,

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Research Metallurgist.

APPROVED:

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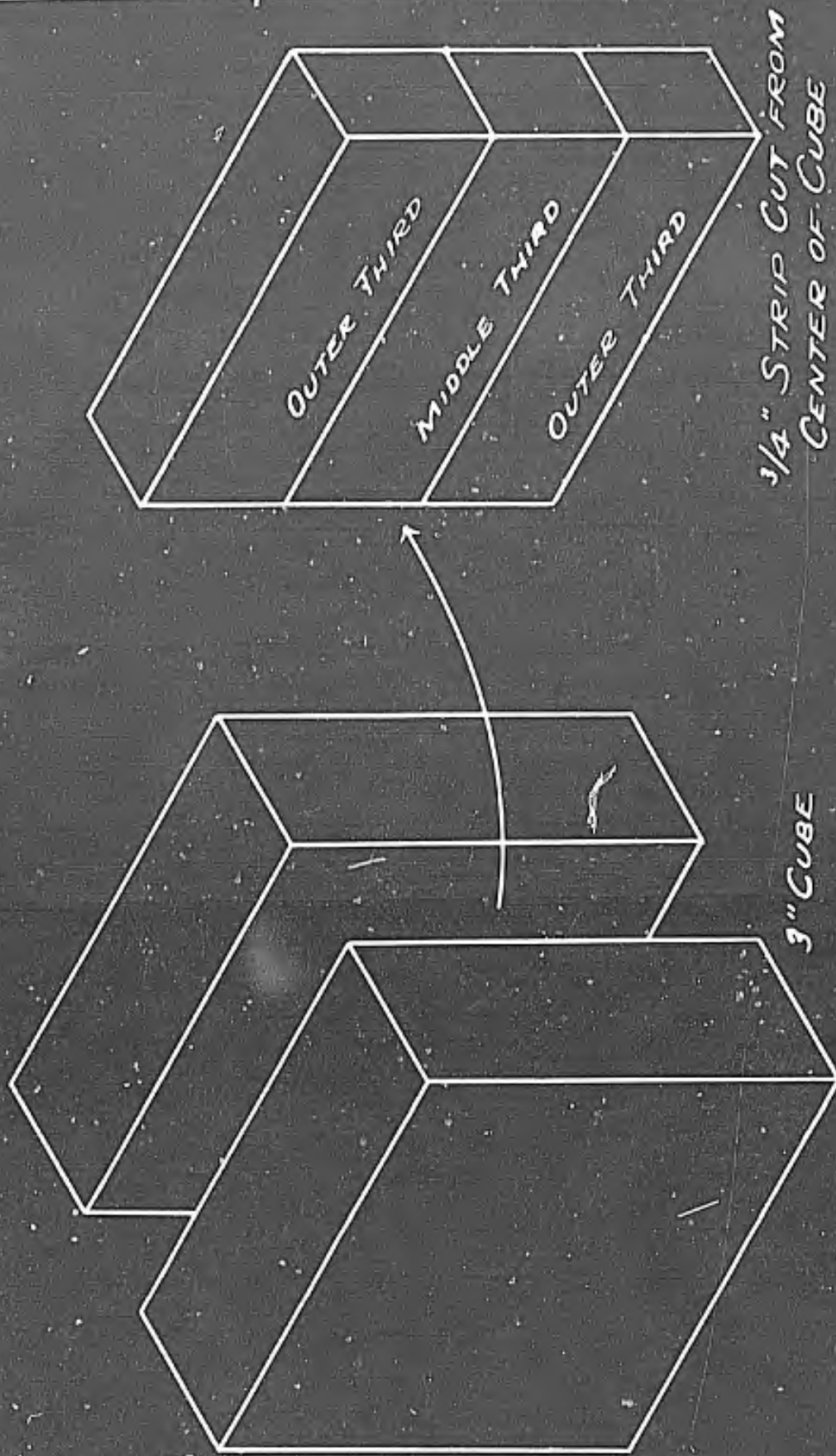


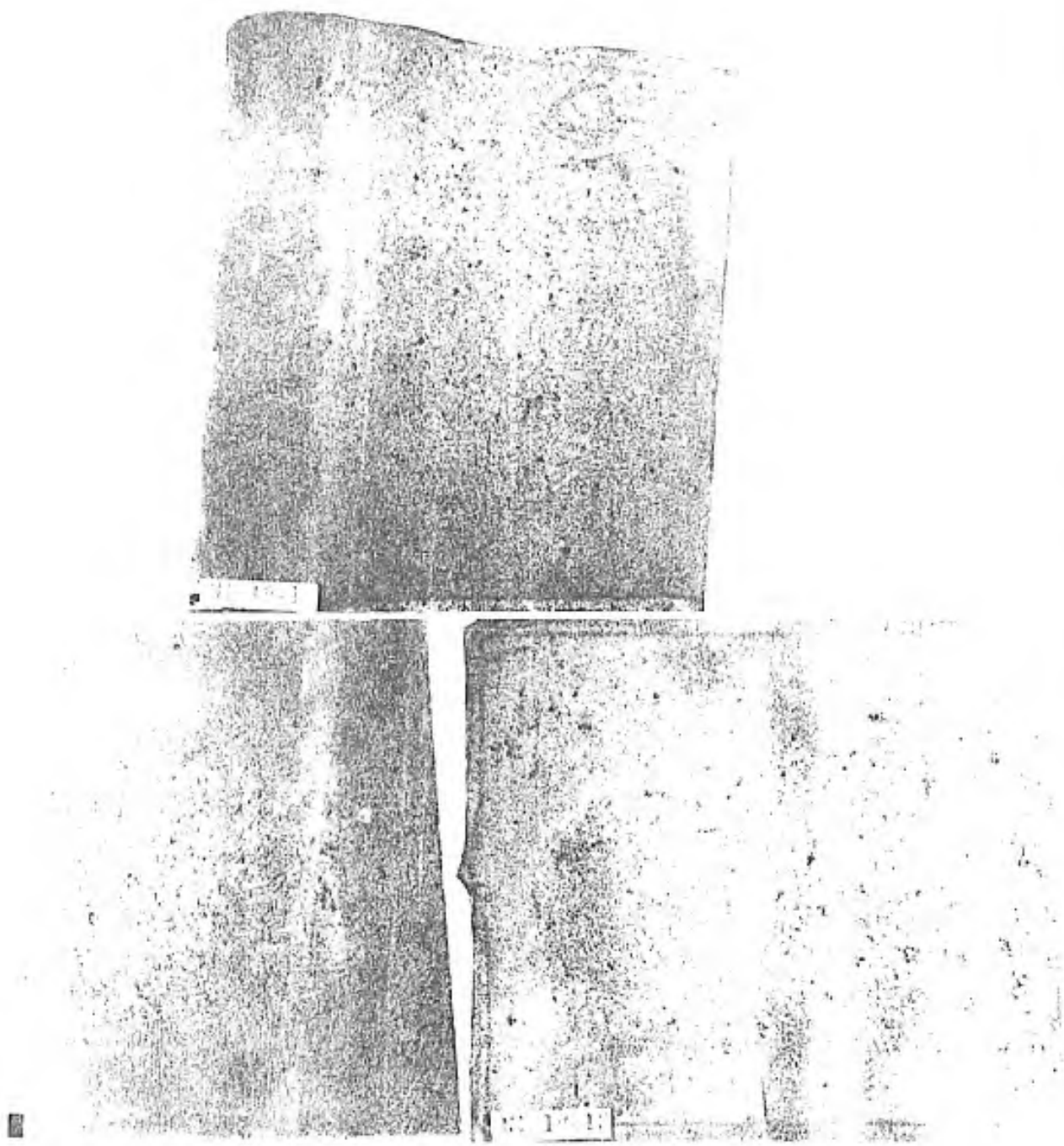
FIG. 1

Figure 2

Macrostructure

Deep Etch - N1-18-16, N1-18-8, N1-18-12

The three sections submitted are very slightly different in macrostructure. A slightly coarse dendritic structure extends for about  $3/4$ " from the top and bottom surface of each plate. A central area approximately 1.5" thick shows a randomly oriented dendritic structure and contains quite prominent, partially etched-out interdendritic nonmetallics.



1 2 3  
 100 μm  
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 LABORATORY OF CELLULAR PHYSIOLOGY  
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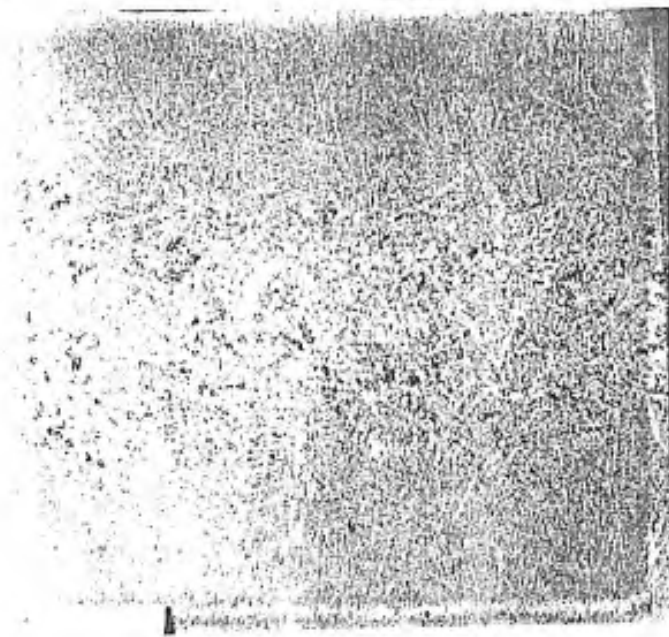
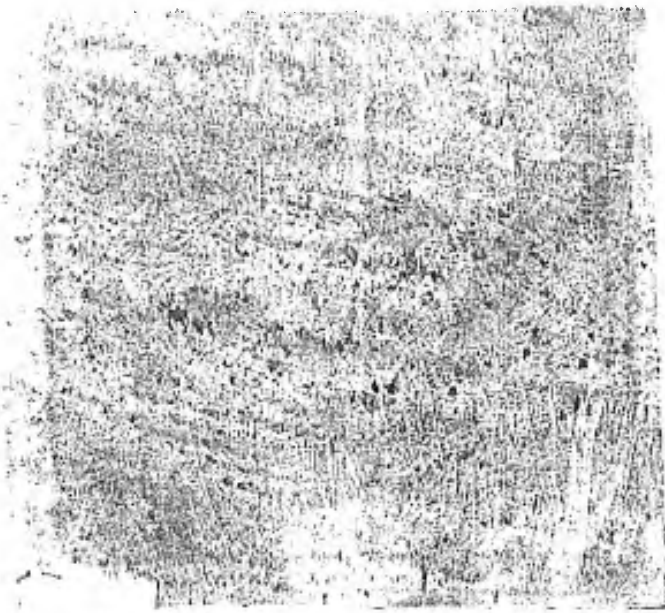
FIG. 2

Figure 3

Macrostructure

Deep Etch - N1-21-16, N1-21-8, N1-21-12

The section stamped N1-21-8 shows a structure quite similar to that described for the two previous groups. The remaining two sections show very little columnar dendritic structure near the outer surfaces and have very coarse and deeply etched-out nonmetallics in the central portion.



100 μm

100 μm

100 μm

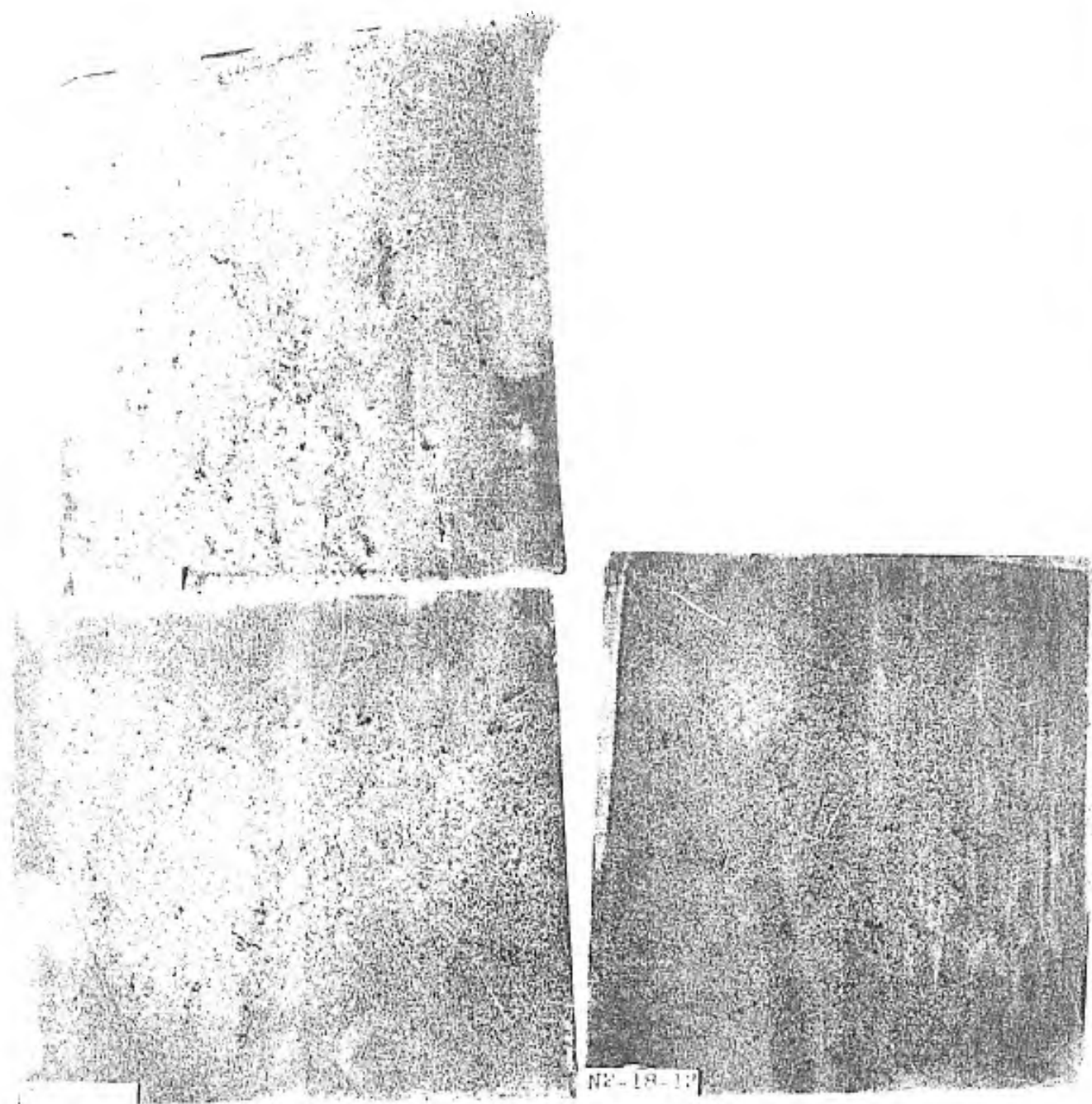
FIG. 3

Figure 4

Macrostructure

Deep Etch - N2-18-16, N2-18-8, N2-18-12

The dendritic structure at the top and bottom surfaces of the plate is reasonably fine and extends for  $1/2''$  to  $3/4''$  from the surface. The central portion shows a structure very similar to that described for the previous group.



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FIG. 4

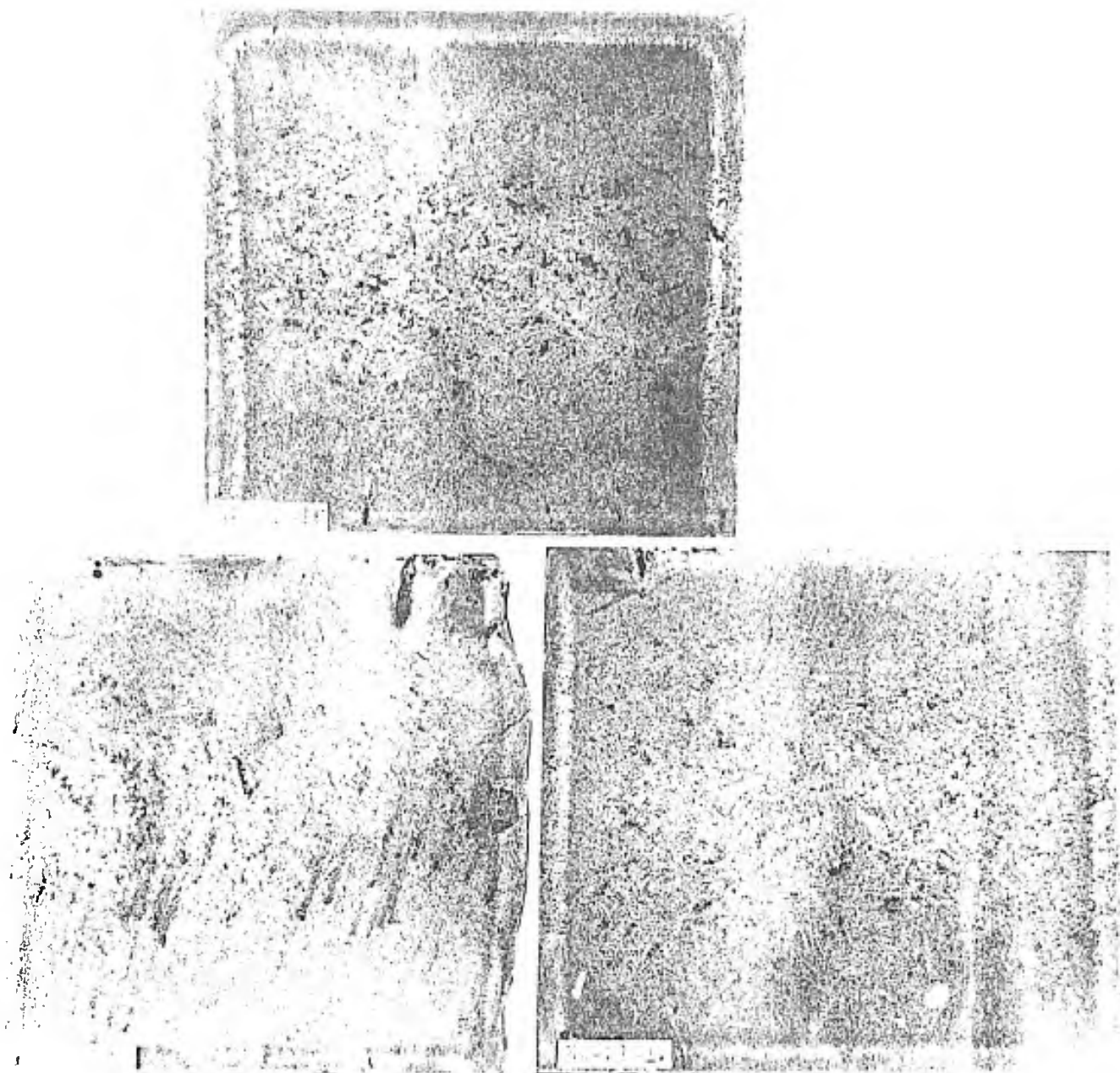


Figure 5

Macrostructure

Deep Etch - N2-21-16, N2-21-8, N2-21-12

The metal is reasonably clean and has a medium fine columnar dendritic structure near the top and bottom surfaces. These areas are approximately  $3/4$ " wide. A very coarse randomly oriented structure showing large chains of nonmetallics is present in the central area.



1000X  
1000X  
1000X

FIG. 5

Figure 6

Macrostructure

Oberhoffer's Etch

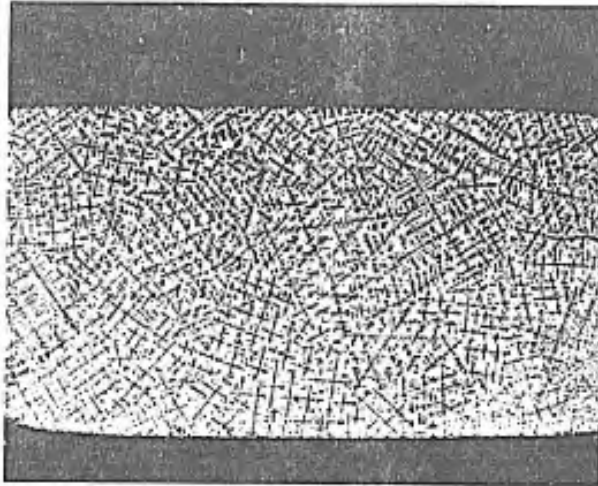
The homogenizing temperature of 2100°F produces a slightly greater degree of diffusion of dendritic segregation than the homogenizing temperature of 1825°F.

Samples shown in Figures 6a, 6b, and 6c were homogenized at 1825°F. Samples shown in Figures 6d, 6e, and 6f were homogenized at 2100°F. All were given a subsequent double normalizing treatment. (4 hrs. at 1700°F, air cooled, 1 hr. at 1675°F, air cooled.)

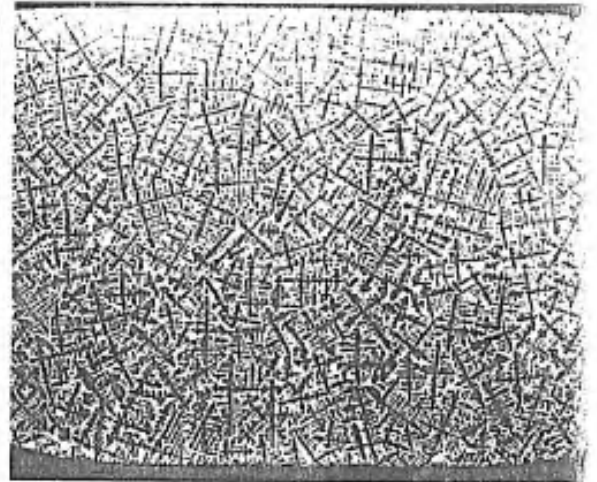
X3

MA-3197  
MA-3198  
MA-3199  
MA-3200  
MA-3201  
MA-3202

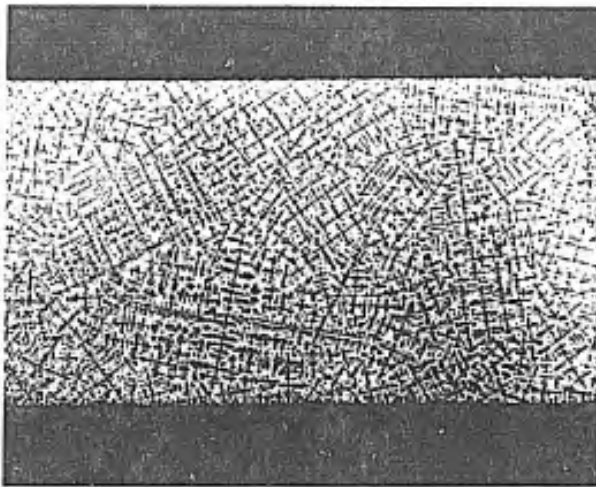
Figure 6



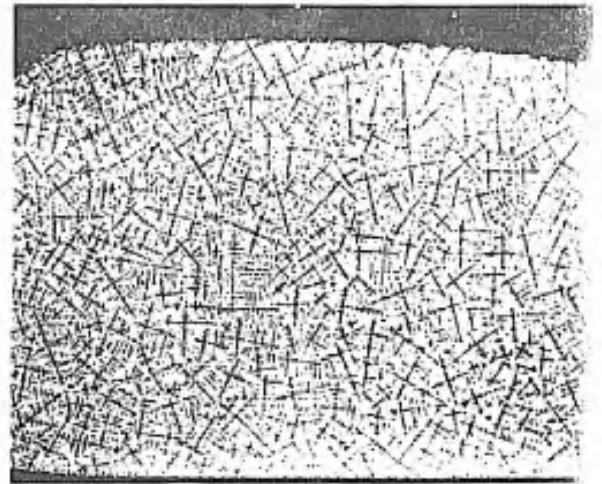
a. NI-18-8



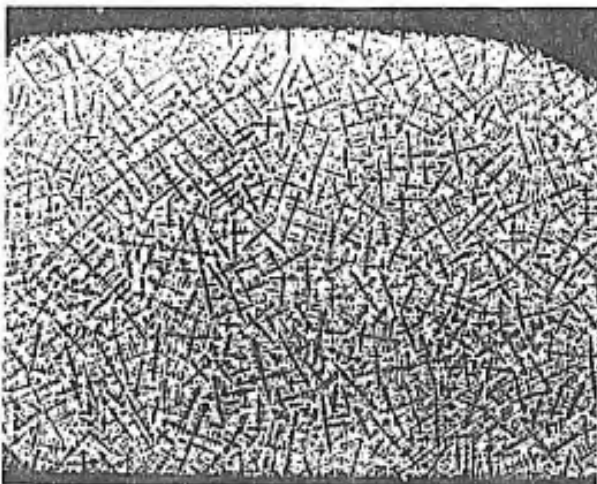
d. NI-21-8



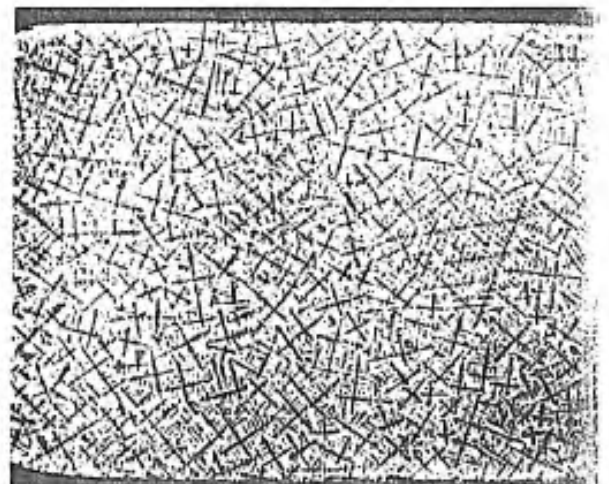
b. NI-18-12



e. NI-21-12



c. NI-18-16



f. NI-21-16

Figure 7  
Macrostructure

Oberhoffer's Etch

The homogenizing temperature of 2100<sup>o</sup>F produces a slightly greater degree of diffusion of dendritic segregation than the homogenizing temperature of 1825<sup>o</sup>F.

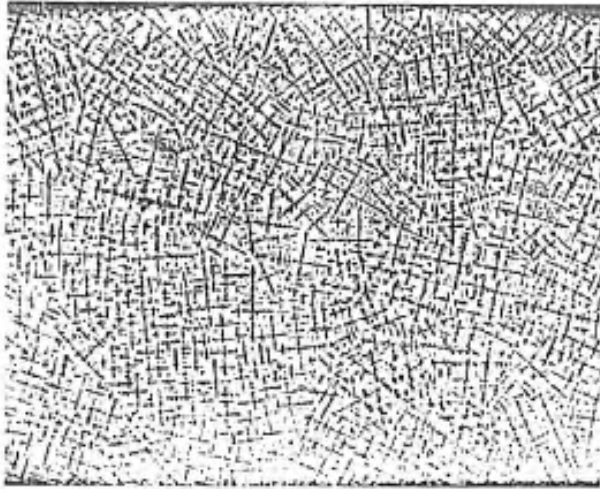
Samples shown in Figures 7a, 7b, 7c were homogenized at 1825<sup>o</sup>F.

Samples shown in Figures 7d, 7e, and 7f were homogenized at 2100<sup>o</sup>F. All were given a subsequent single normalize - (5 hrs. at 1700<sup>o</sup>F).

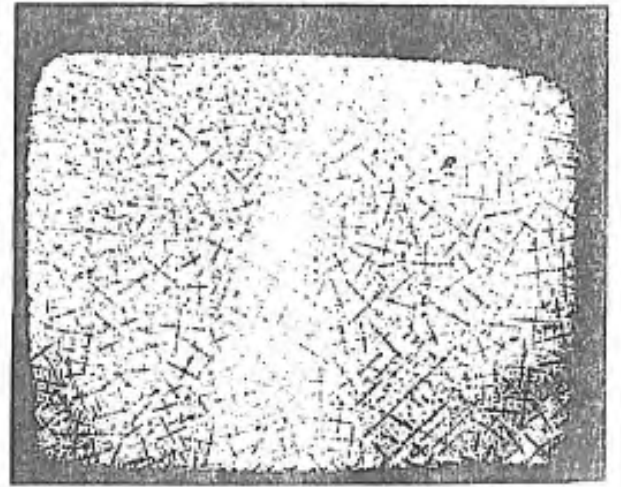
X3

MA-3203  
MA-3204  
MA-3205  
MA-3206  
MA-3207  
MA-3208

Figure 7



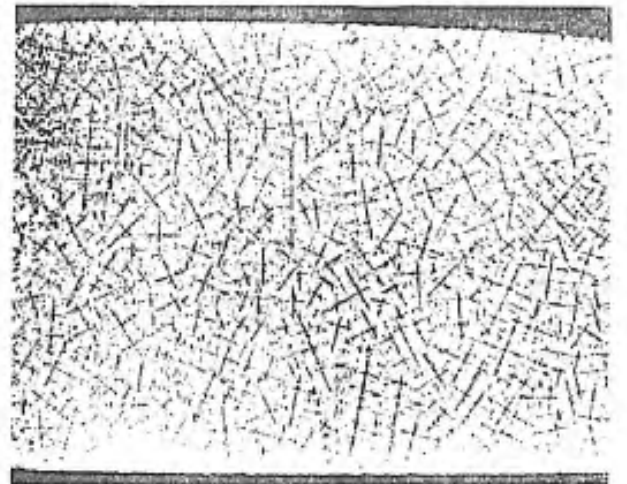
a. NII-18-8



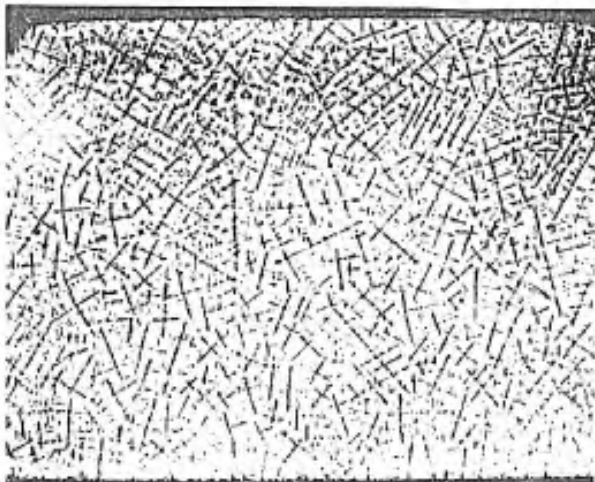
d. NII-21-8



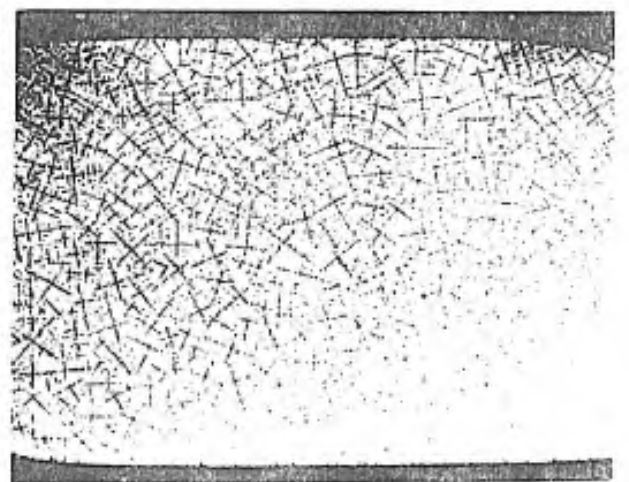
b. NII-18-12



e. NII-21-12



c. NII-18-16



f. NII-21-16

Figure 8

Structure and Heat Treatment

(a) NI-18-8

Heated to 1825°F, held 8 hours, cooled to black. Reheated to 1250°F, 4 hours, air cooled. Normalized at 1700°F, 4 hours, air cooled, reheated to 1675°F for 1 hour, air cooled. Drawn at 1050°F, 6 hours, air cooled.

Grain size 3-4.

X100

MA-3145

(b) NI-18-12

Heated to 1825°F, held 12 hours, cooled to black. Reheated to 1250°F, 4 hours, air cooled. Normalized at 1700°F, 4 hours, air cooled, reheated to 1675°F for 1 hour, air cooled. Drawn at 1050°F, 6 hours, air cooled.

Grain size 4-5.

X100

MA-3146

(c) NI-18-16

Heated to 1825°F, held 16 hours, cooled to black. Reheated to 1250°F, 4 hours, air cooled. Normalized at 1700°F, 4 hours, air cooled. Reheated to 1675°F for 1 hour, air cooled. Drawn at 1050°F, 6 hours, air cooled.

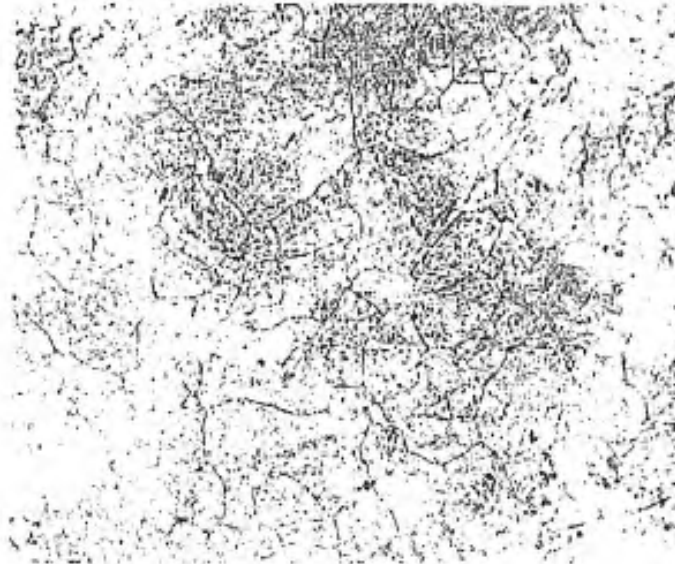
Grain size 4-5.

X100

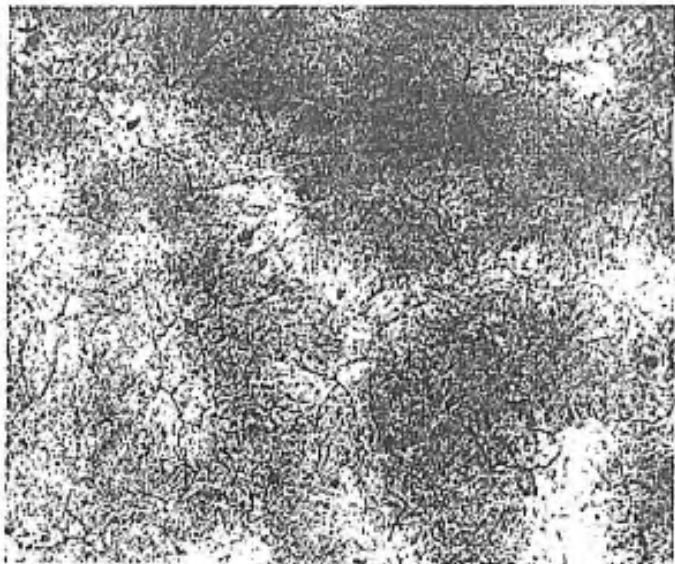
MA-3147

Light 1% Nital Etch

Figure 8



a. NI-18-8



b. NI-18-12



c. NI-18-16

W.A. 639-3490



Figure 9

Structure and Heat Treatment

(a) NI-21-8

Heated to 2100°F, held 8 hours, cooled to black. Reheated to 1250°F for 4 hours, air cooled. Normalized at 1700°F for 4 hours, air cooled. Reheated to 1675°F for 1 hour, air cooled. Drawn at 1050°F for 6 hours, air cooled.

Grain size 3-4.

X100

MA-3148

(b) NI-21-12

Heated to 2100°F, held 12 hours, cooled to black. Reheated to 1250°F for 4 hours, air cooled. Normalized at 1700°F for 4 hours, air cooled. Reheated to 1675°F for 1 hour, air cooled. Drawn at 1050°F for 6 hours, air cooled.

Grain size 4-5.

X100

MA-3149

(c) NI-21-16

Heated to 2100°F, held 16 hours, cooled to black. Reheated to 1250°F for 4 hours, air cooled. Normalized at 1700°F for 4 hours, air cooled. Reheated to 1675°F for 1 hour, air cooled. Drawn at 1050°F for 6 hours, air cooled.

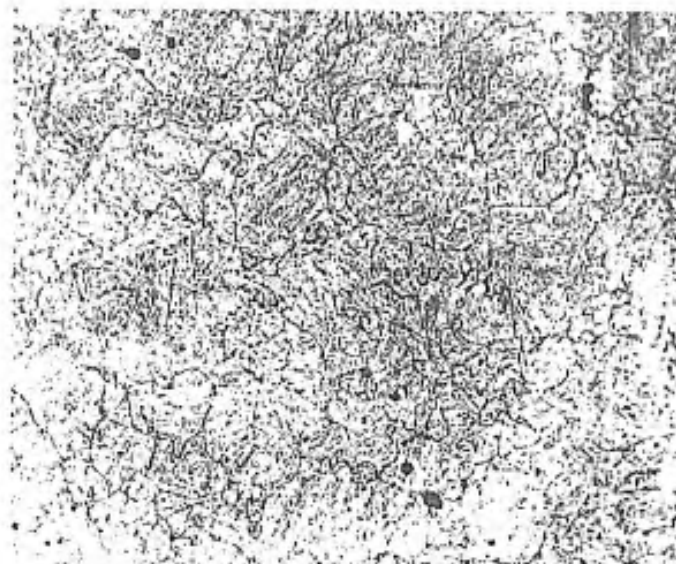
Grain size 4-5.

X100

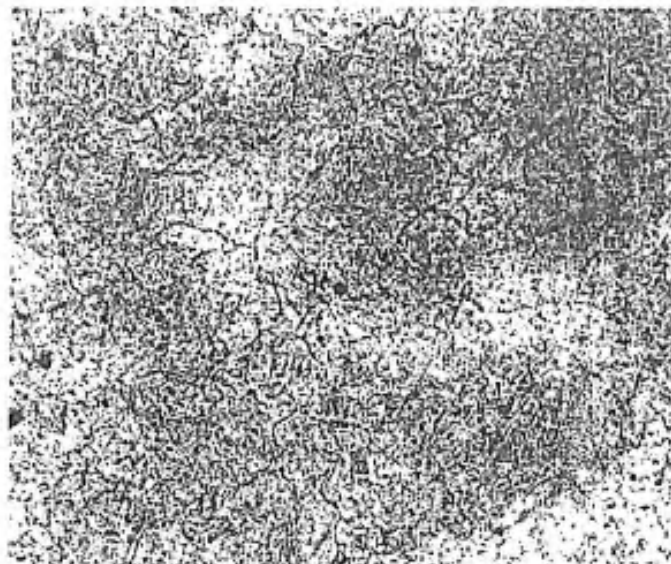
MA-3150

Light 1% Nital Etch.

Figure 9



a. NI-21-8



b. NI-21-12



c. NI-21-16

W.A.639-3391

Figure 10

Structure and Heat Treatment

(a) NII-18-8

Heated to 1825°F, held 8 hours, cooled to black.  
Reheated to 1250°F for 4 hours, air cooled. Normalized  
at 1700°F for 5 hours, air cooled. Drawn at 1050°F for  
6 hours, air cooled.

Grain size 4-5.

X100

MA-3151

(b) NII-18-12

Heated to 1825°F, held 12 hours, cooled to black.  
Reheated to 1250°F for 4 hours, air cooled. Normalized  
at 1700°F for 5 hours, air cooled. Drawn at 1050°F for  
6 hours, air cooled.

Grain size 4-5.

X100

MA-3152

(c) NII-18-16

Heated to 1825°F, held 16 hours, cooled to black.  
Reheated to 1250°F for 4 hours, air cooled. Normalized  
at 1700°F for 5 hours, air cooled. Drawn at 1050°F for  
6 hours, air cooled.

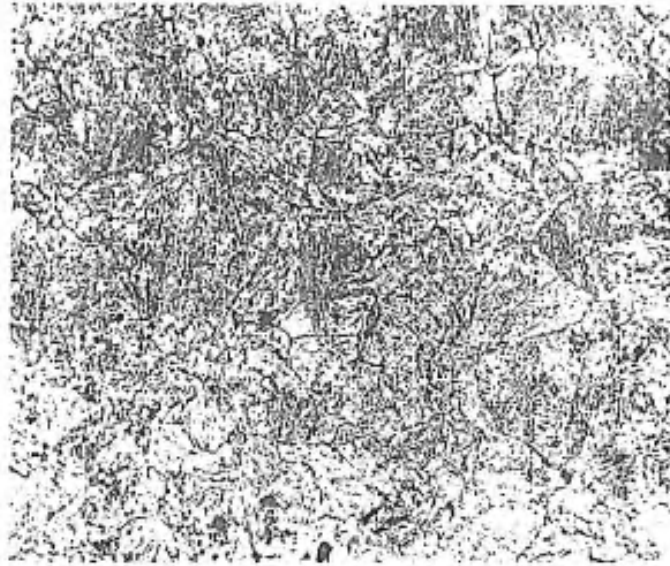
Grain size 3-4.

X100

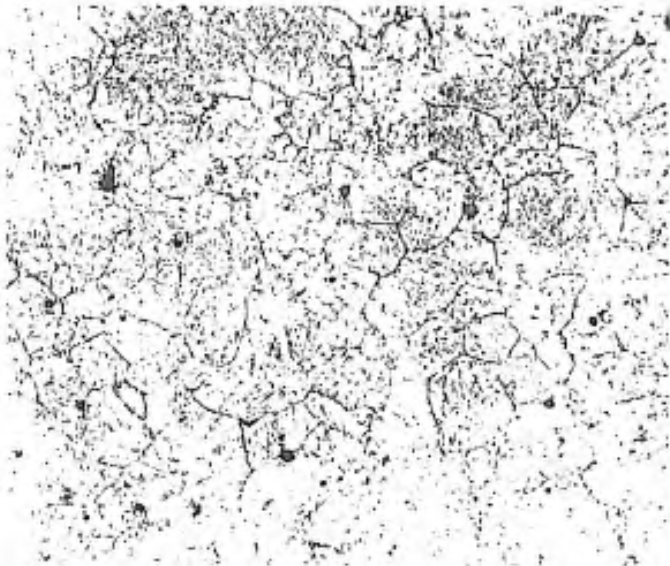
MA-3153

Light 1% Nital Etch.

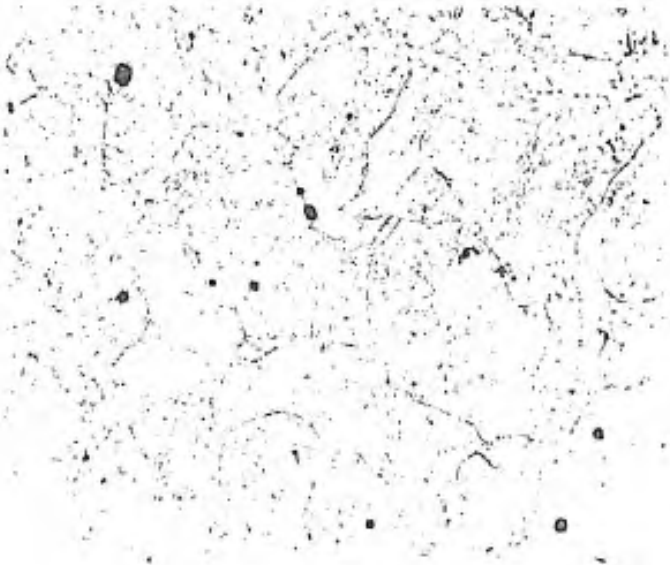
Figure 10



a. NII-18-8



b. NII-18-12



c. NII-18-16

6-0-1-10-3-1

Figure 11

Structure and Heat Treatment

(a) NII-21-8

Heated to 2100°F, held 8 hours, cooled to black.  
Reheated to 1250°F for 4 hours, air cooled. Normalized  
at 1700°F for 5 hours, air cooled. Drawn at 1050°F for  
6 hours, air cooled.

Grain size 6.                      X100                      MA-3154

(b) NII-21-12

Heated to 2100°F, held 12 hours, cooled to black.  
Reheated to 1250°F for 4 hours, air cooled. Normalized  
at 1700°F for 5 hours, air cooled. Drawn at 1050°F for  
6 hours, air cooled.

Grain size 5-6.                      X100                      MA-3155

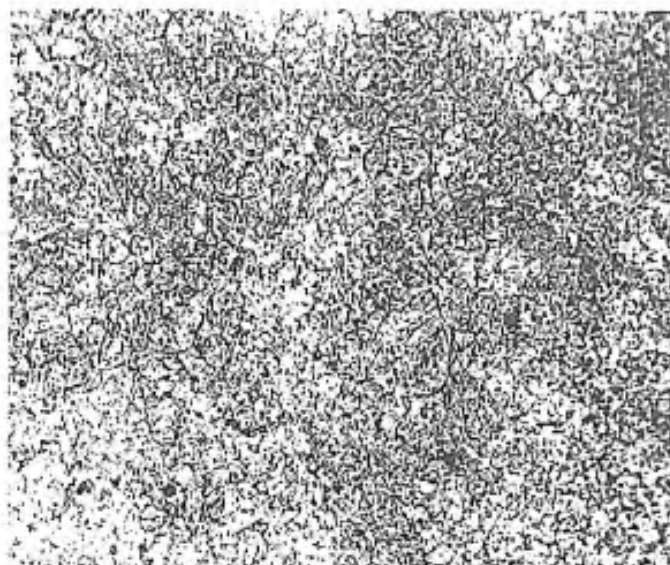
(c) NII-21-16

Heated to 2100°F for 16 hours, cooled to black.  
Reheated to 1250°F for 4 hours, air cooled. Normalized  
at 1700°F for 5 hours, air cooled. Drawn at 1050°F  
for 6 hours, air cooled.

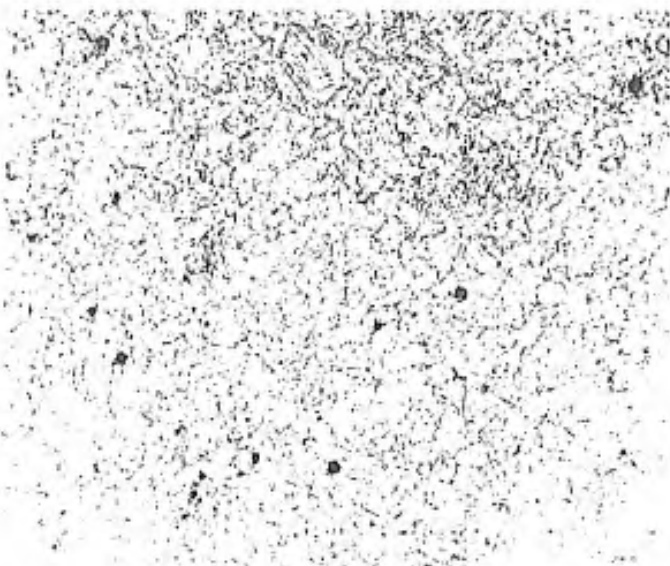
Grain size 5-6.                      X100                      MA-3156

Light 1% Nital Etch.

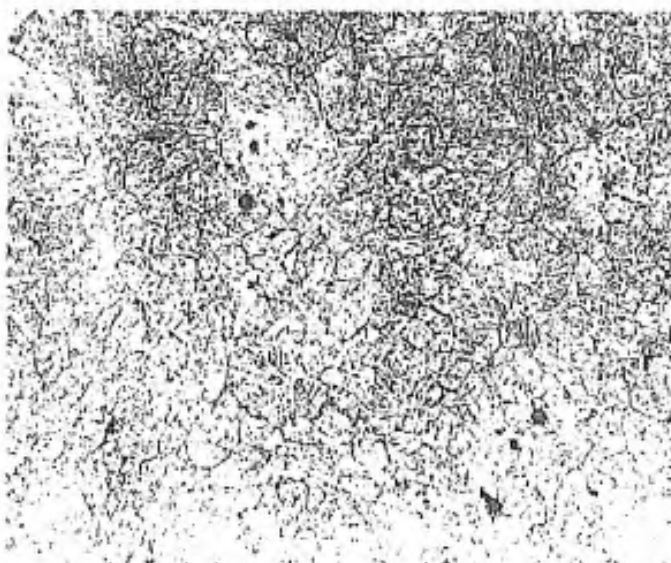
Figure 11



a. NII-21-5



b. NII-21-12



c. NII-21-16

W.A. 11-21-5-3-143