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METALLURGICAL EXAMINATION AND BALLISTIC PROPERTIES OF FOUR NICKEL ALLOYS

By

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August 14, 1941

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WATERTOWN, MASS.

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Metallurgical Examination and Ballistic Properties of Four Nickel Alloys

Purpose

The purpose of this investigation was to determine the metallurgical characteristics and ballistic properties of several nickel alloys.

Introduction

The following nickel alloys in the form of 18x18x1/2" rolled plate were submitted by the International Nickel Co. with their letter of November 26, 1940.

1. New Type, Age-Hardenable Nickel.
2. Beryllium Nickel.
3. "K" Monel.
4. "Z" Nickel.

Conclusions

The following conclusions are based upon the results of this investigation:

1. The ballistic properties of the new age-hardenable nickel alloy were superior to those of the Beryllium-Nickel, "K" Monel, and "Z" Nickel alloys. The ballistic limit of the new age-hardenable nickel alloy was 350 f/s above the specifications.

2. With the exception of "K" Monel, these alloys were magnetic.

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3) Due to the high nickel content of these alloys, it is questionable that they can be considered for armor construction at this time.

Results

1. Chemical Analysis

Chemical analyses of the four plates are given in Table I. See page 2A.

2. Macroscopic Examination

Y-1519 New Type Age-Hardenable Nickel - This metal shows no etched-out impurities and has a very fine macrograin.

Y-1520 Beryllium Nickel - This metal shows a fine and uniform macrostructure throughout, with no traces of impurities.

M-1631-K "K" Monel - There appear to be no prominent impurities in this metal. Macrostructure is reasonably uniform.

N-9954-Z "Z" Nickel - This metal has the same characteristics as those described for Y-1520.

Figure 1 illustrates the macrostructure of these alloys. Bars marked "2" were cut at right angles to bars marked "1".

3. Microscopic Examination

The distribution of nonmetallic inclusions in the various samples is shown in Figure 2. The beryllium nickel alloy is very clean, while the new type age-hardenable nickel and the Z-Nickel is fairly clean with a uniform distribution of fine nonmetallics present. See Figures 2a, 2b, and 2e. One sample of the K-Monel was relatively dirty. See Figures 2c and 2d. A fine segregate was evident in the grain boundaries of the new type age-hardenable nickel alloy. See Figs. 3a, 3b, 4a, and 4b.

Table I

Chemical Compositions

Alloy	C	Mn	Fe	S	Si	Cu	Ni	Al	Be	Other Metals	Brinell Hardness (3000kg)	Heat Treatment
Y1519 New Type Age-Hardenable Nickel	.23	.10	.47	.005	.07	.13	93.40	--	--	Al&Ti	382	Aged 16 hrs. at 1100°F., furnace cooled to 900°F. for 16 hrs.
	Traces of Cr, Co, Ca, Mg, Sn, and Pb.											
Y1520 Beryllium Nickel	.03	trace	.18	.005	.07	.04	98.03	--	1.62	Al	394	Aged 16 hrs. at 930°F.
	Traces of Ca, Co, Sn, and Pb.											
M-1631-K "K" Monel	.07	.25	.53	.005	.28	28.96	66.44	2.84	--	Al&Ti	277	Aged 16 hrs. at 1100°F., furnace cooled to 900°F. for 16 hours.
	Traces of Ca, Ag, Cr, Sn, and Pb.											
N9954Z "Z" Nickel	.18	.18	.17	.005	.20	.03	98.54	—	—	Al&Ti	332	Aged 16 hrs. at 930°F.
	Traces of Ca, Co, Cr, Sn, and Pb.											

Pronounced grain boundary segregates and evidence of a white constituent were present in the Beryllium-Nickel alloy. See Figures 5a, 5b, and 5c. The K-Monel had a fine uniform structure. See Figures 6a, 6b. No grain boundary constituent was present in this alloy, see Figures 7a, and 7b. Considerable banding was evident in the Z-Nickel alloy, see Figures 8b, 9a, 9b, 10a, and 10b. Typical structure of these bands at 2000 diameters is shown in Figure 9b.

The grain size of each alloy was determined by the Jeffries Method as shown below in Table II.

Table II

Grain Size Measurements

Jeffries Method

Alloy	No. of Grains per Sq. MM.
New Type Age-Hardenable Nickel 1519	340
Beryllium Nickel 1520	56-62
"K" Monel 1631	420
"Z" Nickel N9954Z	187 near segregations 40 away from "

4. Magnetic Characteristics

The following materials were strongly attracted by the magnet.

New Type Age-Hardenable Nickel 1519
Beryllium Nickel 1520
Z-Nickel N9954Z

The K-Monel 1631 was not attracted by the magnet.

5. Physical Tests

The physical tests are reported in Table III.

Table III

Alloy	Tensile Strength Lbs./Sq. In.	% Elong.	Cont. of Area %	Remarks
New Type Age-Hardenable Nickel				
Y1519-1	204,000	21.4	40.7	Cupped, pitted.
Y1519-2	205,500	21.4	41.1	" "
Beryllium Nickel				
Y1520-1	168,000	6.4	8.7	Irregular break, laminated structure granular.
Y1520-2	177,500	7.1	9.8	" "
"K" Monel				
M1631K-1	152,000	26.4	50.2	Cupped, pitted.
M1631K-2	153,500	27.1	51.7	Full cup, pitted.
"Z" Nickel				
N9954Z-1	171,000	13.6	17.6	Irregular break, laminated, granular.
N9954Z-2	168,000	13.6	15.0	" "

Note: No. 2 bars were cut at right angles to the No. 1 bars.

In all cases the properties obtained are those of heat treatment superimposed on hot working only, without any cold work component.

6. Ballistic Tests

The results of the ballistic tests are given in Table IV.

Table IV

Ammunition: Preloaded Cal. .30 A.P. M2
" Cal. .50 A.P. T1E9

Distance from Muzzle to Plate - 100 Yds.

Plate Normal to Fire. Size - 18" x 18" x 1/2"

Alloy	Brinell Hardness	Ballistic Limit F/S	Remarks
Y1519 New Type Age-Hardenable Nickel	382	2450 Cal..30 A.P.	Good ductility. Passed spec. by 350 f/s.
Y1520 Beryllium Nickel	394	2150 Cal..30 A.P.	Failed due to lack of ductility. One 5/8" back spall at 2500 f/s. penetration, Cal..30 A.P. ammunition.
M1631-K "K" Monel	277	1950 Cal..30 A.P.	Good ductility. Failed to pass spec. by 150 f/s.
N9954Z "Z" Nickel	332	2050 Cal..30 A.P.	Good ductility. Failed to pass spec. by 50 f/s.

Note: All above plates were penetrated at a striking velocity of 1700 f/s. Cal. .50 A.P. ammunition with no spalling.

Test Procedure and Materials

Metallurgical examination included chemical analyses, spectrographic analyses; macro and microscopic examination, grain size measurements by the Jeffries Method, magnetic characteristics, physical tests, and ballistic tests. The ballistic tests were conducted at Watertown Arsenal with preloaded Cal. .30 A.P. and Cal. .50 A.P. ammunition.

Discussion

The failure of the beryllium-nickel plate under the ballistic test was probably due to the presence of pronounced grain boundary segregates (Figures 5a, 5b, and 5c) accompanied by a relatively high hardness. The new type age-hardenable nickel alloy had excellent ballistic properties not withstanding the fact that some fine grain boundary segregate (Figures 3a, 3b, 4a, and 4b) was present. This plate was heat treated to a satisfactory Brinell hardness of 388.

The Brinell hardness of the K-Monel metal (277) is too low for good ballistic plate. It is believed that with a hardness of 366/388 Brinell this material would have passed the ballistic limit. This material had a fine uniform grain, in fact the finest grain of the series of plates submitted (see Table IV for comparative grain size measurements).

The "Z" nickel alloy had a Brinell hardness of 332 which is slightly below that required for good ballistic plate. A pronounced banded structure was present in these plates (Figures 8b, 9a, 9b, 10a, and 10b). As noted in Table II, the grain size near the segregated area in this material was relatively smaller.

The macrostructure of these nickel alloys showed that these compositions were free from laminations (see Figure 1).

Although the K-Monel may have possibilities for nonmagnetic armor, it is believed that this material should not be considered for this purpose at this time due to its high nickel base and the fact that nickel is considered a strategic element.

Mr. A. Hurlich made the metallographic examination covered in this report.

Respectfully submitted,

E. L. Reed

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Research Metallurgist.

APPROVED:

S. B. RITCHIE,
Lt. Col., Ord. Dept.,
Director of Laboratory.

Figure 1

Macrostructure

Y-1519

This metal shows no etched-out impurities and has a very fine macrograin.

M-1631-K

There appear to be no prominent impurities in this metal. Macrostructure is reasonably uniform.

N9954-Z

This metal has the same characteristics as those described for Y-1520.

Y-1520

This metal shows a fine and uniform macrostructure throughout, with no traces of impurities.

Note: - Bars marked No. 2 were cut at right angles to bars marked No. 1.

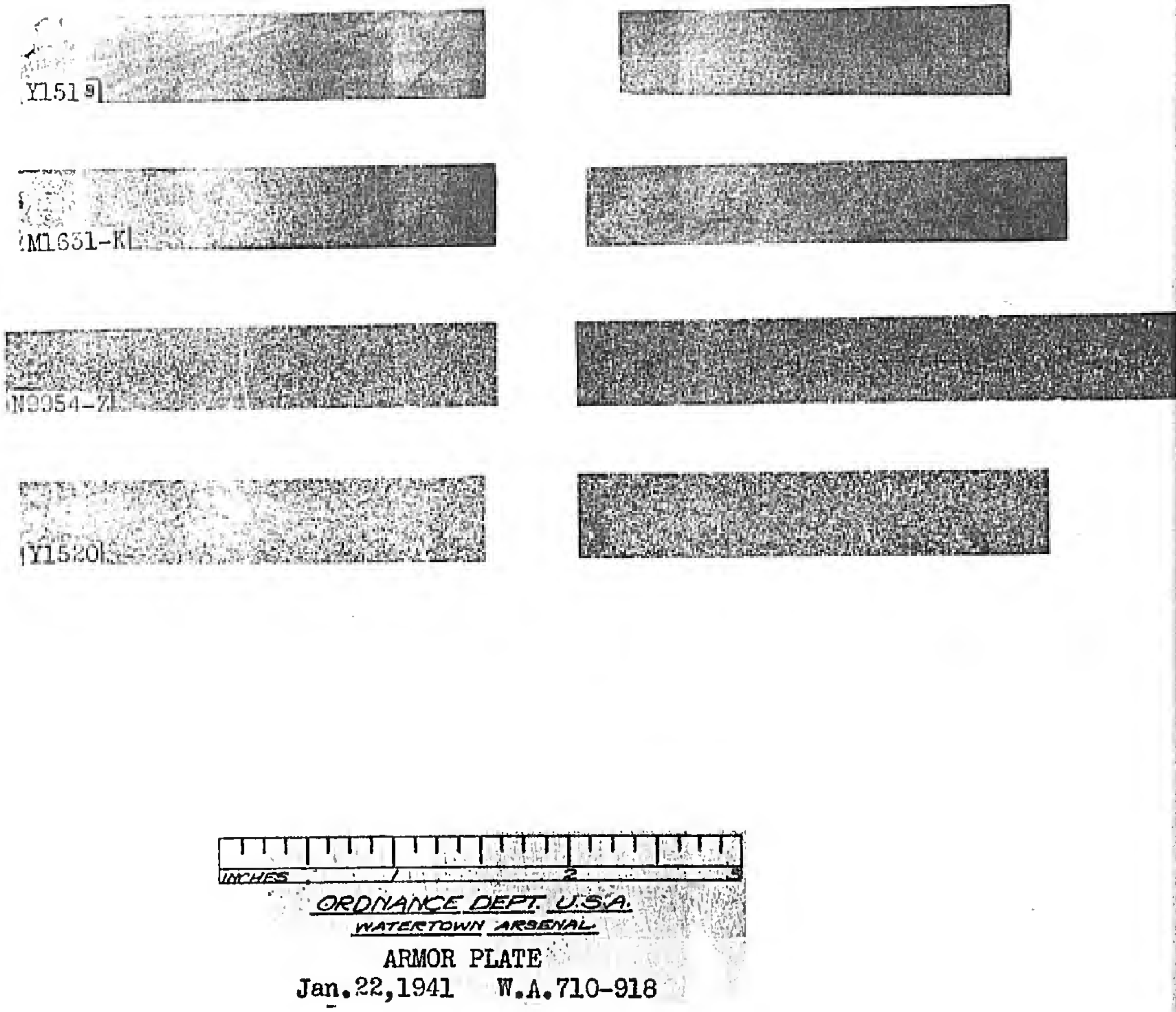

Y1519
M1631-K
N9954-Z
Y1520
INCHES
ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL
ARMOR PLATE
Jan.22,1941 W.A.710-918

FIG. 1

Figure 2

Distribution of Nonmetallic Inclusions

(a) Y1519 New Type Age-Hardenable Nickel

Few uniformly distributed nonmetallic inclusions. Specimen unetched.

X25 MA-3255

(b) Y1520 Beryllium Nickel

Exceptionally clean metal. Specimen unetched.

X25 MA-3256

(c) M-1631-K "K" Monel

A relatively dirty sample. Specimen unetched.

X25 MA-3257

(d) M-1631-K "K" Monel

Another sample of K-Monel. Fairly clean. Specimen unetched.

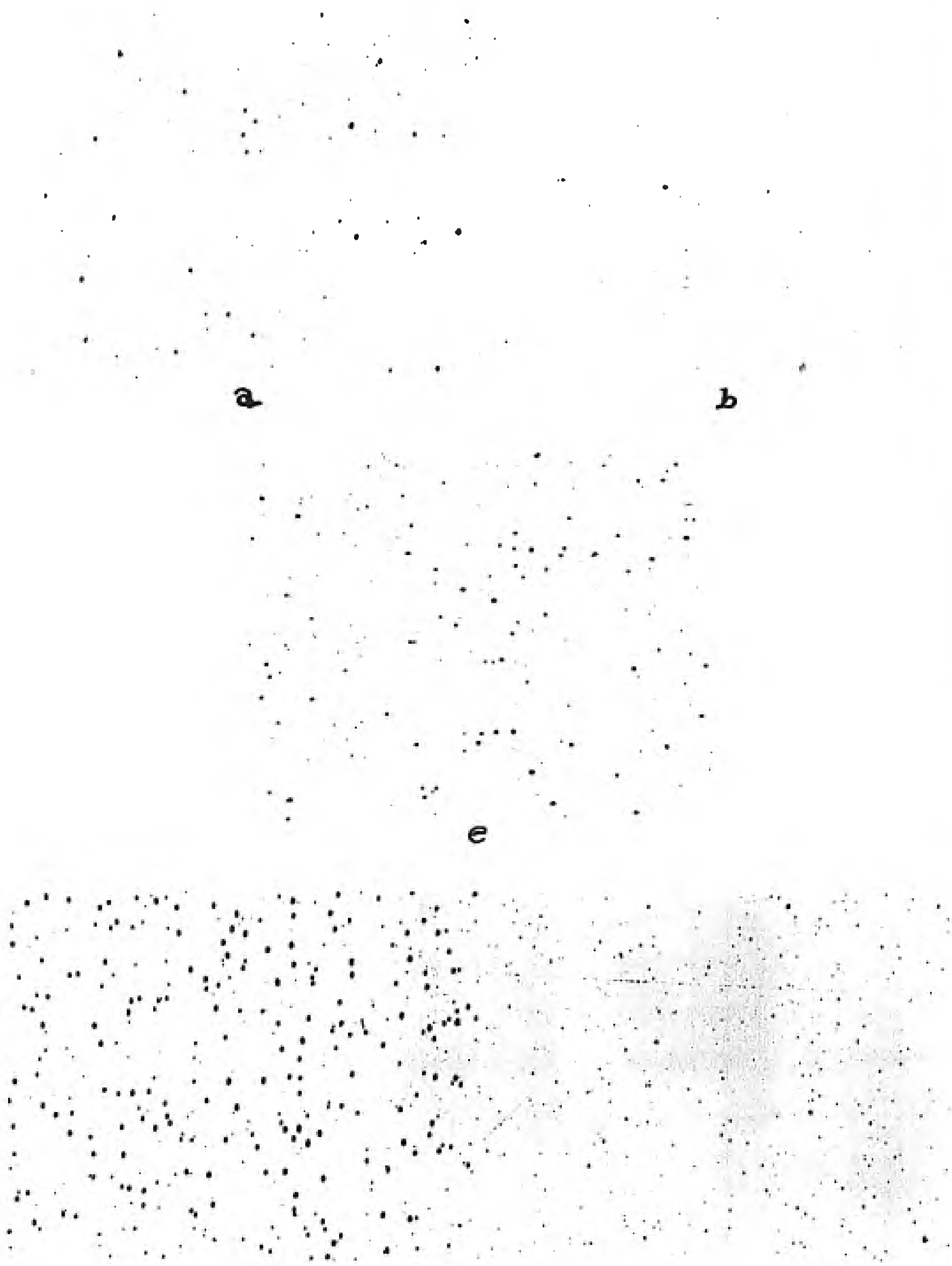
X25 MA-3258

(e) N9954Z "Z" Nickel

Uniformly distributed nonmetallics. Specimen unetched.

X25 MA-3259

Figure 2



W.A.639-3404

Figure 3

Structure of New Type Age-Hardenable Nickel

(a) Y1519

Uniform equiaxed grain size. Grain size measurement 340 grains/mm^2.

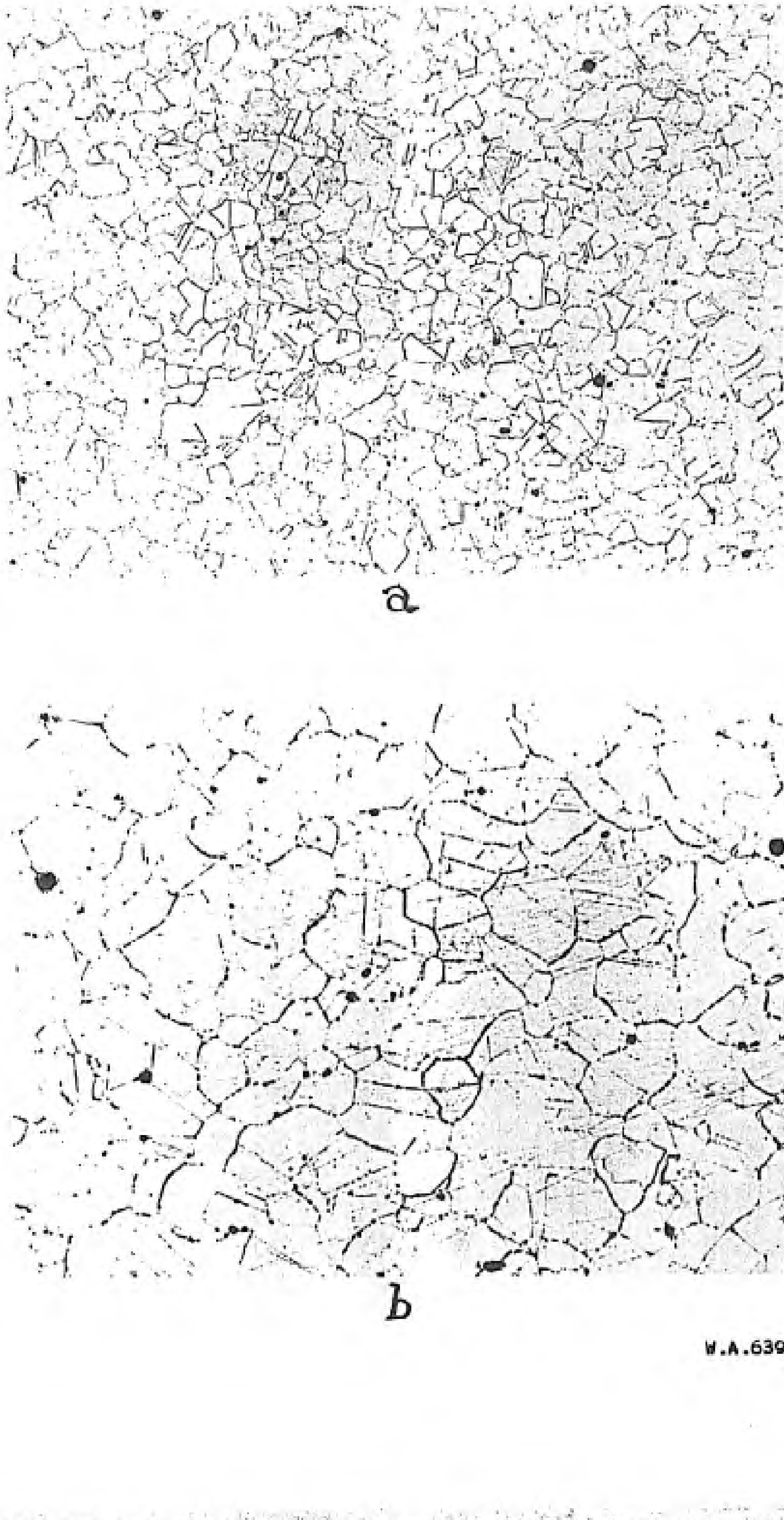
X100 MA-3272

(b) Same as (a), showing fine grain boundary segregate.

X250 MA-3273

Electrolytic Etch: 5% HAc, 10% HNO_3, 85% H_2O

Figure 3



a

b

W.A.639-3405

Figure 4

Structure of New Type Age-Hardenable Nickel

(a) Y1519

Same as 3(a). Gray cubic crystals at grain boundaries.

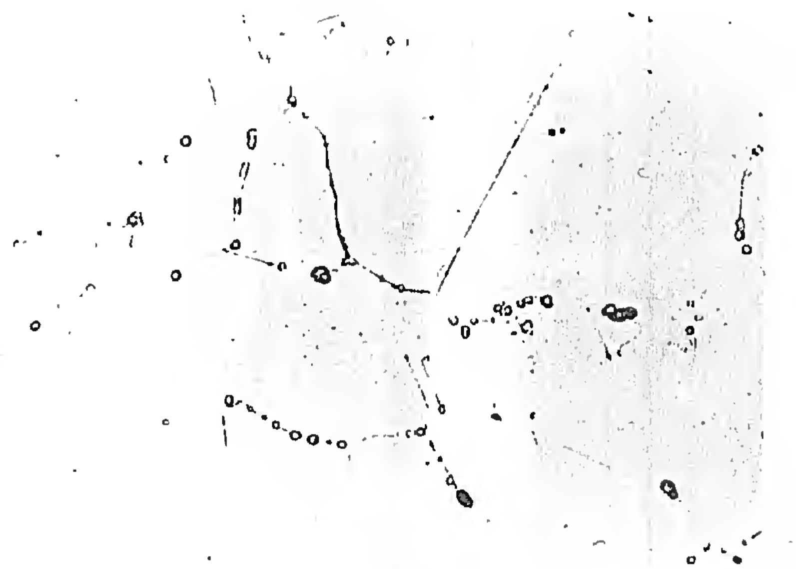
X1000 MA-3267

(b) Same as above. Examined under high magnification.

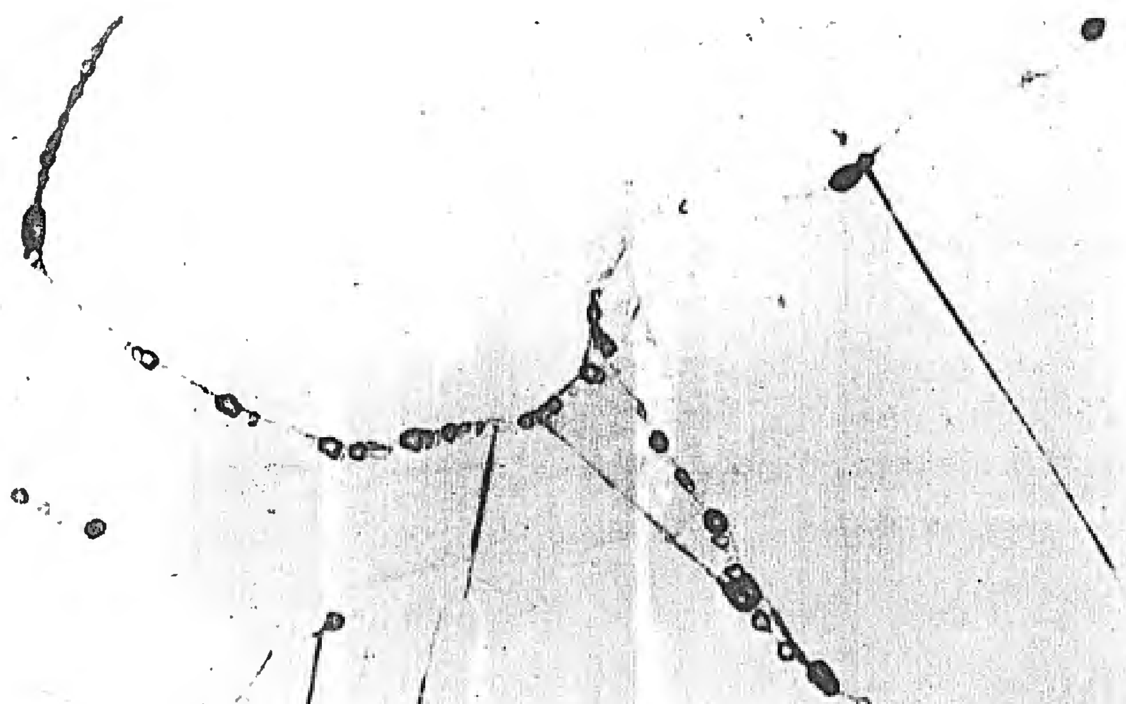
X2000 MA-3277

Electrolytic Etch: 5% HA_c, 10% HNO_3, 85% H_2O

Figure 4



a



b

W.A. 639- 3406

Figure 5

Structure of Beryllium Nickel

(a) Y1520

Segregates, dark brown in color in the grain boundaries. Segregates of white constituent scattered throughout the structure. Grain size measurement 56-62 grains/mm^2.

X100 MA-3271

(b) Same as (a). Showing banded structure and grain boundary segregates with same white constituent.

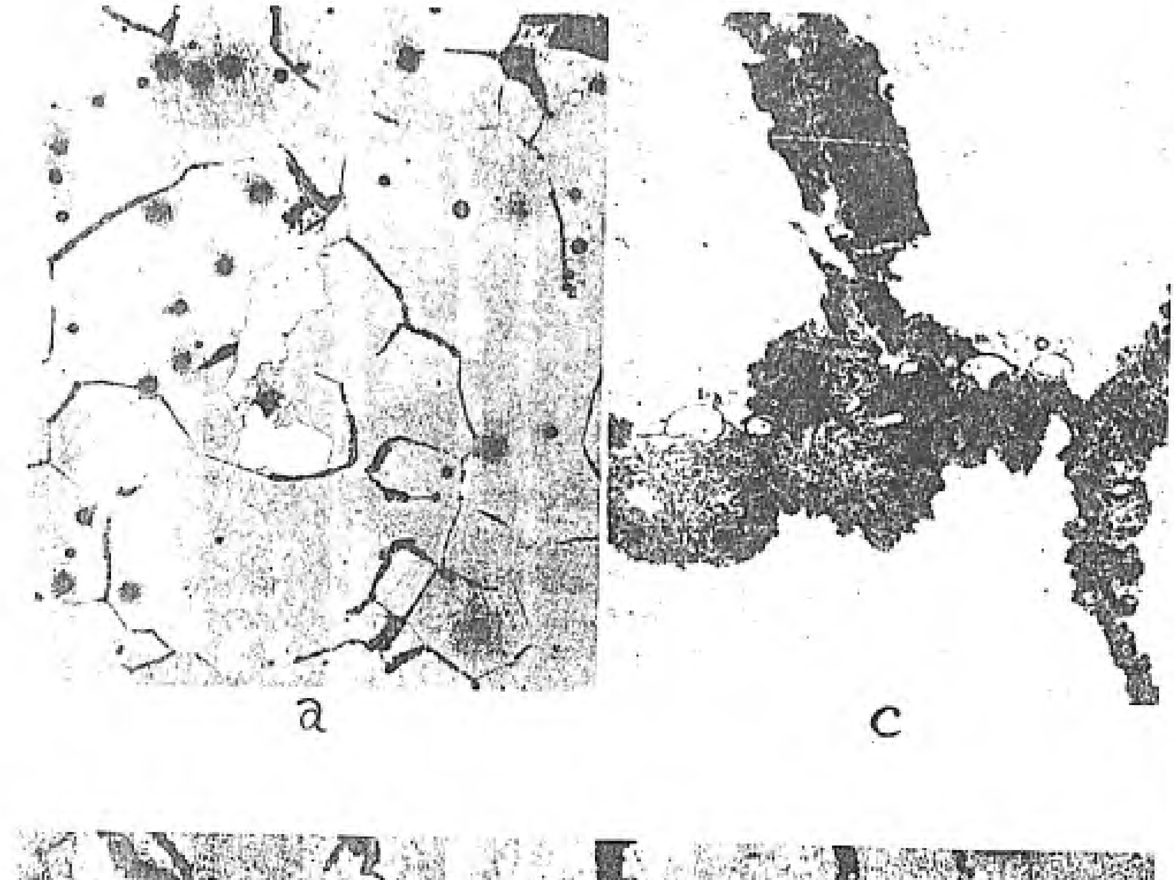
X250 MA-3264

(c) Same as (b). Showing grain boundary segregate under high magnification.

X1000 MA-3265

Electrolytic Etch 5% HA_c, 10% HNO_3, 85% H_2O

Figure 5



K.A.639-3407

Figure 6

Structure of "K" Monel

(a) M-1631-K "K" Monel

Uniform grain size - 420 grains/mm^2.

X100 MA-3270

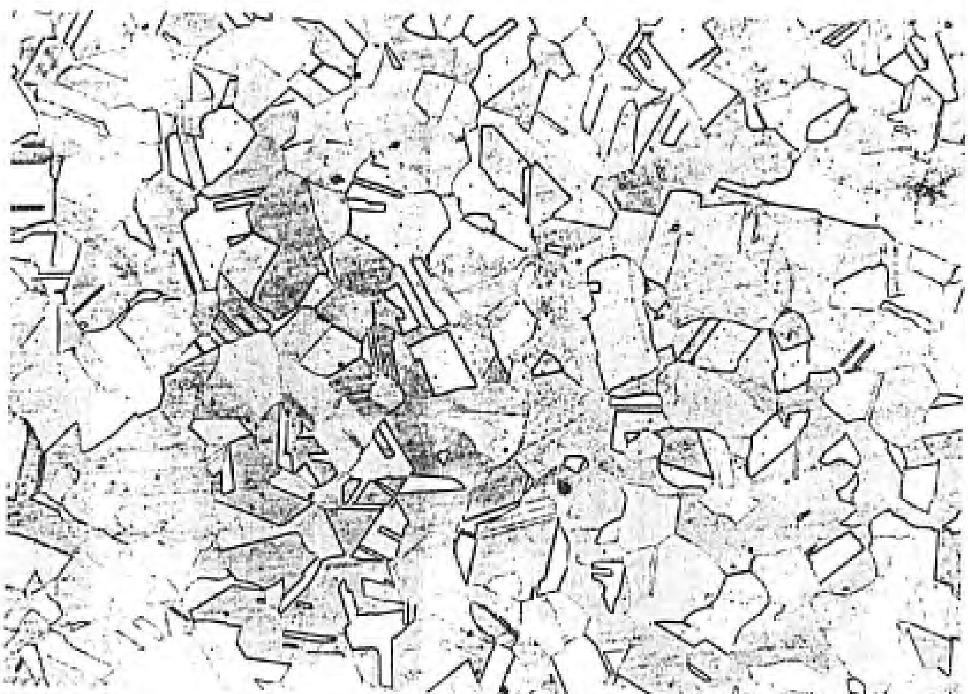
(b) Same as (a).

X250 MA-3274

Electrolytic Etch: 5% HA_c, 10% HNO_3, 85% H_2O

Figure 6

a



b

W.A.639-3408

Figure 7

Structure of "K" Monel

(a) Same as 6(a). Note absence of grain boundary segregates.

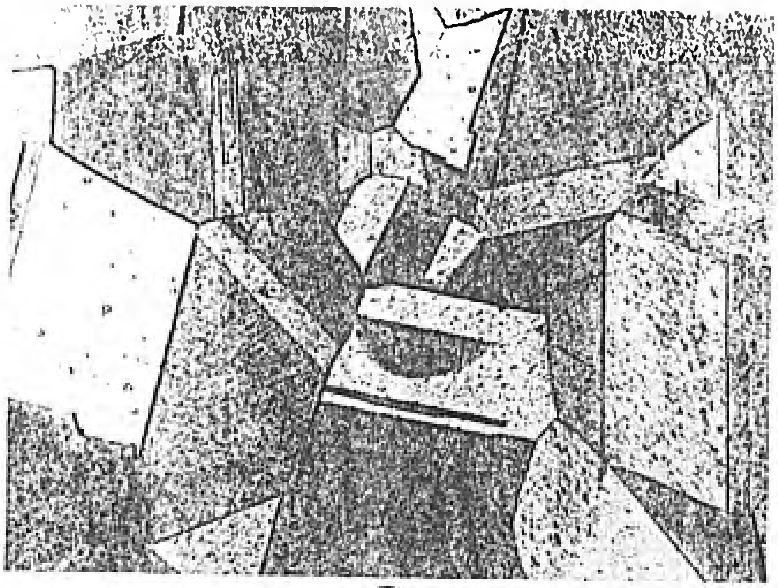
X1000 MA-3266

(b) Same as above.

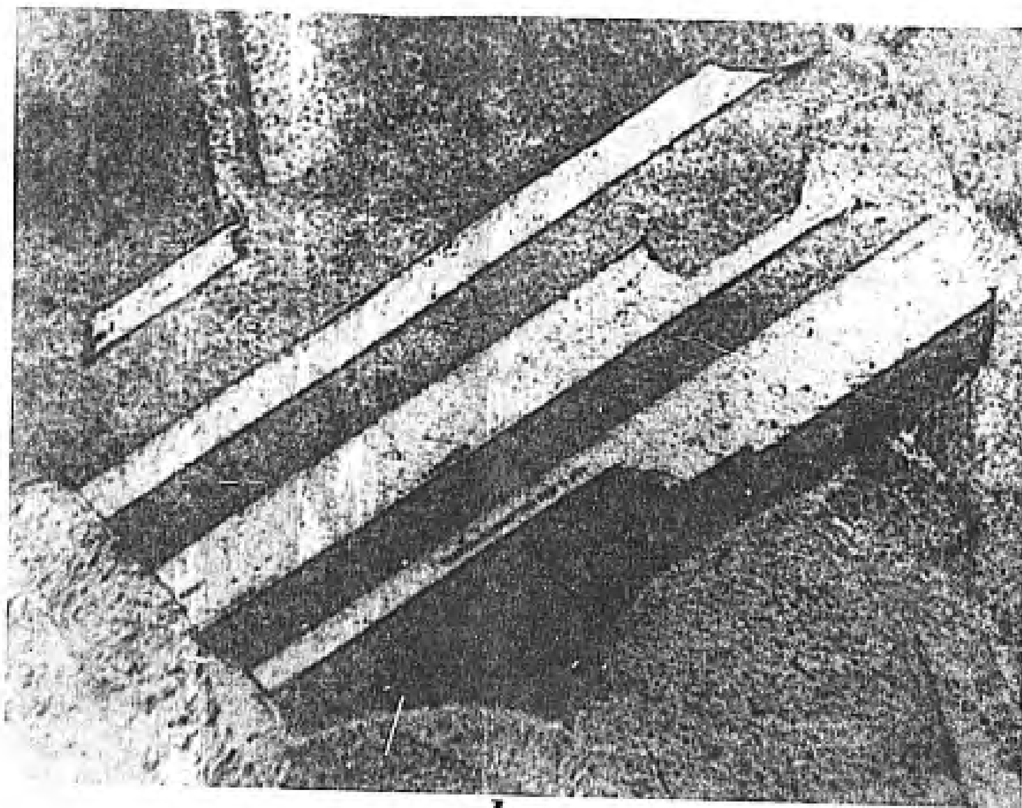
X2000 MA-3278

	5% HAc
Electrolytic Etch	10% HNO_3
	85% H_2O

Figure 7



a



b

W.A.639-3409

Figure 8

Structure of "Z" Nickel

(a) N9954 "Z" Nickel

Microstructure of area free from segregations. Grain size measurement 40 grains/mm^2 in this area.

X100 MA-3269

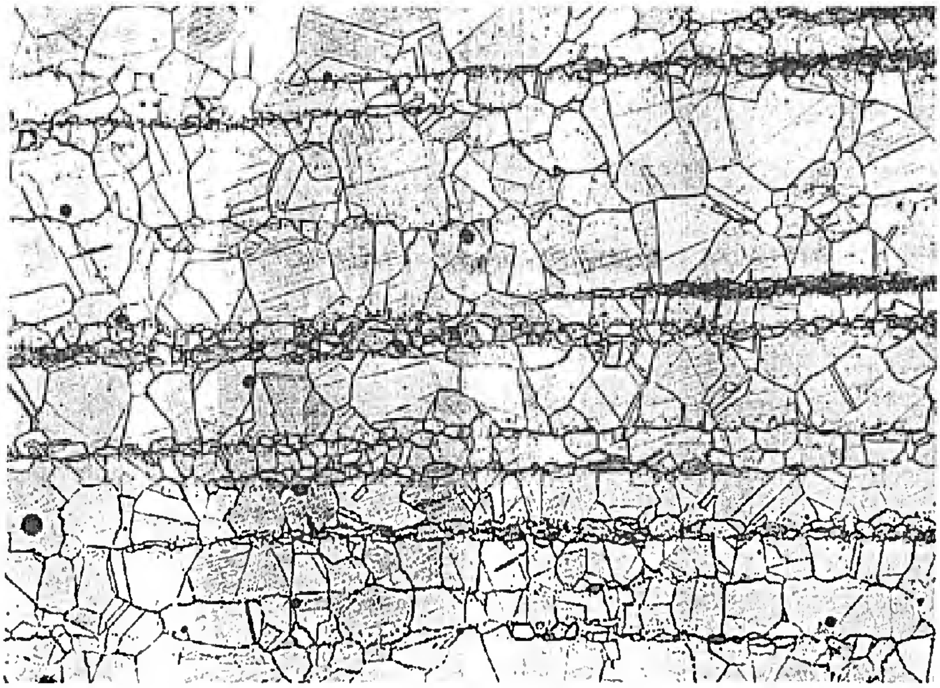
(b) Same as above. Showing a banded condition. Grain size measurement 187 grains/mm^2 in this area.

X100 MA-3268

Electrolytic etch 5% HA_c, 10% HNO_3, 85% H_2O

Figure 8

a



b

W.A.639-3410

Figure 9

Structure of "Z" Nickel

(a) Same as 8(a).

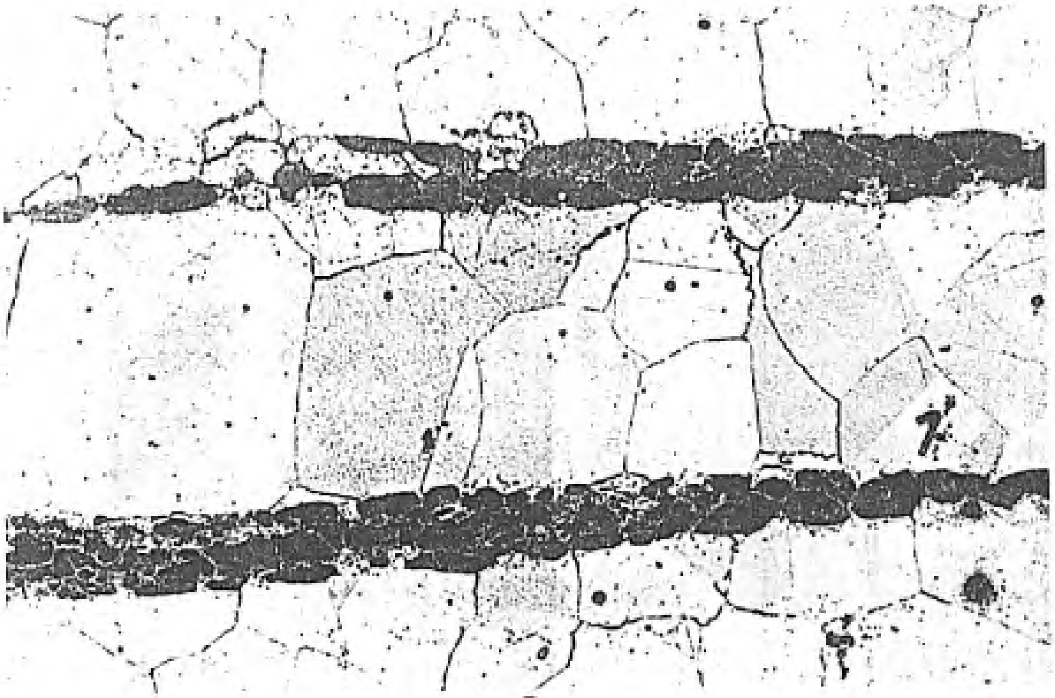
X250 MA-3263

(b) Microstructure of one of the bands shown in (a). Note the presence of light gray inclusions and a fine constituent.

X2000 MA-3276

Electrolytic Etch 5% HA_c, 10% HNO_3, 85% H_2O

Figure 9



a

b

W.A.639-3411

Figure 10

Structure of "Z" Nickel

(a) N9954 "Z" Nickel

Microstructure of banded area showing spheroidized constituent in band and segregate near the band.

X1000 MA-3261

(b) Showing light gray inclusions in band. A fine grain boundary segregate is present in the banded area.

X1000 MA-3260

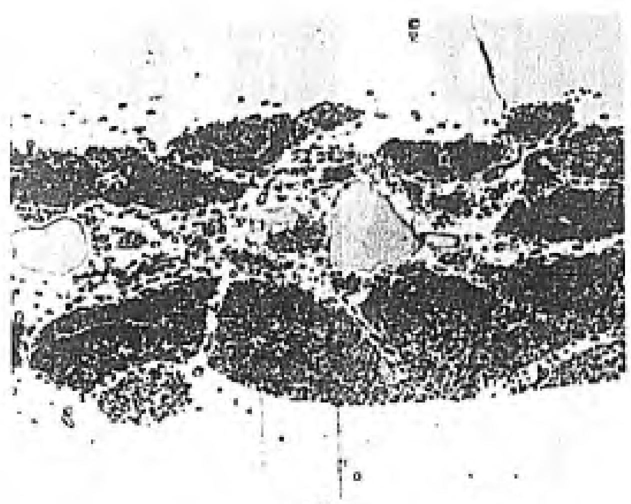
(c) Fine grain boundary segregate in area away from bands.

X1000 MA-3262

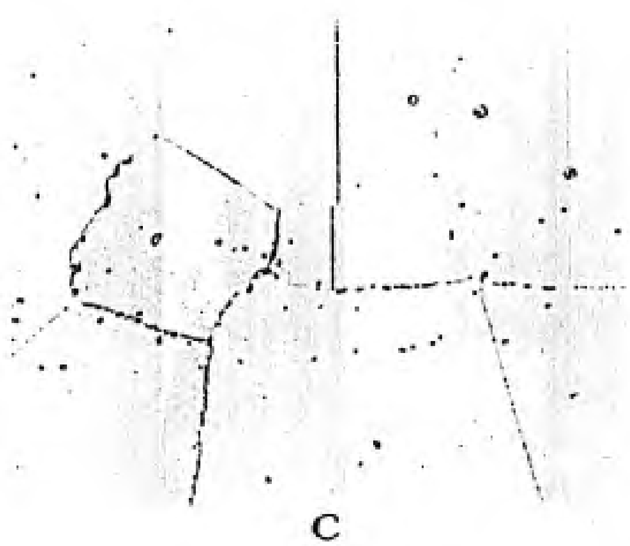
Electrolytic Etch 5% HA_c 10% HNO_3 85% H_2O

Figure 10

a



b



C

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