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N66-22932 (ACCESSION NUMBER)	(THRU)
20 (PAGES)	1 (CODE)
CR-54747 (NASA CR OR TMX OR AD NUMBER)	17 (CATEGORY)

FACILITY FORM 602

[redacted]

GD

GENERAL DYNAMICS

ASTRONAUTICS

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A2136-1 (REV. 6-61)

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

THE EFFECTS OF COLD ROLLING ON THE NOTCHED AND UNNOTCHED TENSILE PROPERTIES OF TYPE 310 STAINLESS STEEL AT + 75°F, -320°F, AND -423°F

MRG - 293
February 2, 1962

Prepared by: J. D. Gruner

GENERAL DYNAMICS/CONVAIR

MRG-293

2 February 1962

SUBJECT: The Effects of Cold Rolling on the Notched and Unnotched Tensile Properties of Type 310 Stainless Steel at +75°F, -320°F, and -423°F

N66-22932

ABSTRACT: The effects of various degrees of cold rolling on the notched and unnotched longitudinal and transverse tensile properties of Type 310 stainless steel sheet were determined at +75°F, -320°F and -423°F. Test results showed that this material exhibits good notched toughness at cryogenic temperatures. The notch toughness at -320°F and -423°F improved with increased cold rolling until a maximum was reached at approximately 60% reduction. Further cold working decreased the low temperature notch toughness.

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9 February 1962

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FROM: Materials Research Group, 592-1

SUBJECT: The Effects of Cold Rolling on the Notched and Unnotched Tensile Properties of Type 310 Stainless Steel at +78°F, -320°F and -423°F

BACKGROUND & PURPOSE:

A test program was conducted to determine the effects of various degrees of cold rolling on the low temperature notched and unnotched tensile properties of 310 stainless steel. The purpose of this report is to present the findings of this program.

PROCEDURE:

Notched and unnotched longitudinal and transverse tensile specimens were machined from each thickness of originally annealed 0.080" sheet that was reduced by cold rolling to 0.070", 0.050", 0.030" and 0.016" in thickness. Tensile tests were conducted at room temperature (+75°F), -320°F and -423°F. The latter two temperatures were obtained by immersing the specimens in liquid nitrogen and liquid hydrogen respectively.

A complete chemical analysis was made of the material. Microscopic specimens were prepared and examined from the 0.080" and 0.016" material.

RESULTS & DISCUSSIONS:

Results of the chemical analysis are given in Table I. The chemical composition of the material tested was within the limits specified for Type 310 stainless steel in AMS 5521B. In addition to the elements specified in AMS 5521B the amount of nitrogen was determined. The effects of nitrogen in austenitic stainless are generally similar to those of carbon.

The mechanical properties determined by the smooth and notched tensile tests are compiled in Table II and plotted against the amount of cold work in Figures 1, 2, 3 and 4. Figure 1 was plotted for longitudinal and transverse properties at +75°F, Figure 2 for these properties at -320°F and Figures 3 and 4 for these properties at -423°F.

Examination of Figures 2, 3 and 4 show the annealed material at -320°F and the annealed and 0.070" thickness material (12.5% cold reduction) at -423°F to have a notched unnotched tensile ratio of somewhat less than unity. The notched tensile fractures of these specimens were ductile in appearance and contained distinct shear lips. This indicates that the material did not fail in a brittle manner even though the notched-unnotched ratio was below unity.

Further examination of Figures 1, 2, 3 and 4 show that the notched-unnotched tensile ratio improves significantly with cold reduction until a maximum is reached, then decreases with further cold working. This maximum varies, depending on the temperature and the grain direction. The optimum toughness at low temperatures, considering both grain direction and temperature, appears to be at approximately 60% cold reduction.

Figures 2, 3 and 4 also show the low temperature transverse notched-unnotched tensile ratio of the annealed material to be slightly lower than the longitudinal ratio. In all but the 0.050" thickness material (37.5% reduction) at -320°F the transverse notched-unnotched tensile ratios of the cold worked material were higher than the longitudinal ratios at -320°F and -423°F. The room temperature transverse notched-unnotched tensile ratio was less than the longitudinal ratio at all degrees of cold reduction with the exception of the 0.070" material (12.5% reduction).

At the present time there is no clear cut explanation as to why at low temperatures the notched-unnotched tensile ratio increases with cold working until a maximum is reached, then declines with further cold working. This same phenomenon has been observed in other 300 series stainless steels, particularly in Type 301.

The microstructures of the annealed (0.080") material and the most severely reduced (0.016") material are shown in Figures 5 through 8. Etching this material with electrolytic sodium cyanide revealed the presence of discontinuous networks of grain boundry carbides, see Figures 9 and 10, in the annealed 0.080" material. The mechanical property data show that this material has good notched toughness at extreme low temperature even though these carbides were present. In the severely cold worked 0.016" material, the carbides occurred in streaks of globular carbides elongated in the direction of cold work, see Figures 11 and 12.

SUMMARY:

Although the amount of data from this test program are limited the following conclusions can be made: a) using the notched-unnotched tensile ratio as a basis, cold worked Type 310 stainless steel exhibites good longitudinal and transverse toughness at room temperature, -320°F and -423°F. b) The notched toughness of this material at -320°F and -423°F improves significantly with cold working and reaches an optimum value at approximately 60% cold reduction. Further cold working decreases the notch toughness. This indicates that cold working up to 60% reduction not only increases the strength of Type 310 stainless steel but also increases its resistance to brittle behavior at extreme low temperatures.

c) **Type 310 stainless steel sheet in the cold rolled condition exhibits relatively little directionality in strength, ductility, and toughness properties. Other stainless steels, notably Type 301, exhibit considerable directionality, with markedly reduced toughness in the transverse direction.**

TABLE I

The chemical composition of 310 stainless steel from Heat No. 43631, Washington Steel Corp., Washington, Pa.

	%C	%N2	%Mn	%P	%S	%Si	%Cr	%Ni	%Cu	%Mo
AMS 5521B	.08 Max		2.00 Max	.040 Max	.030 Max	.75 Max	24.00 26.00	19.00 22.00	.50 Max	.50 Max
Test Results	.07	.06	1.64	.026	.015	.52	24.27	20.34	.20	.24

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TABLE II

Low Temperature Mechanical Properties of 310 Stainless Steel at Various Degrees of Cold Rolling

Thickness	% Coldwork	Test Temp.	Grain Direction	Fty KSI	Ftu KSI	% Elong	Notched Ftu KSI	Notch/Unnotched Ratio
.080	0	+78°F	Long	40.3	85.8	46.0	93.9	1.09
.080	0	+78°F	Trans	34.8	86.8	46.0	91.6	1.05
.080	0	-320°F	Long	86.8	163.9	71.0	155.0	
.080	0	-320°F	Long	86.2	163.0	71.5	155.8	
	Avg.	-320°F	Long	86.5	163.5	71.3	155.4	0.95
.080	0	-320°F	Trans	89.2	164.1	69.5	151.3	
.080	0	-320°F	Trans	90.3	165.5	73.0	150.8	
	Avg.	-320°F	Trans	89.8	164.8	71.3	151.1	0.92
.080	0	-423°F	Long	114.0	196.2	54.5	182.3	
.080	0	-423°F	Long	112.5	195.9	50.0	182.5	
	Avg.	-423°F	Long	113.3	196.1	52.3	182.4	0.93
.080	0	-423°F	Trans	115.8	197.3	54.0	179.0	
.080	0	-423°F	Trans	117.1	187.8	34.5	178.2	
	Avg.	-423°F	Trans	116.5	197.1	44.3	178.6	0.91
.070	12.5	+78°F	Long	87.6	100.2	24.0	114.9	1.15
.070	12.5	+78°F	Trans	88.9	100.6	21.5	119.5	1.19
.070	12.5	-320°F	Long	130.4	182.7	53.0	186.4	
.070	12.5	-320°F	Long	131.2	181.7	49.0	186.2	
	Avg.	-320°F	Long	130.8	182.2	51.0	186.3	1.02
.070	12.5	-320°F	Trans	122.5	179.8	52.5	188.3	
.070	12.5	-320°F	Trans	123.6	180.7	55.0	184.6	
	Avg.	-320°F	Trans	123.1	180.3	53.8	186.5	1.03
.070	12.5	-423°F	Long	156.6	221.3	43.0	212.1	
.070	12.5	-423°F	Long	154.7	220.4	42.0	213.2	
	Avg.	-423°F	Long	155.7	220.9	42.5	212.7	0.96
.070	12.5	-423°F	Trans	138.3	215.8	43.5	211.3	
.070	12.5	-423°F	Trans	149.6	214.6	40.5	209.6	
	Avg.	-423°F	Trans	144.0	215.2	42.0	210.5	0.98

TABLE II (continued)

Thickness	% Coldwork	Test Temp.	Grain Direction	Fty KSI	Ftu KSI	% Elong.	Notched Ftu KSI	Notched/Unnotched Ratio
.050	37.5	+78°F	Long	125.1	139.0	8.5	166.9	1.20
.050	37.5	+78°F	Trans	126.4	140.4	8.5	167.2	1.19
.050	37.5	-320°F	Long	164.6	207.3	30.5	236.3	
.050	37.5	-320°F	Long	159.9	208.2	32.0	236.8	
	Avg.	-320°F	Long	162.3	207.8	31.3	236.6	1.14
.050	37.5	-320°F	Trans	168.6	208.1	31.5	234.9	
.050	37.5	-320°F	Trans	161.9	208.2	29.5	234.5	
	Avg.	-320°F	Trans	165.3	208.2	30.5	234.7	1.13
.050	37.5	-423°F	Long	191.7	243.2	31.0	261.3	
.050	37.5	-423°F	Long	189.5	243.2	23.0	261.2	
	Avg.	-423°F	Long	190.6	243.2	27.0	261.3	1.07
.050	37.5	-423°F	Trans	190.6	243.1	31.5	264.8	
.050	37.5	-423°F	Trans	182.9	241.9	32.0	260.4	
	Avg.	-423°F	Trans	186.8	242.5	31.8	262.6	1.08
.030	62.5	+78°F	Long	160.5	166.9	4.0	181.3	1.09
.030	62.5	+78°F	Trans	149.5	180.5	5.0	181.3	1.00
.030	62.5	-320°F	Long	210.9	235.7	18.5	262.9	
.030	62.5	-320°F	Long	209.9	236.6	18.0	263.5	
	Avg.	-320°F	Long	210.4	236.2	18.3	263.2	1.11
.030	62.5	-320°F	Trans	197.4	247.0	16.0	292.4	
.030	62.5	-320°F	Trans				300.7	
	Avg.	-320°F	Trans	197.4	247.0	16.0	296.6	1.20
.030	62.5	-423°F	Long	241.5	264.0	3.0	295.4	
.030	62.5	-423°F	Long	237.7	275.6	17.5	297.4	
	Avg.	-423°F	Long	239.6	269.8		296.4	1.10
.030	62.5	-423°F	Trans	224.5	279.4	14.5	317.7	
.030	62.5	-423°F	Trans	222.9	280.7	17.0	324.4	
	Avg.	-423°F	Trans	223.7	280.1	15.5	321.1	1.15
.016	80.0	+78°F	Long	171.4	186.8	2.0	199.4	1.07
.016	80.0	+78°F	Trans	162.3	210.3	3.5	209.8	1.00
.016	80.0	-320°F	Long	235.2	256.2	9.0	269.7	
.016	80.0	-320°F	Long	236.2	254.7	9.0	264.7	
	Avg.	-320°F	Long	235.7	255.5	9.0	267.2	1.05

TABLE II (continued)

Thickness	% Coldwork	Test Temp.	Grain Direction	Fty KSI	Ftu KSI	% Elong.	Notched Ftu KSI	Notched/Unnotched Ratio
.016	80.0	-320°F	Trans	245.6	286.3	10.0	327.8	
	80.0	-320°F	Trans				307.1	
	Avg.	-320°F	Trans	245.6	286.3	10.0	317.5	1.11
.016	80.0	-423°F	Long	255.6	294.6	6.5	315.1	
.016	80.0	-423°F	Long	258.6	292.2	9.0	318.3	
	Avg.	-423°F	Long	257.1	293.4	7.8	316.7	1.08
.016	80.0	-423°F	Trans	257.6	316.4	8.0	345.7	
.016	80.0	-423°F	Trans	263.7	314.1	7.5	363.9	
	Avg.	-423°F	Trans	260.7	315.8	7.8	354.8	1.13

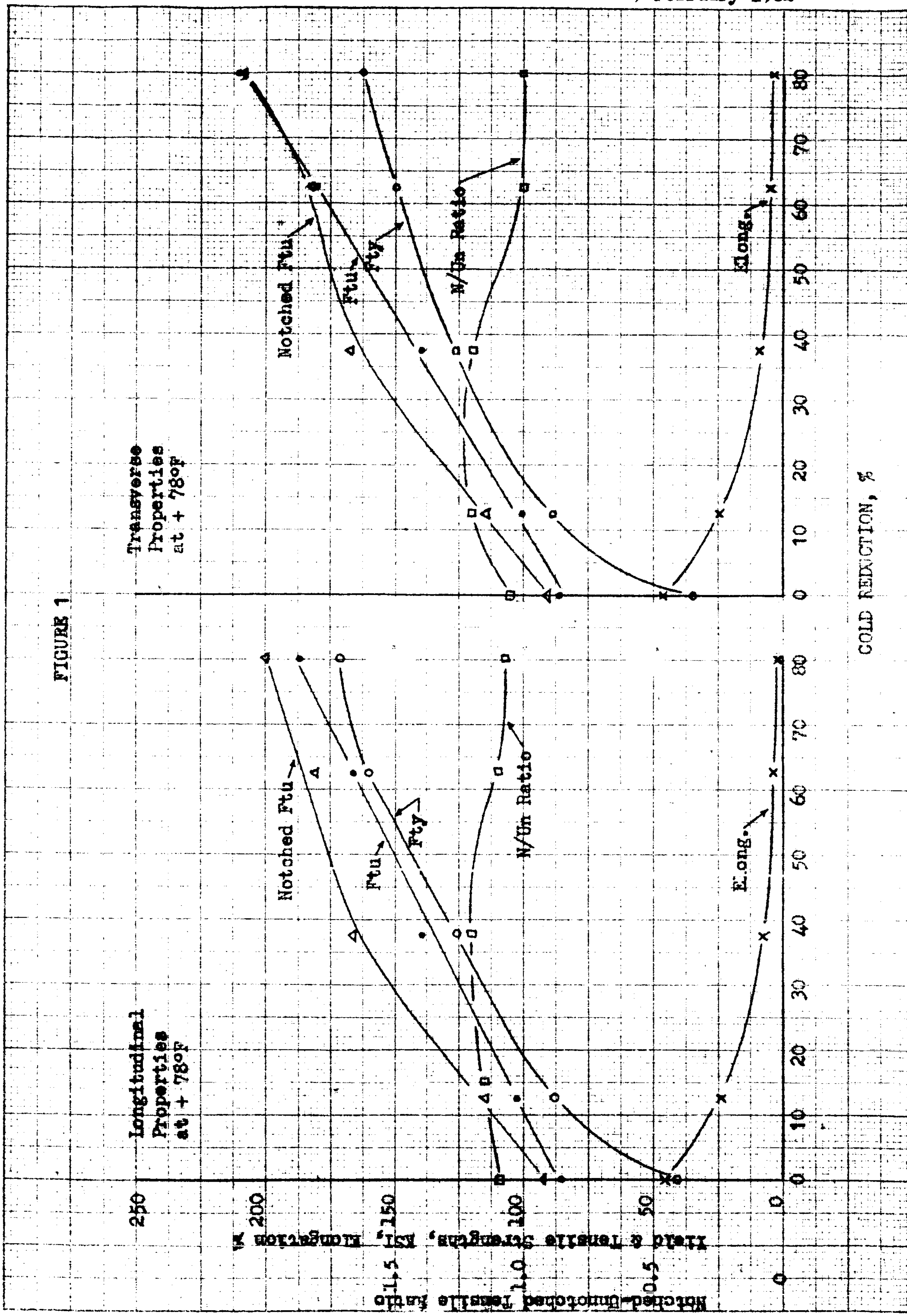

Longitudinal Properties at + 78°F
Transverse Properties at + 78°F
Notched Ftu
Ftu
Fty
N/Un Ratio
Elong.
Yield & Tensile Strengths, KSI, Elongation %
Notched-Unnotched Tensile Ratio
COLD REDUCTION, %
250
200
150
100
50
0
1.5
1.0
0.5
0
0
10
20
30
40
50
60
70
80

FIGURE 1

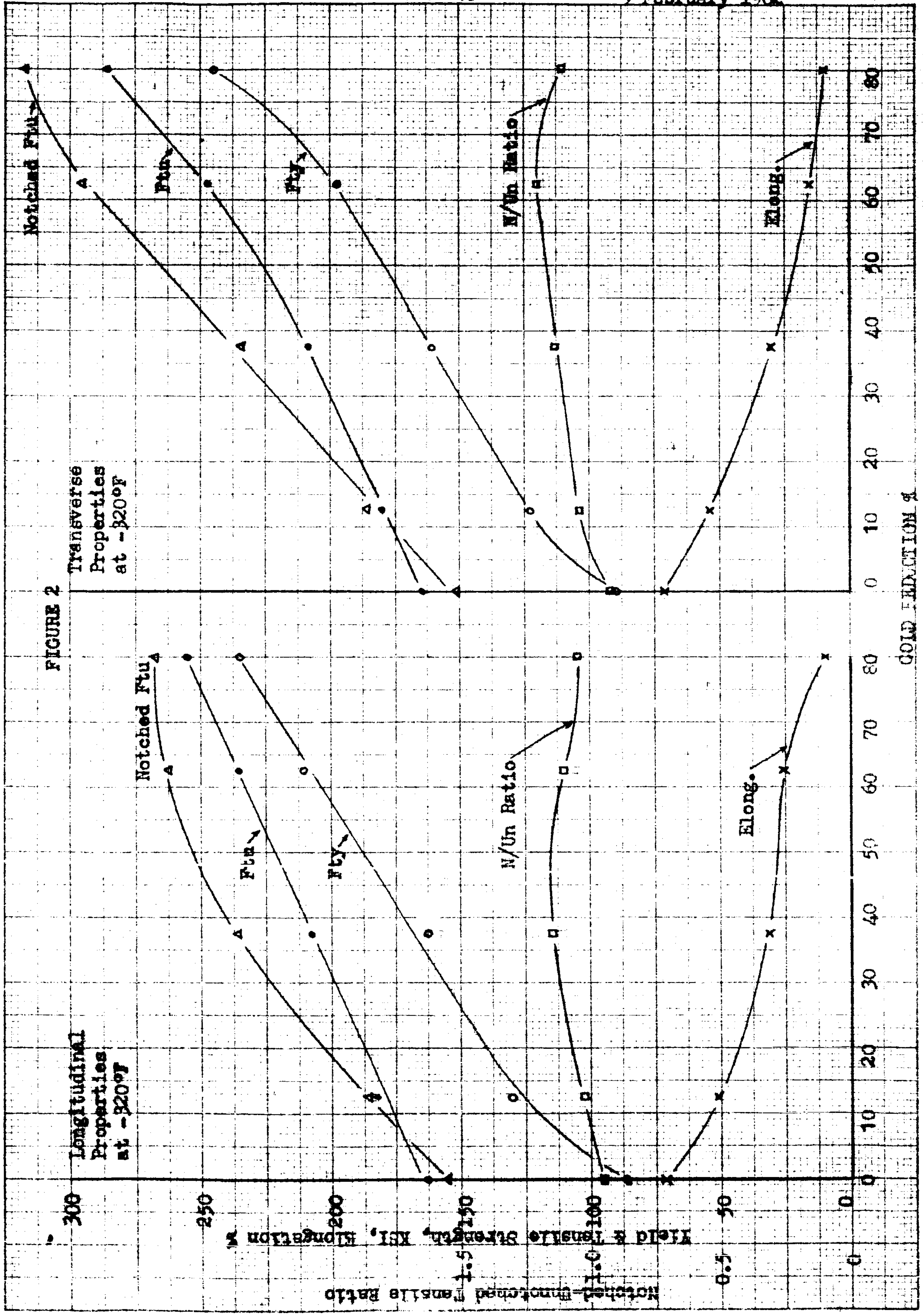

Longitudinal Properties at -320°F
Transverse Properties at -320°F
Notched Ftu
Ftu
Fty
N/Un Ratio
Elong.
COLD REDUCTION %
Yield & Tensile Strength, KSI, Elongation %
Notched-Unnotched Tensile Ratio

FIGURE 2

FIGURE 3

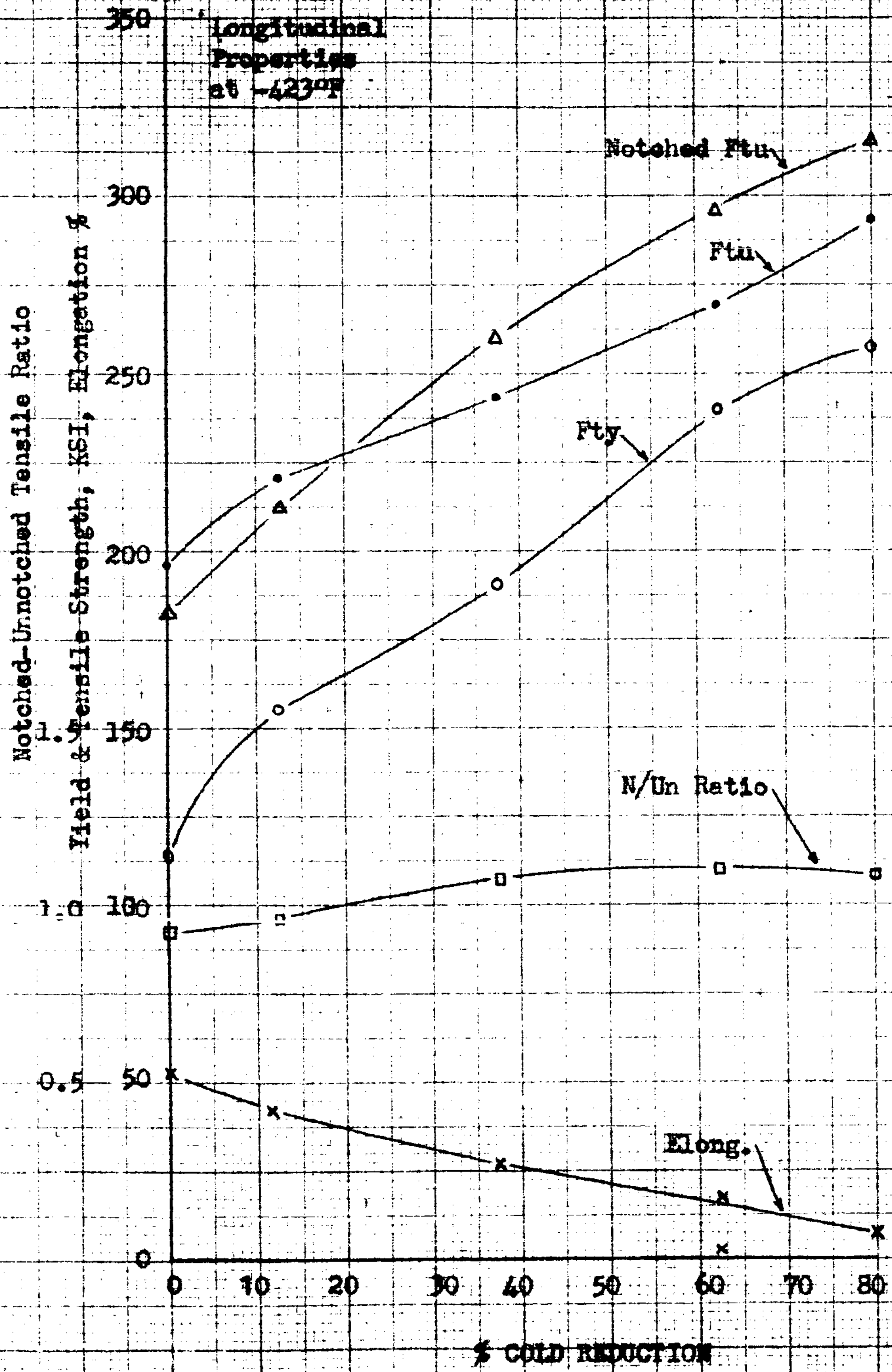
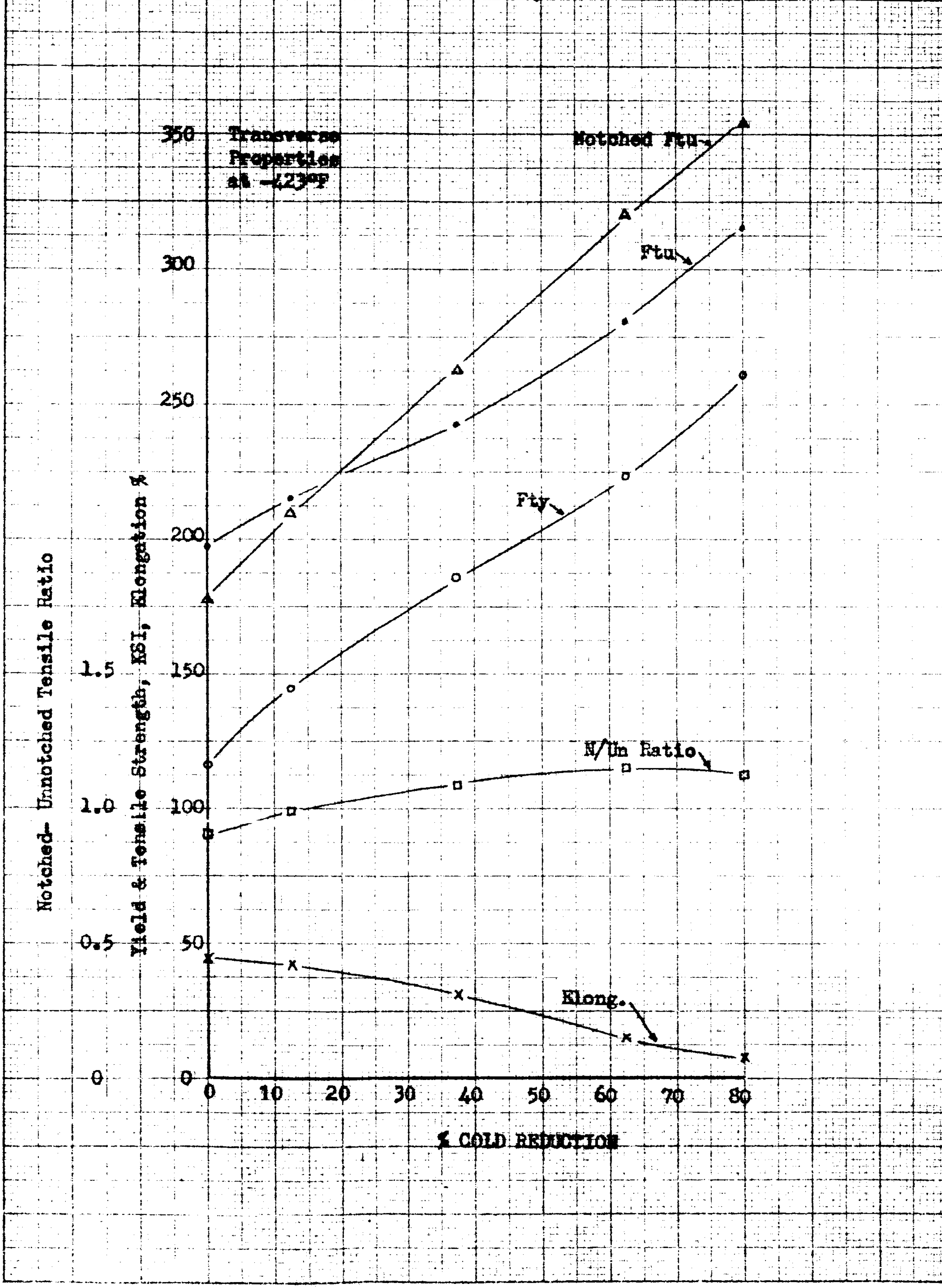
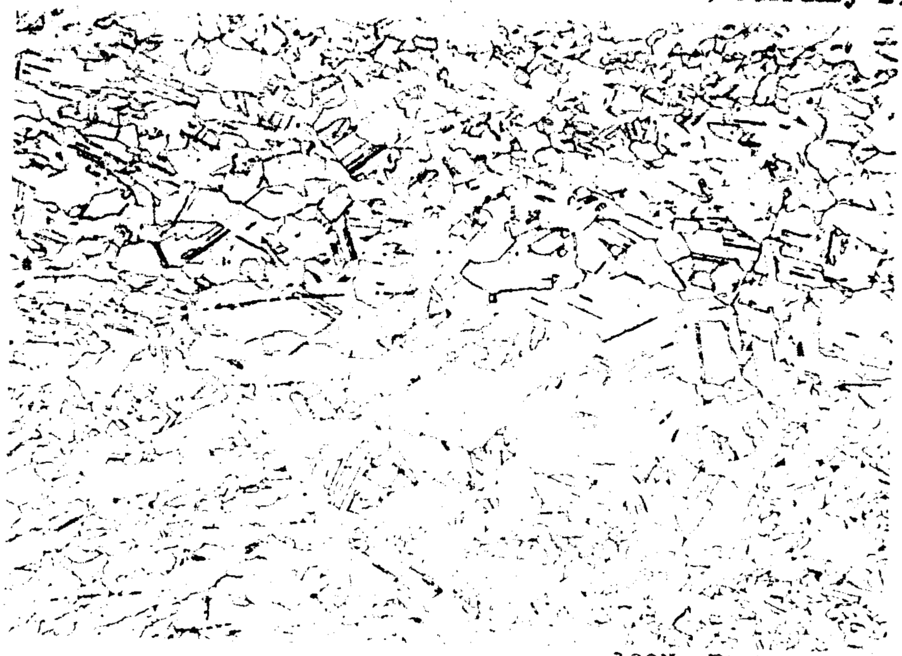

Longitudinal
Properties
at -423°F
Notched Ftu
Ftu
Fty
N/Un Ratio
Elong.
Notched-Unnotched Tensile Ratio
Yield & Tensile Strength, KSI, Elongation %
350
300
250
200
1.5 150
1.0 100
0.5 50
0
0 10 20 30 40 50 60 70 80
% COLD REDUCTION

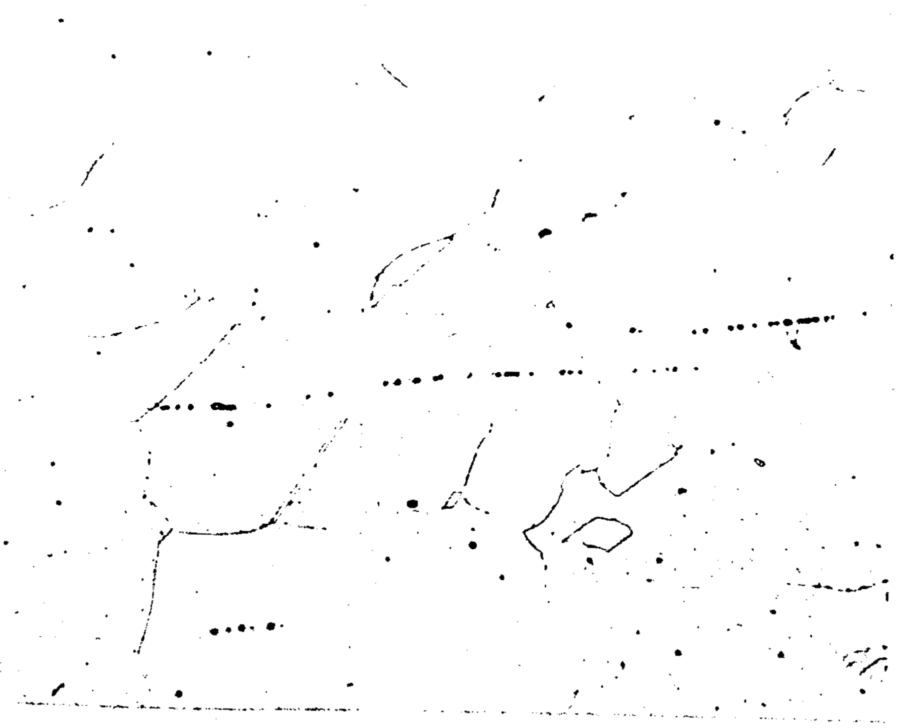
FIGURE 4


Transverse
Properties
at -423°F
Notched Ftu
Ftu
Fty
N/Un Ratio
Elong.
Notched- Unnotched Tensile Ratio
Yield & Tensile Strength, KSI, Elongation %
350
300
250
200
150
100
50
0
1.5
1.0
0.5
0
0
10
20
30
40
50
60
70
80
% COLD REDUCTION



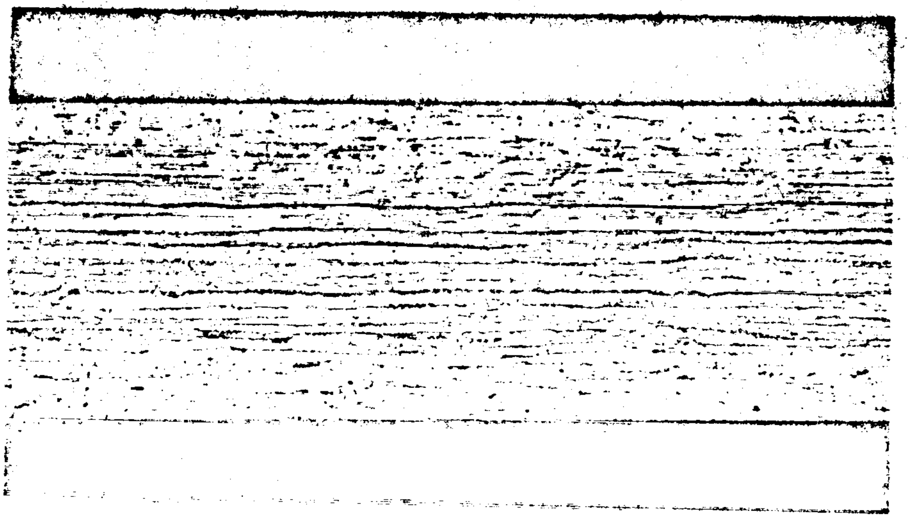
100X Etched-Oxalic

FIGURE 5 - The microstructure of a longitudinal section of the annealed 0.080" thickness material. A relatively small amount of inclusions and foreign particles are visible in a recrystallized austenitic matrix.



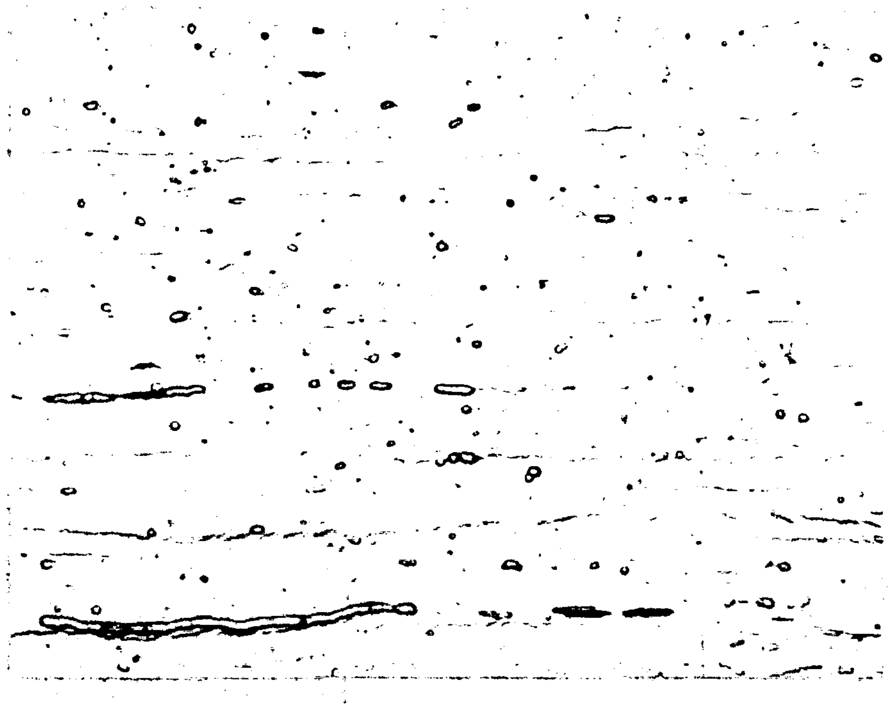
500X Etched-Oxalic

FIGURE 6 - A higher magnification view of the microstructure from the annealed .080" thickness material.



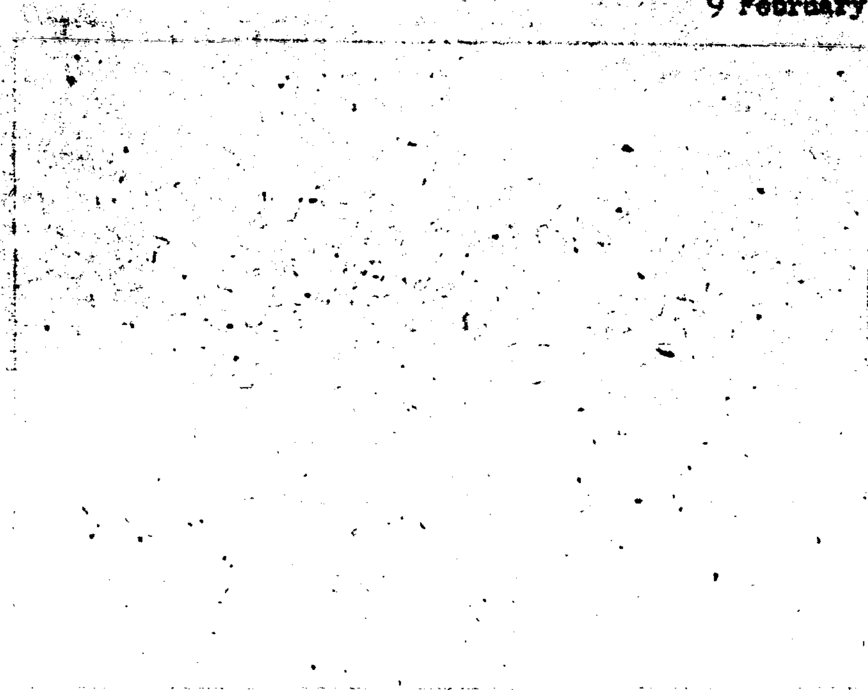
100X Etched-Oxalic

FIGURE 7 - The microstructure of a longitudinal section of the 0.016" thickness material. This material has been severely cold worked (80% reduction)



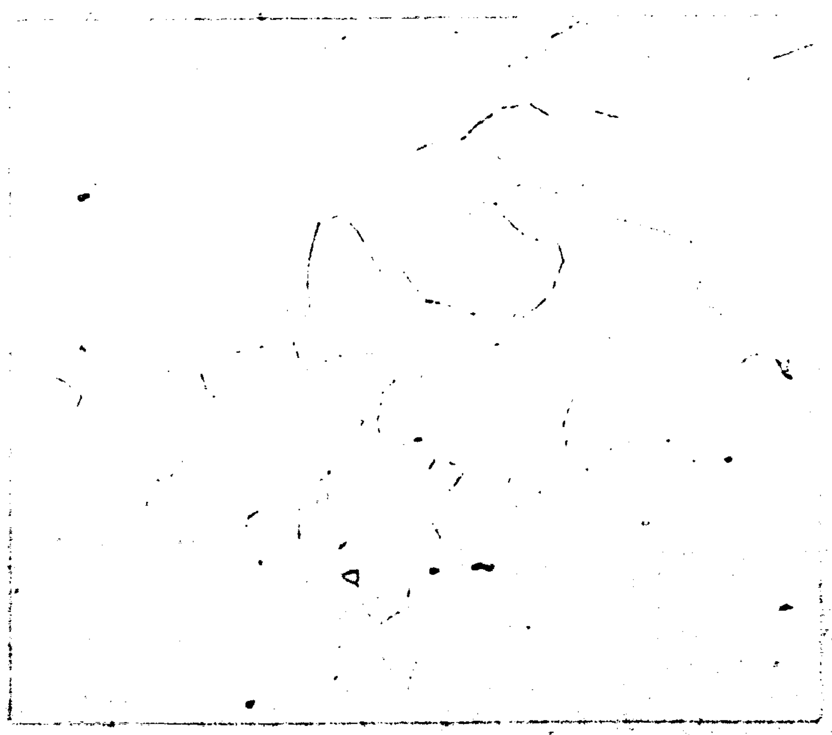
500X Etched-Oxalic

FIGURE 8 - A higher magnification of the microstructure of the 0.016" thickness material.



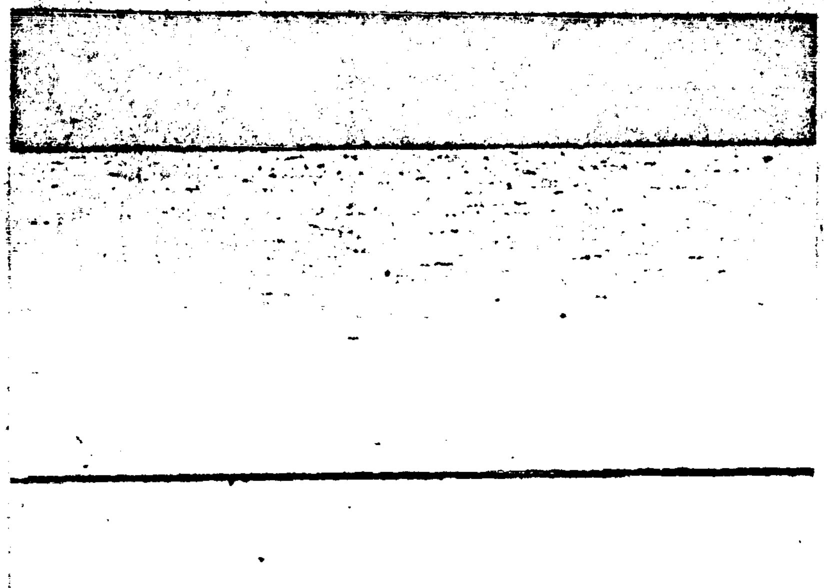
100X Etched-Sodium Cyanide

FIGURE 9 - The presence of a discontinuous net work of grain boundry carbides, shown as dark lines, was determined by electrolytically etching with sodium cyanide.



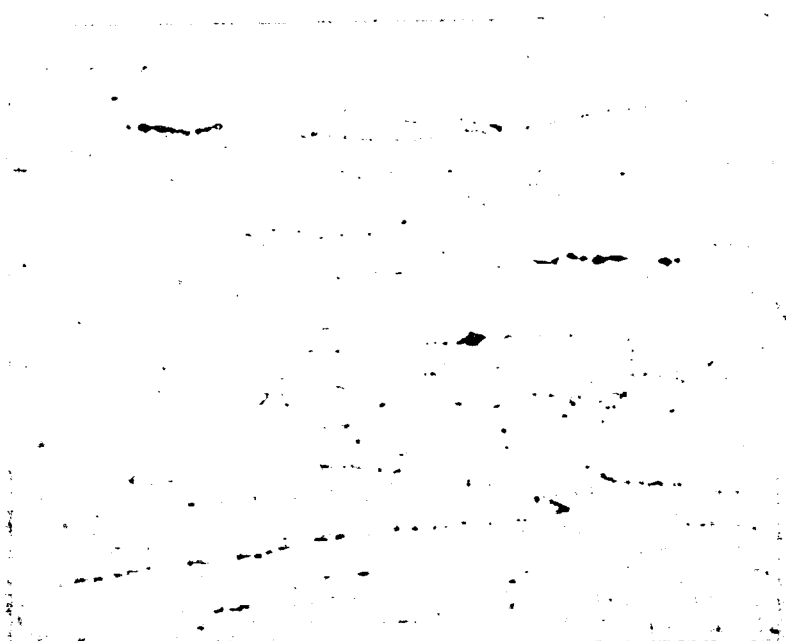
500X Etched-Sodium Cyanide

FIGURE 10 - A higher magnification of the discontinuous network of grain boundry carbides revealed by the electrolytic sodium cyanide etch.



100X Etched-Sodium Cyanide

FIGURE 11 - A longitudinal cross section of the 0.016" material electrolytically etched with sodium cyanide. The network of globular carbides has been elongated in the driection cold work.



500 X Etched-Sodium Cyanide

FIGURE 12 - A higher magnification of the elongated network of globular carbides in the 0.016" material

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