NASA/MSFC Contract NAS 8-11282

Solar Reference: SO 6-1616-7

PROGRESS REPORT 3

PERIOD COVERED 1 September through 30 September 1964

DESIGN, FABRICATION, AND TESTING OF PRESSURIZATION AND PROPELLANT FEED DUCTING SYSTEMS

SUBMITTED TO

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama

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SOLAR
San Diego, California
A DIVISION OF INTERNATIONAL HARVESTER COMPANY

ER 1474-3

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INTRODUCTION

This is the third progress report on the program to provide design, fabrication, and testing services leading to optimum pressurization and propellant feed ducting systems under National Aeronautics and Space Administration - Marshall Space Flight Center Contract Number NAS11-282.

The period covered by this report is 1 September through 30 September 1964.

This program is being conducted under the direction of Solar Aerospace Engineering with Mr. H. T. Mischel as Program Manager. Mr. D. E. Henry is NASA Contract Technical Supervisor.

TASK ORDER NO. R-ME-IV-S-1

The Phase 1 effort, the candidate material survey, was completed during this period. While an evaluation of all the data gathered during this survey has not been completed, a draft of the material survey report is included as Appendix A. It is envisioned that this evaluation will be continuing throughout the program with this report being modified continuously. This report and the data contained therein will form a basis for each of the directions chosen during the remainder of this program.

During this period evaluations were sufficient to bolster the theory that low temperature forming with liquid nitrogen could result in some degree of success at forming materials which had been previously considered too difficult for bellows.

Twenty-six materials were evaluated during this survey and it is obvious that a close scrutiny of all the possible usages is necessary in order to avoid a program direction which would result in a too-diluted coverage of each of the important materials. Therefore, an overall plan has been formulated for the remainder of the program. With regard to the choice of candidate materials, it is envisioned that three (3) basic groups of materials be investigated. These are the titaniums, the aluminums, and the work-hardened stainless steels. The super-alloys, including Inconel 718, while showing properties which are excellent for some applications, have been studied to a great extent by prior work in the bellows field. Inconel 718 consistently shows itself to have better properties than most

of the other super-alloys, tending to lower the degree of advantage to be gained by pursuing them. Inconel 718, at the present time, is being used in great quantities by Solar and other ducting manufacturers on various stages of Saturn, and work to develop forming techniques with this alloy is felt to be redundant.

Titanium

Solar recommends the investigation of commercially pure titanium, Ti-55, for its superior formability and Ti5Al2.5Sn for its superior strength and high ductility at low temperatures. It is felt that hot forming techniques are too valuable to dismiss in this study, and, instructions have been issued to the Solar Manufacturing Engineering Department to proceed with the development of a concept for the necessary modifications to existing forming equipment at Solar in order to result in a successful hot forming technique.

Aluminum

It has been found, in the survey, that a comparison of the elongation properties vs temperature indicates that forming at -320°F would be desirable since elongation of most of these materials increases, in some instances as much as 300%, when the temperature of the material is reduced to -320°F during work. Since most aluminum alloys exhibit this tendency, it has been necessary again to be selective using other characteristics of the material, such as strength, weldability and availability, as parameters for the decision. Therefore, the alloys to be investigated are 5083, 5086, 2219 and 6061.

Work-Hardened Austenitic Stainless Steels

It has been found that austenitic stainless steels from annealed to full-hard exhibit this same tendency of increasing elongation when reduced to -320°F. It has long been recognized that formability of full-hard stainless steel at room temperature has been difficult at best, or impossible. Therefore, most stainless steel bellows are formed in the annealed condition and since these alloys are non-hardenable by any heat treatment methods, the low strength and fatigue life of the resultant bellows has been a function of the original annealed properties. It is envisioned that by using cold reduced materials, which have strength to density ratios in some instances as high or higher than Inconel 718, that an inexpensive substitute for Inconel 718 in high pressure systems might be found. The materials to be investigated in this phase are 304ELC, 316 and 321. Another interesting facet of this approach is the possibility of cold working at -320°F. Papers on work performed by Arde-Portland, Inc., and by General Dynamics/Astronautics, have indicated that austenitic stainless steels, cold reduced at liquid nitrogen temperatures, exhibit mechanical properties in excess of those materials cold-reduced at room temperature.

Since the degree of advancement must be measured by its ultimate usage in a vehicle system, the plan for pursuing this study program has developed into the following basic steps. The material survey was the initial requirement for any advancement, the gathering of data for evaluation purposes, so that further work might be directed on materials which show some degree of possible success. The second phase is the investigation of the

properties of the material which are indicative of formability. In general it is felt that the lower limit of these properties are in the weld zones, therefore, welding studies will be performed prior to any formability studies. During this phase weld techniques will be utilized which will either guarantee greater degrees of elongation or will be shown to be unacceptable for further formability tests. Following this weldability study, actual forming tests will be performed on samples of materials by the actual forming of the bellows themselves. Bellows samples will be made with increasing convolution heights to split-out to determine the actual limit of formability. Bellows samples will then be made for engineering evaluation of spring rate, fatigue life, critical squirm pressures and other parameters which must be considered in the design of an actual piece of hardware. The guiding rule throughout this investigation is a step by step procedure designed to prevent investigation of materials or processes due to some problem or inability to demonstrate advantage, would be redundant.

During this period, the Ti5Al2.5Sn material was received. The research department, under the direction of the program manager, prepared a procedure for performing welding and forming studies on this alloy. This procedure is included as Appendix B. The Ti55 commercially pure alloy is expected at Solar on 19 October.

The concept for modifying existing forming equipment so that forming may be accomplished with liquid nitrogen has been formalized and is contained in the report as Appendix C. Instructions have been issued to the manufacturing division at Solar to proceed with the actual design of the

elements of this equipment and the manufacturing planning. After investigation of their results in the next reporting period, instructions will be given to commence construction of the equipment. Instructions have also been issued to the manufacturing engineering department to proceed with the development of equipment which will be capable of hot-forming titanium into bellows.

While an attempt will be made to utilize as much as possible the existing tooling at Solar and therefore avoid remaking tools, it has been found that in the two areas of hot forming and cold forming it will be necessary to make new dies for each of these methods. It is felt that in order to evaluate an advancement it is necessary to make or attempt to make identical bellows at room temperature conditions in the manner presently used in the industry. Therefore, these new dies will be fabricated identical to existing tools which are presently being used.

During this period the investigation of the use of high energy rate forming was continued. The most feasible and economic approach appears to be electro hydraulic forming. Discussions with representatives from the Cincinnati Electro-Shape Division were held and a source which has this equipment has been located. It is proposed that some material be provided to this vendor for attempts at formability and to determine the effect on material properties. Contact with this vendor will be made in the next reporting period.

PROGRAM GOALS DURING THE NEXT REPORTING PERIOD

The designs for the cold forming equipment will be completed during the next reporting period, and the fabrication of this equipment will be initiated. The concept for hot-forming titanium bellows will be finalized and designs for that equipment will commence during the next reporting period. The program for evaluation of the Ti5Al2.5Sn will commence during the next reporting period and should be near completion at the end of that period. The commercially pure titanium alloy (Ti-55) will be received, procedures for evaluating welding of that alloy will be completed and instructions will be given to commence with that program. The materials previously mentioned as those chosen for further evaluation will be placed on order and procedures for evaluating those weldments will be begun.

APPENDIX A

MATERIAL SURVEY REPORT ER 1552 (PRELIMINARY)

ENGINEERING REPORT

SOLAR

A STUDY OF MATERIAL PROPERTIES

AT CRYOGENIC TEMPERATURES

REPORT ER 1552 ISSUED September 24, 1964

PREPARED BY

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I. INTRODUCTION

It was requested that a candidate material study be performed on sheet materials suitable for ducting and bellows. These materials should have good strength and toughness through a temperature range from +800F to -423F. The following materials were surveyed.

1. INCONEL 718
2. INCONEL X-750
3. K-MONEL
4. HASTELLOY B
5. HASTELLOY C
6. HAYNES 25 (L605)
7. RENE 41
8. RENE 62
9. A-286
10. AISI 301
11. AISI 304
12. AISI 310
13. AISI 321
14. AISI 347
15. N-155
16. AM350
17. AM355
18. AFC 77
19. 9% Ni (ASTM-A353)(2800)
20. 18% Ni MARAGING STEELS
21. BERYLLIUM COPPER (25 ALLOY)
22. PURE TITANIUM
23. 5 AL-2.5 Sn TITANIUM
24. 6 AL-4V TITANIUM
25. 2014 ALUM
26. 2219 ALUM
27. 5052 ALUM
28. 5083 ALUM
29. 5086 ALUM
30. 5154 ALUM
31. 5456 ALUM
32. 6061 ALUM
33. 7039 ALUM
34. 7075 ALUM

In order to compile the data for this report, it was necessary to establish certain ground rules. They are as follows:

1. Data presented is only an indication for any given material. It is not to be construed as a design allowable. It is, generally, an average from several sources, but it may in some cases, represent a single sample. Further, it was found that in any given material, the properties could vary measurably from heat to heat and from one sheet thickness to another.

2. Notched/unnotched tensile ratios are based on data from the heat-treated or cold-rolled condition.

3. A stress concentration factor (K_t) of 6.3 was used wherever possible. It has been found that data from this type of test correlates quite well with service behavior at cryogenic temperatures. This factor (K_t) is based on the expression $K_t = \frac{a}{r}$ where a = half the distance between notches and r= root radius of notches.

4. Strength to density ratios are based on yield strength in the heat-treated or cold-rolled condition as noted.

II. MECHANICAL PROPERTIES DATA

2.1 NICKEL BASE ALLOYS

Except for strength to density ratio, most of these materials seem to be fairly promising candidates for cryogenic application. Tensile and ultimate strengths increase as temperature lowers for all types surveyed. In most cases, elongations under the same conditions remained constant or increased. Notched/unnotched tensile ratios remained nearly constant and well over .9 except for K-Monel and A-286. Weld joint efficiencies were low in all cases. It is known that in at least one case (Inconel 718) this was because welds were tested in the as-welded condition. It is thought that heat treatment or possibly different welding techniques may improve this property.

REVISED DATA | TABLE I | DATE Sept 24, 1964

ALLOY INCONEL 718 | SHEET THICKNESS

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. .295-.297 (1) (2)					
Modulus of Elasticity					
Annealed +AGED	Tensile - 1000 psi		195	232	278
At 1325F, 8 hrs, cool 20F/hr to 1150F, hold for 18 hrs, ac	Yield - 1000 psi		157	185	205
	Elong. in 2"		20	32.5	28.2
.031(3)	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition (3)	Tensile - 1000 psi		204	268	286
	Yield - 1000 psi		183	227	239
AGED + 20% CR	Elong. in 2"		13.2	24.5	28
.031	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio -	$\frac{F_{ty}}{\rho}(10^{-5})$		6.18	7.68	8.08
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 6.3(3) 1.11 1.01 1.02

Weld Joint Efficiencies (same and dissimilar metals) 54(3) 56 61

Resistance to Crack Propagation

Formability

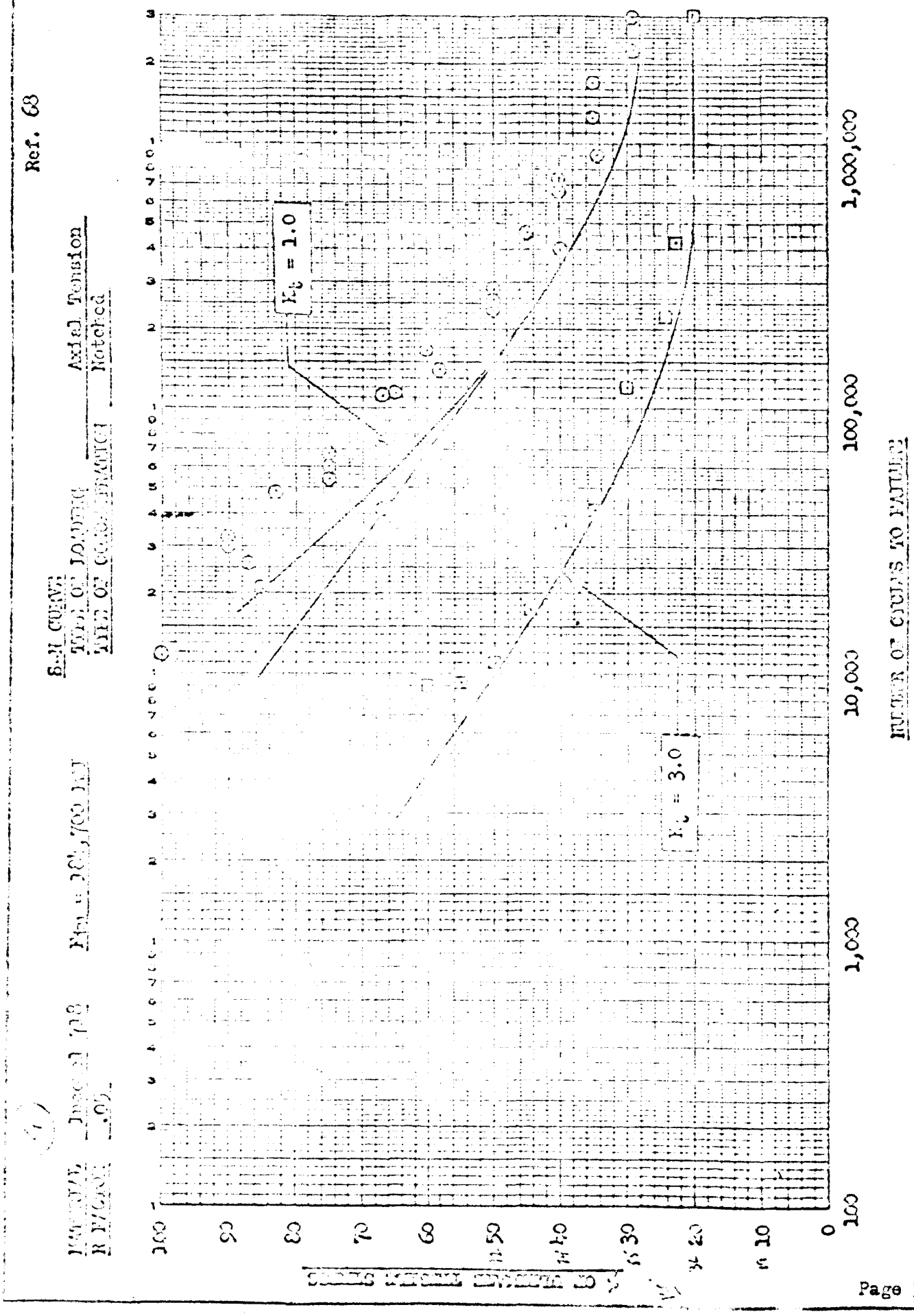
Cleanability

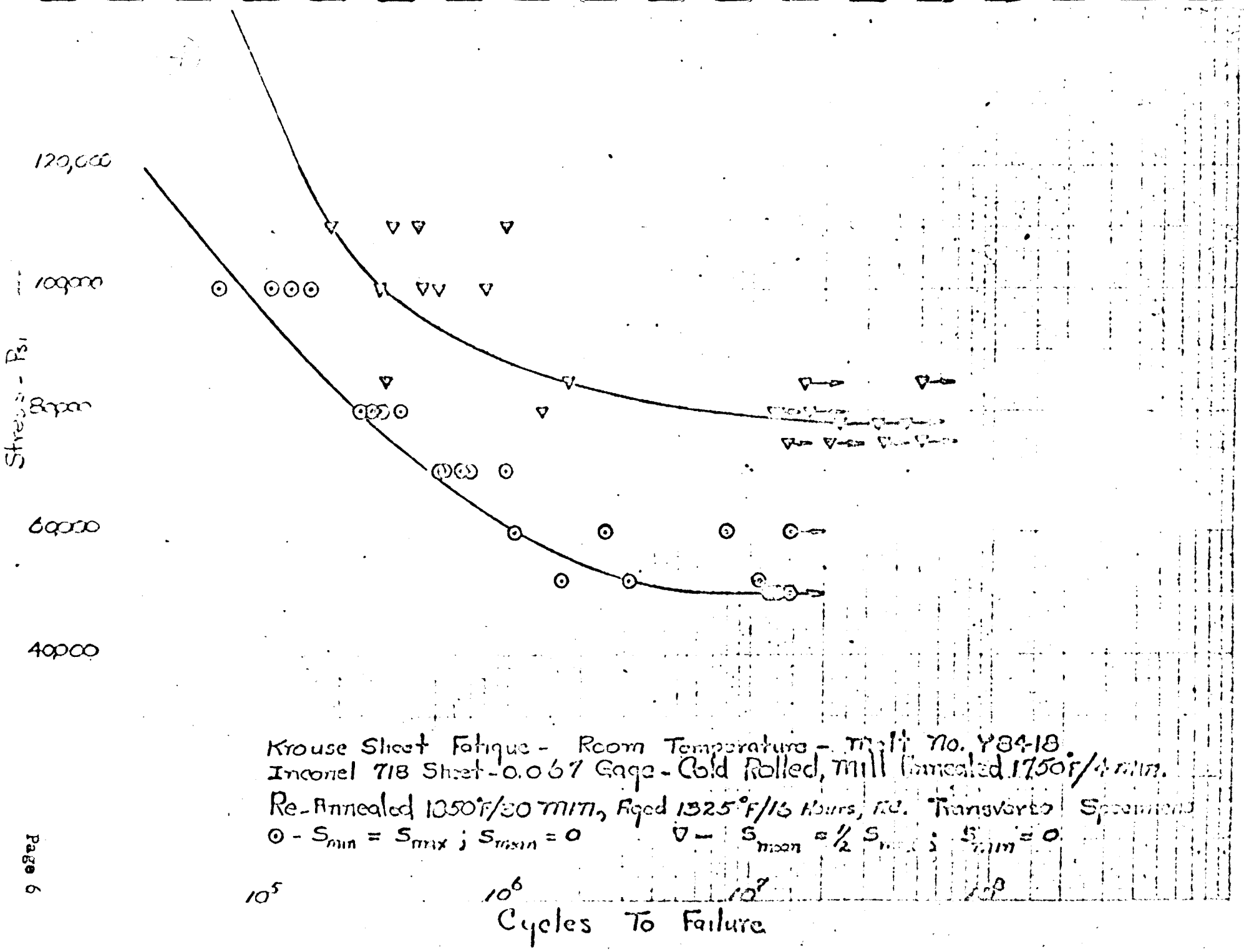
Availability

Cost

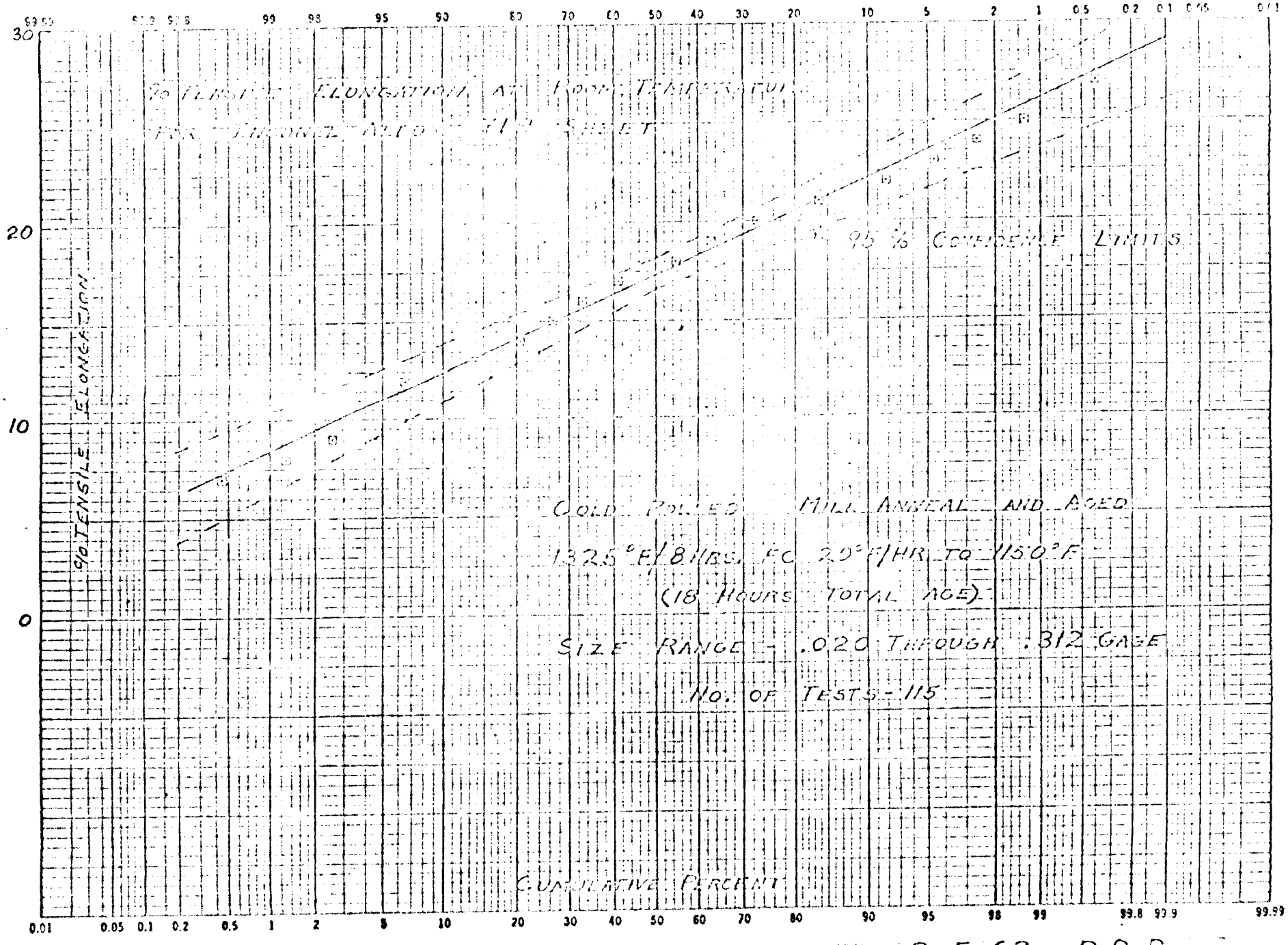
SOURCE-(1) SUPERIOR TUBE CO, (2) NAA REPORT, (3) ERR-AN-400, (4) PROBABILITY DATA/HUNTINGTON ALLOY DIV., INCO.

FATIGUE MANUAL





Krouse Sheet Fatigue - Room Temperature - Heat No. Y84-18
Inconel 718 Sheet - 0.067 Gage - Cold Rolled, Mill Annealed 1750°F/4 min.
Re-Annealed 1850°F/30 min, Aged 1325°F/16 Hours, A.C. Transverse Specimens
⊙ - $S_{min} = S_{max}$; $S_{mean} = 0$ ▽ — $S_{mean} = \frac{1}{2} S_{max}$; $S_{min} = 0$

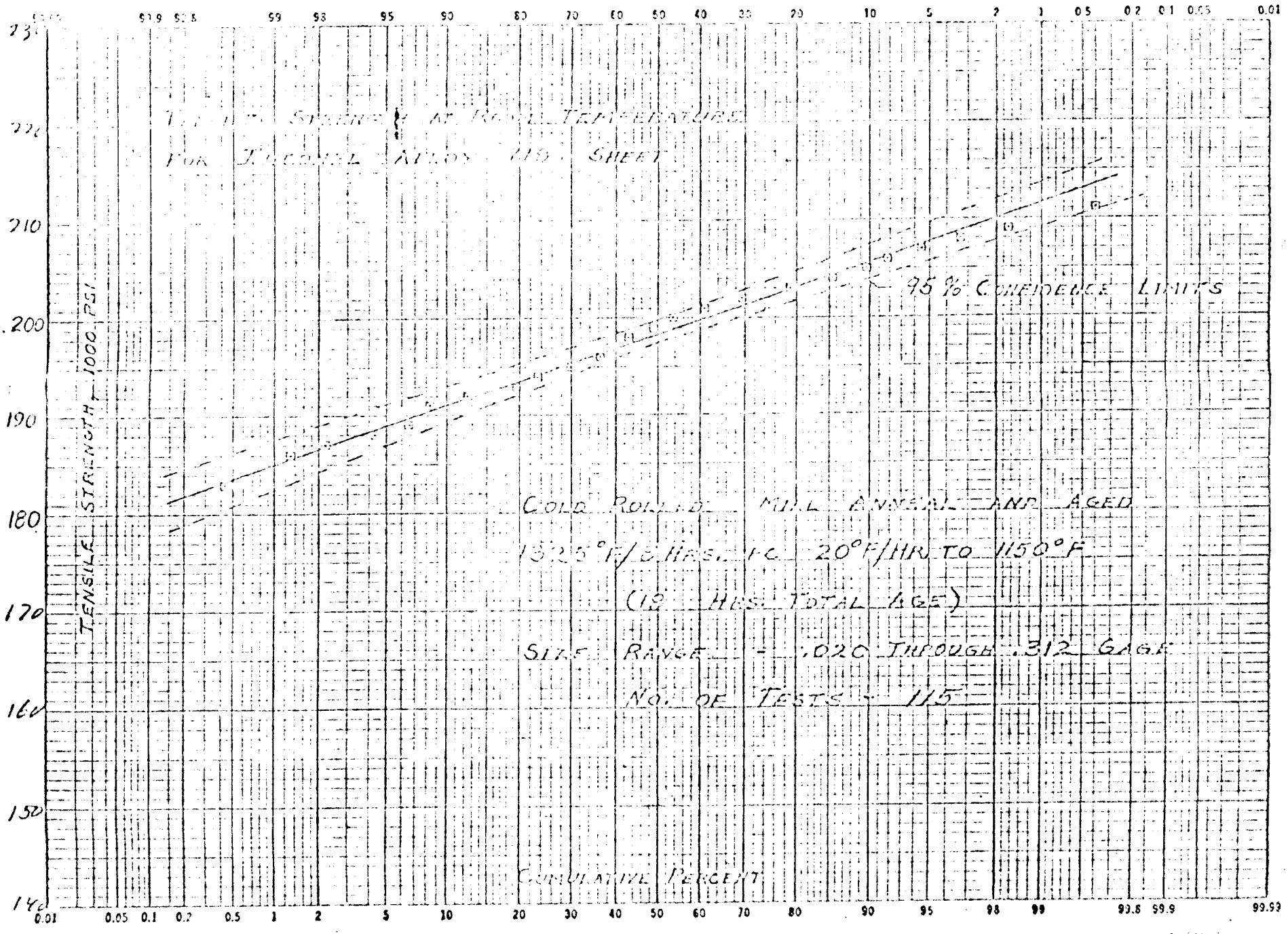


9-5-63 R.D.B.

FIG. 3

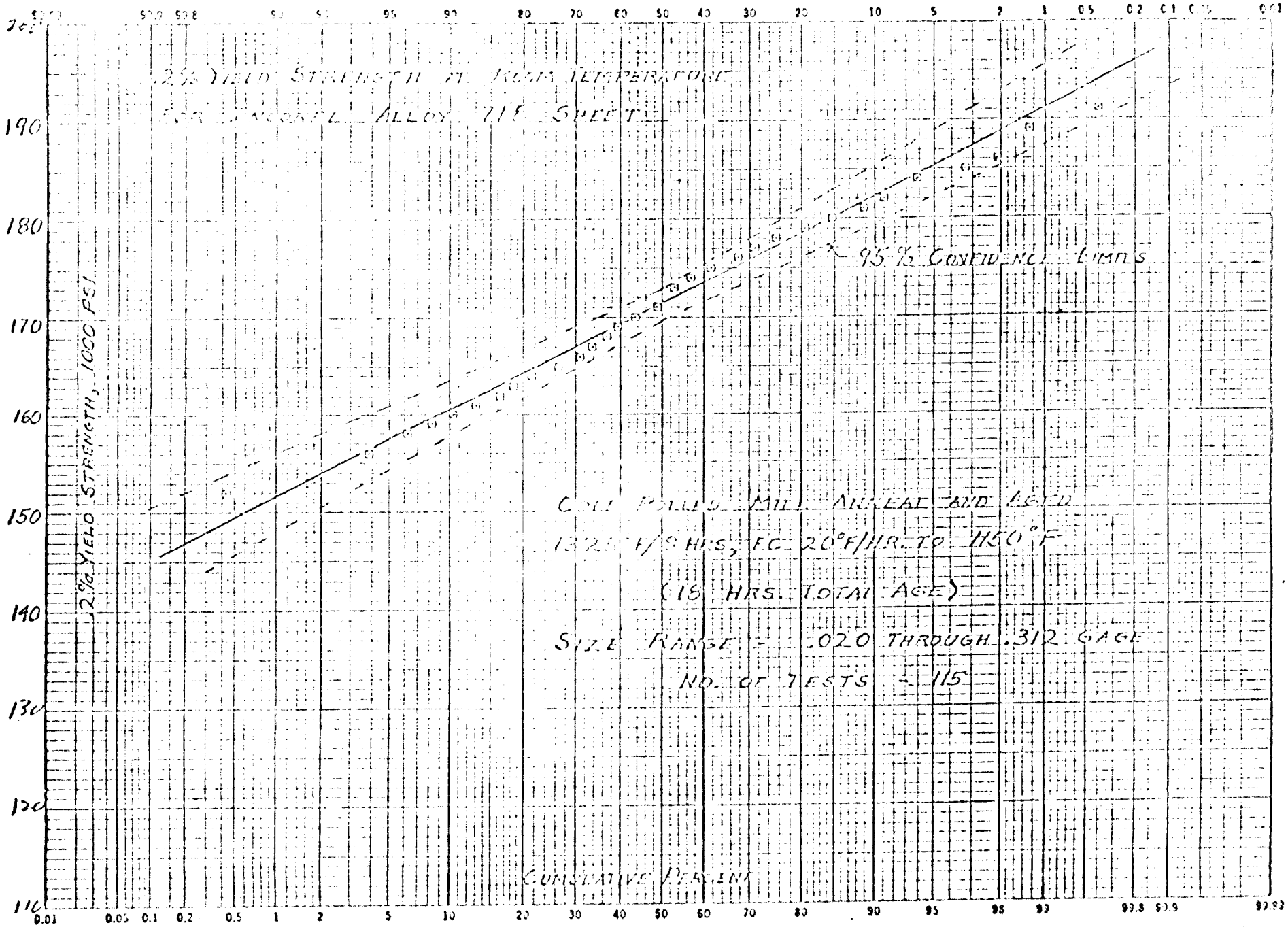
PRO[redacted]ITY [redacted]
X 90 DIVISIONS
KEUFFEL & ESSER CO.

(4)



9-5-63 R.D.B.

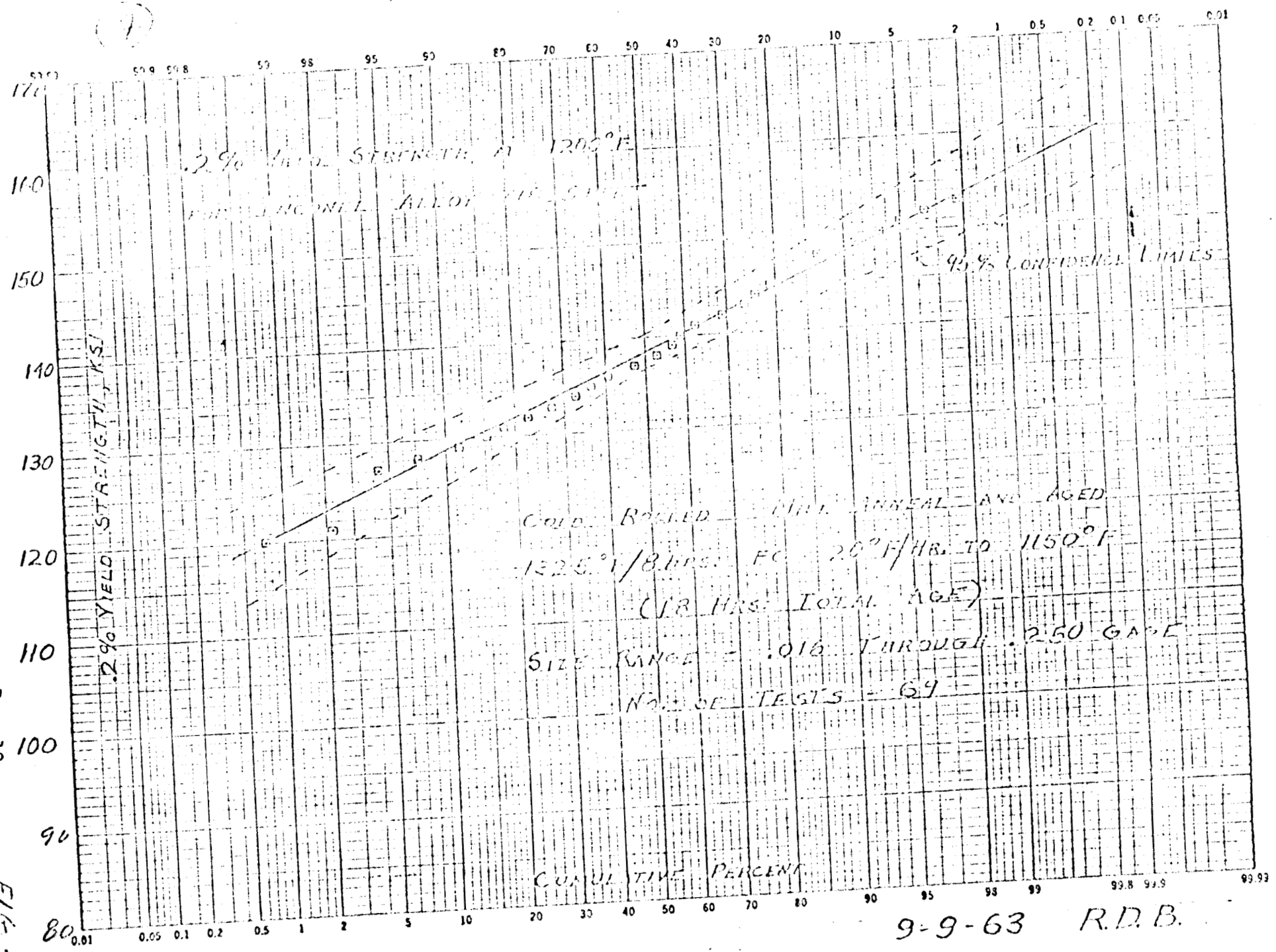
FIG 2



9-5-63 R.D.B.

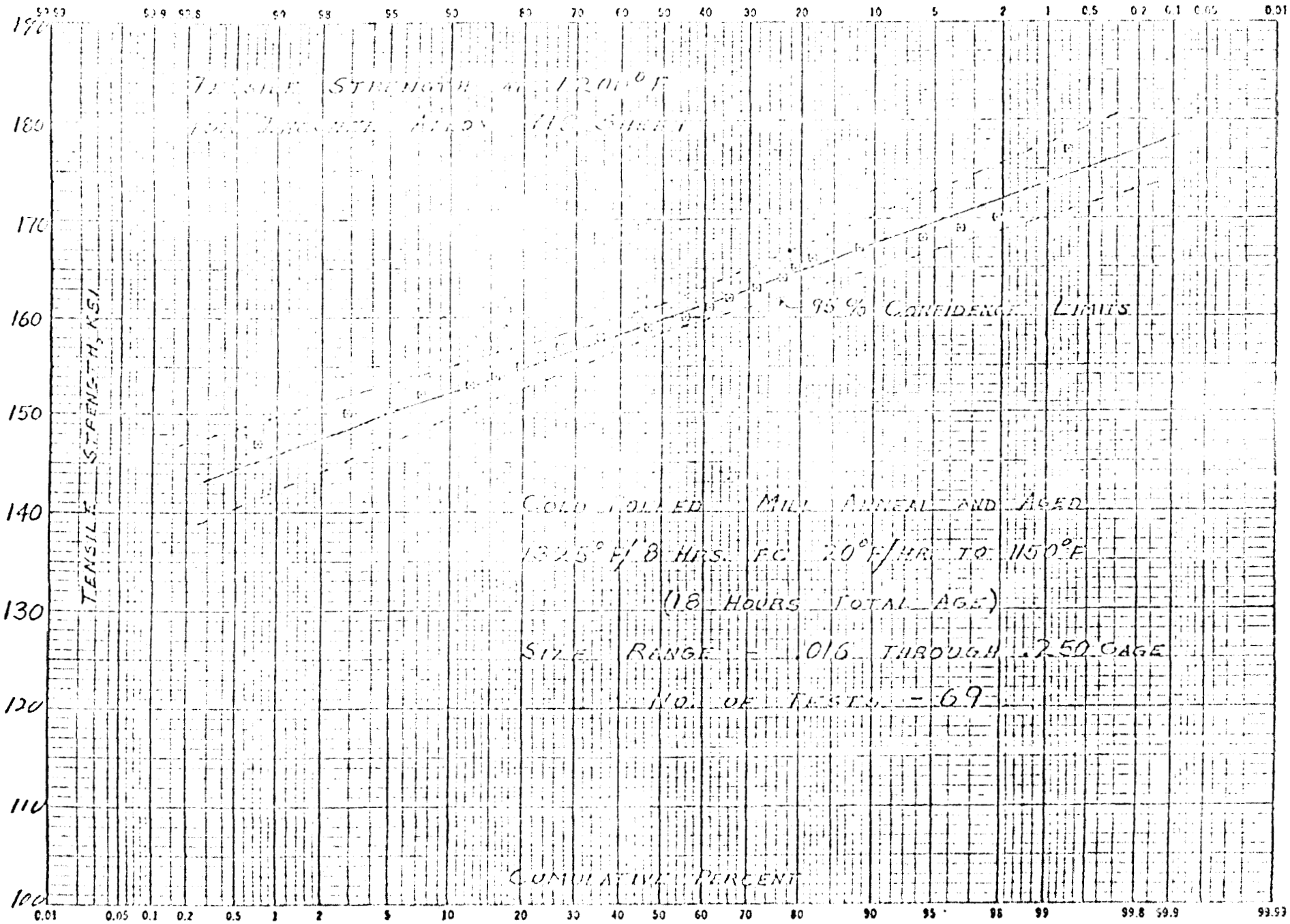
FIG 1

KEUFFEL & ESSER CO.



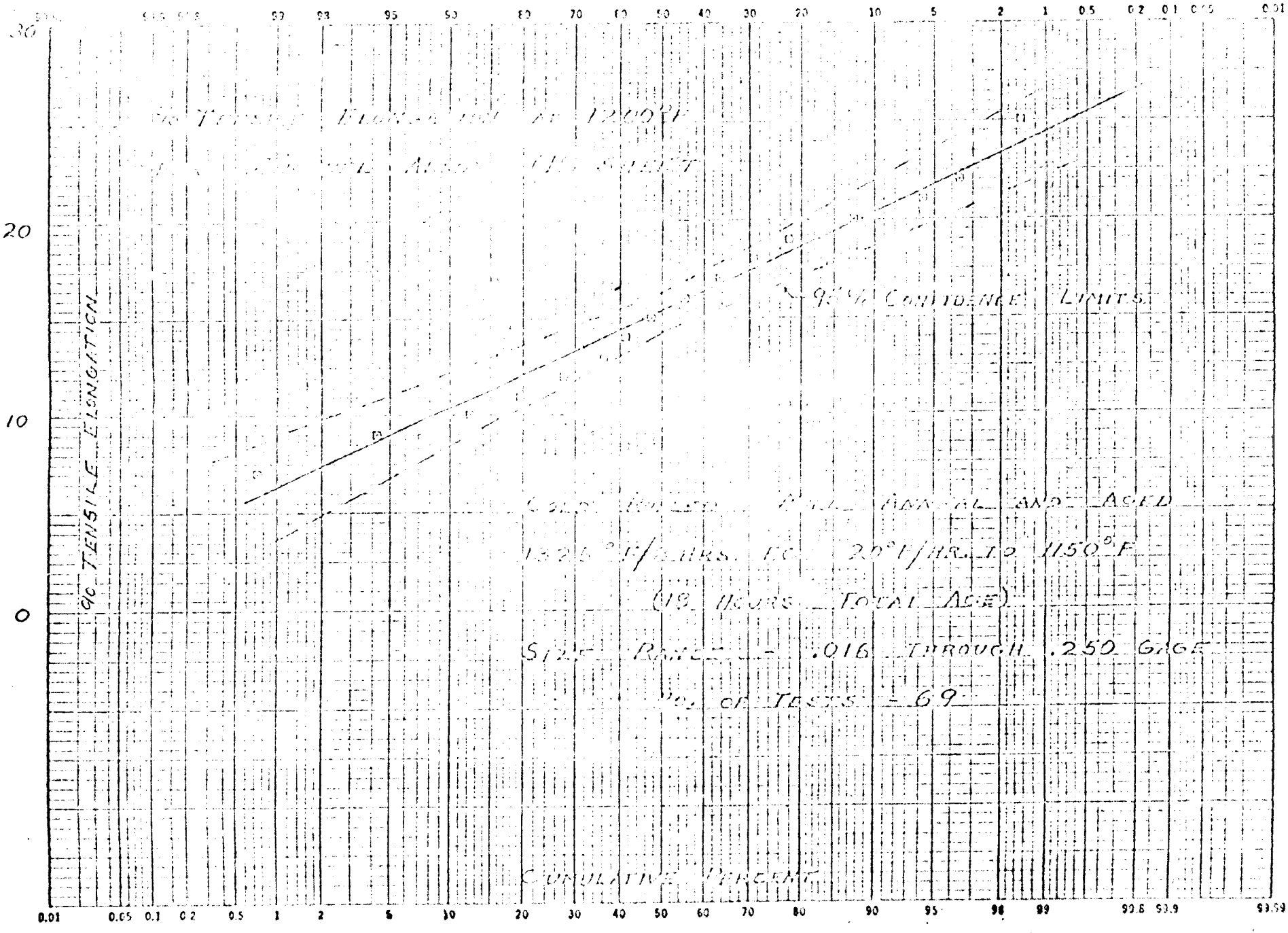
9-9-63 R.D.B.

FIG 4



9-9-63 R.D.B.

FIG. 3



9-9-63 R.D.B.

FIG. 6

REVISED DATA

TABLE I

DATE Sept 24, 1964

ALLOY [illegible] SHEET THICKNESS

[illegible] of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 0.30					
Modulus of Elasticity X 10^6		(5)26.4	30 (3)	30.5	(3) 31
Annealed	Tensile - 1000 psi		110	147	169
(4)	Yield - 1000 psi		47.5	64.7	73.2
SOLUTION TREATED .063 SHT.	Elong. in 2"		49.5	53.5	48.5
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked (1) Condition (4) (2)	Tensile - 1000 psi		174	214	233
	Yield - 1000 psi		118	130	134
SOLUTION TREATED & AGED AT 1300F 20 HR AC	Elong. in 2"		25	31	30
	Bearing - 1000 psi $\frac{e}{D}$ = 2)	235	287 (5)		
.063 SHT	Shear - 1000 psi	85(5)	110		
Str. to Density Ratio - $\frac{F_{tu}}{\rho}(10^{-5})$			3.93	4.34	4.47
Impact Str. (Charpy), ft. lb.V (3)			40	34	

Fatigue Str. Curves at indicated temps.

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 6.3 (4) .97 .86 .85

Weld Joint Efficiencies (same and dissimilar metals) 67 (6) 72 79

Resistance to Crack Propagation

Formability GOOD (2)

Cleanability

Availability

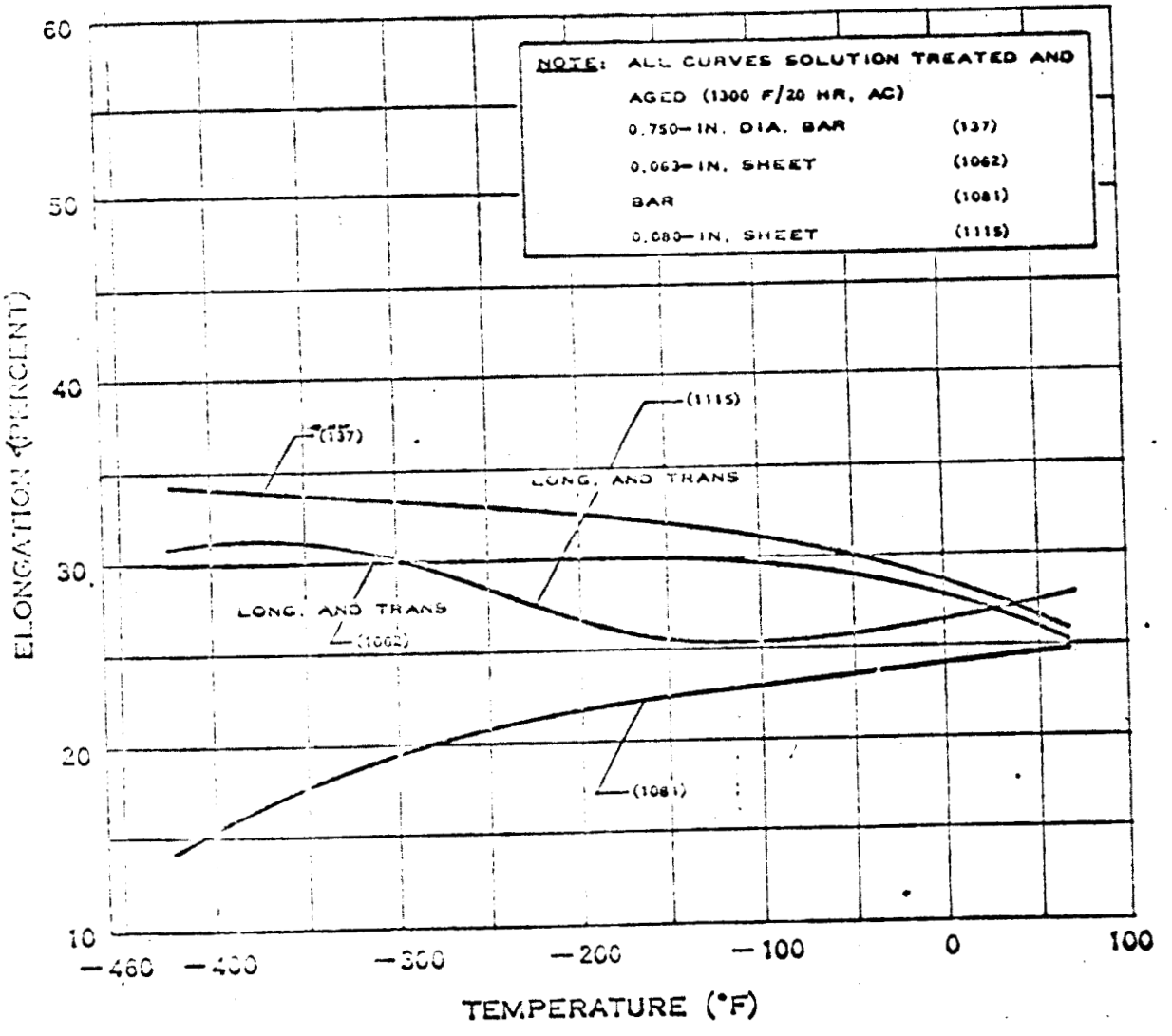
Cost (1)

(2) (3)

[illegible] STRUCTURAL ALLOYS FOR CRYOGENIC SERVICE, RDR 1223, OTS #PB171809,
(4) [illegible] 61-[illegible]-12, (5) WADC TR 55-150-FIG 218, 221, 227 (6) IN-P&VE-M-62-5

OTS # PB 171309

E.2.c

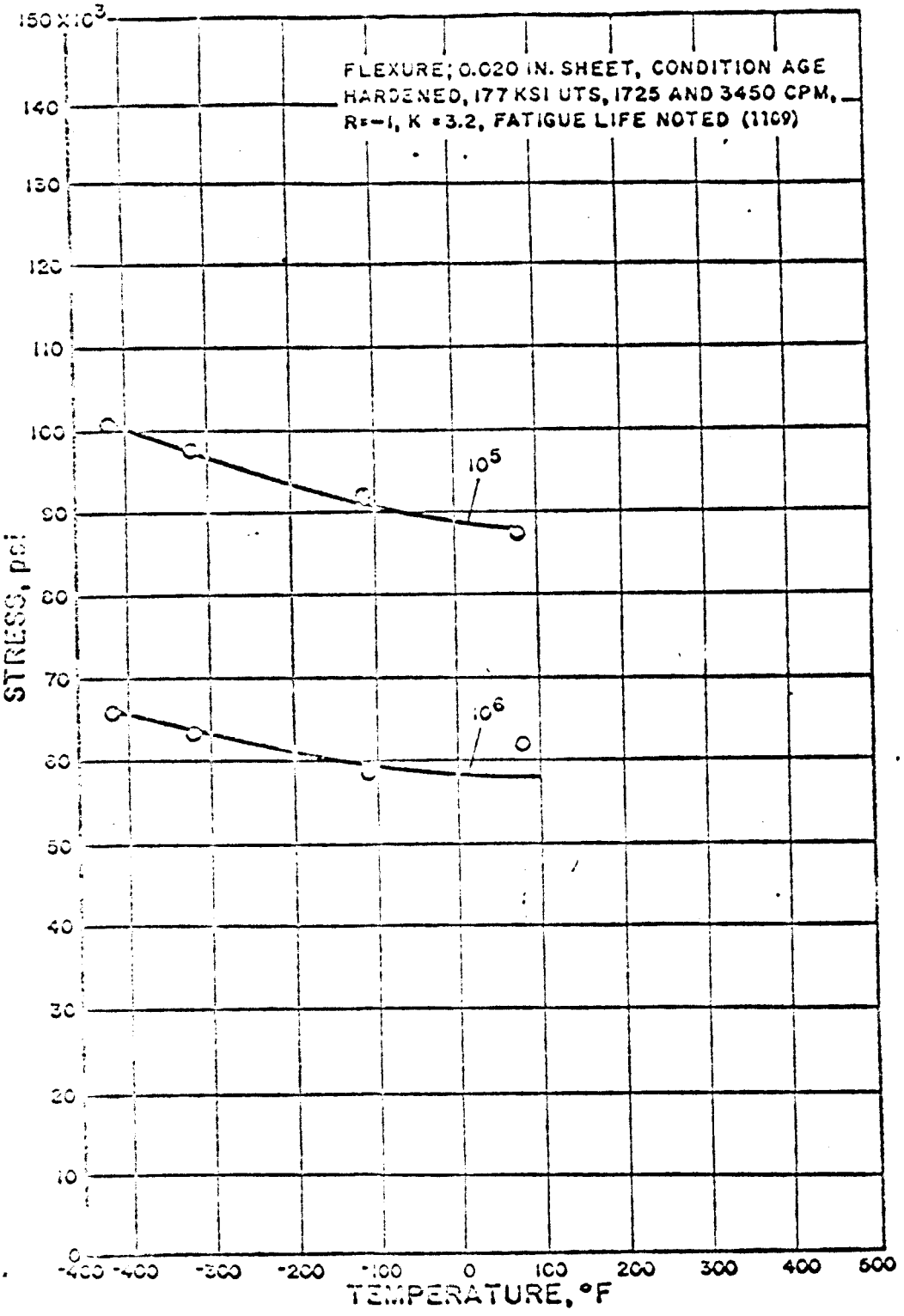


ELONGATION OF INCONEL-X

(7-15-63)

OTS # PB 171802

E.2. n-3

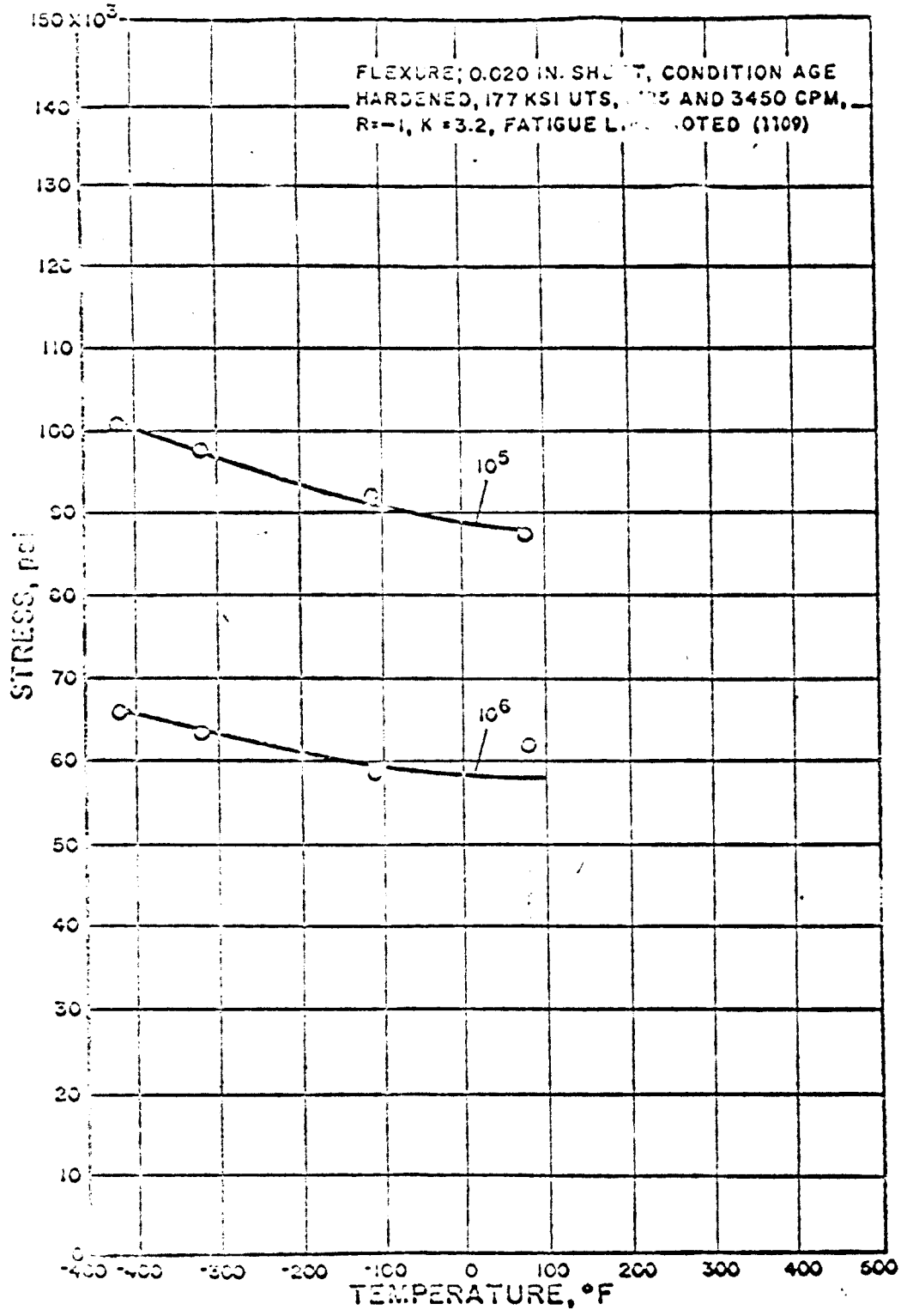


FATIGUE BEHAVIOR OF INCONEL X

(10-15-62)

OTS#PB 171309

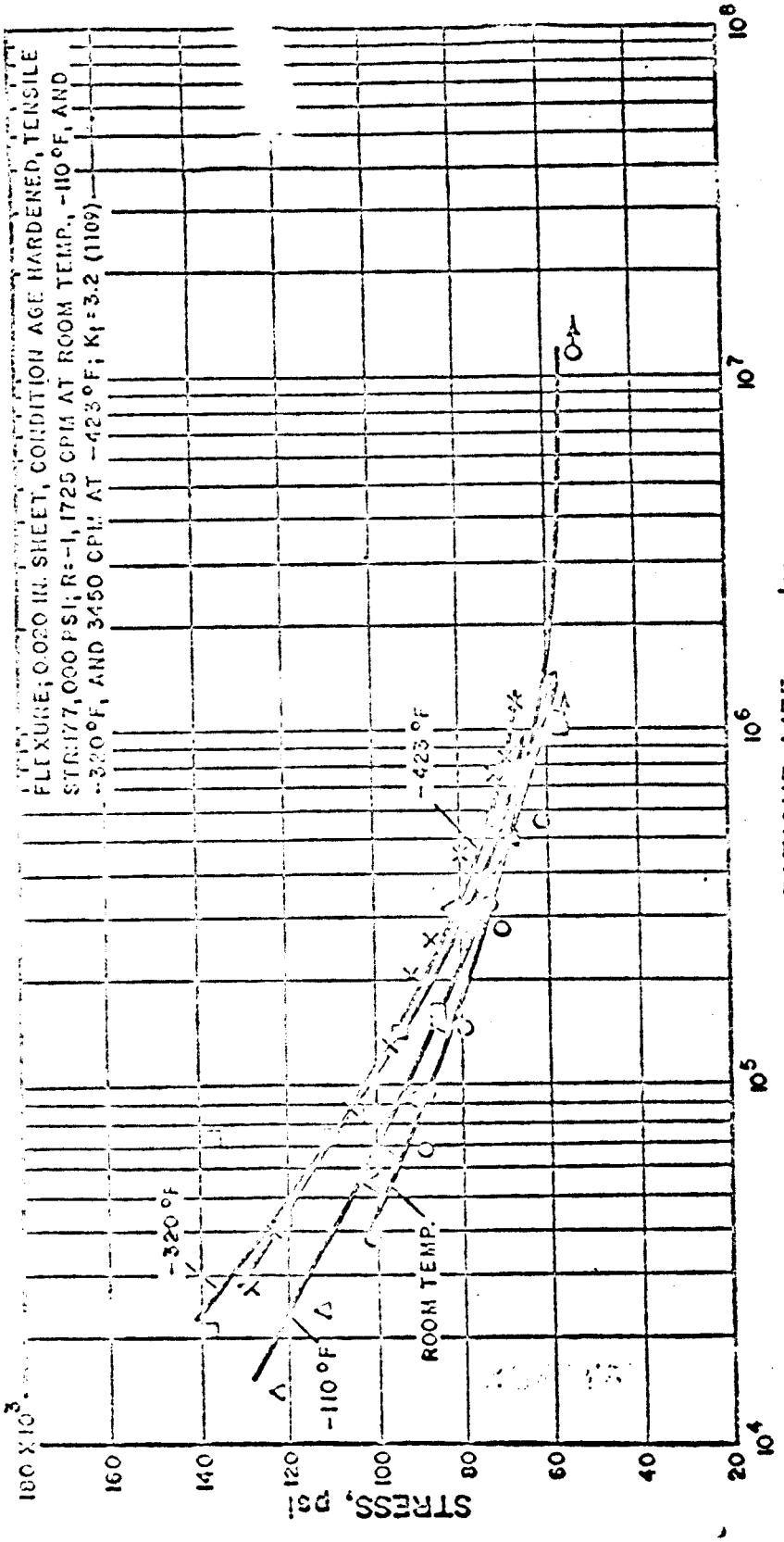
E.2.n-3



FATIGUE BEHAVIOR OF INCONEL X

OTS # PB171809

E.2.n-2

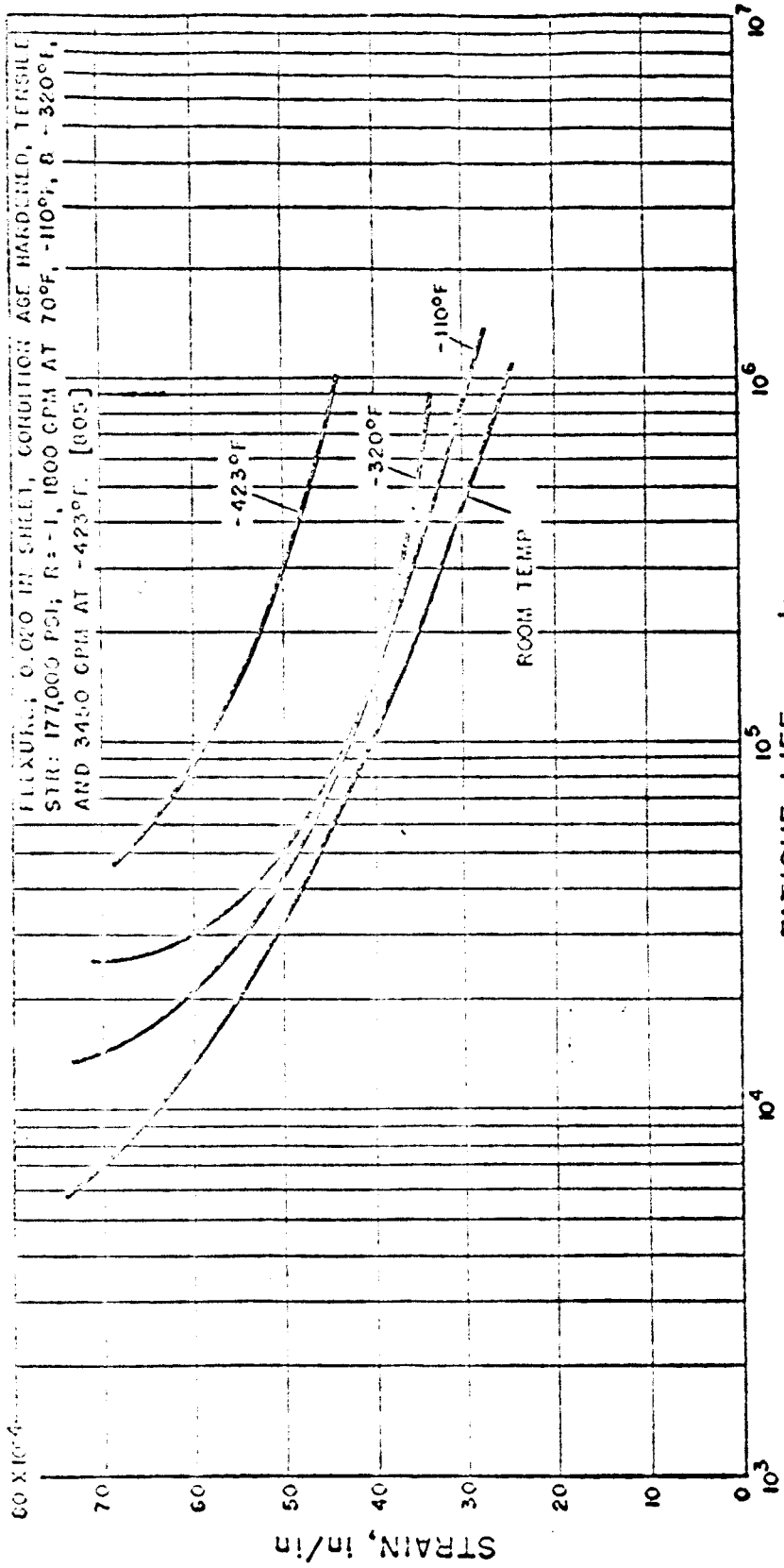


FATIGUE BEHAVIOR OF INCONEL X

(10-15-62)

OTS # PB171809

E.2.n



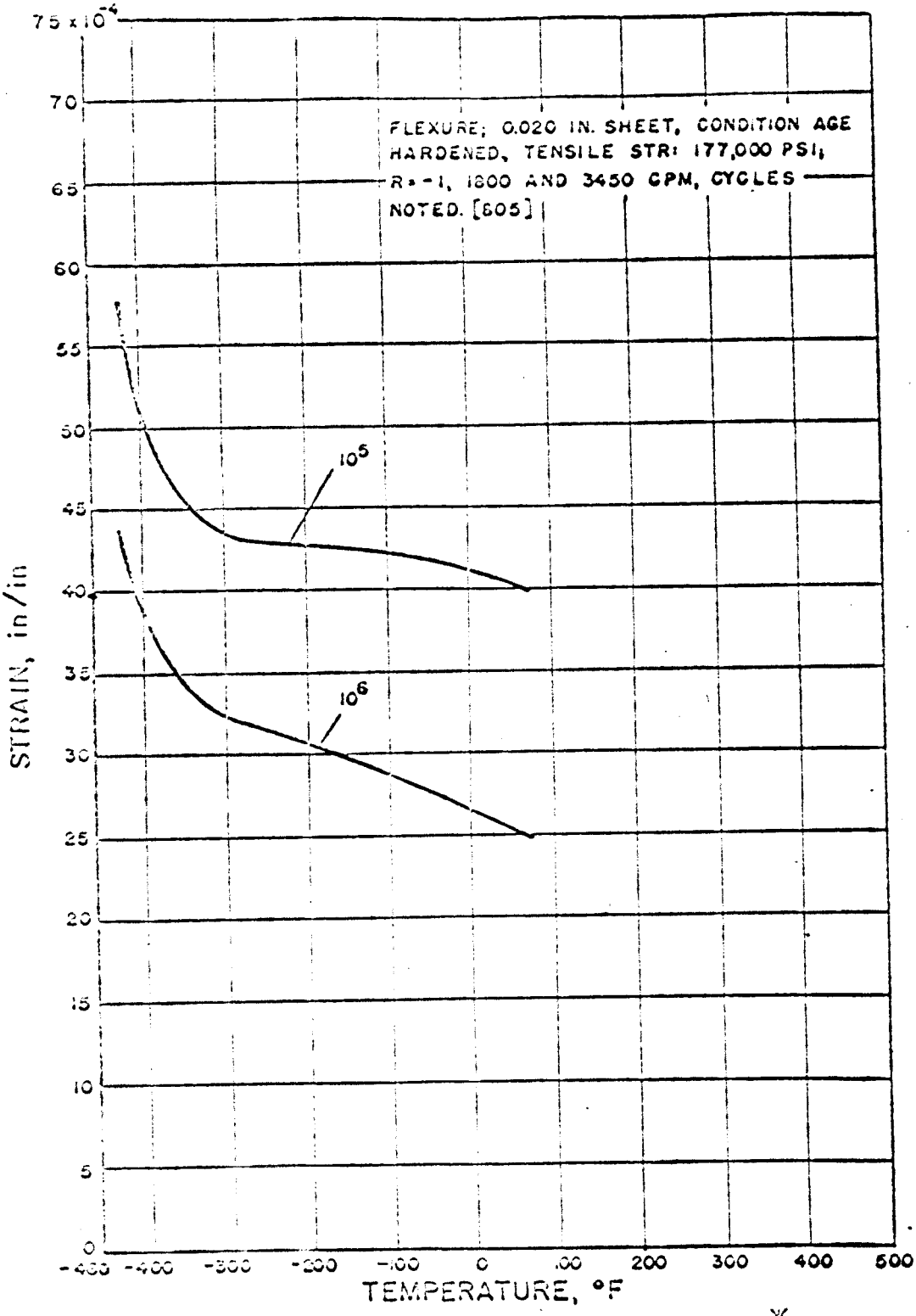
FATIGUE LIFE, cycles

FATIGUE BEHAVIOR OF INCONEL*X

*THE INTERNATIONAL NICKEL COMPANY

OTS # PB 171309

E.2.n-1

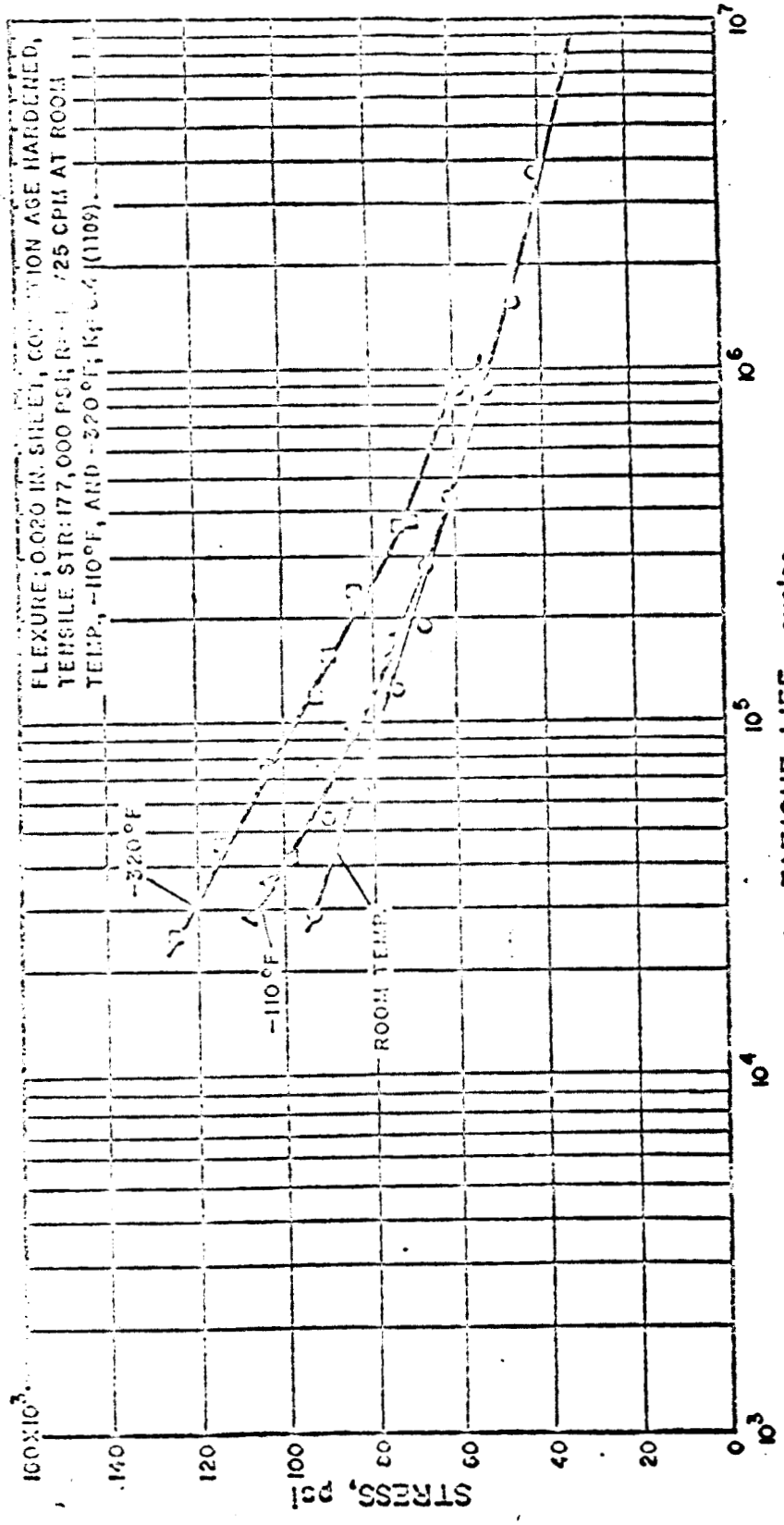


FATIGUE STRENGTH OF INCONEL*X

*THE INTERNATIONAL NICKEL COMPANY

OTS # PB 171809

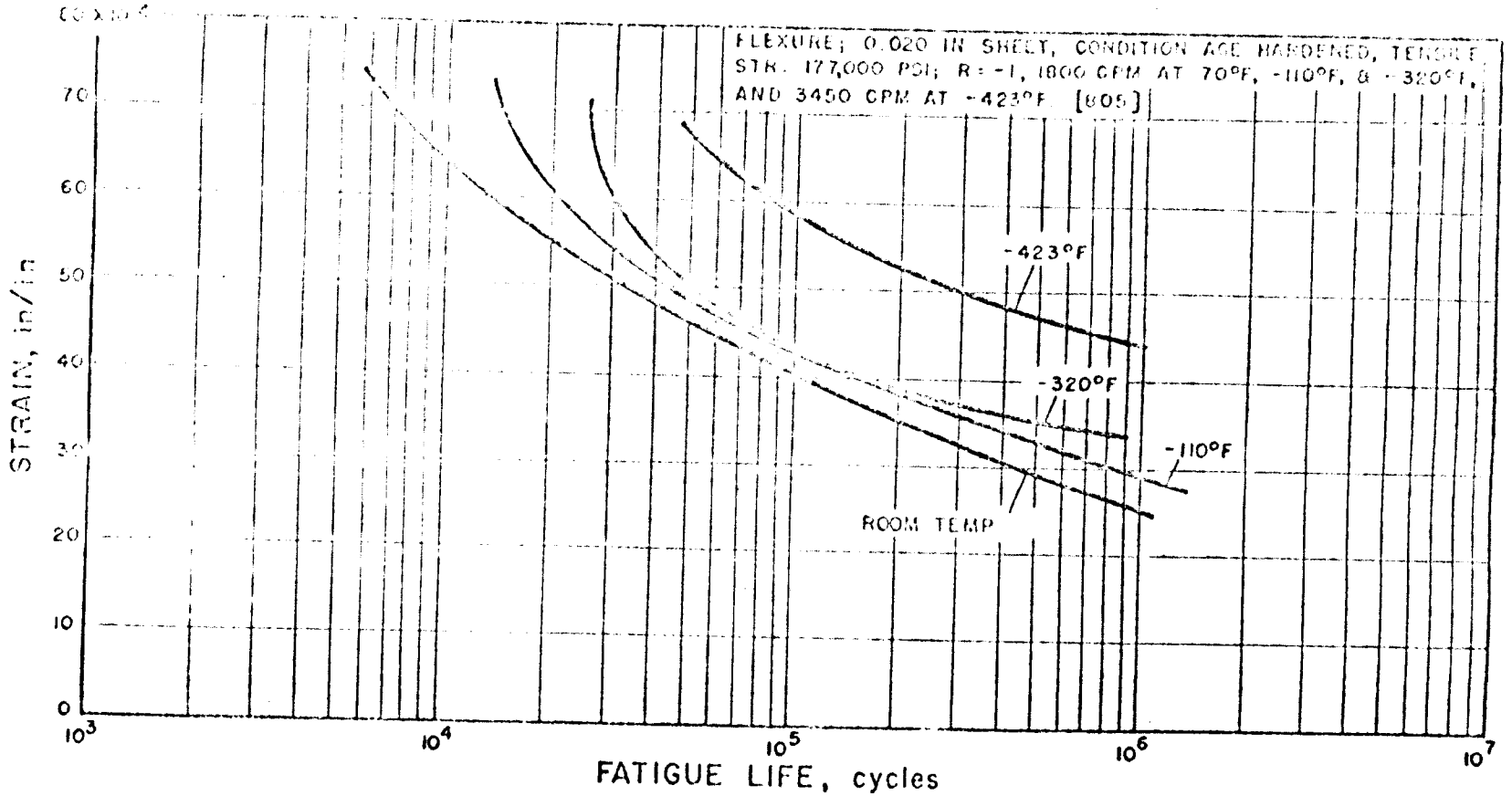
E.2.n-4



FATIGUE BEHAVIOR OF INCONEL X

(10-15-62)

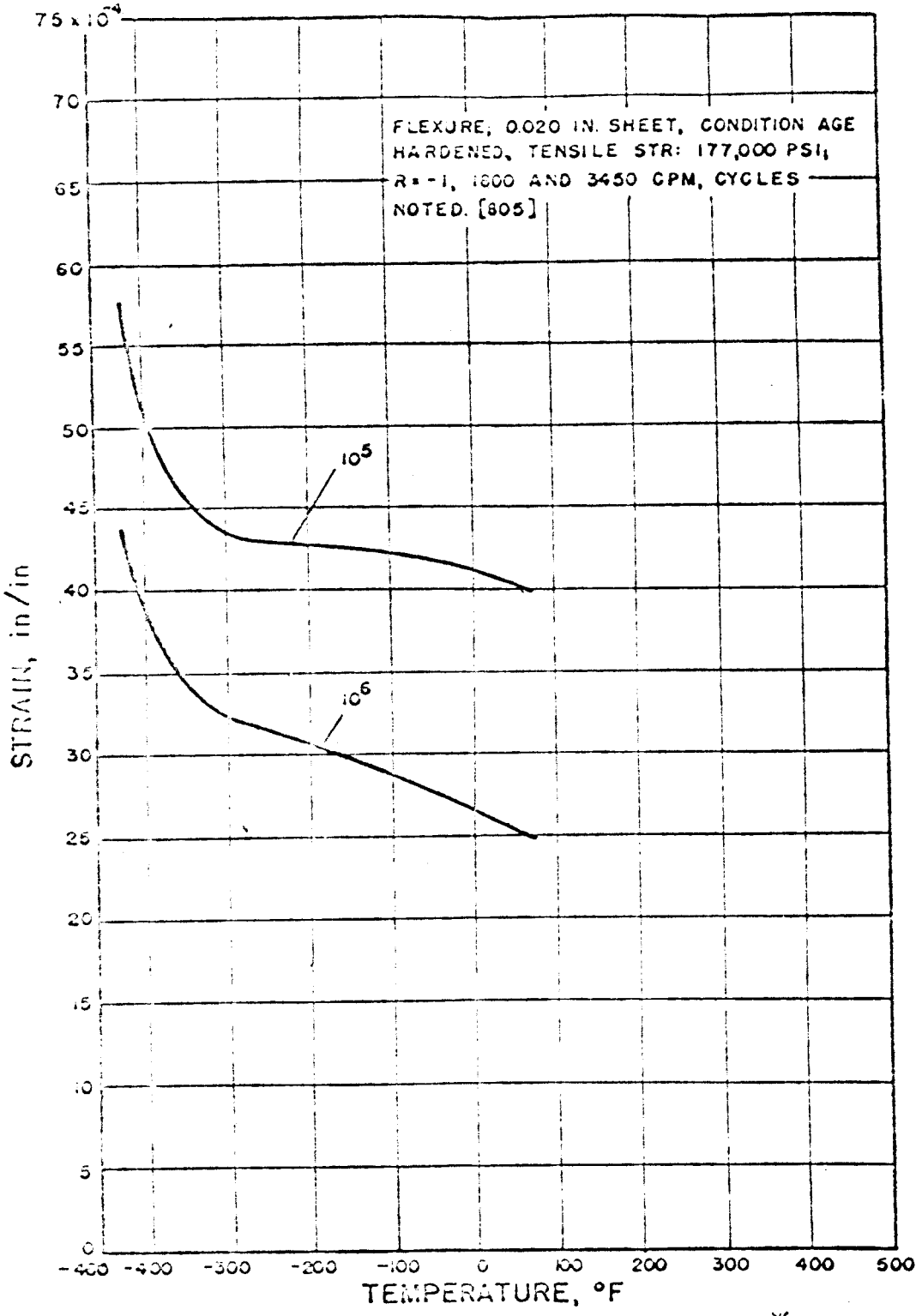
PB171809



FATIGUE BEHAVIOR OF INCONEL*X

*THE INTERNATIONAL NICKEL COMPANY

OTS # PB171809



FATIGUE STRENGTH OF INCONEL*X

*THE INTERNATIONAL NICKEL COMPANY

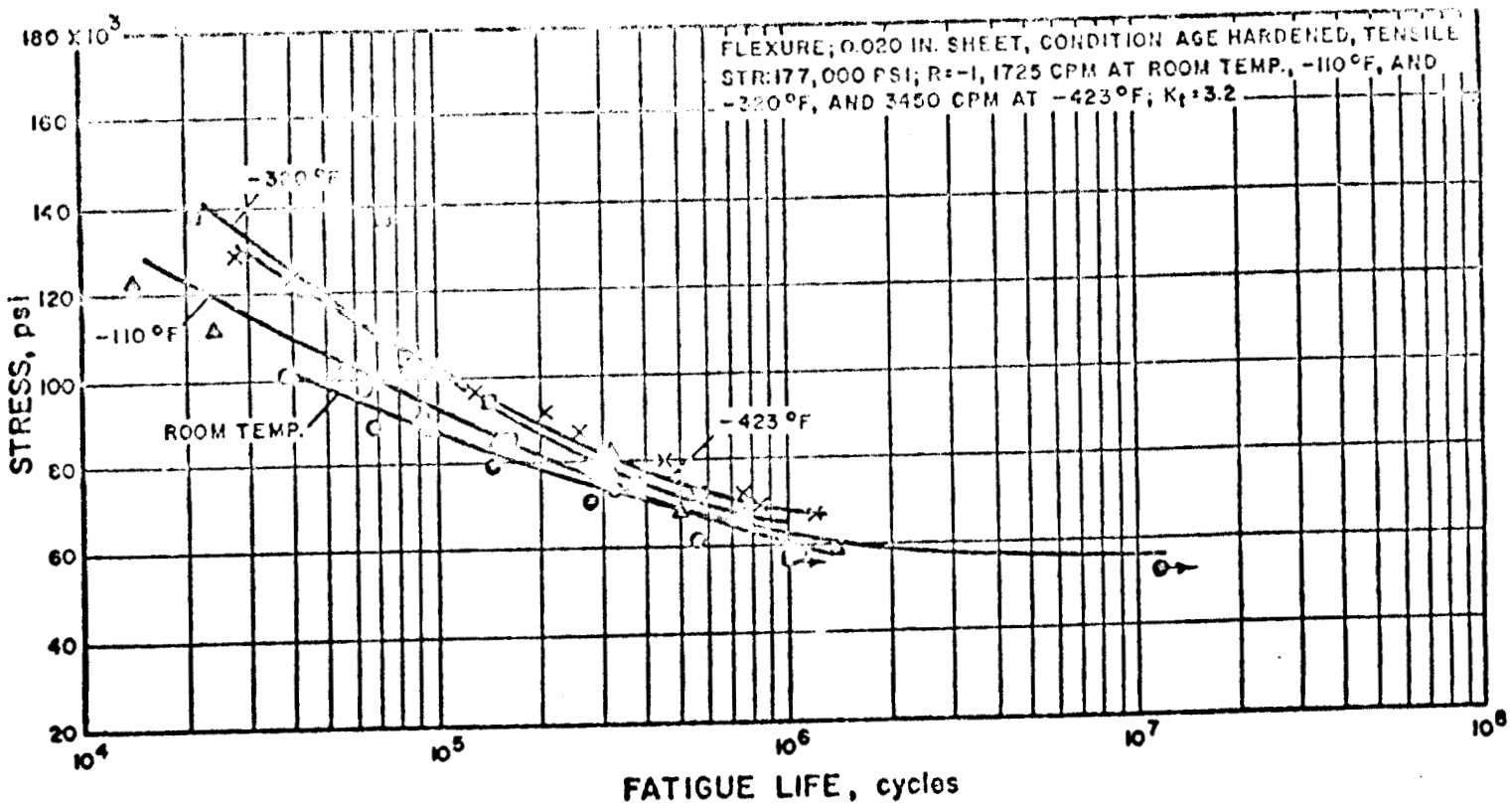


FIGURE 51. NOTCHED (K_T = 3.2) FATIGUE BEHAVIOR OF ANNEALED AND AGE-HARDENED INCONEL "X" NICKEL

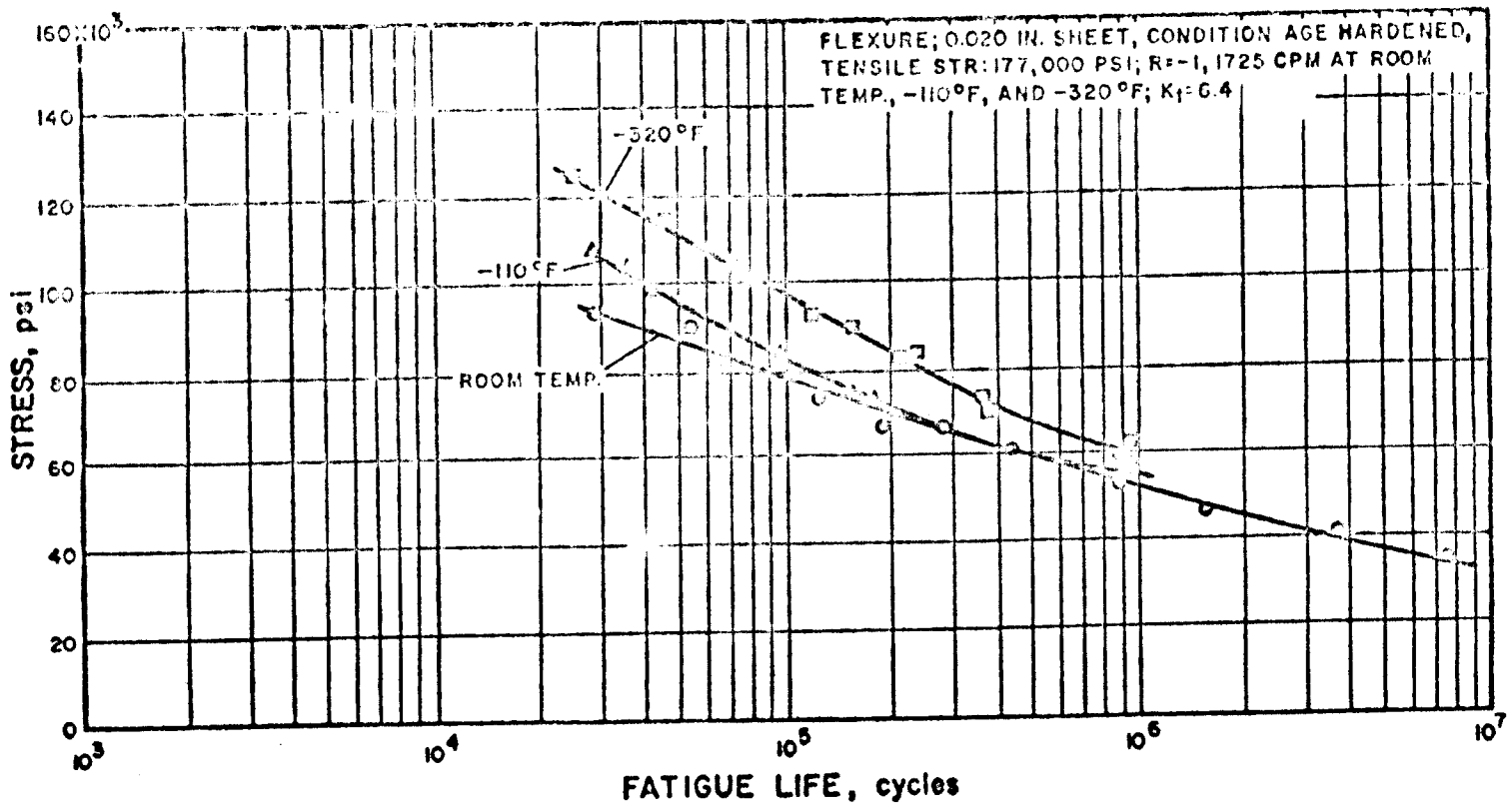


FIGURE 56. NOTCHED (K_T = 6.4) FATIGUE BEHAVIOR OF ANNEALED AND AGE-HARDENED INCONEL "X" NICKEL

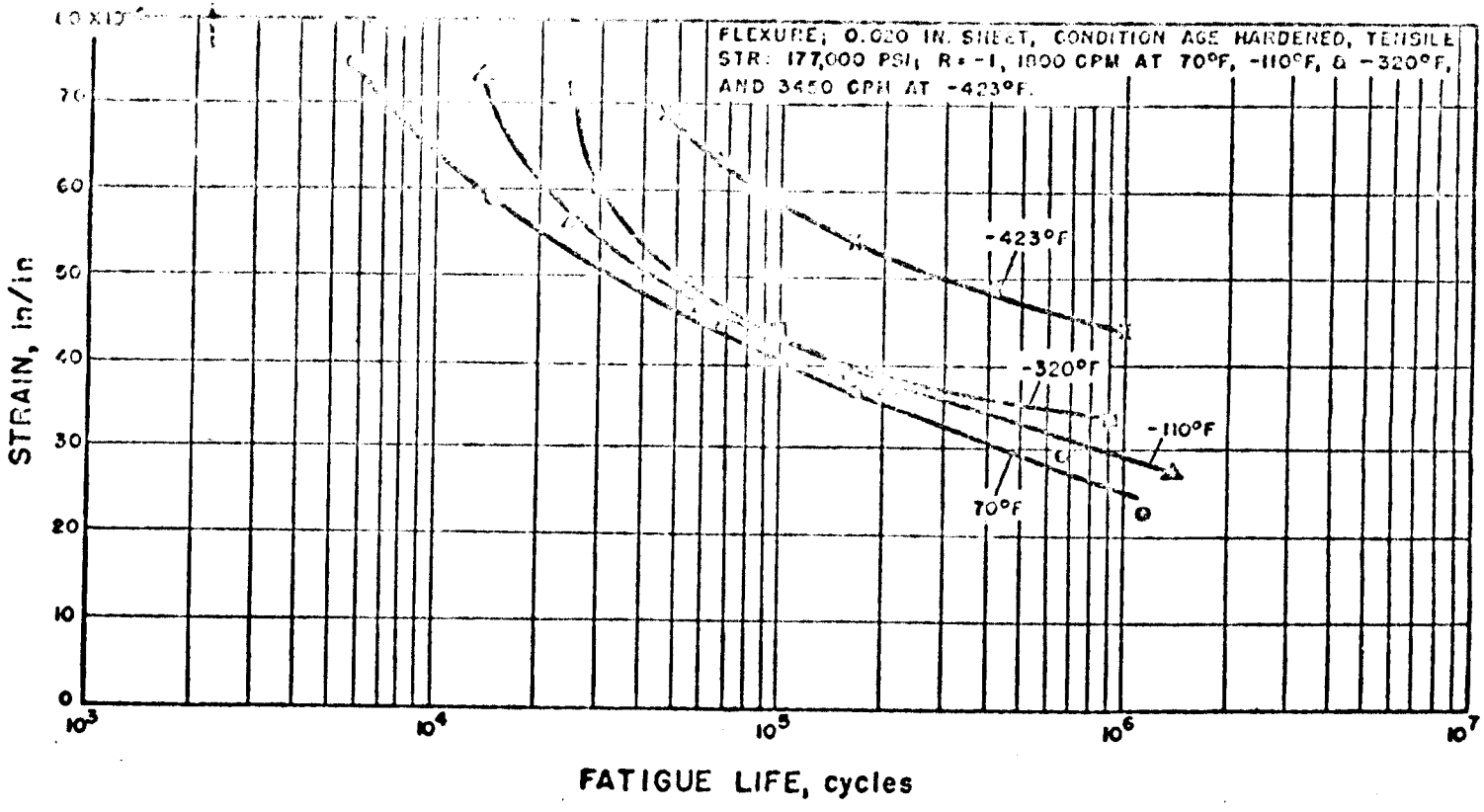


FIGURE 37. UNNOTCHED (K_T = 1) FATIGUE BEHAVIOR OF ANNEALED AND AGE-HARDENED INCONEL "X" NICKEL

REVISED DATA

TABLE I

DATE September 21, 1961

ALLOY [illegible]

SHEET THICKNESS

Properties of Sheet Material		300°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. .303(4)					
Modulus of Elasticity X 10^6 (2)			26		30
Annealed	Tensile - 1000 psi		91	131	147
.020 SHT (1) (3)	Yield - 1000 psi		40	61	68
	Elong. in 2"		32	36	27
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		131-154(3)	153-183(1)	170-200
	Yield - 1000 psi		87-97.3(1)	104-120	120-136
HTMD 1000-1100F 16 HR .020 SHT	Elong. in 2"		22	29-30	29-28
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio -	$\frac{F_{tu}}{\rho}(10^{-5})$		3.01	3.66	4.19
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No LOX ok, FLUORINE ok, IF PSSSIVATED

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 6.3(1)(3) 1.12-.93 1.15-.95 1.18-.99

Weld Joint Efficiencies (same and dissimilar metals) % 92-93(1) 93-95(3) 95-99

Resistance to Crack Propagation

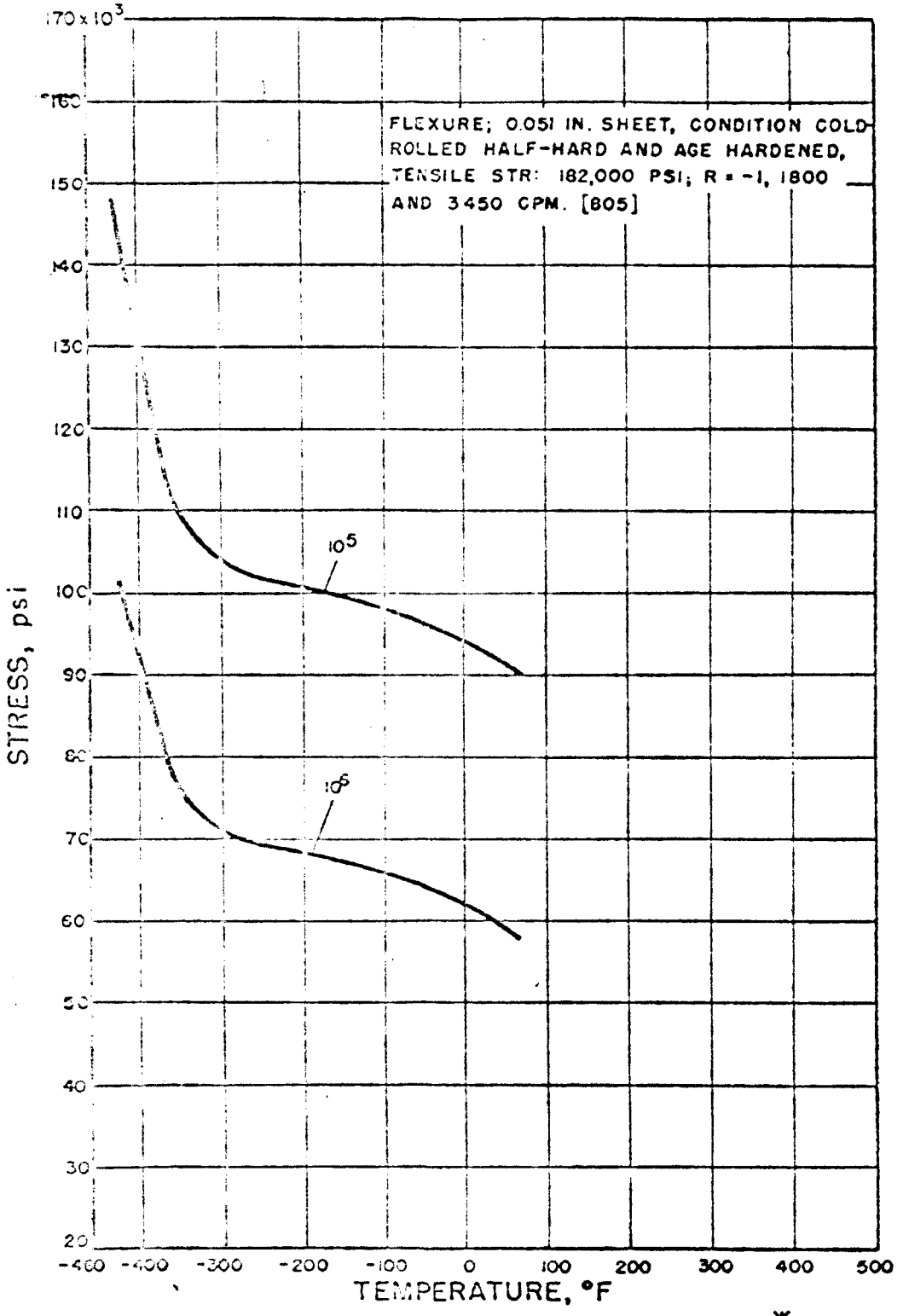
Formability [illegible] (3)

Cleanability

Availability

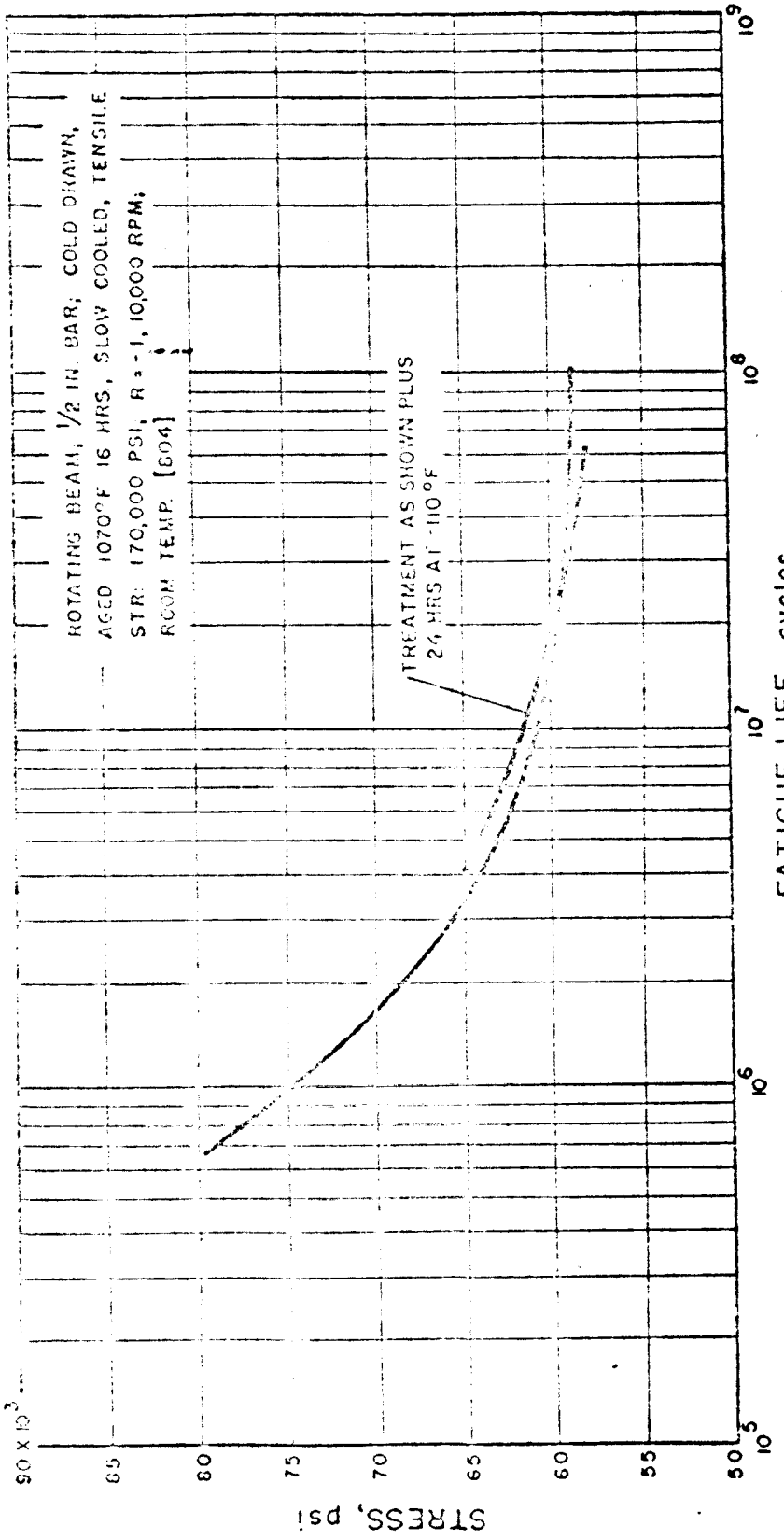
Cost

[illegible] (1) [illegible] 61-[illegible]-12, (2) ASD-TR-62-351, (3) RDR 1223, (4) DMIC 129



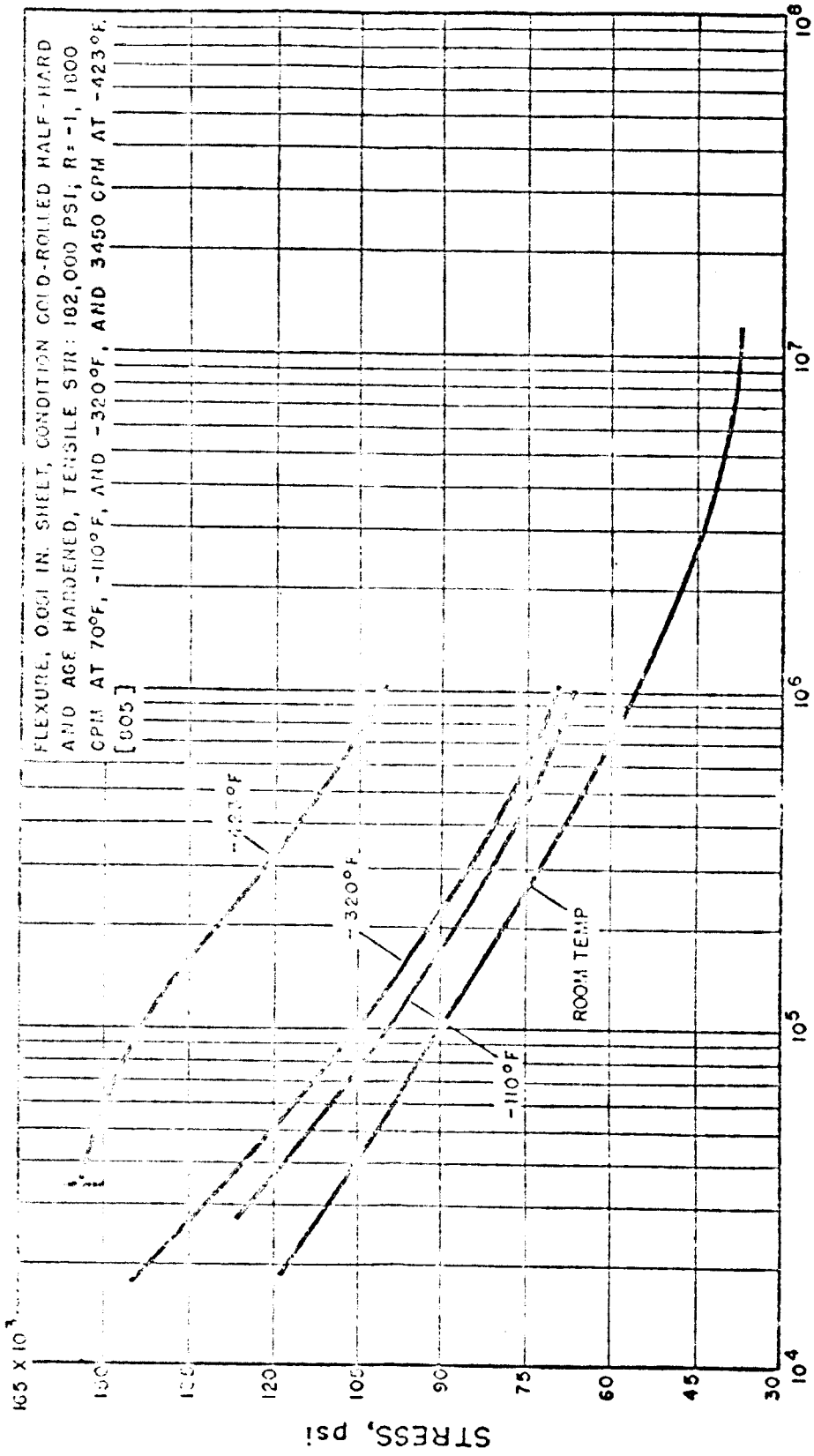
FATIGUE STRENGTH OF K MONEL*

* THE INTERNATIONAL NICKEL CO.



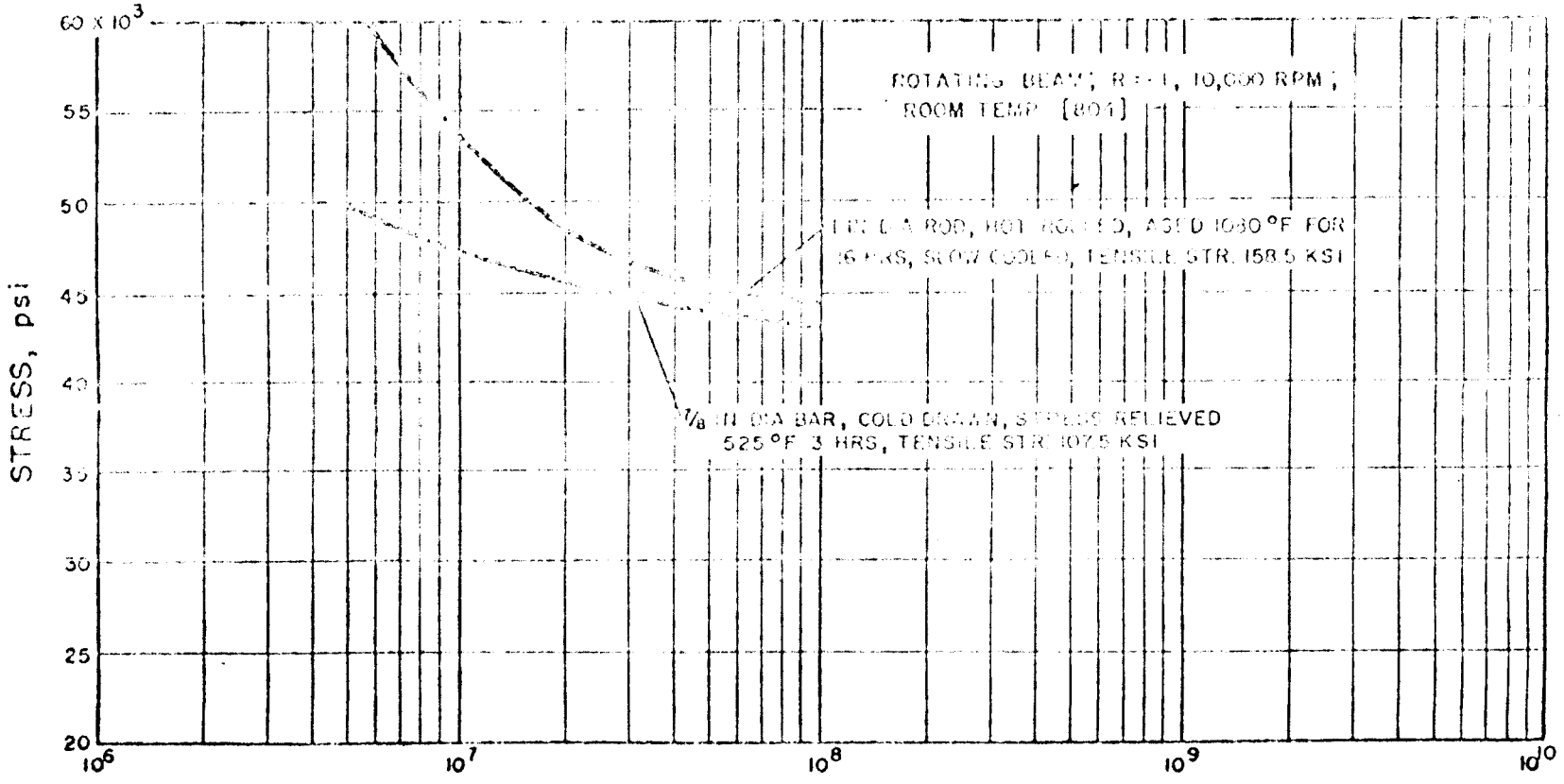
FATIGUE BEHAVIOR OF K MONEL*

* THE INTERNATIONAL NICKEL CO.



FATIGUE BEHAVIOR OF K MONEL*

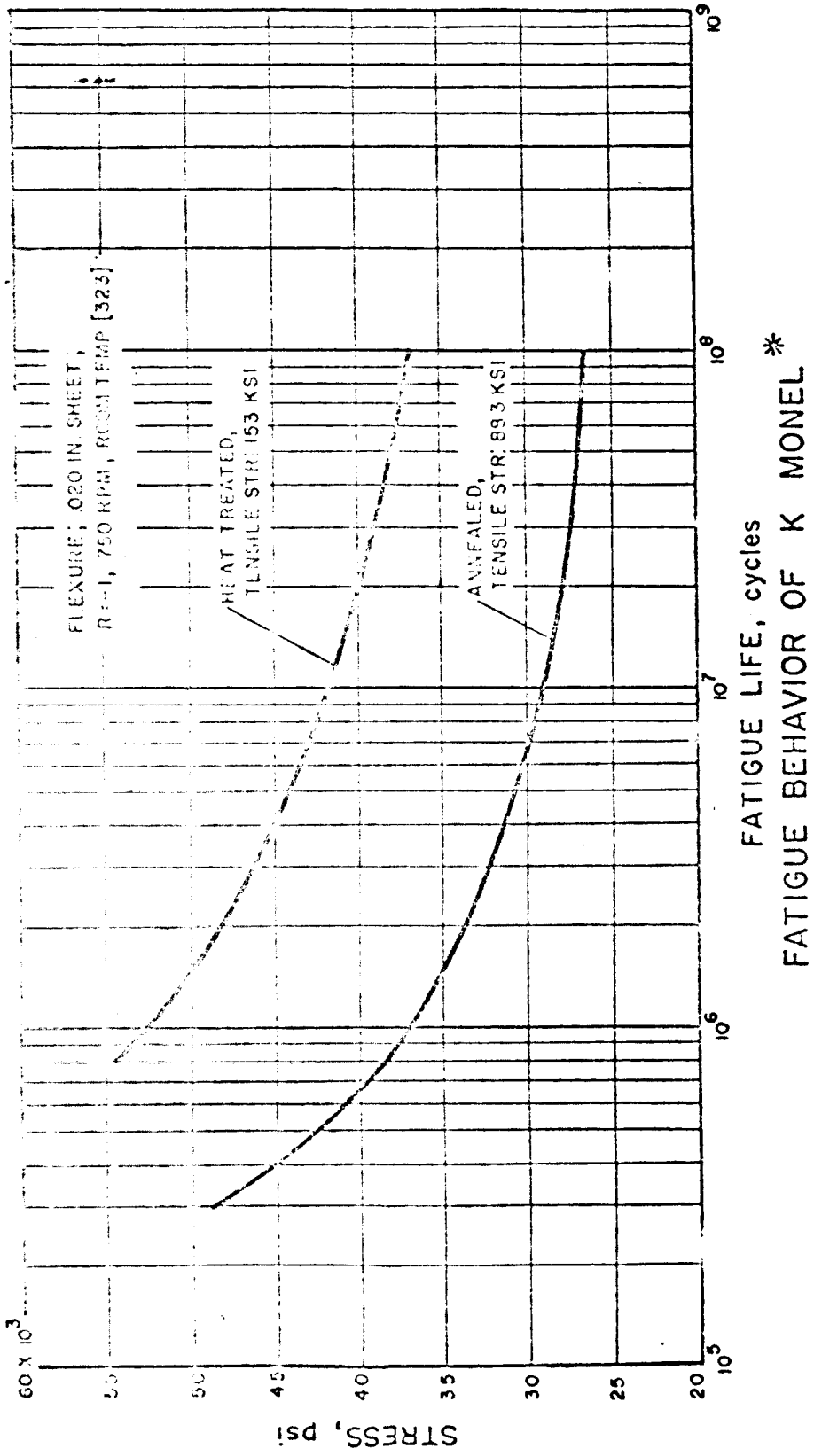
*THE INTERNATIONAL NICKEL CO.



FATIGUE BEHAVIOR OF K MONEL *

* THE INTERNATIONAL NICKEL CO.

E.3.n



FATIGUE BEHAVIOR OF K MONEL*

*THE INTERNATIONAL NICKEL CO.

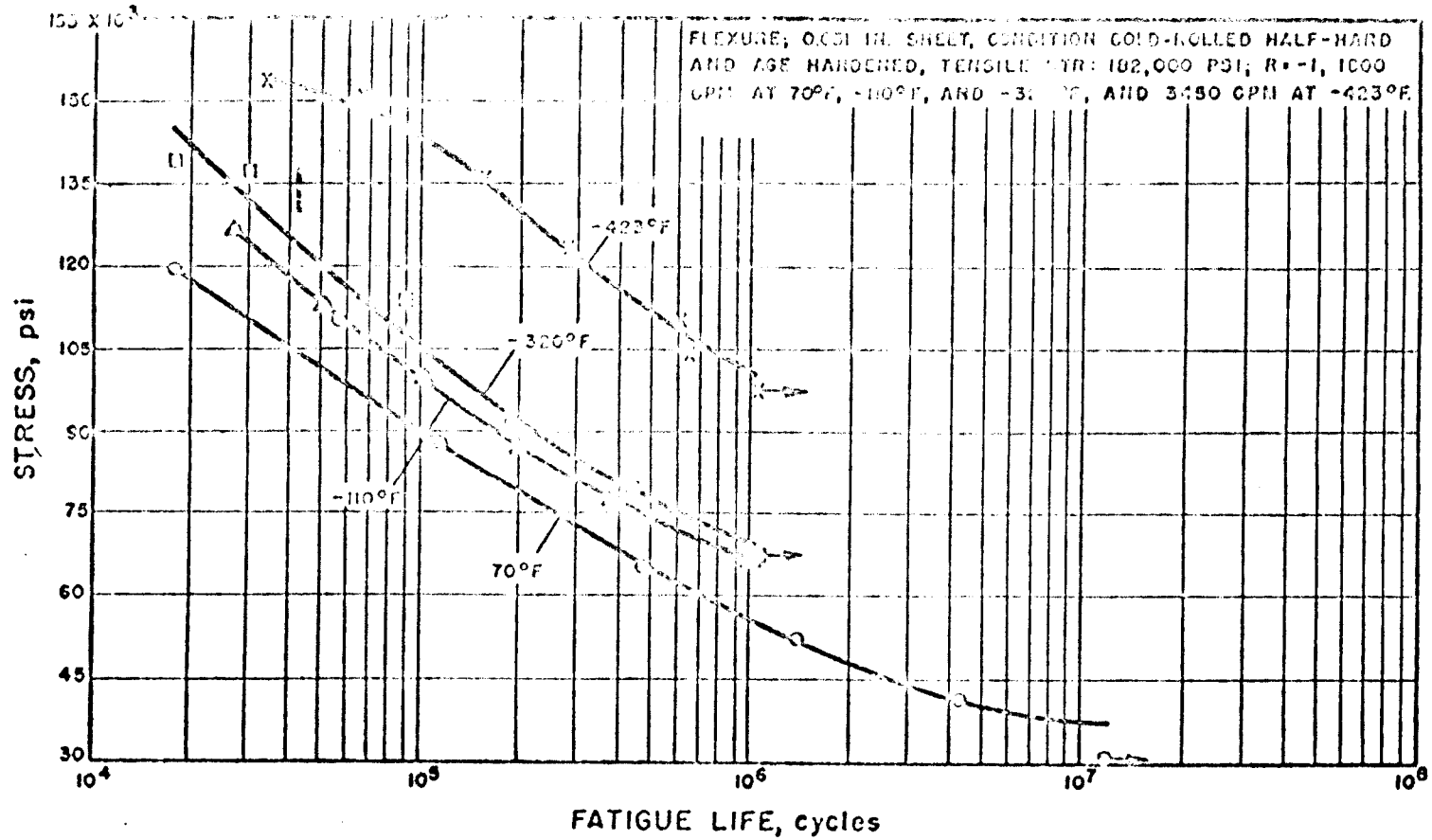


FIGURE 28. UNNOTCHED (K_T = 1) FATIGUE BEHAVIOR OF COLD-ROLLED AND AGE-HARDENED "K" MONEL NICKEL

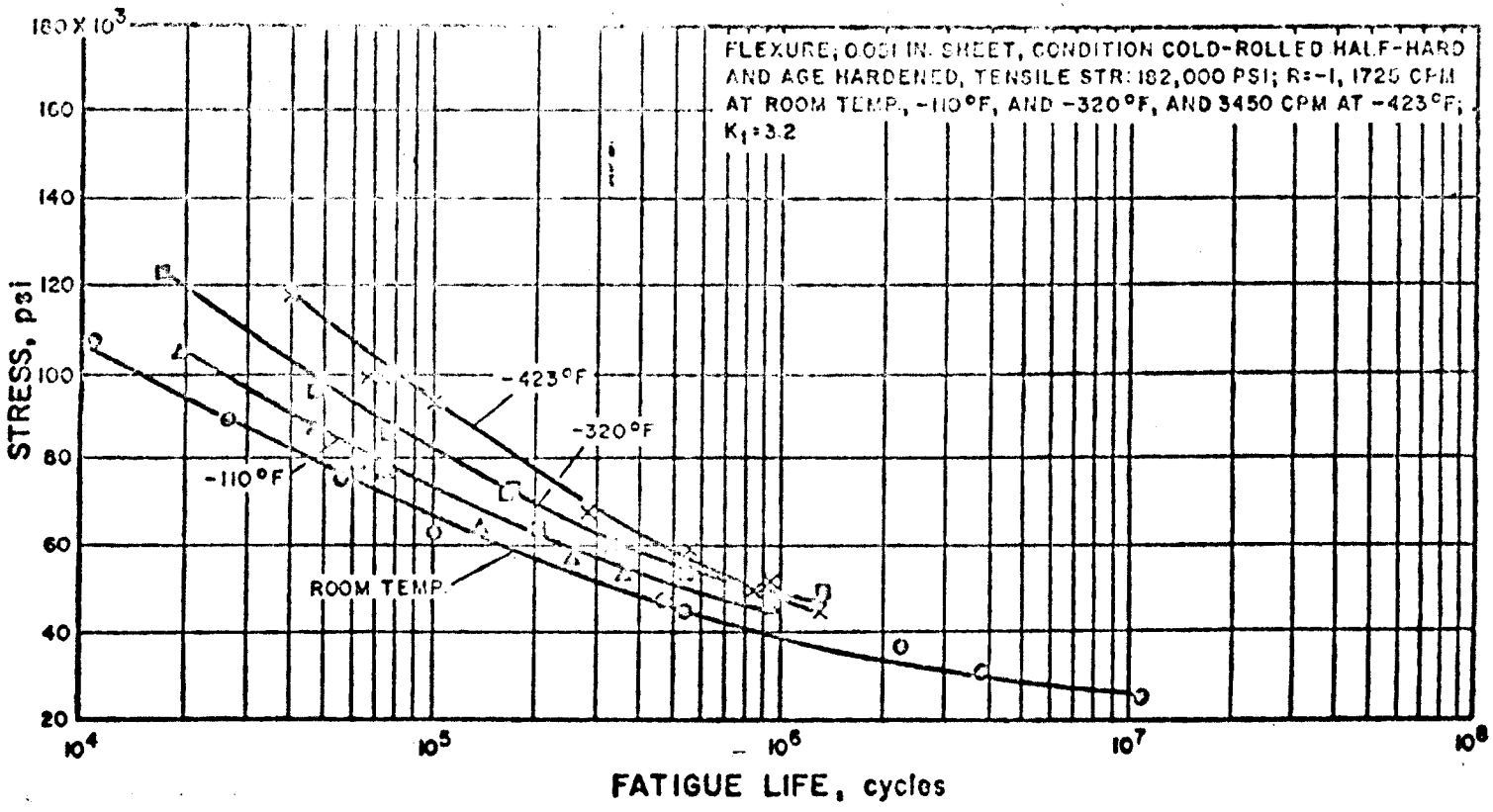
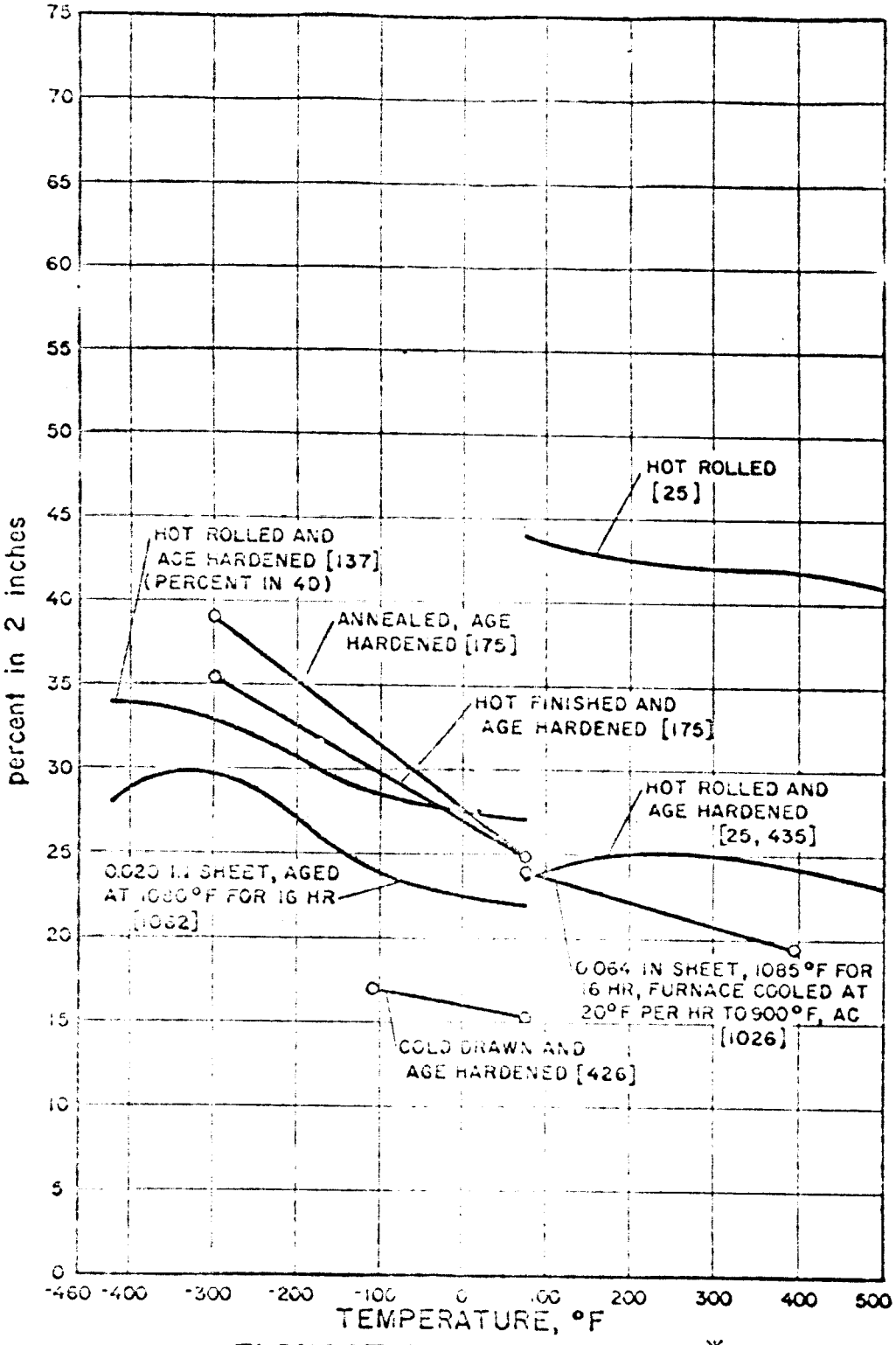


FIGURE 43. NOTCHED (K_T = 3.2) FATIGUE BEHAVIOR OF COLD-ROLLED AND AGE-HARDENED "K" MONEL NICKEL

ASD-TDR-351

CRYOGENIC MATERIAL DATA HAND BOOK PB 171807



ELONGATION OF K MONEL*

* THE INTERNATIONAL NICKEL CO

[illegible] DATA TABLE I DATE September 24, 1964

ALLOY [illegible] SHEET THICKNESS

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. (1) .334					
Modulus of Elasticity X 10^6		25.7	29.5		
Annealed	Tensile - 1000 psi	113	(2) 130	170	
	Yield - 1000 psi	40.7	55	(3) 80	
2100-2150F	Elong. in 2"		50	58	
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		191	228	283
	Yield - 1000 psi		177	(4) 208	(4) 240
40% CR .011	Elong. in 2"		3	12	16
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - [illegible] (10^{-5})			5.36	6.30	7.28
Impact Str. [illegible] (7)			35	37	39

Fatigue Str. Curves at indicated temps.

[illegible]

[illegible] Sensitivity - Yes or No

[illegible] Sensitivity

[illegible] Tensile Ratio (K_t value) 6.3 (1) 1.15 1.16 1.09

[illegible] Joint Efficiencies (same and dissimilar metals) (1) 56 52(5) (1) 51

[illegible] Propagation

[illegible]

Chemicality

Availability

Cost

[illegible] - (1) [illegible] (2) DMIC 132, (3) MONOGRAPH 13, (4) STRUCT. ALLOYS FOR [illegible] (5) [illegible]-15594, (6) DMIC 132, (7) MONOGRAPH 13

TABLE I DATE September 24, 1964

[illegible] SHEET THICKNESS

[illegible] of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. .323 (2)					
Modulus of Elasticity			31 (2)		
Annealed	Tensile - 1000 psi		124	173	201
2225F & RAC .034	Yield - 1000 psi		68.3 (1)	99.6 (1)	119
	Elong. in 2"		47.7	58.2	49.7
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		168	219	241
	Yield - 1000 psi		140 (1)	171 (1)	188
20% COLD ROLLED +AGED 16HR @ 1100F .034	Elong. in 2"		19	27	23.6
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - [illegible] (10^{-5})			4.38	5.35	5.88
Impact Str. (Charpy), Ft. lb.			56	47.5	45
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 6.3(1) 1.03 .97 .96

Weld Joint Efficiencies (same and dissimilar metals)

Resistance to Crack Propagation

[illegible] (3) [illegible] ERICHSEN CUP DEPTH 9.5-10.5 MM

Clad Ability

Availability

Cost

[illegible]-(1) [illegible]-400, (2) DMIC 132, (3) HAYNES STELLITE CO

[illegible] DATA | TABLE I | DATE September 24, 1964

ALLOY [illegible] 25 ([illegible]) | SHEET THICKNESS

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. (3) .330					
Modulus of Elasticity		29.7 (4)	33.5		
Annealed	Tensile - 1000 psi	112 (5)	155		
.040	Yield - 1000 psi	40 (4)	70		
	Elong. in 2"	72 (5)	55		
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition (1)	Tensile - 1000 psi		164	255	268
(2)	Yield - 1000 psi		126	181	208
20% COLD ROLLED	Elong. in 2"		16	23	20
.020	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio -	$\frac{F_{ty}}{}$ (10^{-5})		3.82	5.49	6.30
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No LOX ok

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 6.3 1.03 (1) (2) .91 .98

Weld Joint Deficiencies (same and dissimilar metals) 80 (1)(2) 70 77

Resistance to Crack Propagation

Formability (2) [illegible]

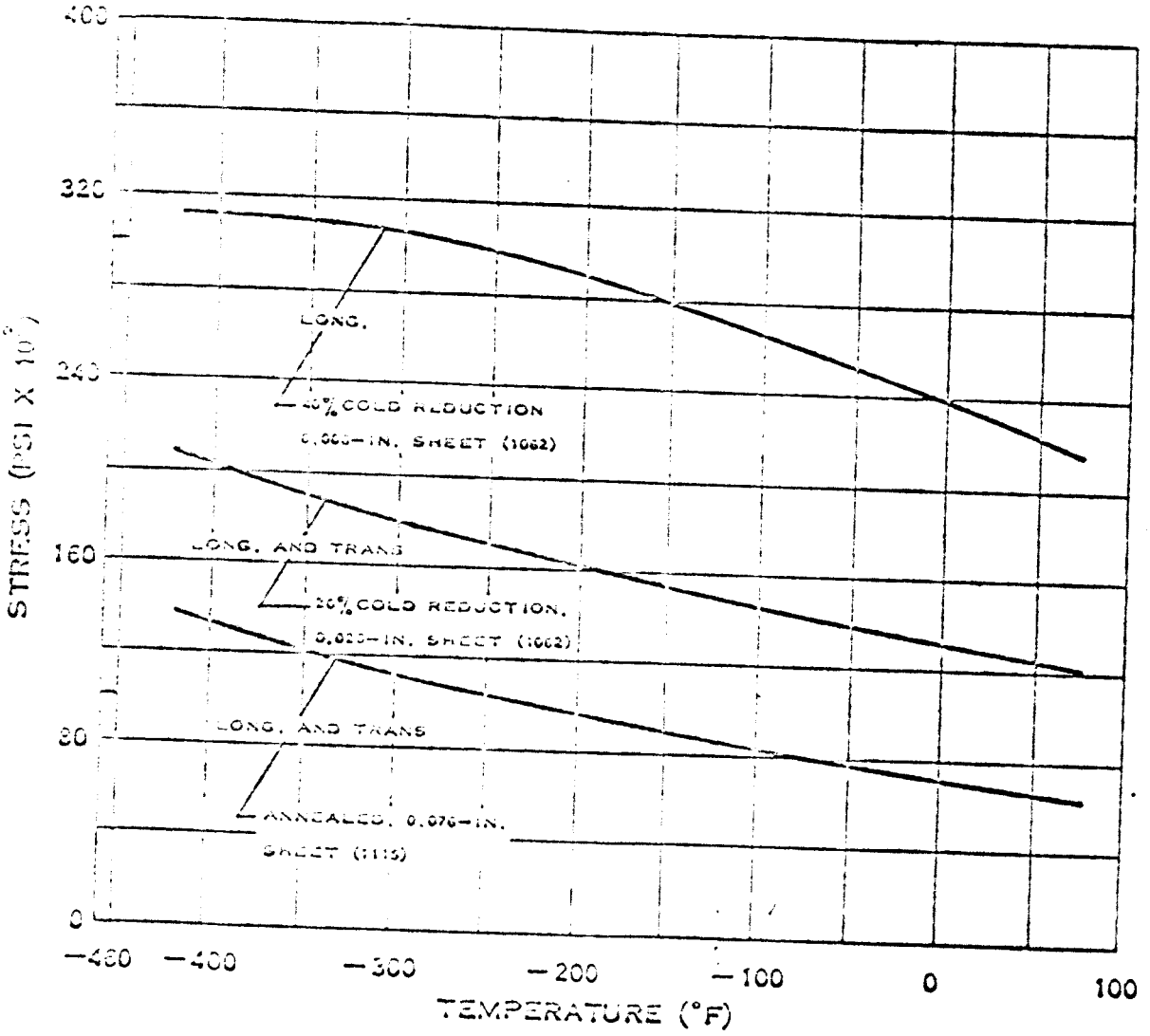
Cleanability

Availability

Cost

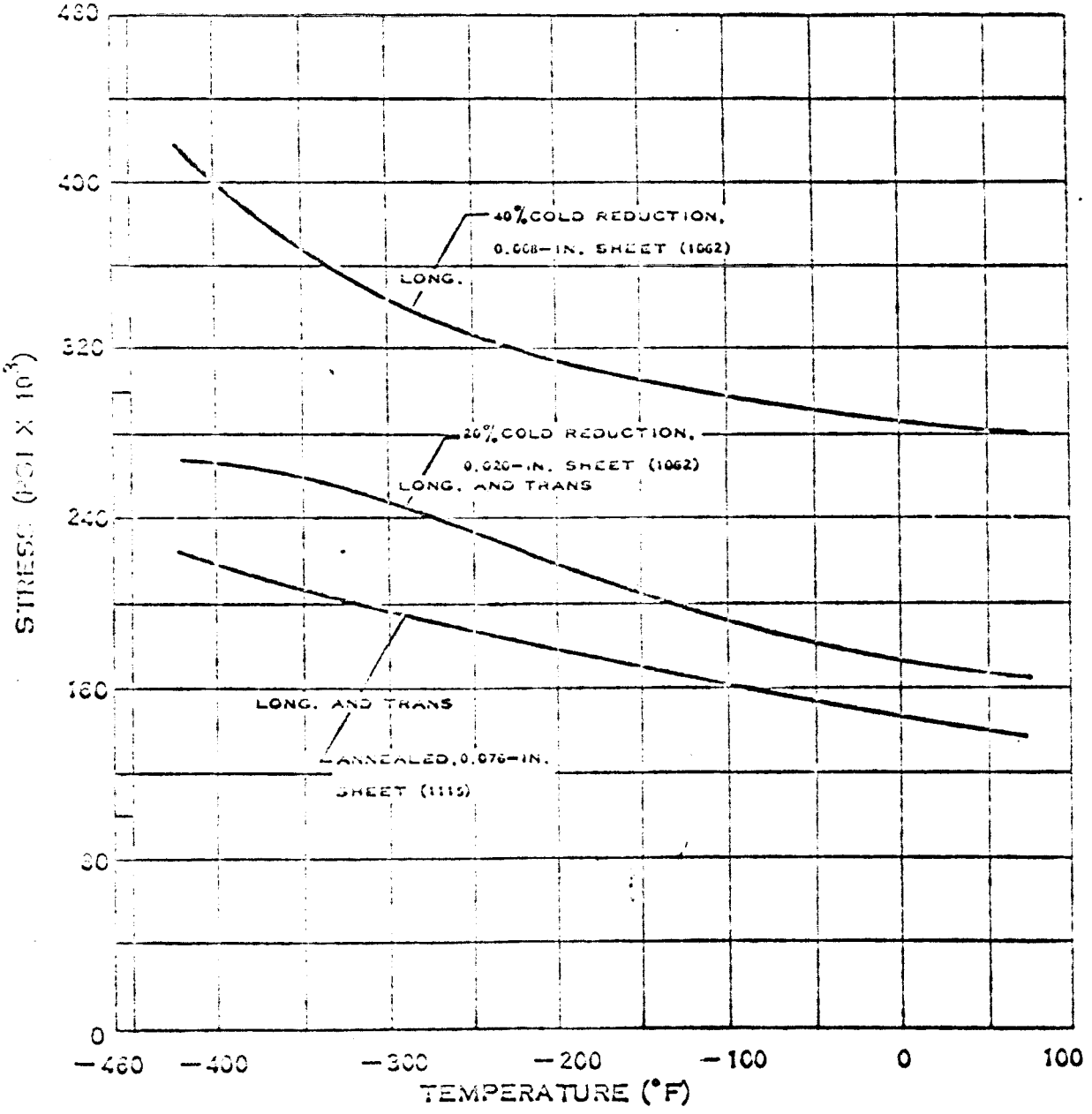
[illegible] (1) [illegible]-12, (2) RDR 1223, (3) DMIC 150, (4) ARDC TR 59-66
(5) [illegible]

B.3.c



YIELD STRENGTH OF L-605

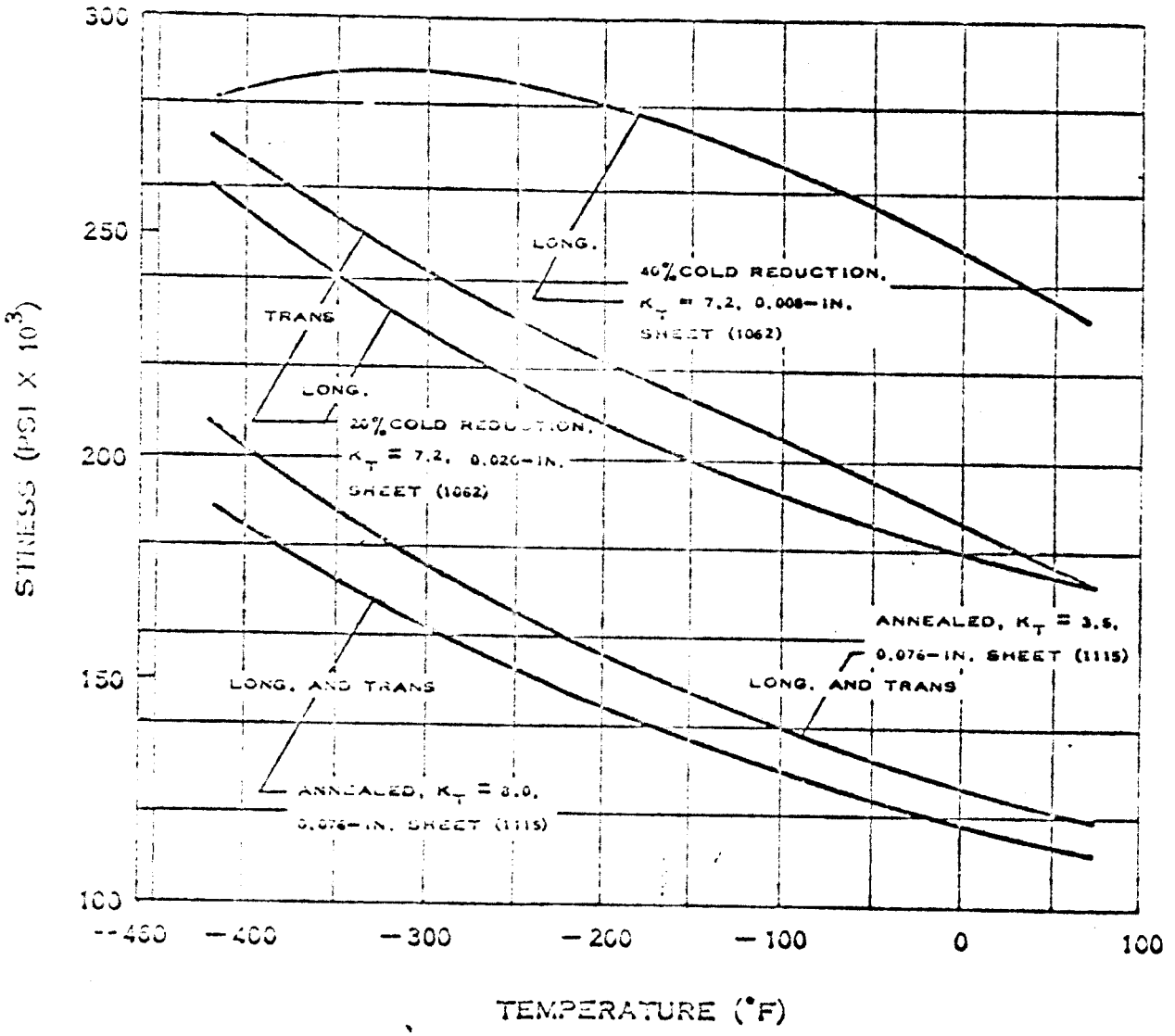
B.3.b



TENSILE STRENGTH OF L-605

(7-15-63)

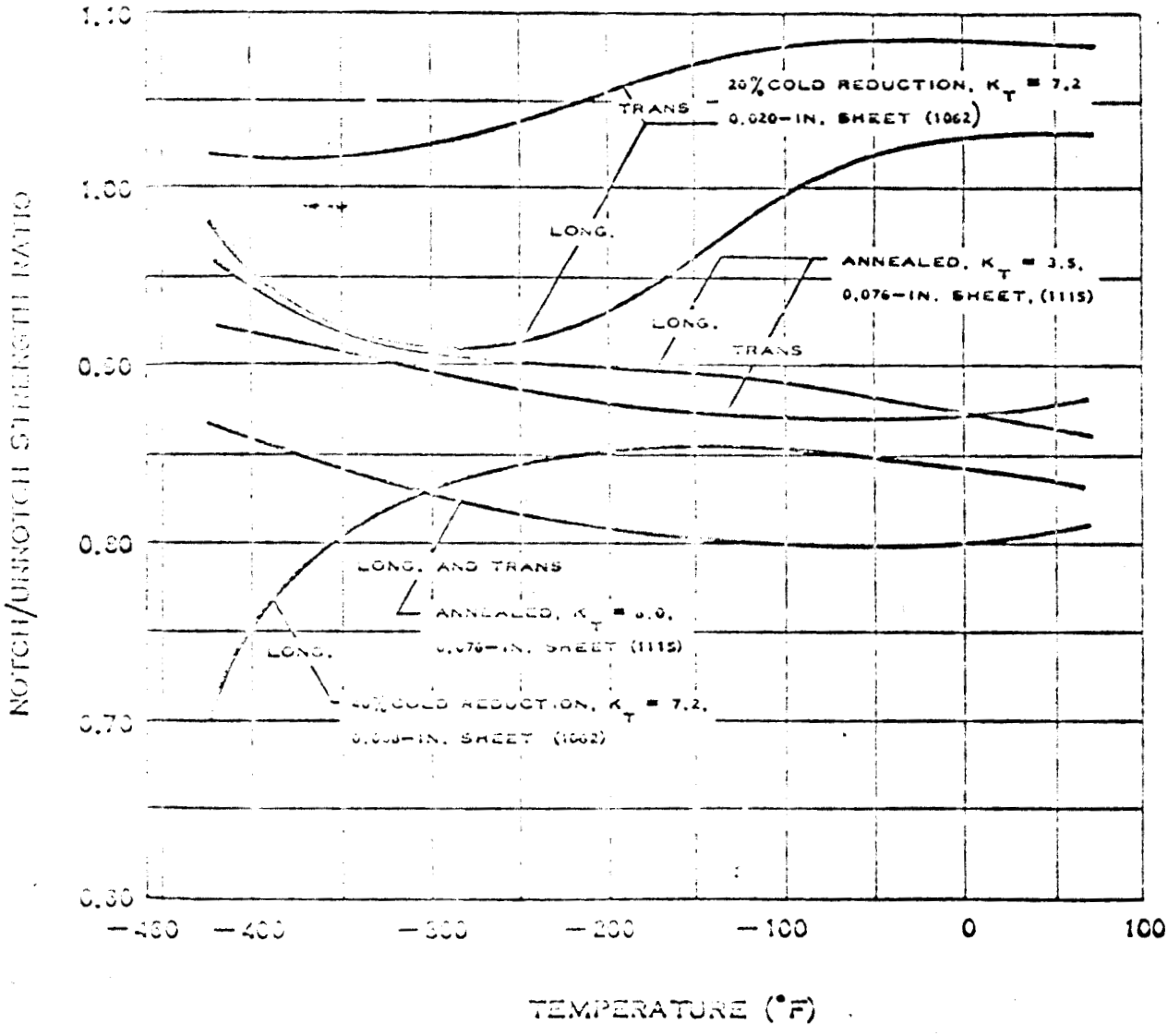
3.3.b-1



NOTCH TENSILE STRENGTH OF L-605

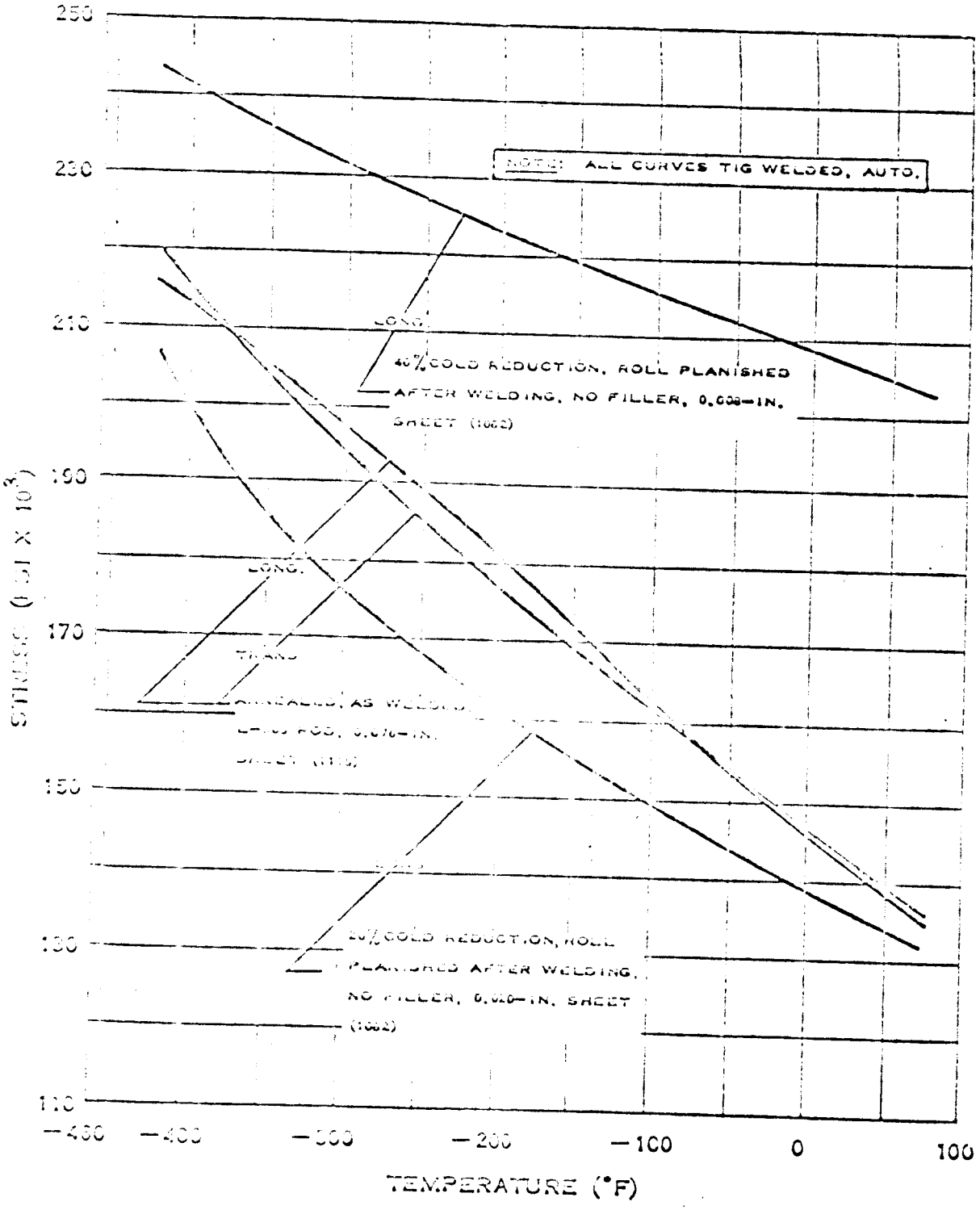
(7-15-63)

3.3.2-2



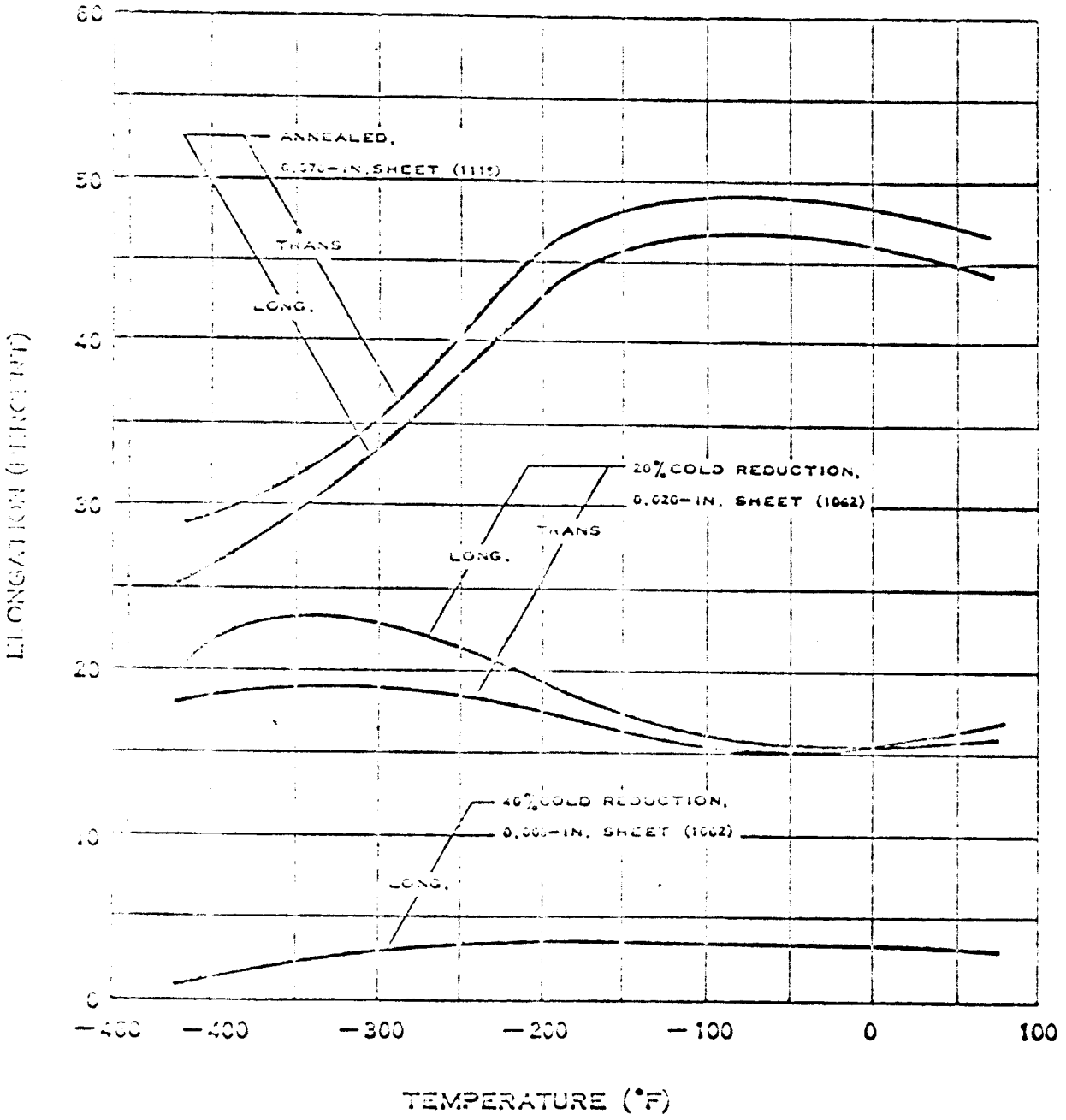
NOTCH STRENGTH RATIO OF L-605

B.3.b-3



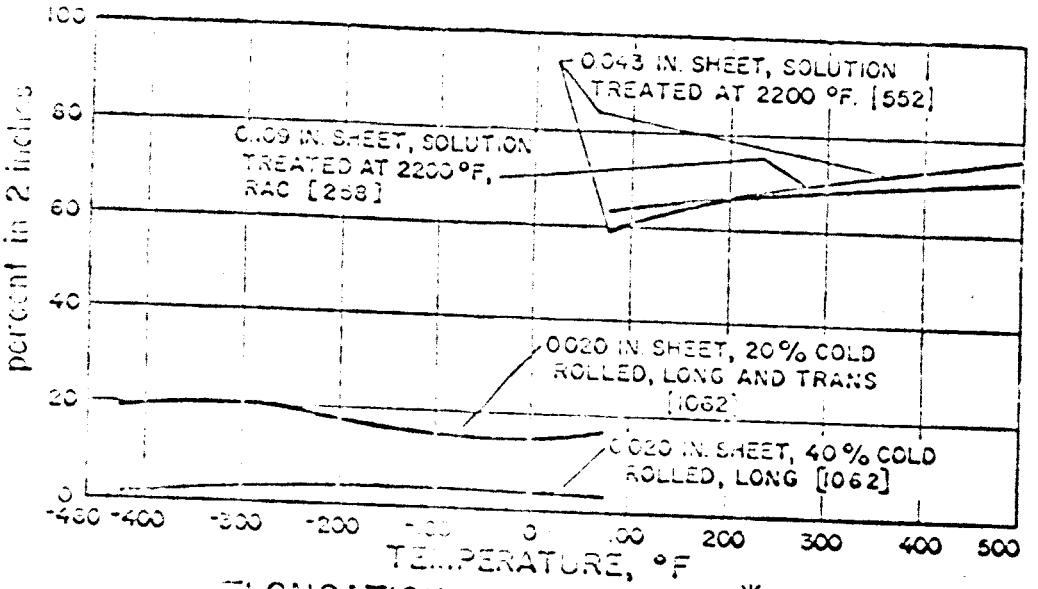
TENSILE STRENGTH OF L-605

B.3.c

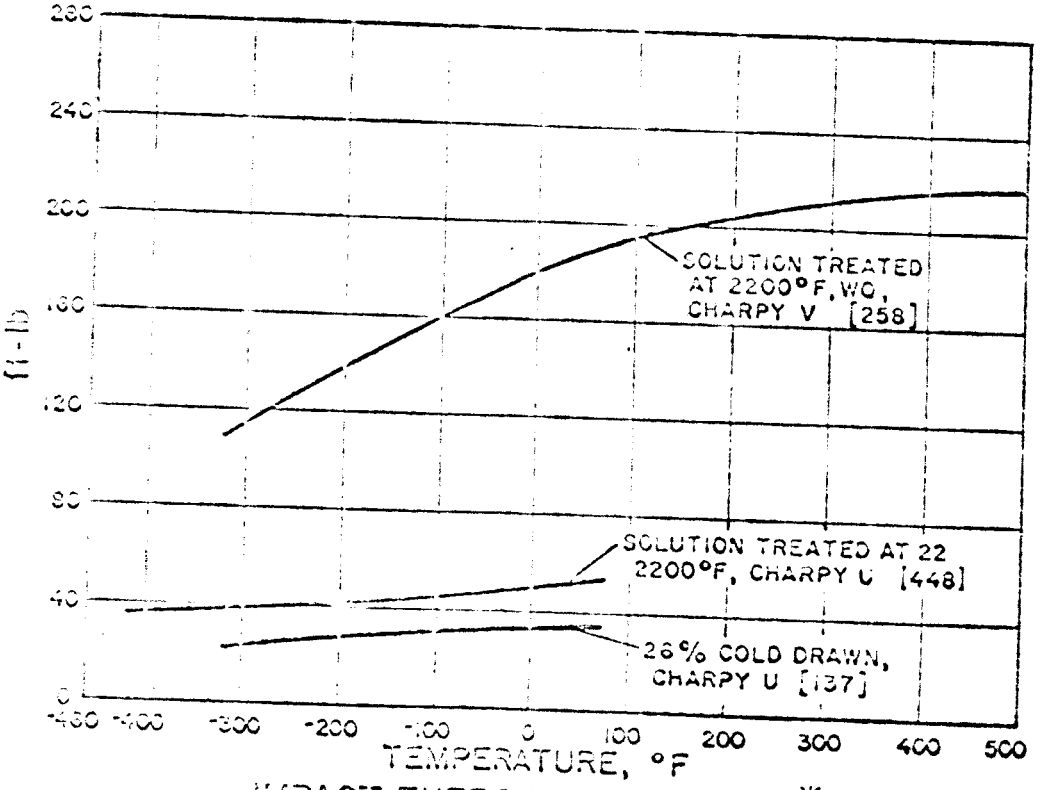


ELONGATION OF L-605

(7-15-63)



ELONGATION OF STELLITE* 25



IMPACT ENERGY OF STELLITE* 25

*UNION CARBIDE CORPORATION.

[illegible] DATA

TABLE I

DATE September 24, 1964

[illegible] SHEET THICKNESS

[illegible] Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. .296					
Modulus of Elasticity	(3)	28.3	28.4 (4)	30.4 (4)	31
Annealed (1) [illegible]	Tensile - 1000 psi		134	178	223
	Yield - 1000 psi		71.9	94.1	126
	Elong. in 2"		48	51	44
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
[illegible] or Cold Worked (1)(2) Condition [illegible] 1950F AS + 16 HR AT 1400F AS [illegible]	Tensile - 1000 psi		181	202	212
	Yield - 1000 psi		138	161	179
	Elong. in 2"		18	9	6
	Bearing - 1000 psi $\frac{e}{D}$ = 2)	3[illegible]4	370		
	Shear - 1000 psi	107 (5)	115		
Str. to Density Ratio - [illegible]			4.6	5.37	5.97

[illegible] Str. ([illegible]), ft. lb.

Fatigue Str. Curves at indicated temps.

[illegible]

LOM or Liquid Embrine Sensitivity - Yes or No

[illegible] Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) (1)(2) 6.3 .91 .94 .99

[illegible] Efficiencies (same and dissimilar metals)(4) 70 76 75

[illegible] to Crack Propagation

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] (1) [illegible] 61-[illegible]-12, (2) RDR 1223, (3) CANNON MUSKEGON, (4) ASD-TDR-62-258, [illegible] 61-529

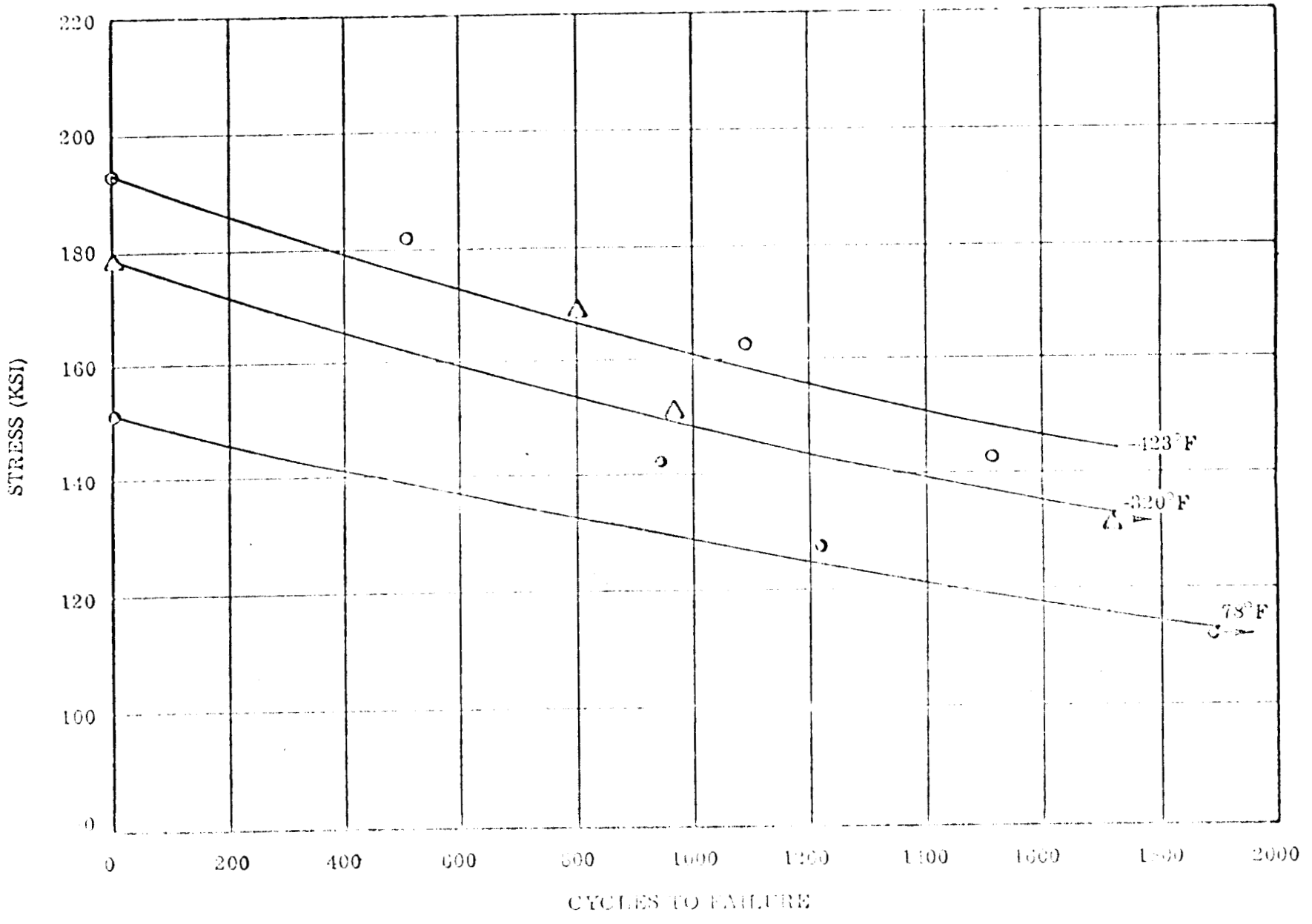


Figure 8. S. N. Curve, René 41 Alloy (Longitudinal Joint No. 1)

TABLE I DATE September 2[illegible], 19[illegible]

[illegible] SHEET THICKNESS

[illegible]		[illegible]°F	R.T.	-320°F	-423°F
[illegible]					
[illegible]					
[illegible]	[illegible] - 1000 psi				
	[illegible] - 1000 psi				
	[illegible]				
	[illegible] - 1000 psi ($\frac{e}{D}$ = 2)				
	[illegible] - 1000 psi				
[illegible] Condition	[illegible] - 1000 psi	[illegible]	210		
	[illegible] - 1000 psi	[illegible]	160		
	[illegible]				
	[illegible] - 1000 psi $\frac{e}{D}$ = 2)				
	[illegible] - 1000 psi				
Str. to [illegible]					
Impact [illegible]					
[illegible]					
[illegible]					
[illegible] Fluorescent Sensitivity - Yes or No					
[illegible] Sensitivity					
[illegible] Tensile Ratio (K_t value)					
[illegible] (same and dissimilar metals)					
[illegible] to Crack Propagation					
[illegible]					
[illegible]					
[illegible]					
Cost					

New High Temperature Superalloy Is Weldable

René 62 resists cracking during welding; is stronger than René 41 below 1350 F.

A NEW nickel-base wrought alloy, René 62, has been developed to fill the need for a readily weldable, high strength metal for service at temperatures up to 1500 F. Because of its freedom from post-weld cracking, the alloy is expected to be useful for welded sheet metal assemblies such as turbine engine frames. Although still not commercially available, six production size heats (see table for composition) have been melted and processed to sheet by three producers.

COMPOSITION (%) OF RENÉ 62 COMPARED TO OTHER SUPERALLOYS

Alloy →	René 62	René 41	In-718
Al	1.25	1.52	0.6
Cb	2.25	—	5.2
Ti	2.50	3	0.8
Mo	9	10	3
Cr	15	19	19
Fe	22.5	—	18
C	0.05	0.12	0.04
Mn	low	—	—
Si	low	—	—
B	0.01	—	—
Co	—	11.3	—
Ni	Bal	Bal	Bal

Cracking and age hardening

Strain age cracking (or post-weld cracking) is a problem often encountered with high strength superalloys. During the heat treatment following welding, rigid structures tend to pull themselves apart because of residual welding stresses, distortion caused by aging reactions, and non-uniform heating and cooling. When these high restaining forces cause deformation that exceeds the ductility of the weld area, the structure will crack. And while cracking most often occurs during post-weld heat treatment, it can also happen during welding, particularly if the thickness of the material requires more than one weld pass.

René 62 helps to beat these problems since it is ductile in the aging temperature range, and because it also has a slow rate of age hardening that allows stresses to be relieved by deformation before the embrittling aging reaction occurs.

Specifically, the age hardening rate for René 62 falls approximately half-way between that of René 41 and IN-718, as Fig 1 shows. René 41 must be cooled from 2050 F to 1000 F in 8 sec or less in order to maintain a maximum hardness of 63 Rockwell A. René 62, on the other hand, does not reach this hardness level until approximately 100 sec.

And, while elongation of René 62 is at a minimum at lower temperatures, it increases to over 20% at 1400 F. René 41 undergoes a severe drop in elongation, e.g., from 20% to approximately 8%, around 1300 F and is, therefore, more prone to cracking after welding.

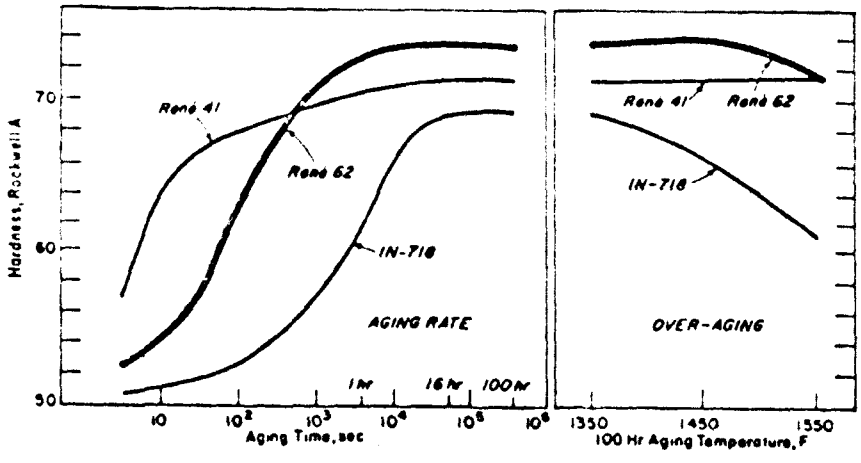
Strength better below 1350 F

Yield and tensile strength of René 62 are compared with those of IN-718 and René 41 in Fig 2. René 62 maintains a strength advantage over René 41 and IN-718 below 1350 F. Above that temperature, strength drops below that of René 41 but remains much higher than that of IN-718.

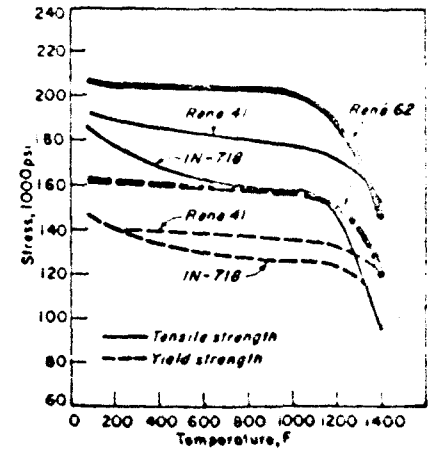
Heat treatment to produce the desired properties in René 62 is as follows: mill anneal at 2000 F for 10 to 60 min and water quench. Age by holding at 1400 F for 16 hr, air cooling and re-aging at 1200 F for 24 hr, followed by air cooling. If possible, weldments should be solution treated a second time before aging in order to relieve fabrication stresses. ■■

Circle No. 600

Based on a paper presented to the 6th National SAMPE Symposium, Seattle, Nov 18-20, 1963.



1. Aging rate of René 62 is midway between that of René 41 and IN-718.



2. Comparative strength of René 62.

[illegible]

TABLE I DATE [illegible]

[illegible] SHEET THICKNESS [illegible]

[illegible]	800°F	R.T.	-320°F	-423°F
[illegible]		(1)		
[illegible] 10^6		(3) 29.1		
[illegible] Tensile - 1000 psi		92.9	151	195
[illegible] Yield - 1000 psi		45.1	72.9	99.9
[illegible] in 2"		29	57	56
[illegible] - 1000 psi ($\frac{d}{D}$ = 2)				
[illegible] - 1000 psi				
[illegible] - 1000 psi		166	203	232
[illegible] - 1000 psi		77 (1) (2)	122 (1) (2)	139
[illegible] in 2"		15	23	18
[illegible] - 1000 psi ($\frac{d}{D}$ = 2)				
[illegible] - 1000 psi				
[illegible]		3.36	4.25	4.65
[illegible]		55.4	52.6	50.4
[illegible]				

[illegible]

[illegible] - Yes or No

[illegible]

[illegible] (mg value) [illegible] (1).96 .88 .87

[illegible] and dissimilar metals)

[illegible]

[illegible]

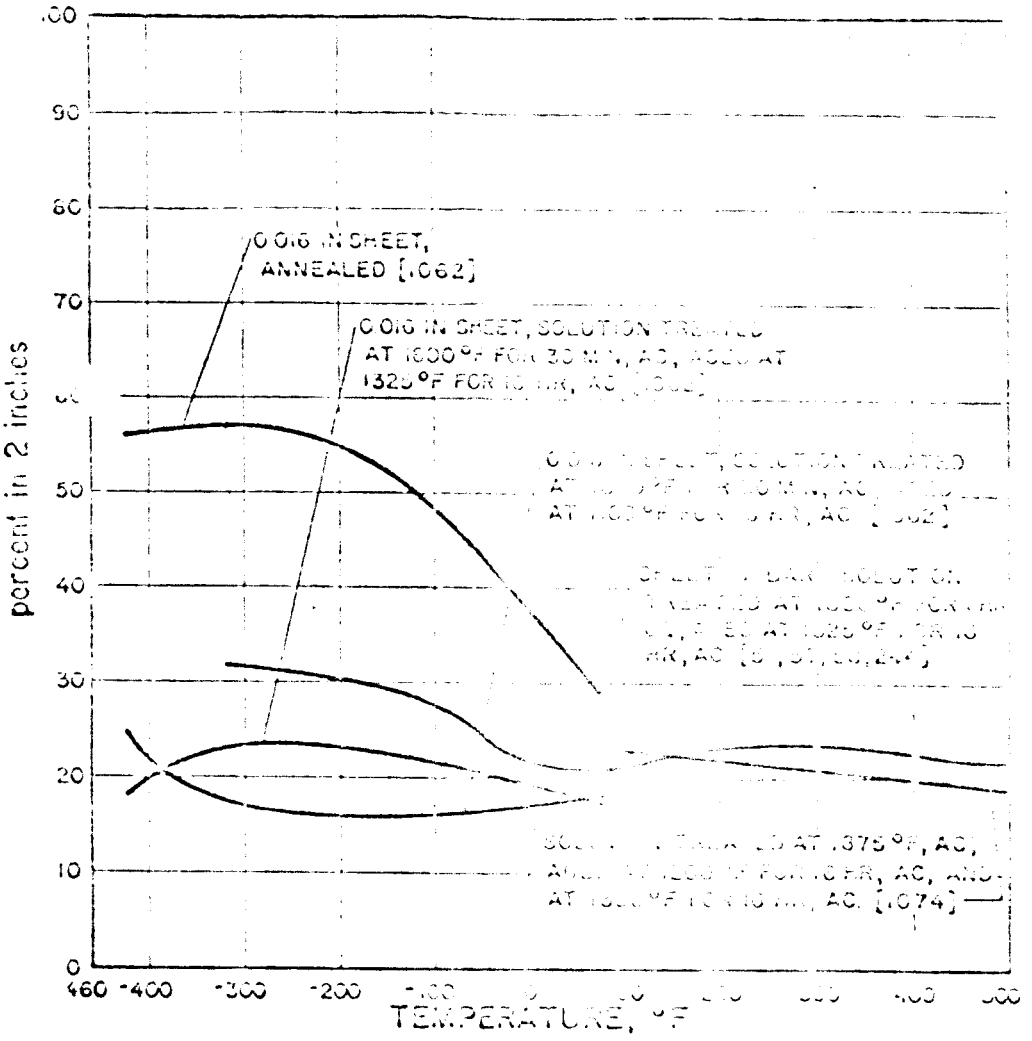
[illegible]

[illegible]

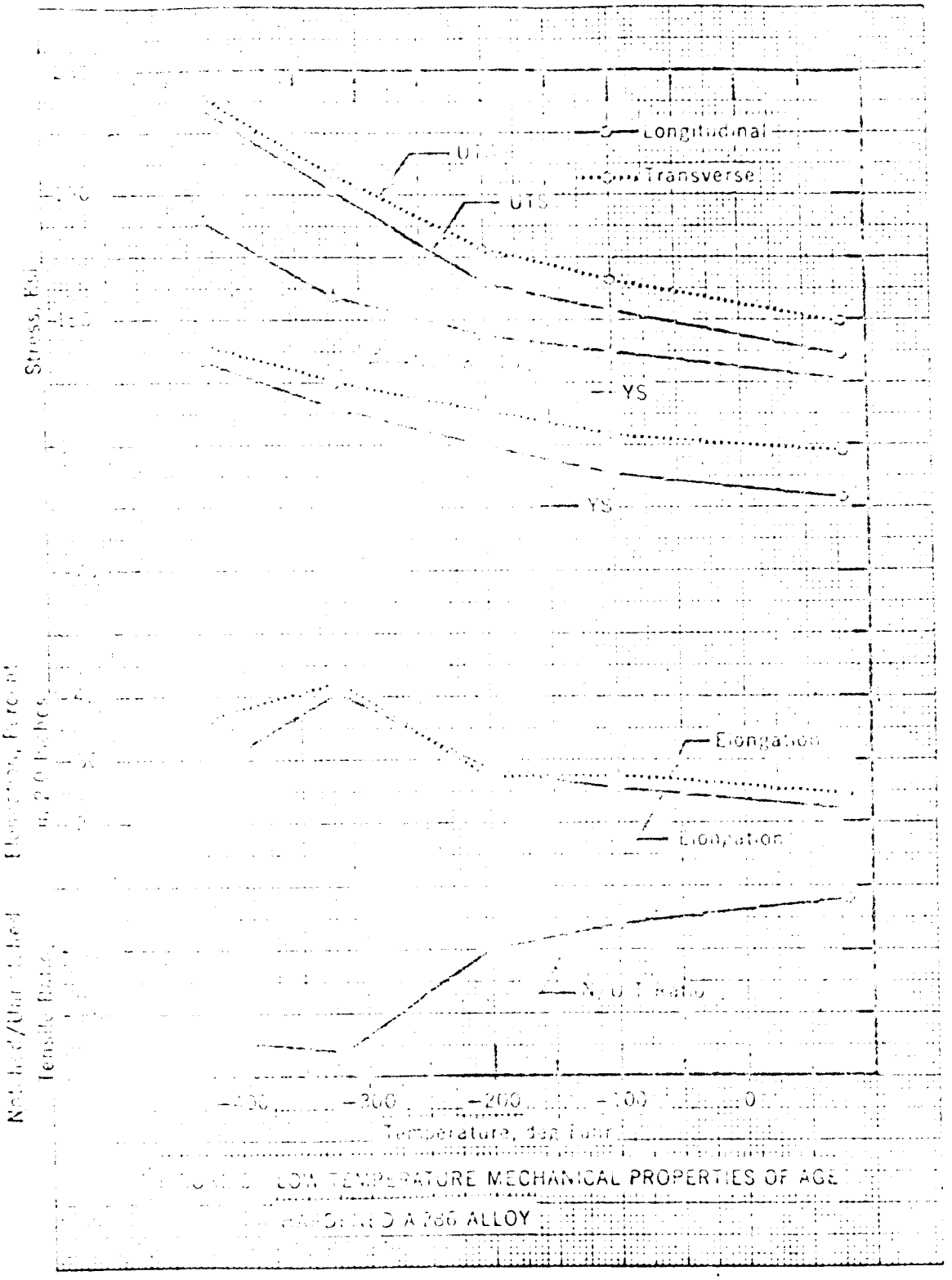
[illegible]

[illegible] (1) [illegible], (2) [illegible] (3) ALLEGHENY LUDLUM, [illegible] (5) [illegible], (6) CRYOGENIC HANDBOOK PB171309

[illegible]



ELONGATION OF A-286 STAINLESS STEEL



LOW TEMPERATURE MECHANICAL PROPERTIES OF AGE HARDENED A 286 ALLOY

AGE HARDED @ 1350°F/16HR AC

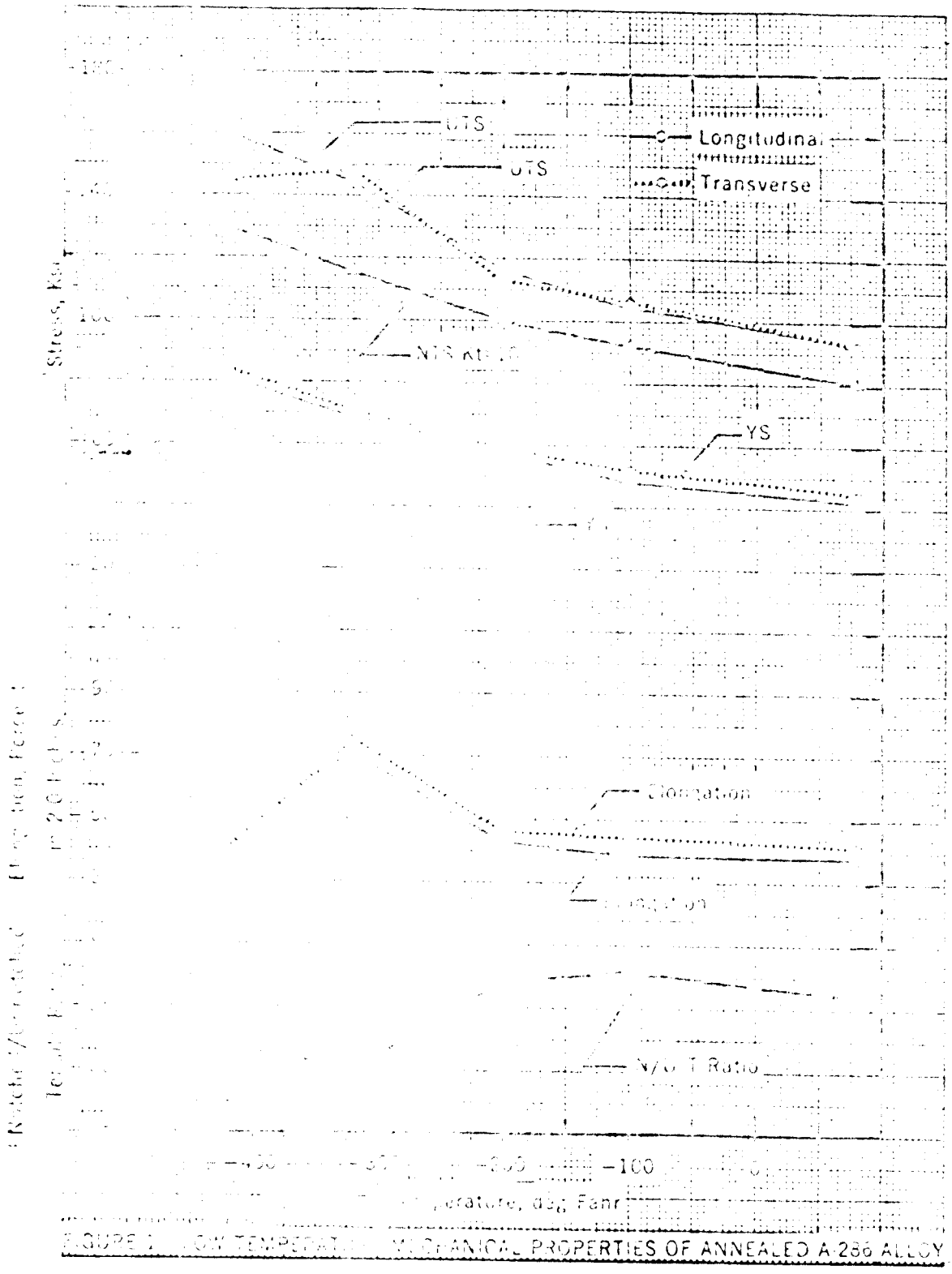


FIGURE 1 LOW TEMPERATURE MECHANICAL PROPERTIES OF ANNEALED A-286 ALLOY

.050 WALL ANNEALED

[illegible] STAINLESS STEELS

[illegible] the [illegible] of [illegible] 347, the 300 series stainless steels studied all [illegible] to be candidates for further study. The strength to density ratios are [illegible] for all, but the [illegible] 347. Tensile and Ultimate strengths increase as [illegible] lowers. [illegible] increases as temperature lowers to -320F and [illegible]. Type 301 S.S. [illegible] to retain the best elongation property [illegible] -423F, [illegible] Central Dynamics/Astronautics has experimented with Type 301 which [illegible] 35% [illegible] -320F and produced a material with fair elongation properties. Notched/unnotched ratios work all well over 0.90, some even greater than unity.

[illegible] DATE [illegible]

[illegible] SHEET THICKNESS

[illegible]	300°F	R.T.	-320°F	-423°F
[illegible]				
[illegible] (1)		25.3	28.4	30.0
[illegible] Tensile - 1000 psi		105	275	
Yield - 1000 psi (3)		40	55	
[illegible] in 2"		60	[illegible]	
[illegible] - 1000 psi ($\frac{1}{D}$ = 2) (4)		150 MIN		
[illegible] - 1000 psi (4)		[illegible] MIN		
[illegible] - 1000 psi		223	[illegible]	[illegible]
[illegible] - 1000 psi		203	[illegible]	[illegible]
[illegible] in 2"		5.5	19.5	11.5
[illegible] - 1000 psi ($\frac{1}{D}$ = 2)(2)	348	472		
[illegible] - 1000 psi	71 (2)	69.1		
[illegible] (10^{-5})		7.28	8.50	9.[illegible]

[illegible] CURVES ATTACHED

[illegible]

[illegible] - Yes or No LOX ok, FLUORINE ok if passivated

[illegible]

[illegible] Ratio ($K_t^{1.3}$ value) (1) 1.03 .93 .90

[illegible] and dissimilar metals) 78 92 [illegible]

[illegible] to Crack Propagation

[illegible]

Clearability

[illegible]

Cost

[illegible] 267

[illegible]

3. MONOGRAPH 13, N.B.S.
4. MIL-HDBK-5, ANG 5

5. PROPERTIES OF [illegible] MATERIALS, [illegible]

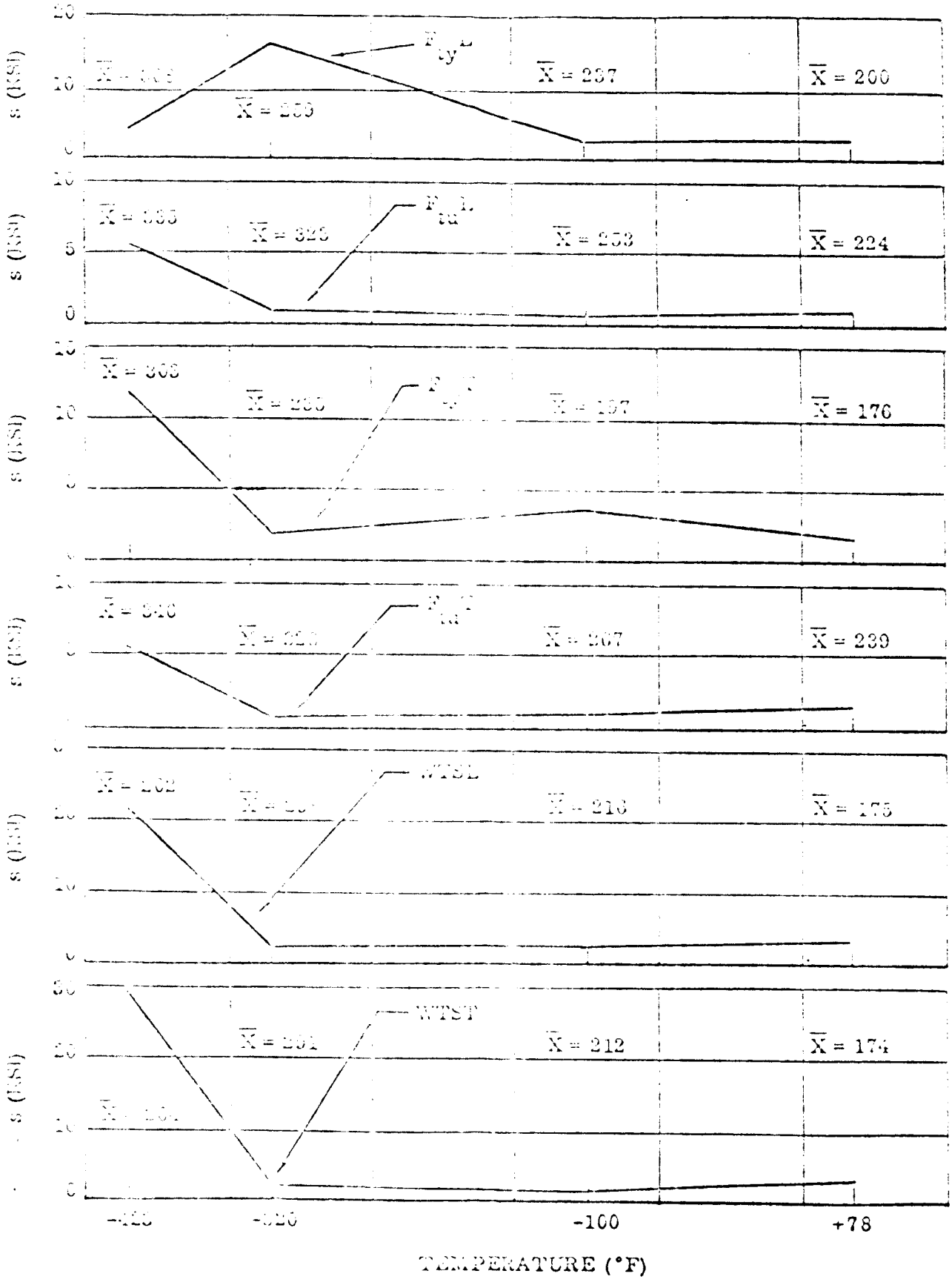


Figure 126. Standard Deviations Versus Temperature (301 SS)

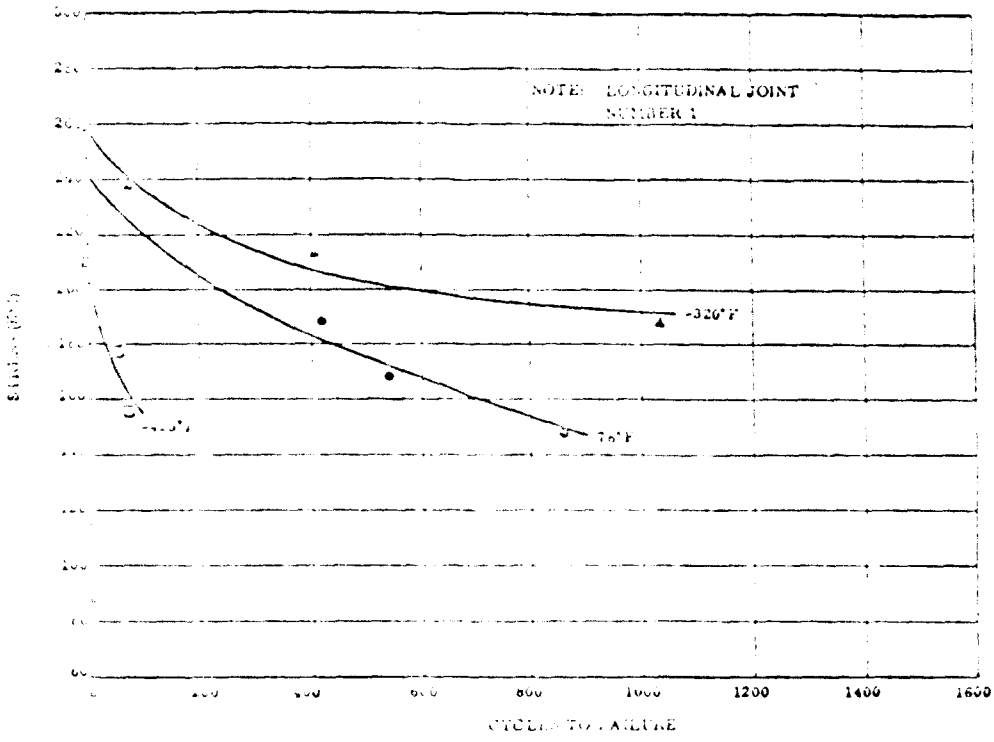


Figure 86. S-N Curve - 301 Stainless Steel (Longitudinal - Joint No. 1)

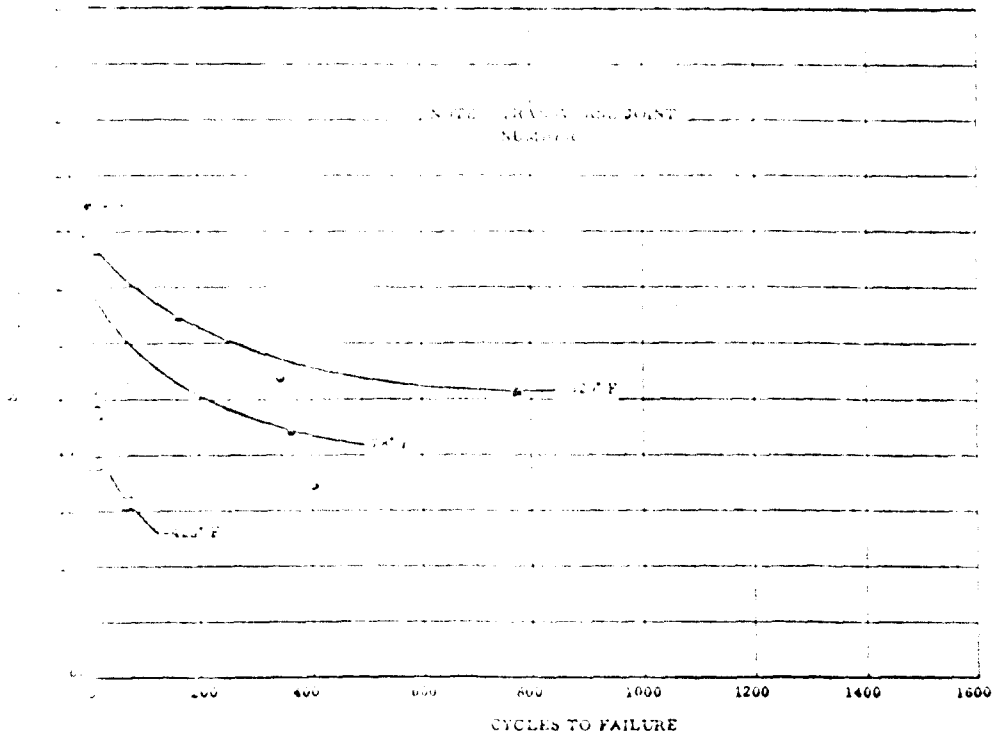


Figure 87. S-N Curve - 301 Stainless Steel (Transverse Joint No. 1)

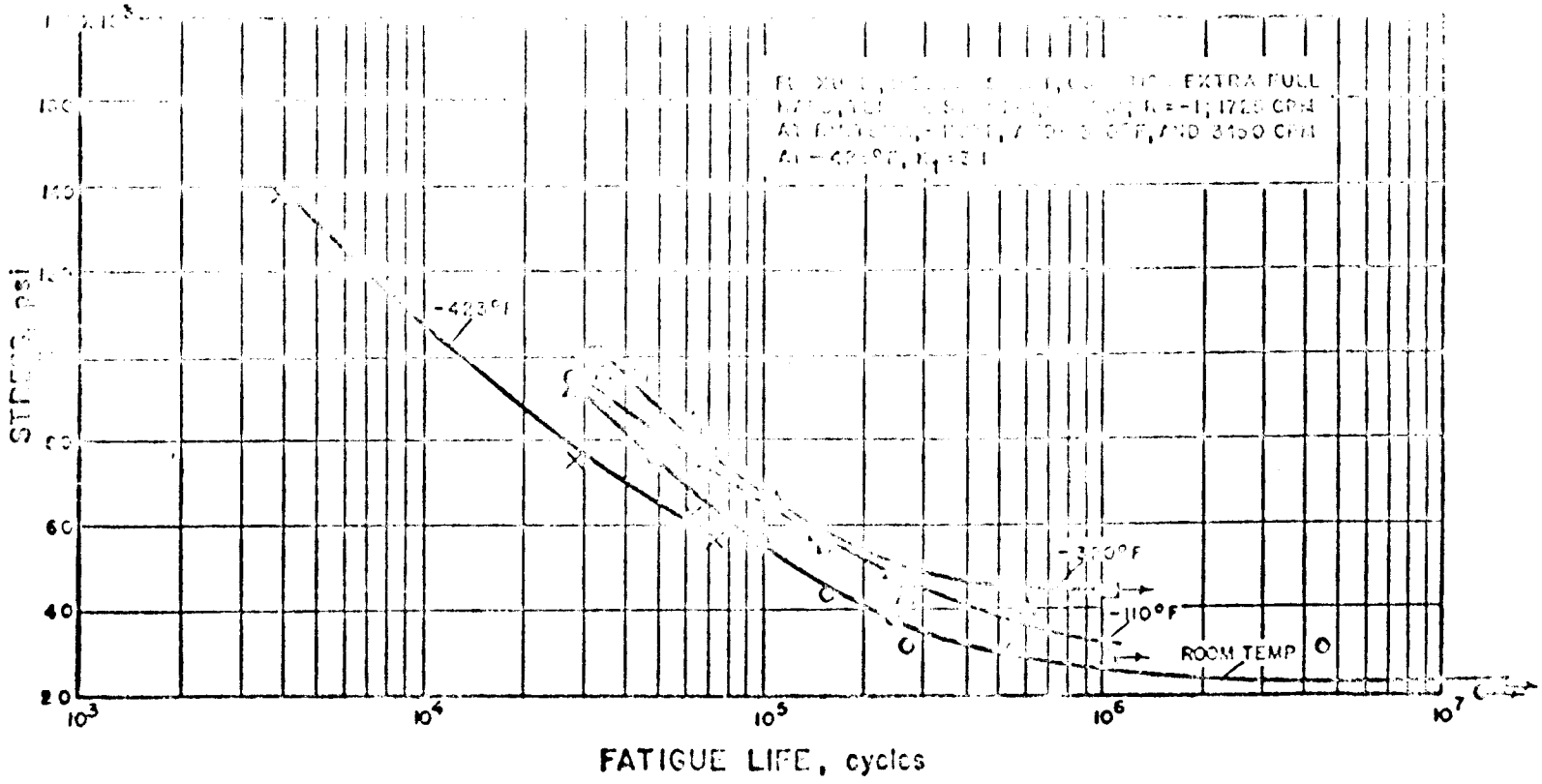


FIGURE 41. NOTCHED (K_T = 3.1) FATIGUE BEHAVIOR OF COLD-ROLLED 301 STAINLESS STEEL

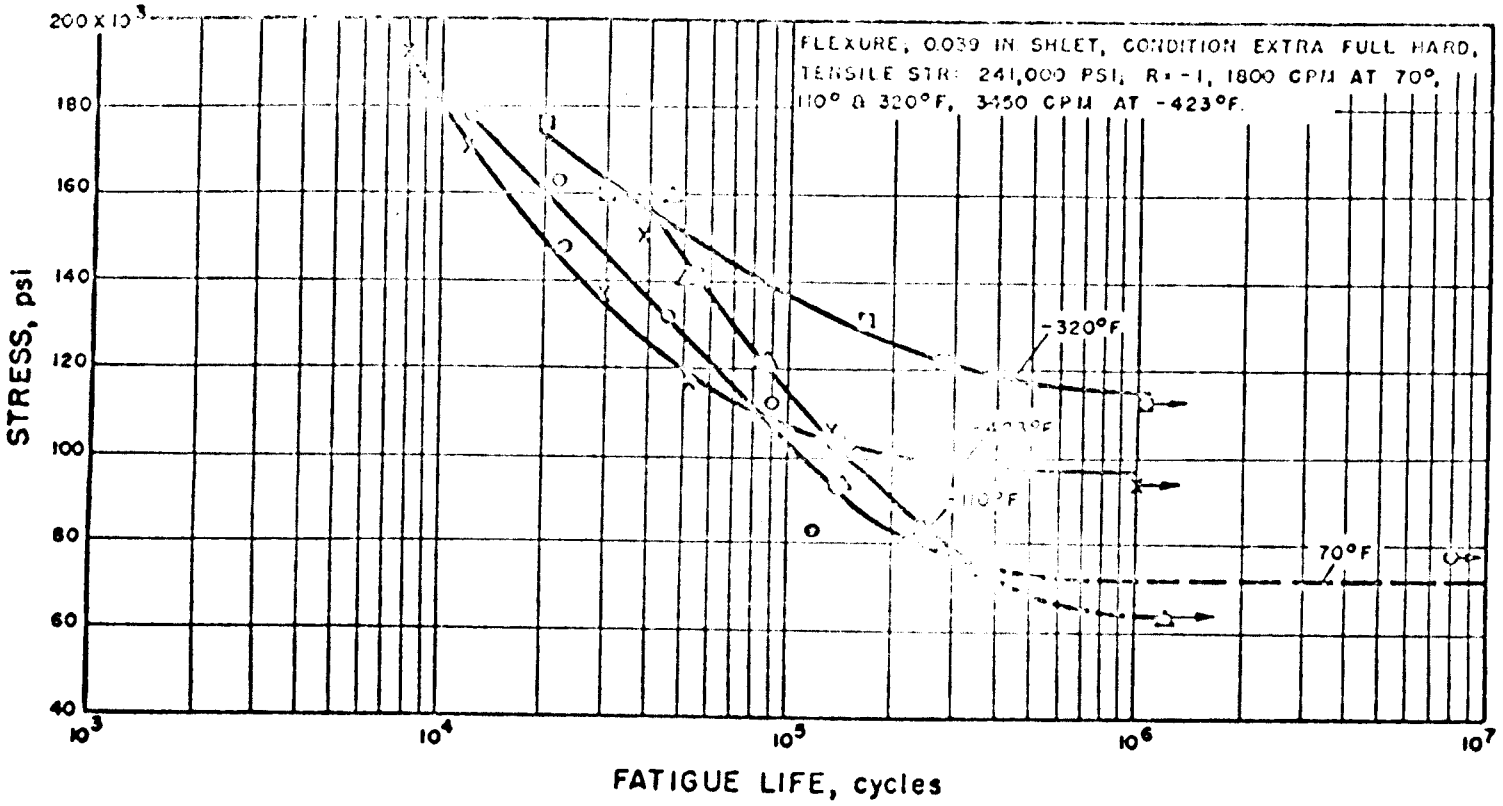
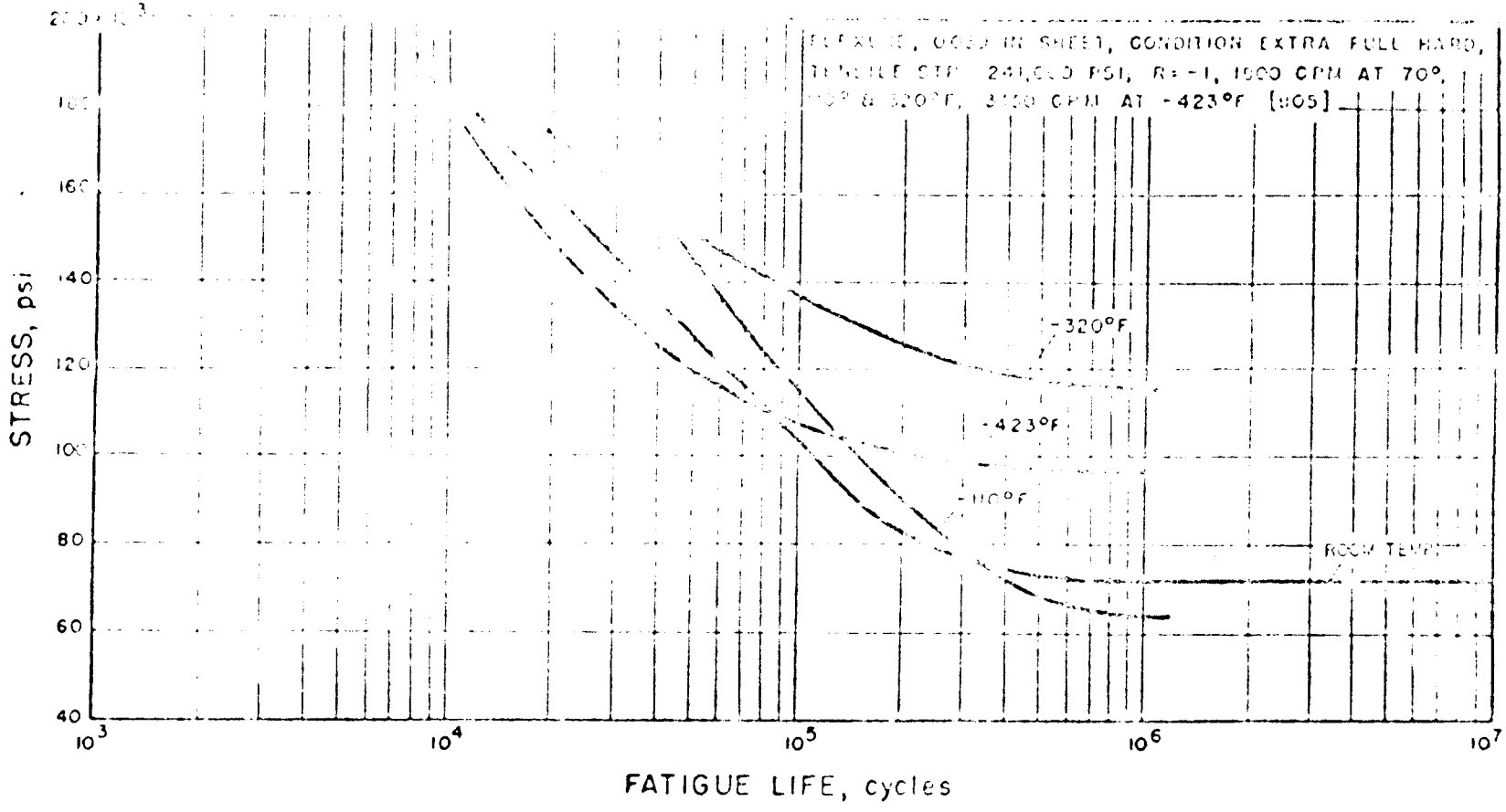
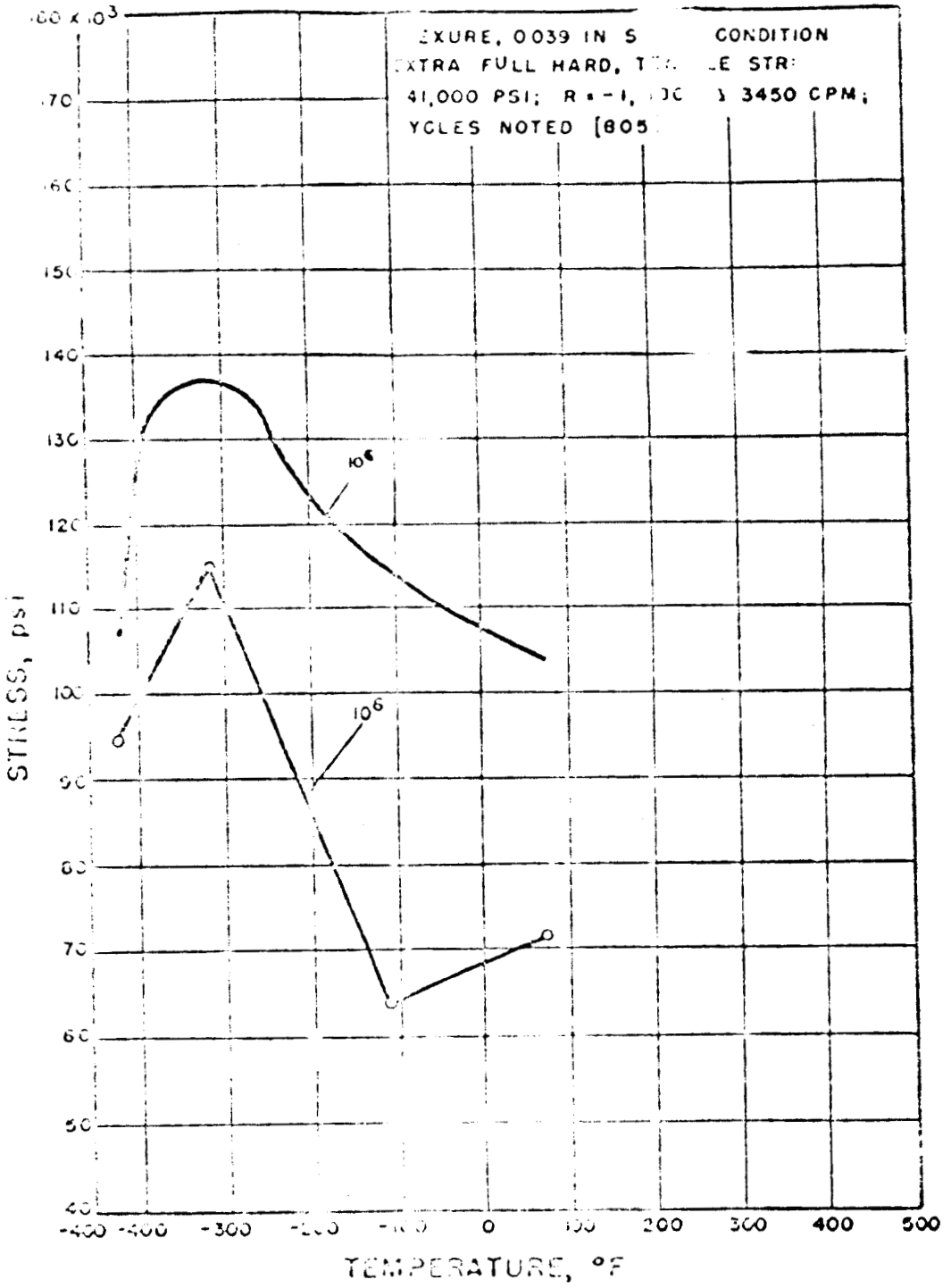


FIGURE 26. UNNOTCHED (K_T = 1) FATIGUE BEHAVIOR OF COLD-ROLLED 301 STAINLESS STEEL



FATIGUE BEHAVIOR OF AISI 301 STAINLESS STEEL



FATIGUE STRENGTH OF AISI 301
STAINLESS STEEL

224

[illegible] DATA TABLE I DATE September 24, 1964

ALLOY [illegible] STAINLESS SHEET THICKNESS 0.012

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 0.24					
Modulus of Elasticity 50% C.R.			25.5	27.1	276
Annealed	Tensile - 1000 psi	(2)	99	220	275
	Yield - 1000 psi	(2)	58	68	75
	Elong. in 2"	(2)	79	42	41
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		180	242	275
	Yield - 1000 psi		158	195	234
50% C.R.	Elong. in 2"		2.5	26.5	1.5
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - $\frac{F_{ty}}{\rho}(10^{-5})$			5.45	6.73	8.08
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No LOX ok, Fluorine ok if passivated

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 6.3	1.11	1.10	1.13
Weld Joint Efficiencies (same and dissimilar metals)	44	89	91

Resistance to Crack Propagation

Formability EXCELLENT

Cleanability

Availability ALL FORMS

Cost

(1) ASD-TDR-62-258
(2) NBS MONOGRAPH 63

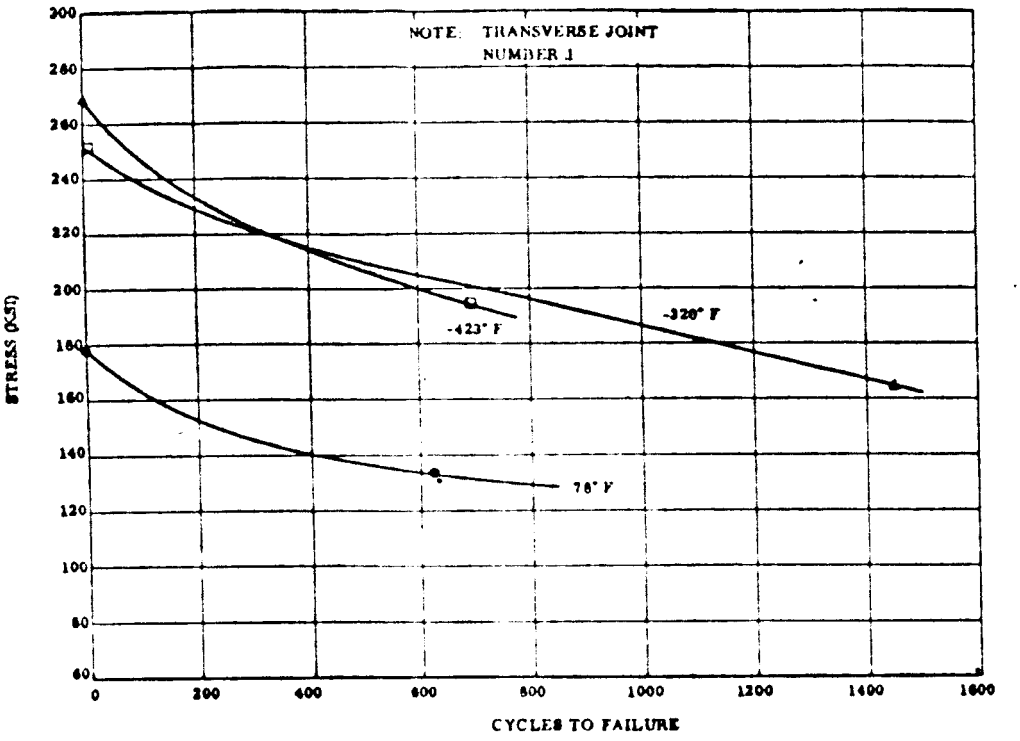


Figure 70. S-N Curve - 304 ELC Stainless Steel (Transverse - Joint No. 1)

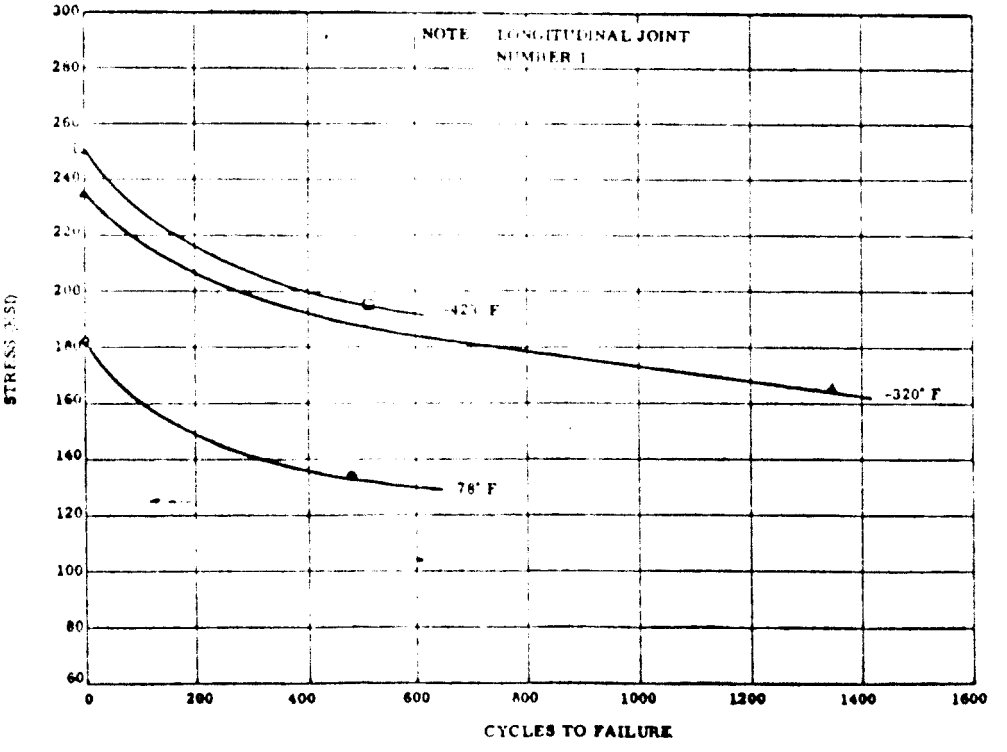


Figure 69. S-N Curve - 304 ELC Stainless Steel (Longitudinal - Joint No. 1)

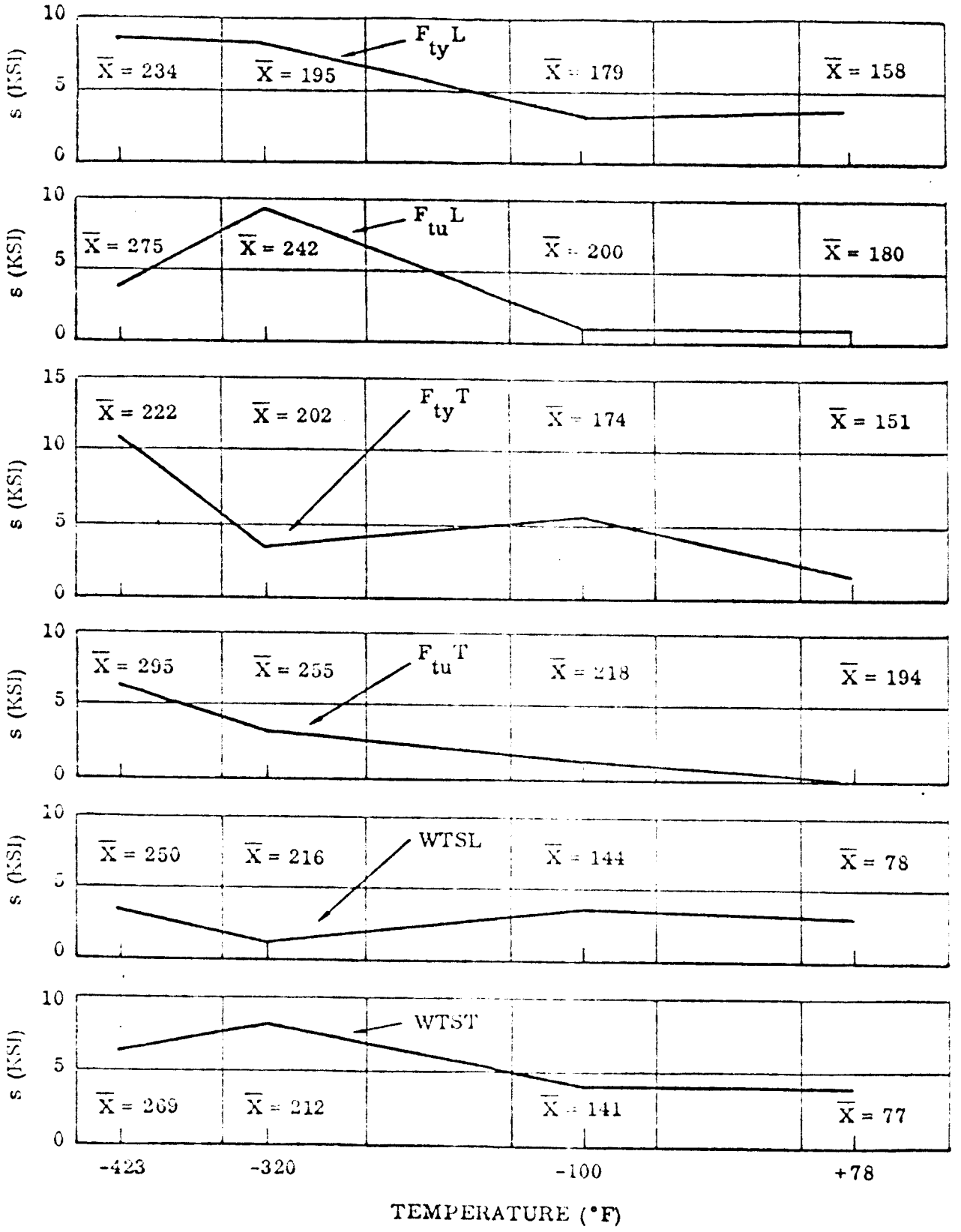


Figure 130. Standard Deviations Versus Temperature (304 SS)

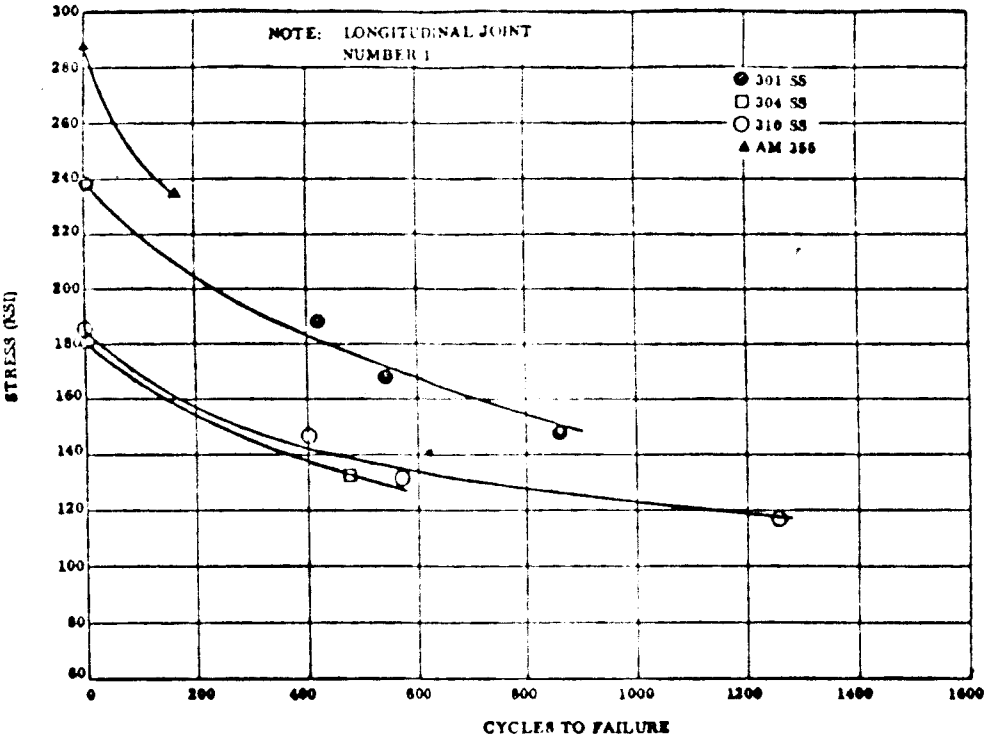


Figure 78. S-N Curve - Stainless Steels at 78°F (Longitudinal - Joint No. 1)

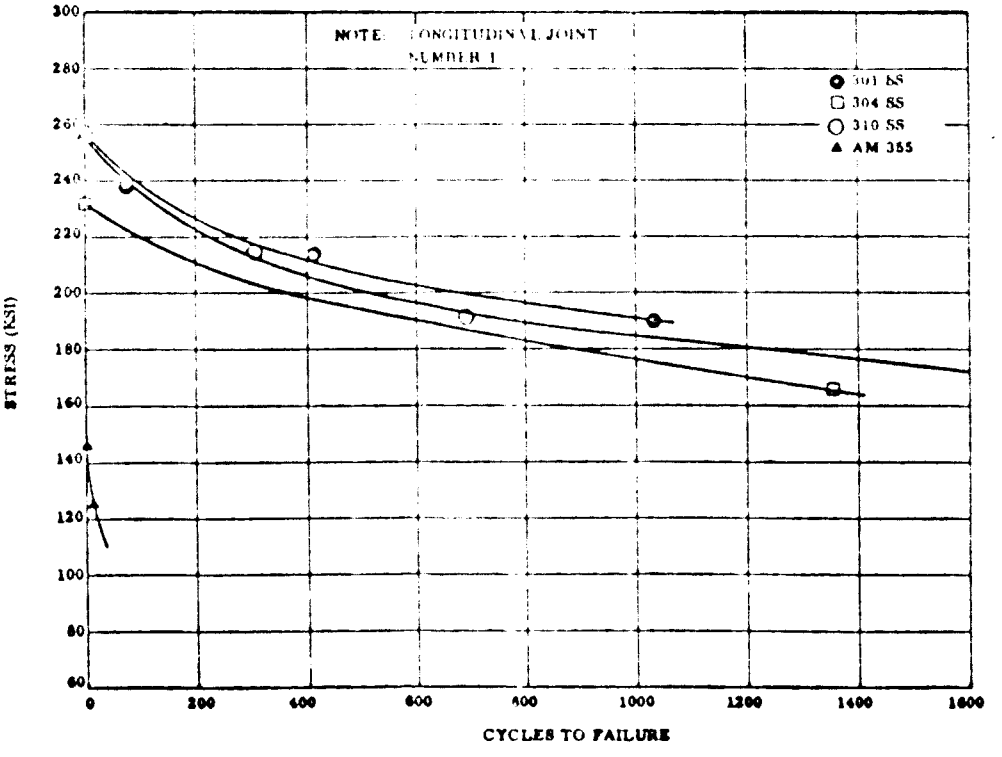


Figure 79. S-N Curve - Stainless Steels at -320°F (Longitudinal - Joint No. 1)

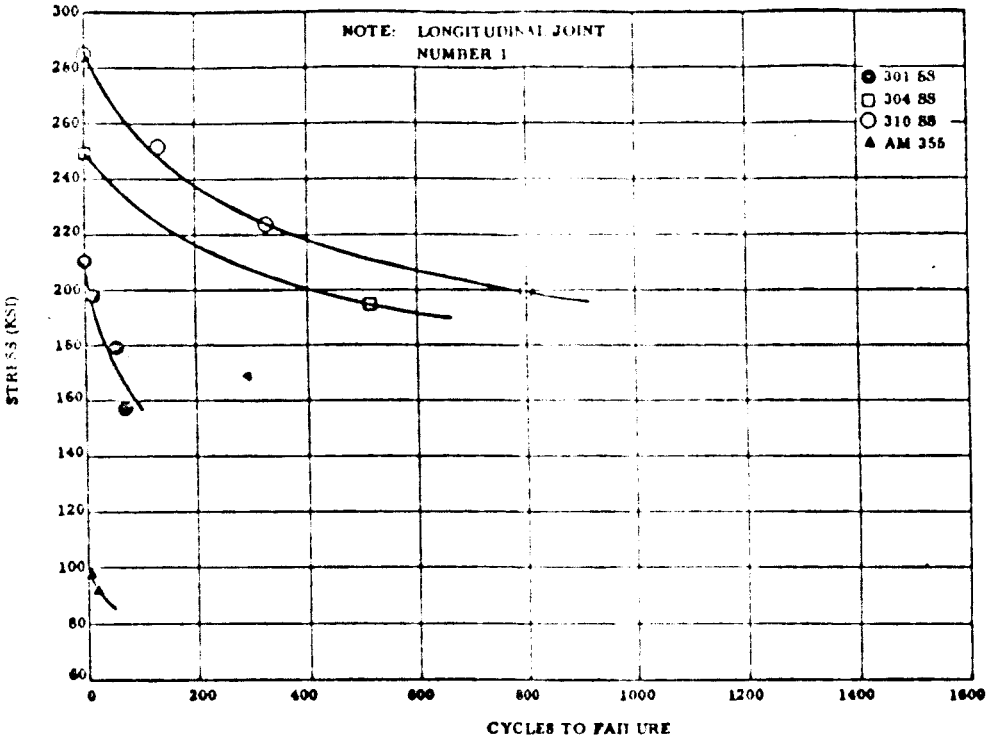


Figure 80. S-N Curve - Stainless Steels at -423°F (Longitudinal - Joint No. 1)

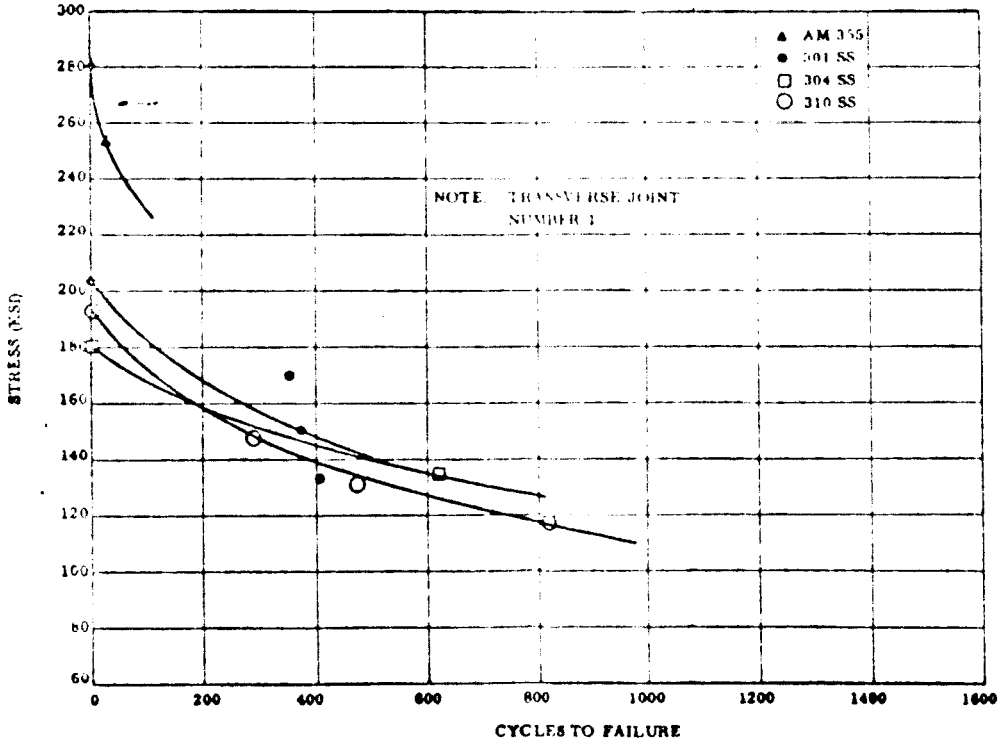


Figure 81. S-N Curve - Stainless Steels at 78°F (Transverse - Joint No. 1)

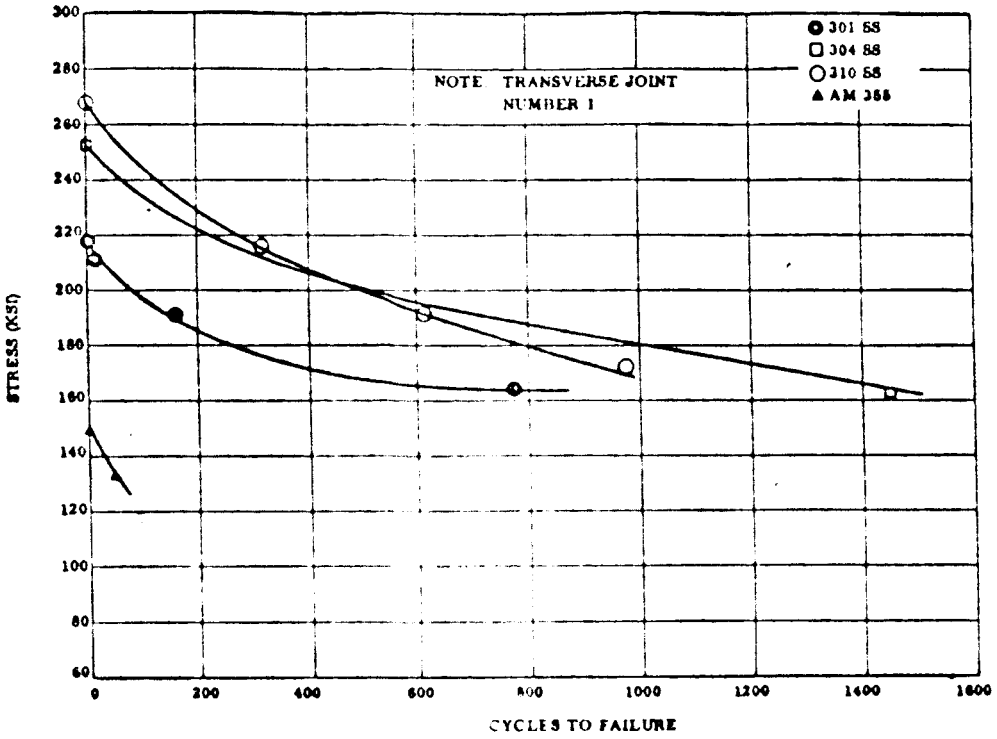


Figure 82. S-N Curve - Stainless Steels at -320°F (Transverse - Joint No. 1)

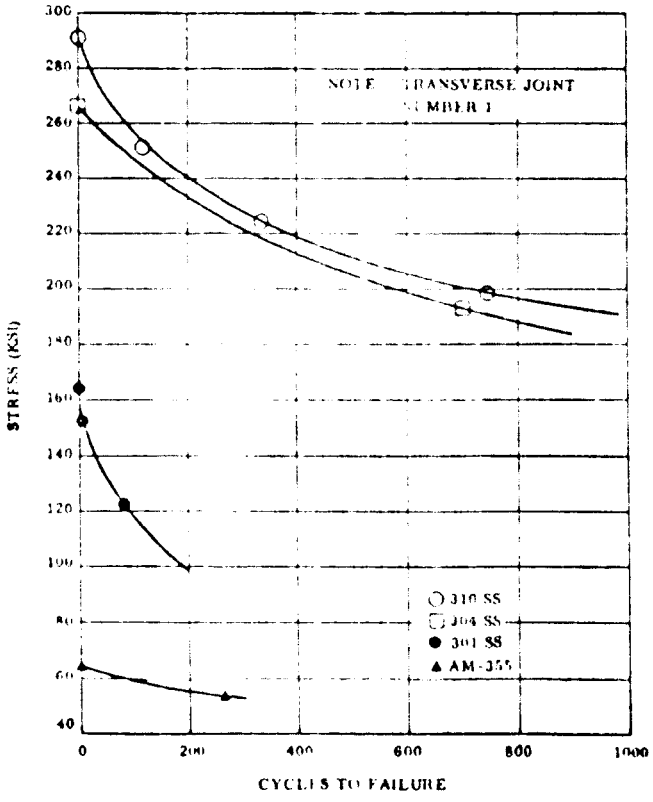


Figure 83. S-N Curve - Stainless Steels at -423°F (Transverse - Joint No. 1)

TABLE I DATE September 24, 1964

ALLOY 310 STAINLESS SHEET THICKNESS .020

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. .287		24	28.5	26.4	26.3
Modulus of Elasticity			85	150	180
Annealed	Tensile - 1000 psi		39	70	95
	Yield - 1000 psi		45	70	40
	Elong. in 2"				
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		181	251	290
	Yield - 1000 psi		157	223	261
75% COLD ROLLED	Elong. in 2"		2	10	5
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - $\frac{Ftu}{\rho}(10^{-5})$			5.42	7.69	9.00
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks

LOX or Liquid Fluorine Sensitivity - Yes or No LOX ok, Fluorine ok passivated

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)	1.07	1.11	1.12
Weld Joint Efficiencies (same and dissimilar metals)	49	66	70

Resistance to Crack Propagation

Formability EXCELLENT

Cleanability

Availability ALL FORMS

Cost

SOURCE - G.D. ARDC TR 59-66, DEPT OF COMMERCE BUREAU OF STDS, ASD-TDR-62-258, ASD-TDR-62-250

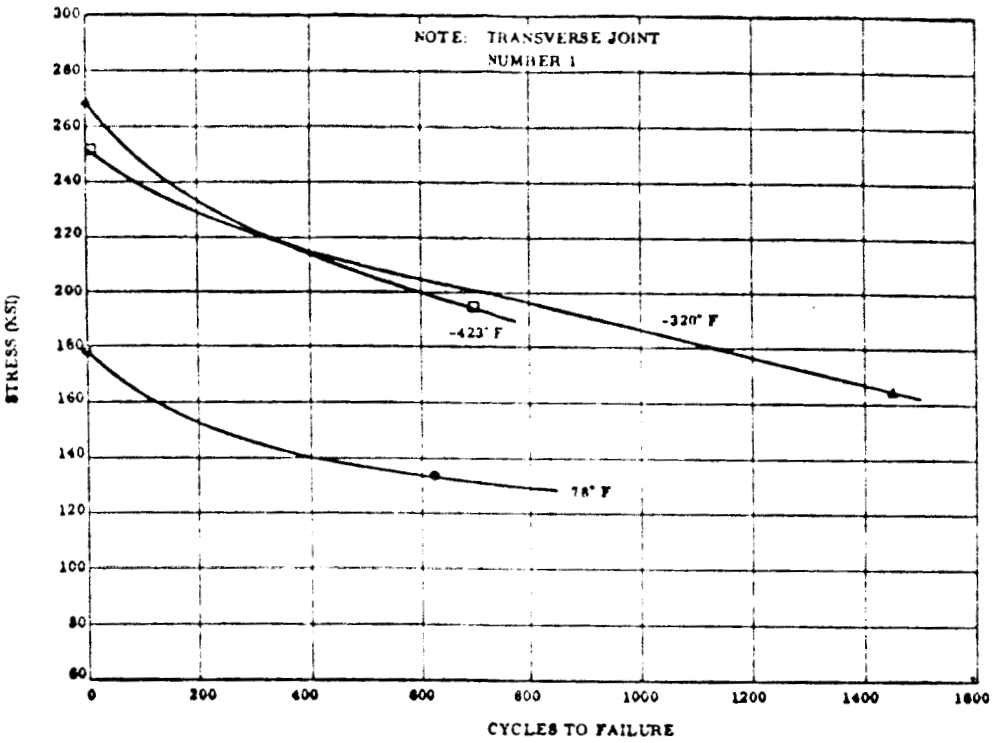


Figure 70. S-N Curve - 304 ELC Stainless Steel (Transverse - Joint No. 1)

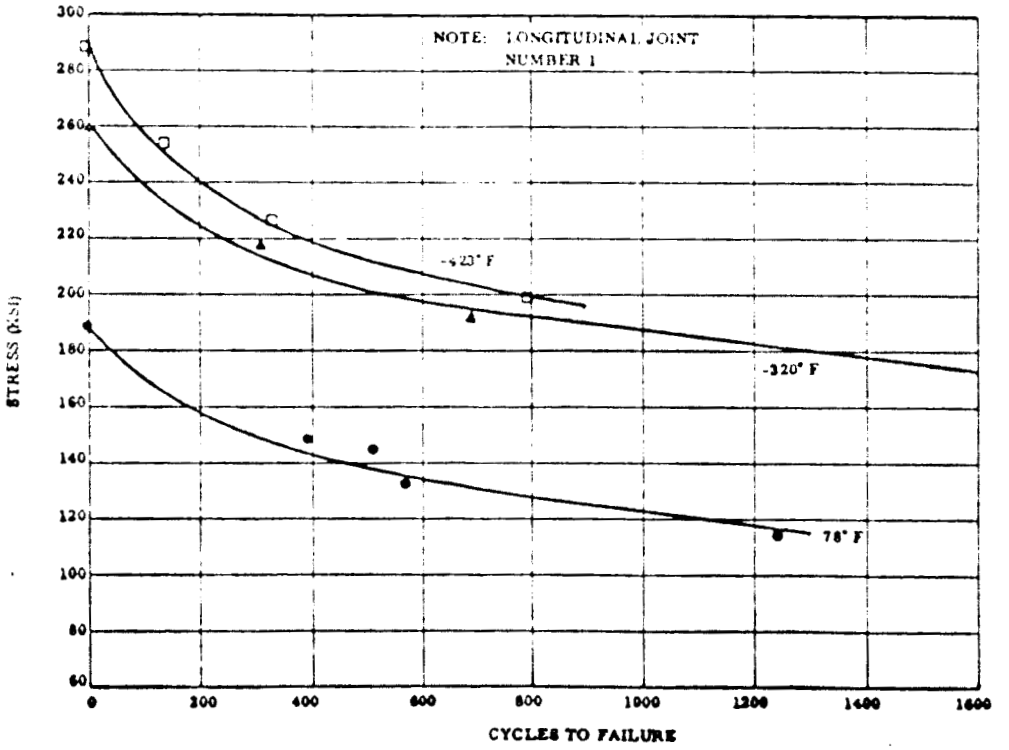


Figure 71. S-N Curve - 310 Stainless Steel (Longitudinal - Joint No. 1)

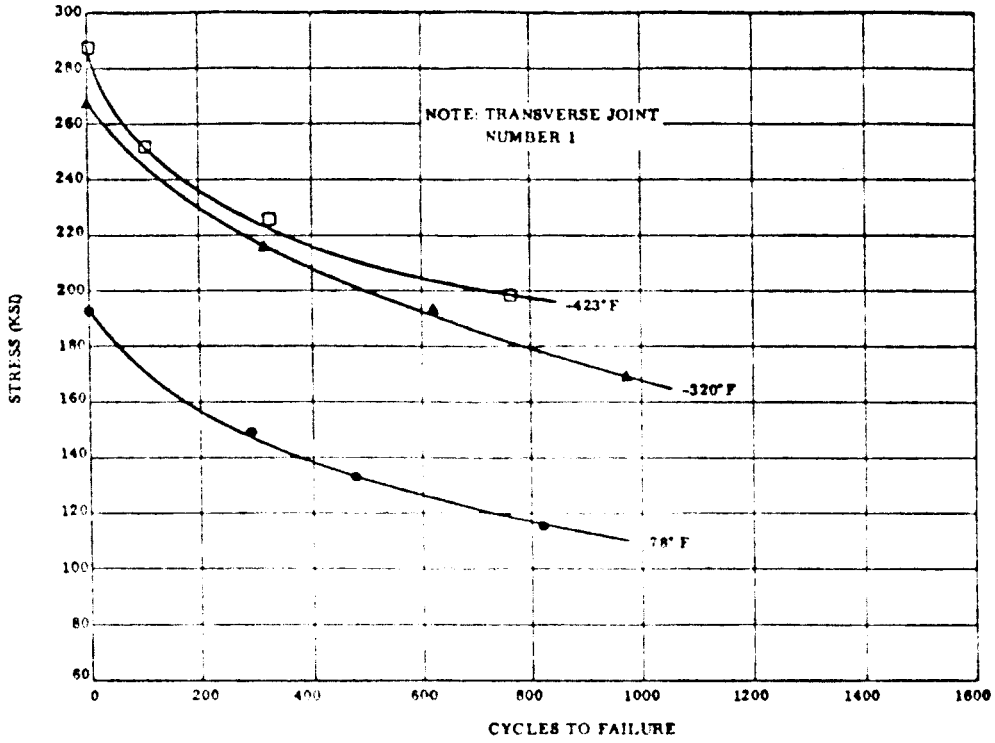


Figure 72. S-N Curve - 310 Stainless Steel (Transverse - Joint No. 1)

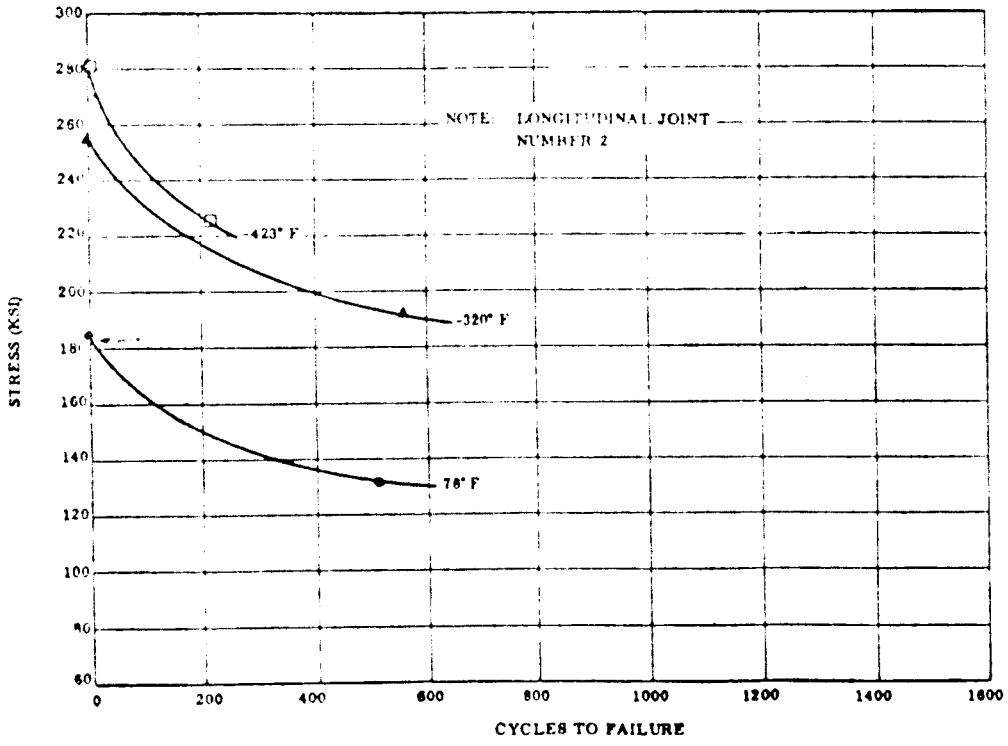


Figure 73. S-N Curve - 310 Stainless Steel (Longitudinal - Joint No. 2)

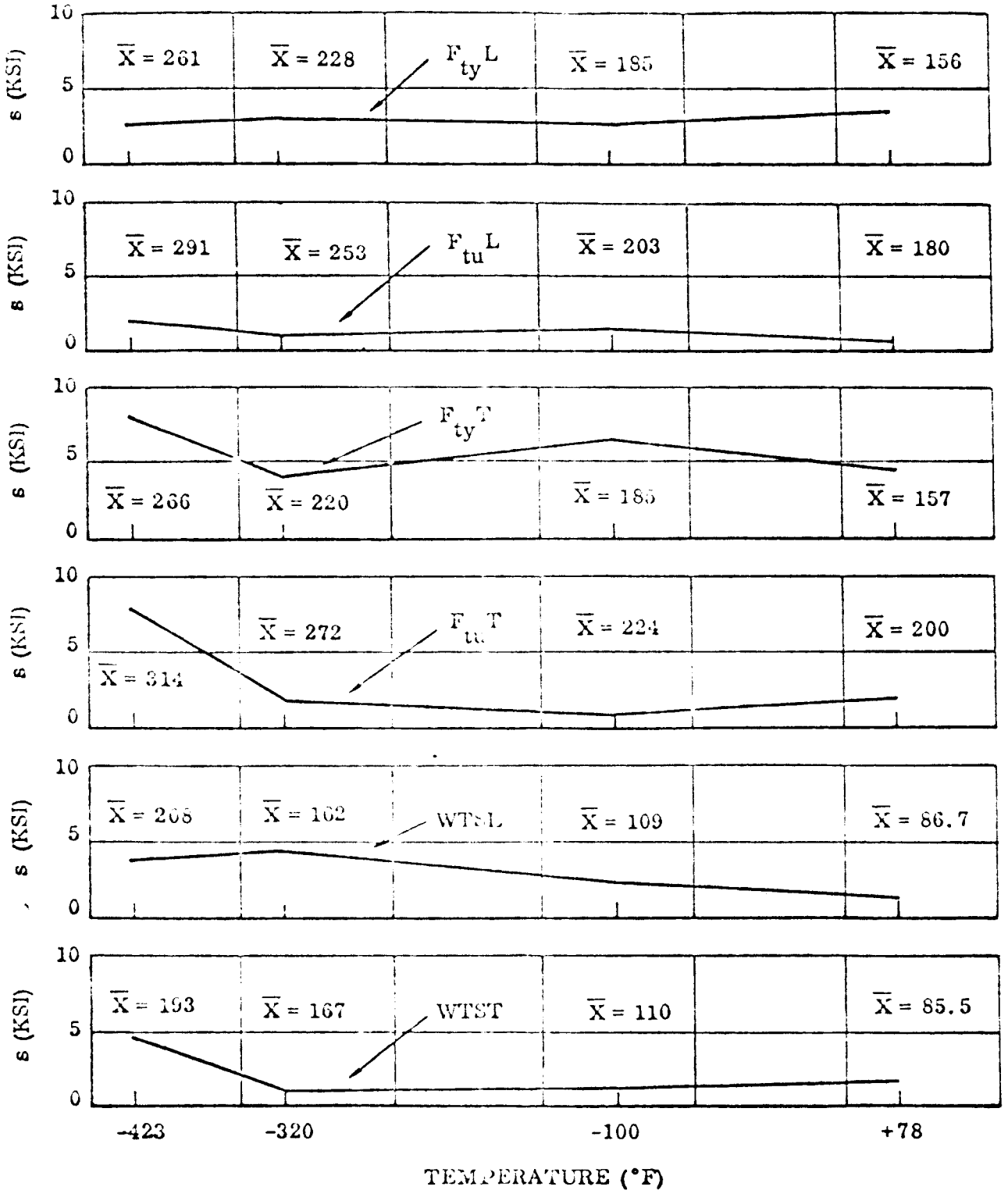


Figure 131. Standard Deviations Versus Temperature (310 SS)

REVISED DATA

TABLE I DATE September 24, 1964

ALLOY 321 STAINLESS SHEET THICKNESS 0.063

SUBZERO ROLLED @ -320F

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 0.285 - 0.290					
Modulus of Elasticity					
Annealed As received	Tensile - 1000 psi		88.9	203	244
	Yield - 1000 psi		34.1	46.5	53.8
	Elong. in 2"		54.8	43.3	33.8
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		196	252	315
	Yield - 1000 psi		187	239	282
35% Cold Work -320F	Elong. in 2"		3.8	10	2.3
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - $\frac{F_{ty}}{\rho}(10^{-5})$			6.45	8.24	9.73
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No LOX ok, Fluorine ok if passivated

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 6.3 (annealed .98 35% C.R. .89 .54

Weld Joint Efficiencies (same and dissimilar metals) +.16 1.29 1.09

Resistance to Crack Propagation

Formability Varies directly as Ni content -10-12% Ni for severe deep draw & spinning.

Cleanability

Availability Full commercial range

Cost

TABLE II.—*Mechanical properties*

Class	Condition or temper	Tensile strength (minimum except where a range is shown)	Yield strength at 0.2 percent offset or at extension indicated [1]		Elongation in 2 inches (minimum)			Reduction in area (minimum) [2]	Hardness [3]	
					Thickness (inches)					
			Minimum	Extension under load	0.015 and under	0.016 to 0.030	0.031 and over		Brinell	Rockwell B Scale
		P. s. i.	*P. s. i.*	*Inches in inches*	*Percent*	*Percent*	*Percent*	*Percent*		
201	A	75,000 120,000	40,000	----	40	40	40	50	217	96
	¼ hard [4]	125,000	75,000	0.0008	20	20	20	--	---	--
	½ hard [4]	150,000	110,000	0125	9	10	10	--	---	--
	¾ hard [4]	175,000	135,000	0141	5	5	7	--	---	--
	Full hard [4]	185,000	140,000	0148	3	4	5	--	---	--
202	A	75,000 110,000	40,000		40	40	40	50	217	96
	¼ hard [4]	125,000	75,000	0008	12	12	12		---	--
	½ hard [4]	150,000	110,000	0125	15	18	18		---	--
301	A	75,000 125,000	30,000		40	45	50	50	201	94
	¼ hard [4]	125,000	75,000	0008	25	25	25			--
	½ hard [4]	150,000	110,000	0125	15	18	18			--
	¾ hard [4]	175,000	135,000	0141	10	12	12		--	
	Full hard [4]	185,000	140,000	0148	8	8	9			
302	A	75,000 110,000	30,000		40	45	50	50	201	--
	¼ hard [4]	125,000	75,000	0008	25	25	25			
	½ hard [4]	150,000	110,000	0125	15	18	18			
304	A	75,000	30,000	----	40	40	40	50	201	94
304L	A	70,000	----	----	40	40	40	50	201	94
305	A	70,000		----	40	40	40	50	201	94
309	A	75,000	30,000	----	40	40	40	50	217	96
310	A	75,000	30,000	----	40	40	40	50	217	96
316	A	75,000 100,000	30,000	----	40	40	40	50	217	96
	¾ hard [4]	125,000	90,000	0110	10	10	10	--	---	--
316L	A	70,000	----	----	40	40	40	50	217	96
321	A	75,000 100,000	30,000	----	40	40	40	50	201	92

TABLE II.—*Mechanical properties* (Cont'd)

Class	Condition or temper	Tensile strength (minimum except where a range is shown)	Yield strength at 0.2 percent offset or at extension indicated [1]		Elongation in 2 inches (minimum)			Reduction in area (minimum) [2]	Hardness [3]	
					Thickness (inches)					
			Minimum	Extension under load	0.015 and under	0.016 to 0.030	0.031 and over		Brinell	Rockwell B Scale
		P. s. i.	*P. s. i.*	*Inches in 2 inches*	*Percent*	*Percent*	*Percent*	*Percent*		
325	A	150,000 [4]	55,000	...	20	20	20	...	192 [5]	92 [5]
	TH	180,000	150,000	...	4 [6]	5	6	...	...	Rc38 (min.) [5]
347	A	75,000 100,000	30,000	...	40	40	40	50	201	94
348	A	75,000	30,000	...	40	40	40	50	201	94
410	A	70,000	35,000	...	20	20	20 [7]	50	201	94
420	A	100,000 [8]	...	...	12	12	15	50	217	96
430	A	70,000	35,000	...	20	20	20 [7]	...	201	94
446	A	75,000	40,000	...	16	16	18	40	201	94

[1] The value obtained at extension under load should not [illegible] however, be taken as the actual yield strength for 0.2 percent permanent set. In case of dispute, the offset method of determining yield strength shall be used.

[2] Applies to plates ½ inch thickness and over.

[3] Maximum. Unless a particular method of hardness determination is definitely specified, either of the methods listed may be used.

[4] Available in sheets and strips only. (See 3.6.1 for heat requirements.)

[5] Twenty-two percent for material over 0.050 inch thick.

[6] Maximum.

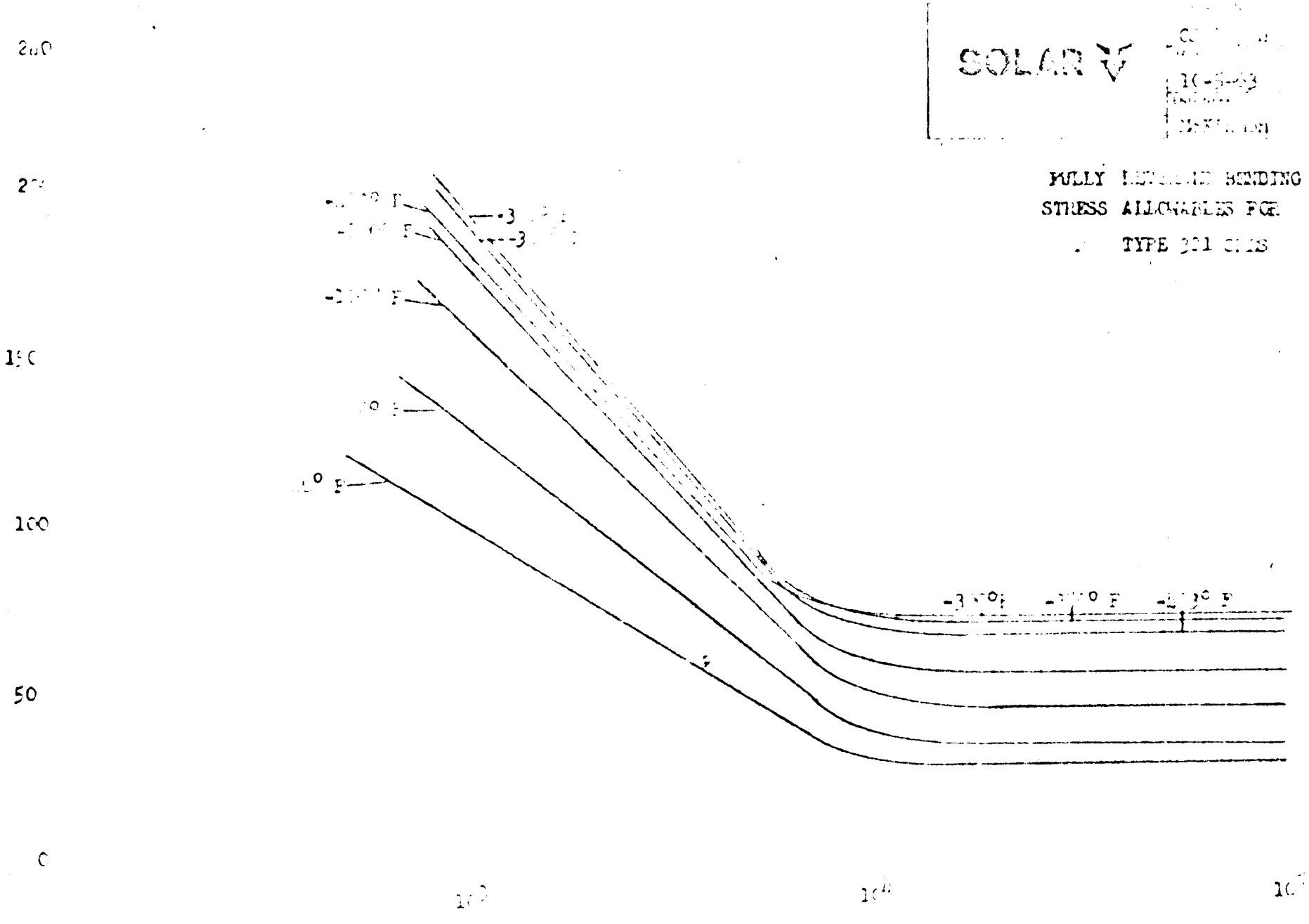
[7] Maximum. For sheet or strip under 0.010 inch, the yield strength shall be 65,000 p. s. i. maximum.

[8] Not applicable to material 0.050 inch thick or less.

[9] Not applicable to material under 0.005-inch thickness.

material. Heat treatment shall be as follows: Heat to 1400° ± 25°F for 1½ hours and cool in air; follow by water quenching within 1 hour to 60°F. plus 0 minus 10°F. for a minimum time of ½ hour. Heat to 1050° ± 10°F. for 1½ hours and air cool to room temperature.

3.7 Resistance to intergranular corrosion (precipitated carbides).—Classes 304 and 316 in thicknesses up to 2 inches, inclusive, and classes 304L, 316L, 321, 347, 348 in all thicknesses shall be free from precipitated carbides which result in intergranular corrosion. Class 304 and 316 material will be acceptable only if unsensitized specimens pass the embrittlement test specified in 4.4.3. Class 304L, 316L, 321, 347, and 348 material will be acceptable only if sensitized specimens pass the embrittlement test.


SOLAR
FULLY
STRESS
TYPE
200
150
100
50
0

TENSILE STRENGTH ALLOWABLE FOR TYPE 321
STAINLESS SUPPORTS, YIELD & SHOCK YIELD
(SIMILAR TO MIL-HDBK-5 "A" VALUES)

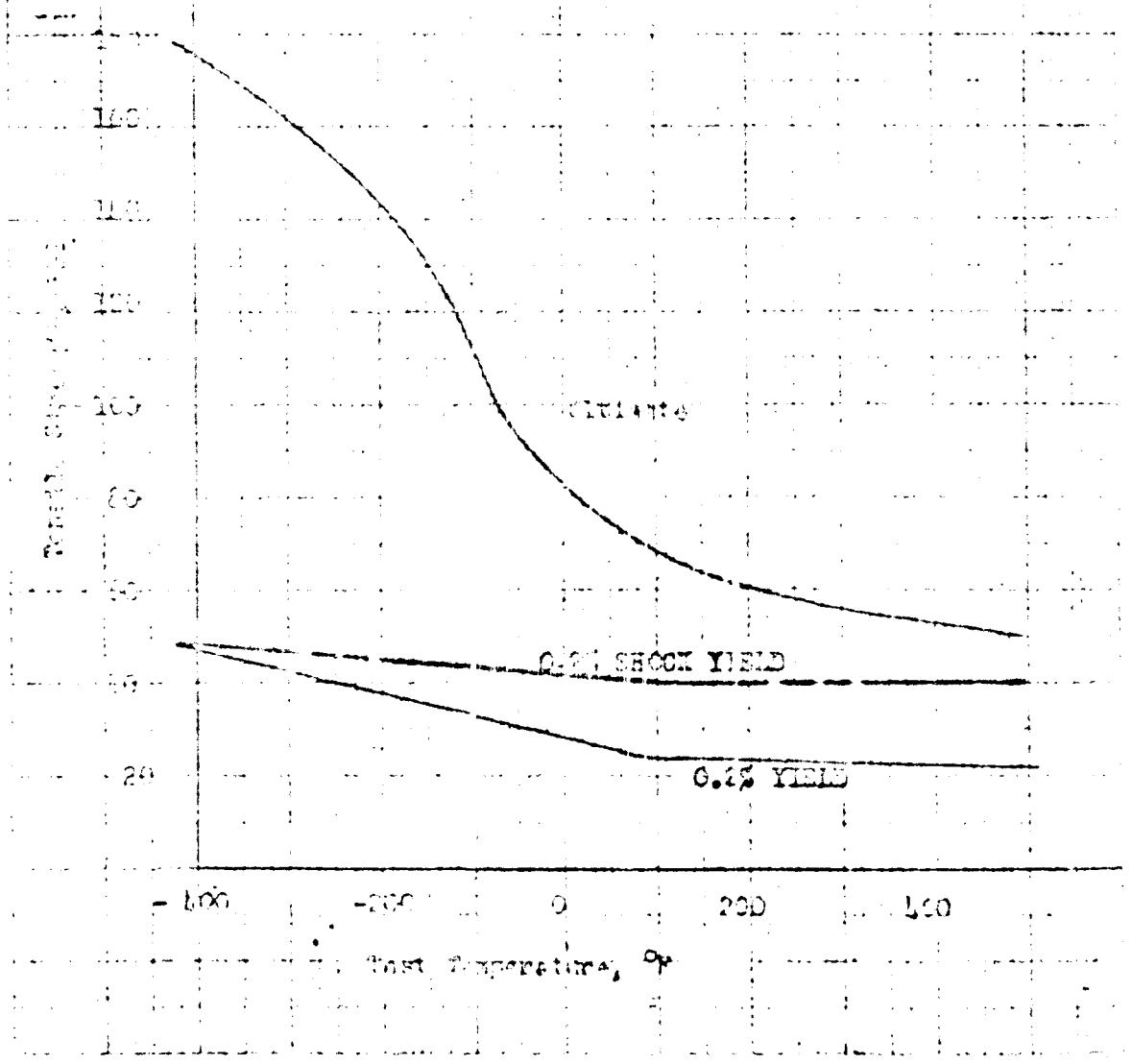


TABLE I DATE September 24, 1964

ALLOY AISI-347 Steel SHEET THICKNESS Full commercial range

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 0.287-0.292					
Modulus of Elasticity 300					
Annealed	Tensile - 1000 psi		94	216	232
	Yield - 1000 psi		36	50	65
	Elong. in 2"		63	42	
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		110	198	248
	Yield - 1000 psi		70	94	102
10% Cold Drawn	Elong. in 2"		47	48	37
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - $\frac{Fty}{\rho}(10^{-5})$			2.41	3.24	3.52
Impact Str. (Charpy) K ft. lb. 62					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No LOX ok, Fluorine ok passivated

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)

Weld Joint Efficiencies (same and dissimilar metals) More difficult than other 18-8 series. Use type 304L rod should be stress relieved.
Resistance to Crack Propagation

Formability Good if Ni content high Stress relief recommended

Cleanability

Availability

Cost

Source: Cryogenic materials data handbook US Dept of Commerce
ARDC TR 59-66, ASD-TDR-62-250

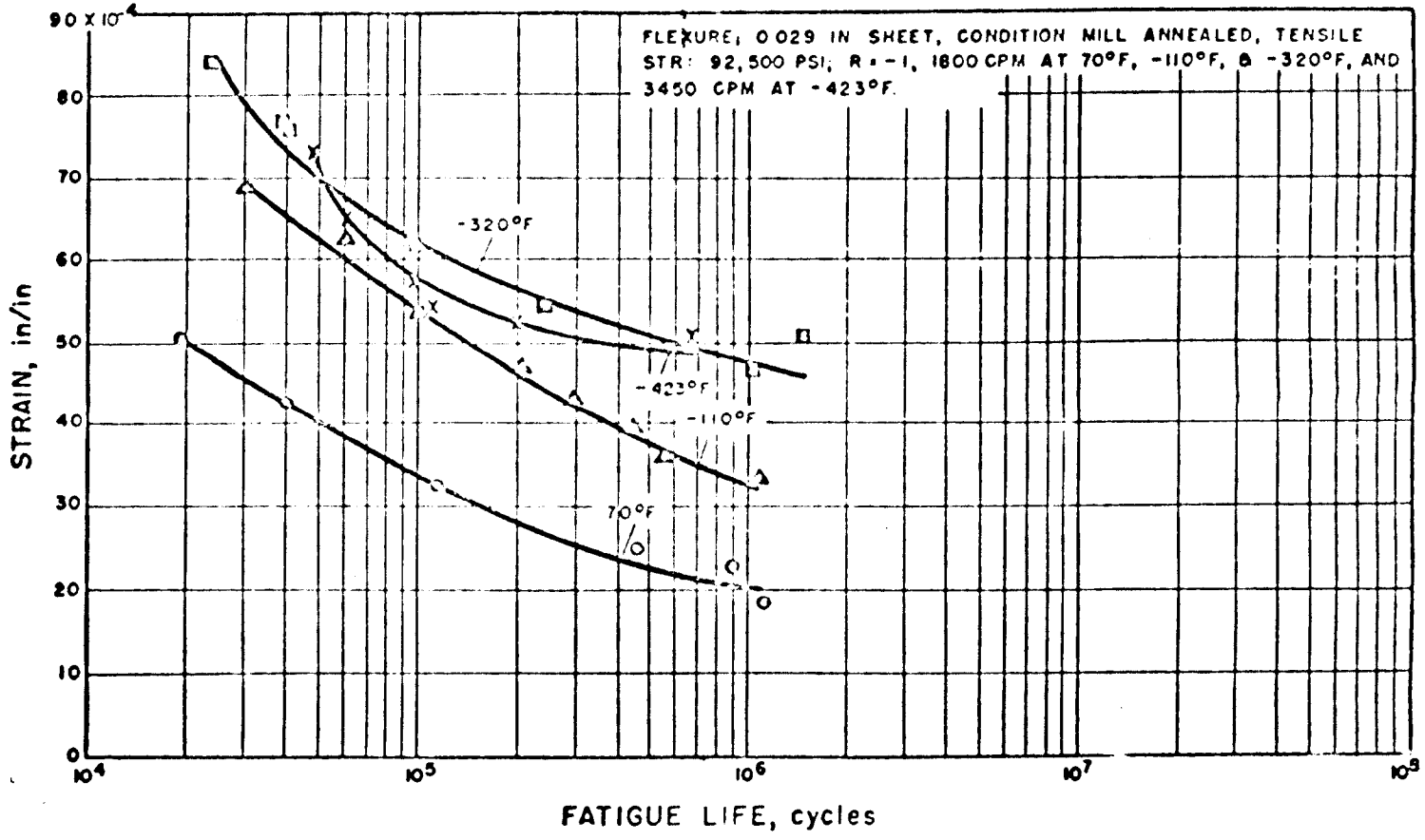


FIGURE 25. UNNOTCHED (K_T = 1) FATIGUE BEHAVIOR OF ANNEALED 347 STAINLESS STEEL

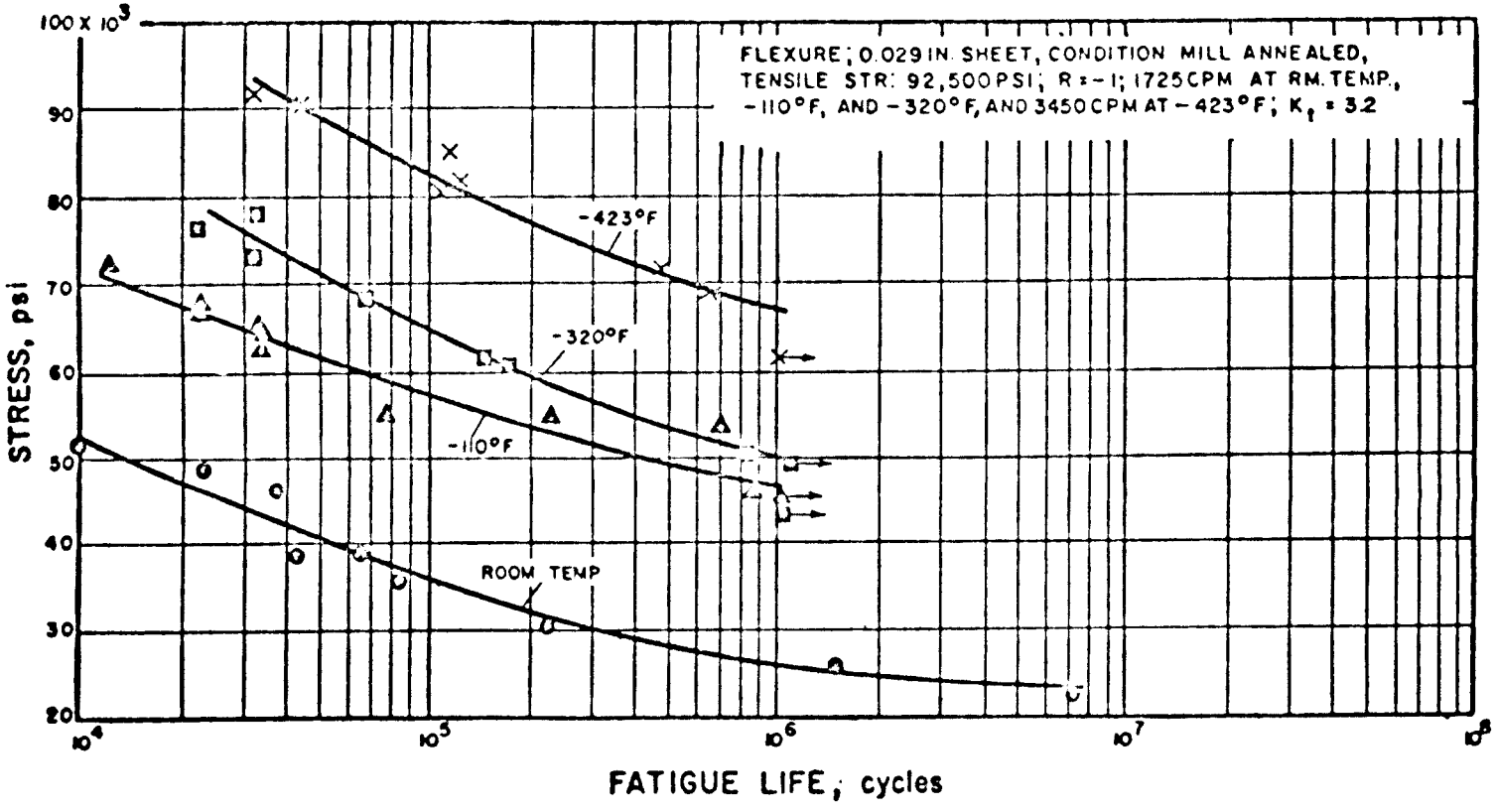


FIGURE 40. NOTCHED (K_T = 3.2) FATIGUE BEHAVIOR OF ANNEALED 347 STAINLESS STEEL

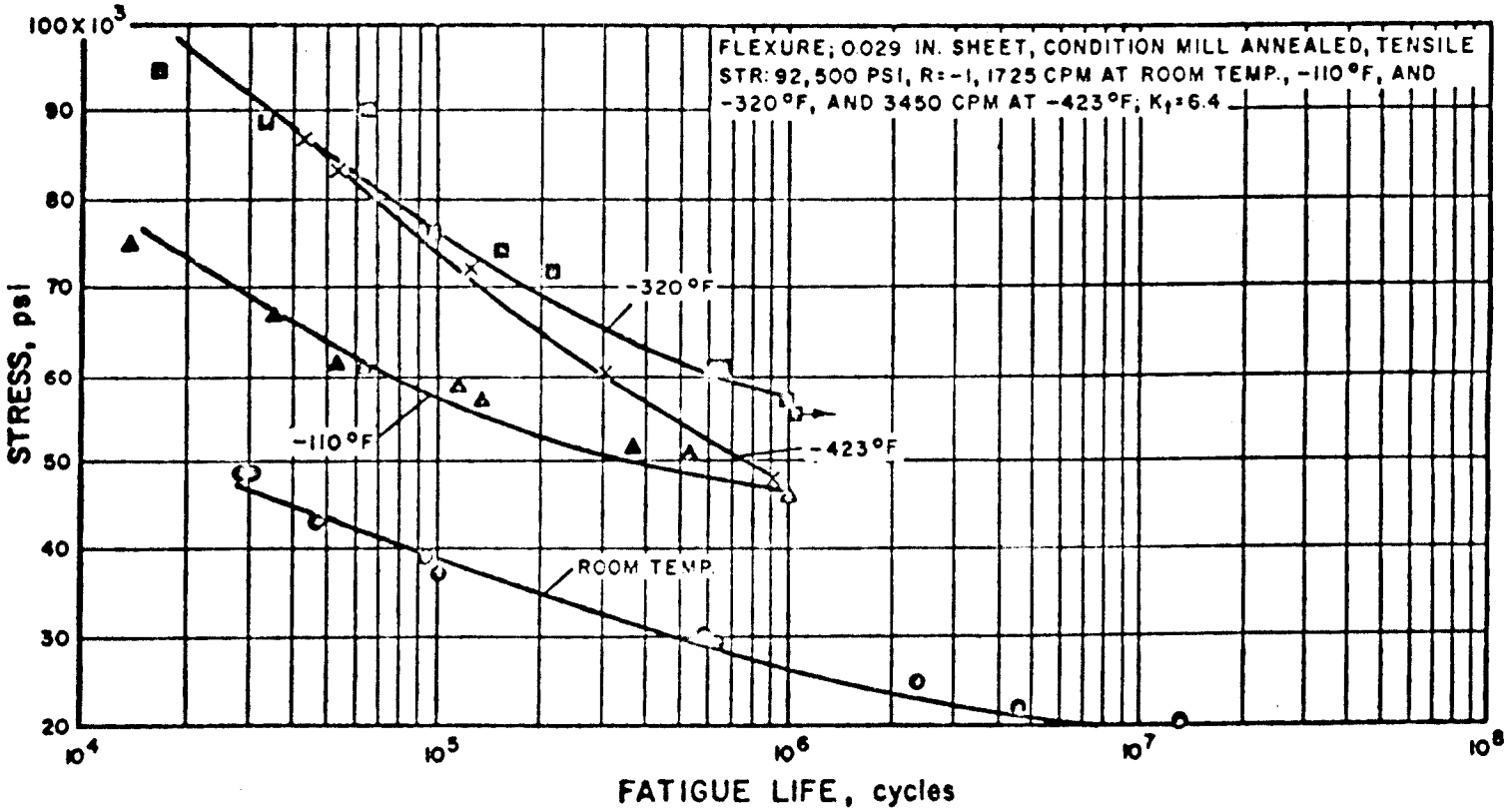


FIGURE 53. NOTCHED (K_T = 6.4) FATIGUE BEHAVIOR OF ANNEALED 347 STAINLESS STEEL

2.3 PRECIPITATION HARDENING STAINLESS STEELS

Only two steels in this class were studied. Neither of them seems to be applicable for temperatures below -320F, since they become brittle below that temperature. Notched/unnotched ratios drop rapidly below room temperature.

TABLE I DATE September 24, 1964

ALLOY AM 350 SHEET THICKNESS

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. .282					
Modulus of Elasticity		19.8	26.2	31	
Annealed	Tensile - 1000 psi	88.9	158	320	210
COND - H	Yield - 1000 psi	35.8	59	60	
	Elong. in 2"			45.4	
	Bearing - 1000 psi	($\frac{e}{D}$ = 2)94.1	134		
	Shear - 1000 psi	68.8	148		
Heat Treated or Cold Worked Condition SCT	Tensile - 1000 psi	190	199	300	310
	Yield - 1000 psi	1.10	163	242	
	Elong. in 2"		13.6	10	1
FRAU	Bearing - 1000 psi	$\frac{e}{D}$ = 2)360	410		
	Shear - 1000 psi	102	120		
Str. to Density Ratio -	$\frac{F_{ty}}{\rho}(10^{-5})$		390	8.56	
Impact Str. (Charpy), ft. lb.			51		
Fatigue Str. Curves at indicated temps.		NO			

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)

Weld Joint Efficiencies (same and dissimilar metals)

Resistance to Crack Propagation BRITTLE AT LOW TEMP

Formability FORMABLE IN H COND.

Cleanability

Availability

Cost

SOURCE-ARDC TR59-66, MATERIALS HANDBOOK, ASD-TDR-63-116
DMIC REPORT 112, WADC TR 58-386, ASD-TDR-62-250

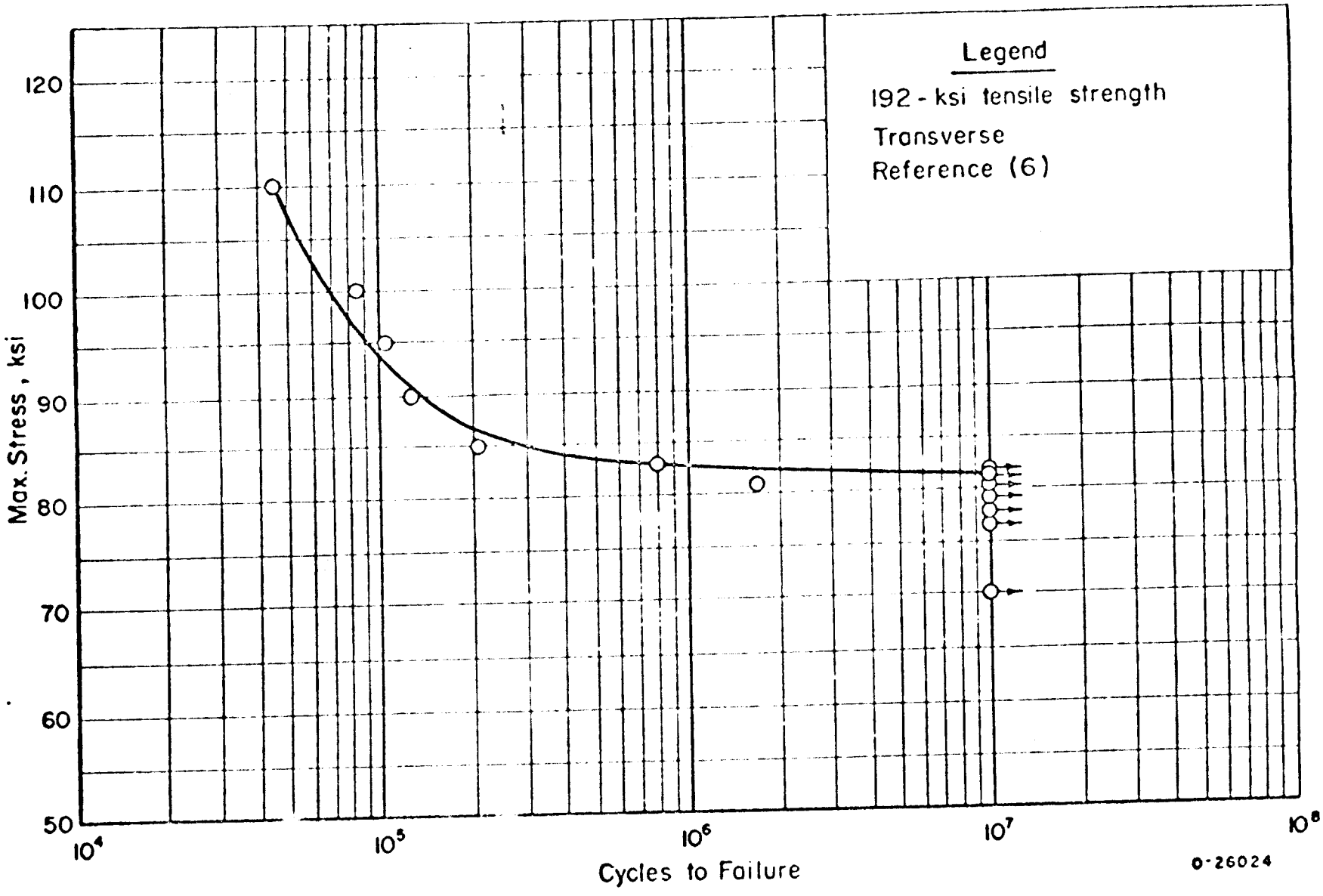


FIGURE 6. S-N CURVE FOR AM 350 (SCT) STAINLESS STEEL SHEET AT ROOM TEMPERATURE UNDER REVERSED BENDING

BATTELLE MEMORIAL INSTITUTE

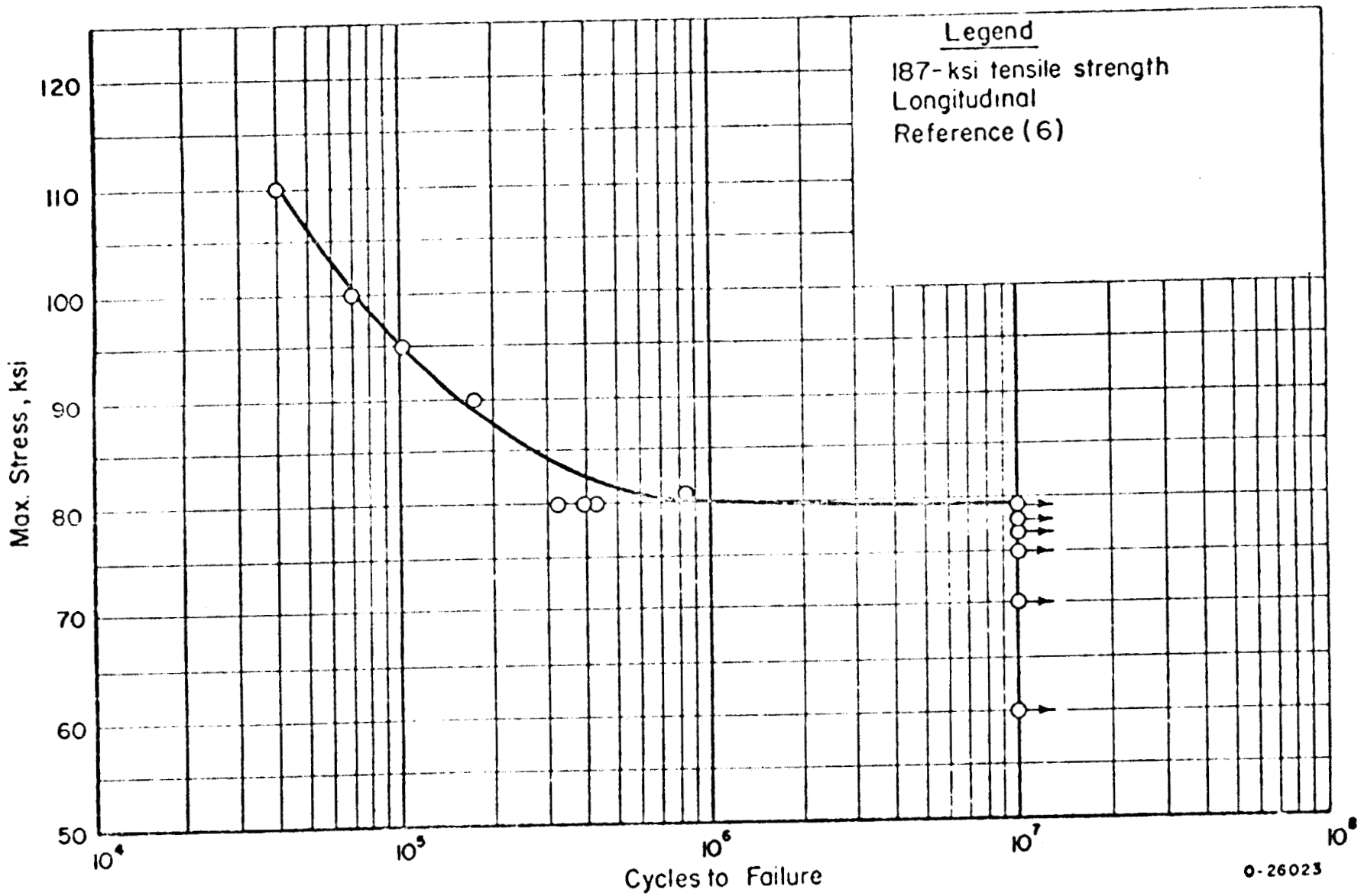


FIGURE 5. S-N CURVE FOR AM 350 (SCT) STAINLESS STEEL SHEET AT ROOM TEMPERATURE UNDER REVERSED BENDING

BATTELLE MEMORIAL INSTITUTE

DMIC MEMORANDUM
BATTELLE MCI

TABLE I DATE _____

ALLOY AM 355 STAINLESS SHEET THICKNESS 0.032

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 281					
Modulus of Elasticity		25.3	31.1	27.9	28.4
Annealed	Tensile - 1000 psi		185		
	Yield - 1000 psi		60		
	Elong. in 2"		30		
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi	203	297	353	347
COLD ROLLED & TEMPERED @ 1000F	Yield - 1000 psi	144	278	328	329
	Elong. in 2"	7.4	5.4	9.5	0
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)	391	439		
	Shear - 1000 psi	119	139		
Str. to Density Ratio - $\frac{F_{tu}}{\gamma}(10^{-5})$			9.87	11.65	11.68
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)	.85	.46	.34
Weld Joint Efficiencies (same and dissimilar metals)	75	77	41

Resistance to Crack Propagation

Formability Relatively brittle even at 78F

Cleanability

Availability All forms

Cost

SOURCE - GD, TH McCunn Allegheny, ASD-TDR-61-529, ASD-TDR-62-258

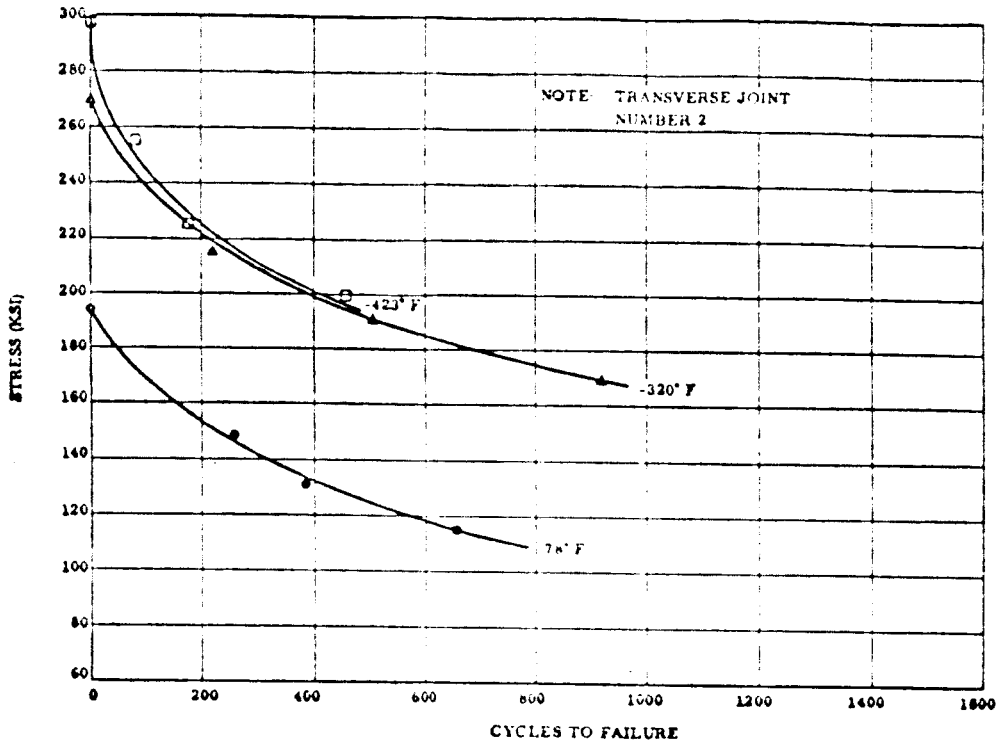


Figure 74. S-N Curve - 310 Stainless Steel (Transverse - Joint No. 2)

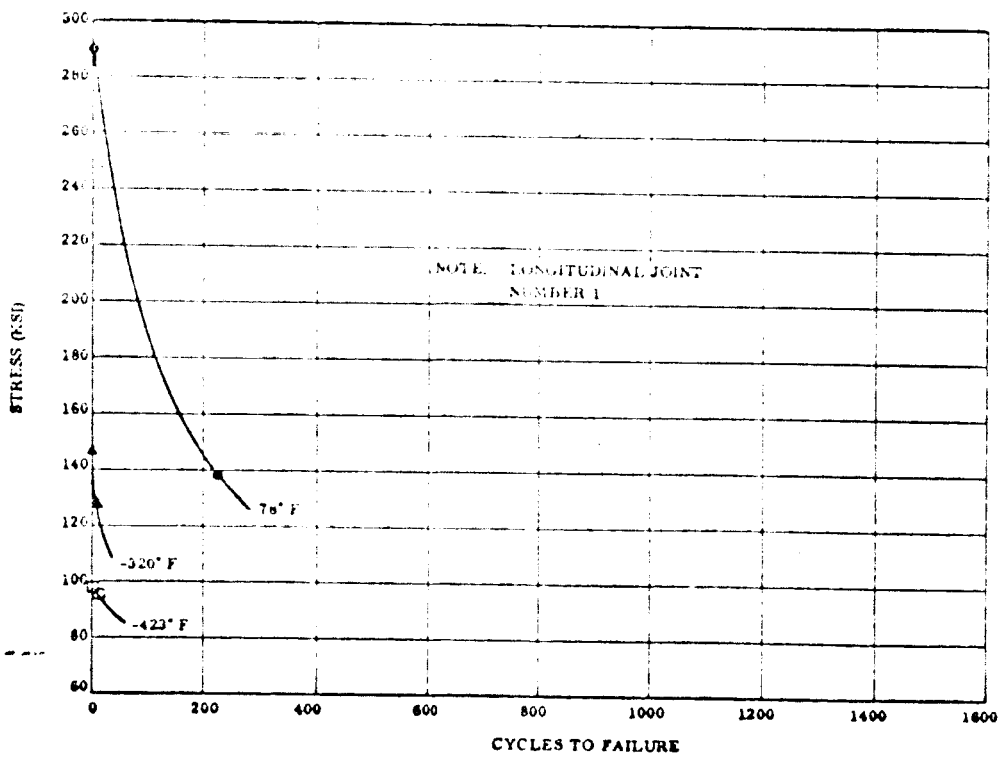


Figure 75. S-N Curve - AM-355 Stainless Steel (Longitudinal - Joint No. 1)

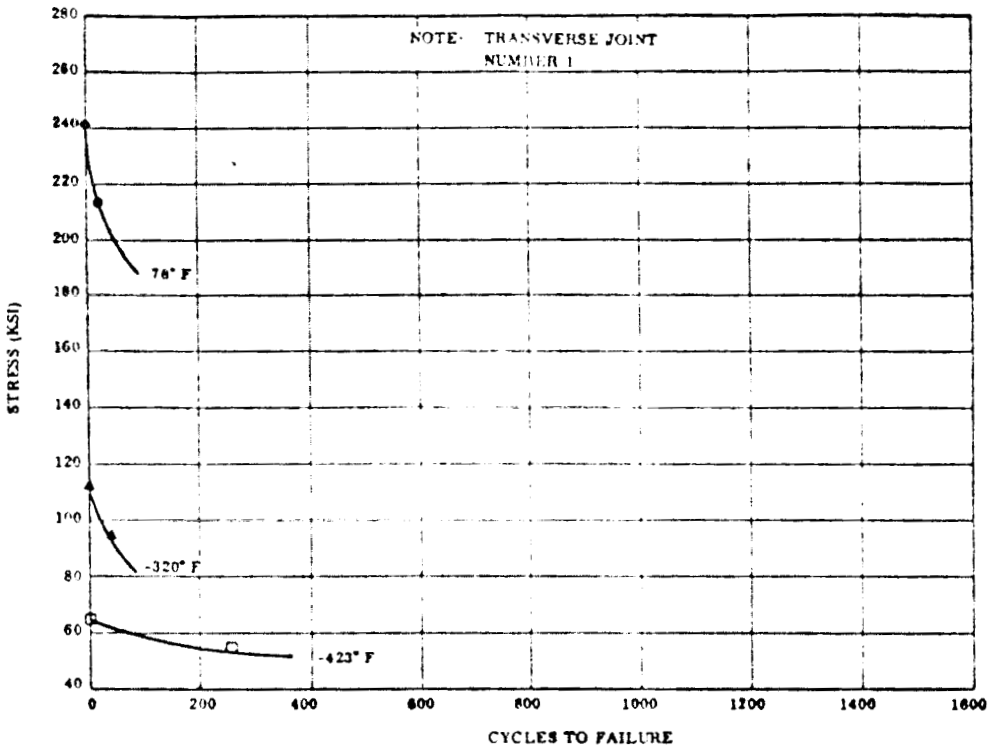


Figure 76. S-N Curve - AM-355 Stainless Steel (Transverse - Joint No. 1)

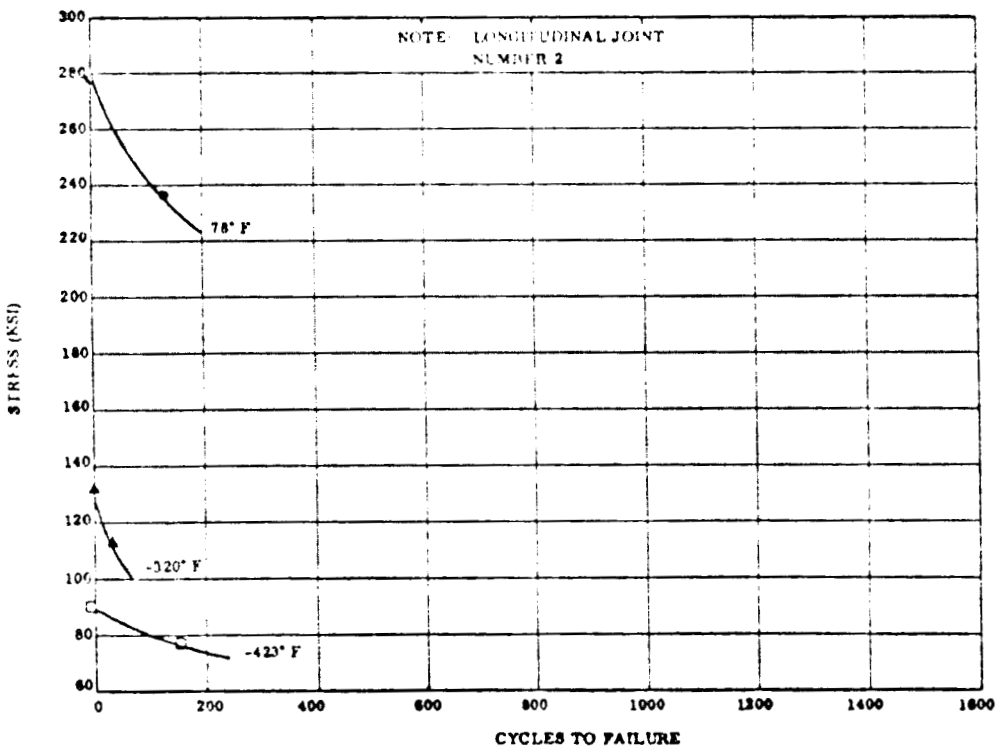


Figure 77. S-N Curve - AM-355 Stainless Steel (Longitudinal - Joint No. 2)

2.4 AFC 77

This steel is a fairly recent development of the CR-MO-CO type alloys. It was originally developed as a high temperature alloy which displayed excellent combinations of properties. Very little testing seems to have been done at sub-zero temperatures. If the available data is any indication, i.e. no decrease in elongation down to -110F and high strength to density ratio, this material is certainly a candidate for further study.

TABLE I DATE September 24, 1961

ALLOY ARC 77 SHEET THICKNESS 0.025-0.100

Properties of Sheet Material		700°F	R.T.	-110F	-320°F	-423°F
Density, lbs/cu. in.						
Modulus of Elasticity						
Annealed	Tensile - 1000 psi		237		262	
Austenitized @ 1900F ½ hr, oil quenched & cooled @ 100F ½ hr	Yield - 1000 psi		182		213	
Temp 700F, 2+2 hr	Elong. in 2"		11		11	
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)					
	Shear - 1000 psi					
	[illegible]		[illegible]		[illegible]	
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		264		294	
	Yield - 1000 psi		255		281	
AS ABOVE PLUS 10% CR	Elong. in 2"		5		6	
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)					
	Shear - 1000 psi					

Str. to Density Ratio -

Impact Str. (Charpy), ft. lb.

Fatigue Str. Curves at indicated temps.

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)

Weld Joint Efficiencies (same and dissimilar metals)

Resistance to Crack Propagation

Formability

Cleanability

Availability

Cost

2.5 NICKEL STEELS

Very little information seems to have been published on 9% Ni (ASTM A353). From what is available, however, it would seem that more testing should be accomplished.

The 18% Ni Ma aging steel seems promising in the annealed state (severe embrittlement at -423F in the aged condition). Elongation holds fairly well and strength to density ratio is good.

TABLE I DATE September 24, 1964

ALLOY 9 NI STEEL (ASTM-A353) SHEET THICKNESS
(2000)

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. .282 (2)					
Modulus of Elasticity $X10^6$(2)			28		30
Annealed	Tensile - 1000 psi				
	Yield - 1000 psi				
	Elong. in 2"				
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition (1)	Tensile - 1000 psi		125.4	179.2	218.8
	Yield - 1000 psi		118.4	159.7	205.3
DOUBLE NORMALIZED 1650F & 1450F; 1050F TEMPER, BAR	Elong. in (LD)		24.2	26.7	18.3
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - $\frac{F_{ty}}{\rho}(10^{-5})$			4.21	5.67	7.40
Impact Str. (Charpy), ft. lb. (T) (1)			52	25.5	
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No NO

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)

Weld Joint Efficiencies (same and dissimilar metals)

Resistance to Crack Propagation

Formability

Cleanability

Availability

Cost

SOURCE (1) MONOGRAPH 63, (2) ASD-TR-62-351

TABLE I

DATE September 28, 1962

ALLOY 9800 STEEL 9% NI

SHEET THICKNESS 040

ASTM-A353 3/8 PLATE

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in.					
Modulus of Elasticity			28		30
Annealed	Tensile - 1000 psi				
	Yield - 1000 psi				
	Elong. in 2"				
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		110	170	218
	Yield - 1000 psi		86	120	159
NORMALIZED FROM 1 50 & 1450F & TEMPERED AT 1050F FOR 2 HRS	Elong. in 2"		32	31	11.5
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio -					
Impact Str. (Charpy), ft. lb.			85	39	29
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No NO

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)

Weld Joint Efficiencies (same and dissimilar metals) 100%

Resistance to Crack Propagation

Formability Good

Cleanability

Availability

Cost $0.33/lb

Source - ASD-TDR-62-35
"Final Results from operation cryogenics"

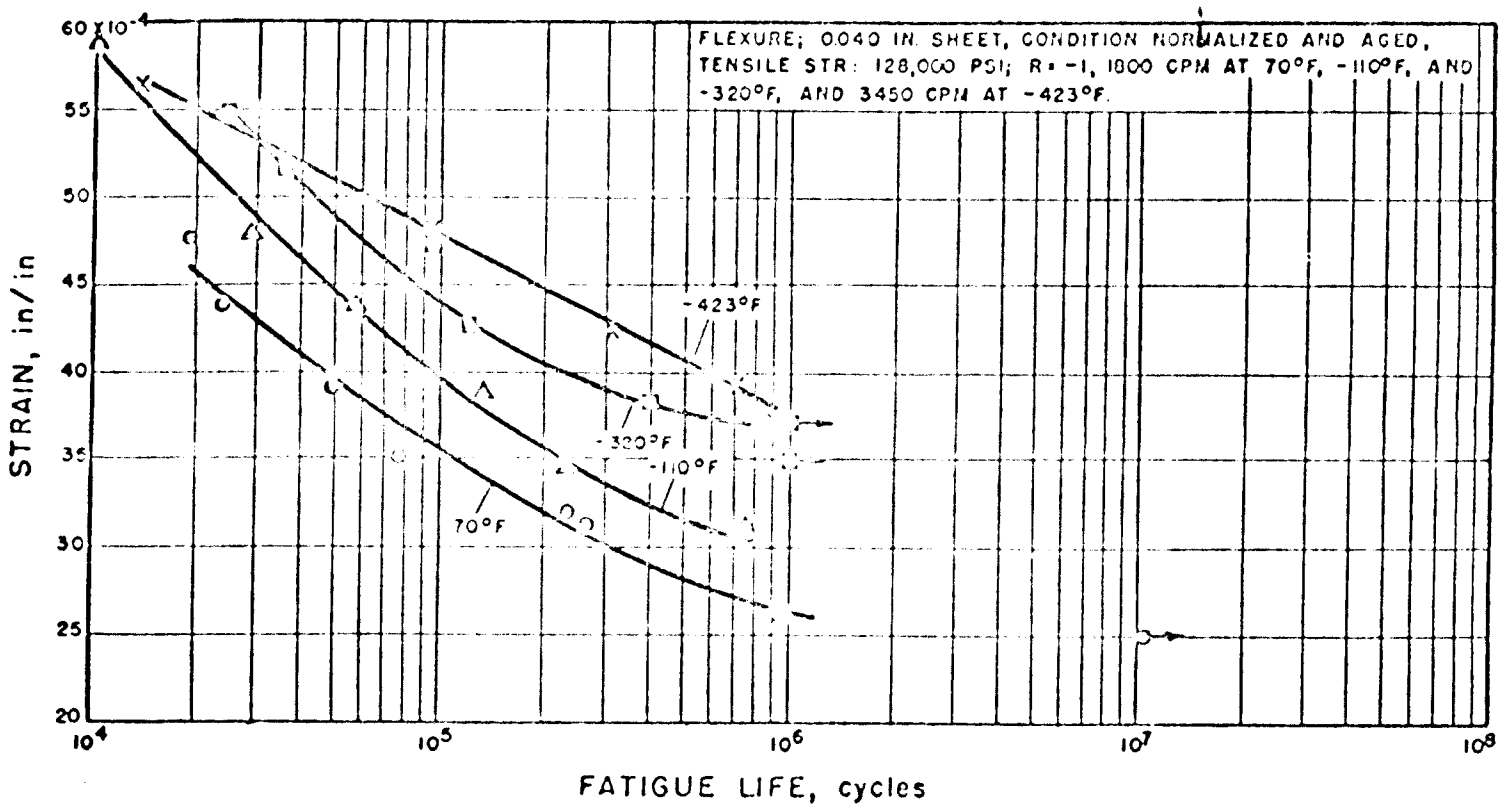


FIGURE 24. UNNOTCHED (K_T = 1) FATIGUE BEHAVIOR OF NORMALIZED AND AGED 2800 STEEL

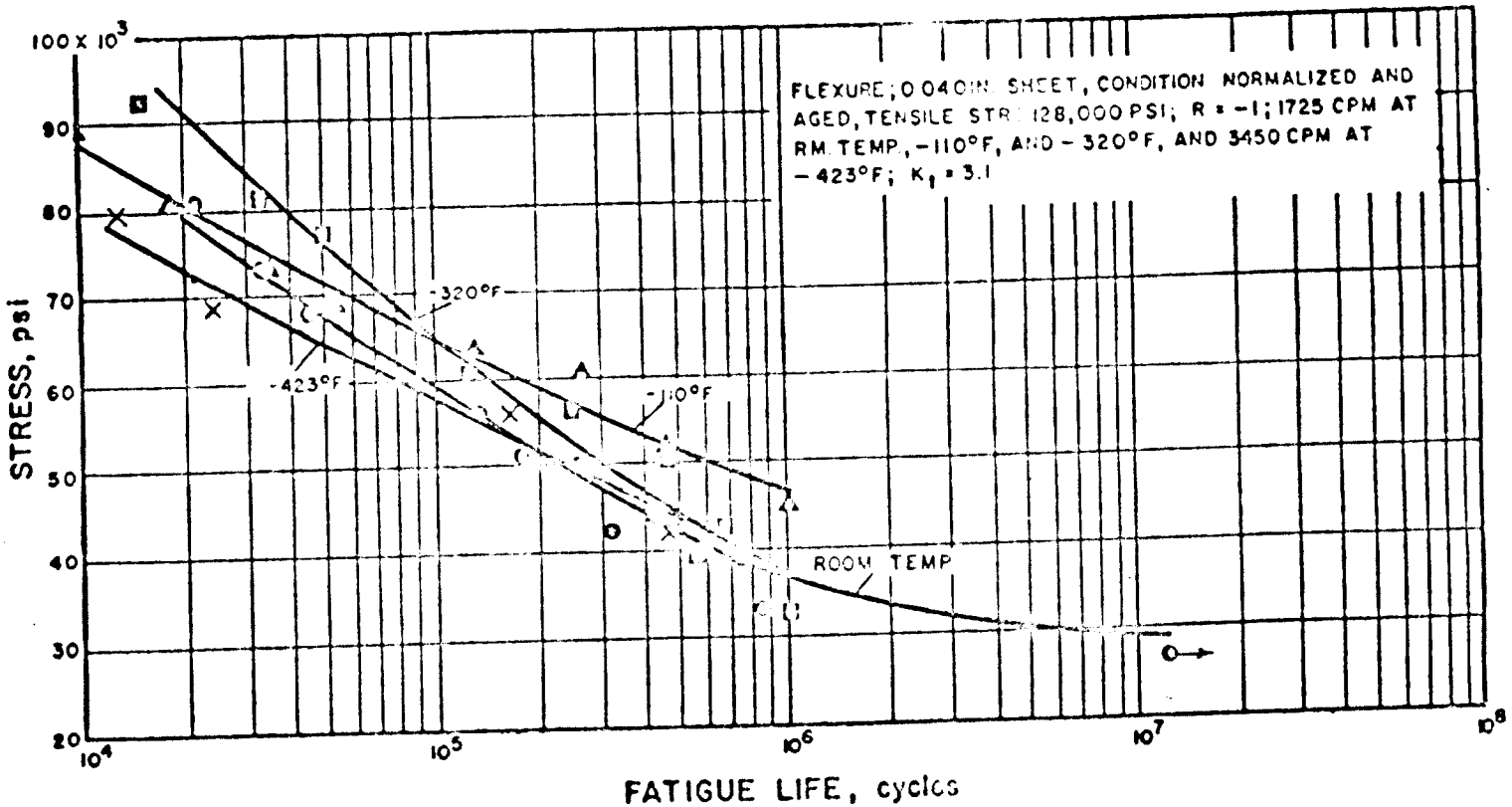


FIGURE 39. NOTCHED (K_T = 3.1) FATIGUE BEHAVIOR OF NORMALIZED AND AGED 2800 STEEL

TABLE I DATE September 24, 1964

ALLOY 18% NICKEL MARAGING STEELS ALMAR 18 SHEET THICKNESS .070

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. .289 (1)					
Modulus of Elasticity X 10^6 (2)	annealed		26.5	27.0	29.7
	aged		24.4	27.5	27.6
Annealed	Tensile - 1000 psi		247 (2)	234	264
	Yield - 1000 psi		213	198 (2)	234
	Elong. in 2"		7.5	9.8	4.3
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000 psi		280	349	3.93
	Yield - 1000 psi		274 (2)	338(2)	385
AGED (900F, 3 hrs AC	Elong. in 2"		3.5	3.5	1.3
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - $\frac{F_{ty}}{\rho}(10^{-5})$			9.49	11.70	13.31
Impact Str. (Charpy), ft. lb.			17	11	
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 6.3 (2)	1.29	1.12	1.23
aged	1.19	1.13	.64

Weld Joint Efficiencies (same and dissimilar metals)

Resistance to Crack Propagation

Formability

Cleanability

Availability

Cost

Source (1) Allegheny-Ludlum Steel Corp, GD- ERR-AN-400

FIGURE 13—Impact properties of Almar 18 bar stock.

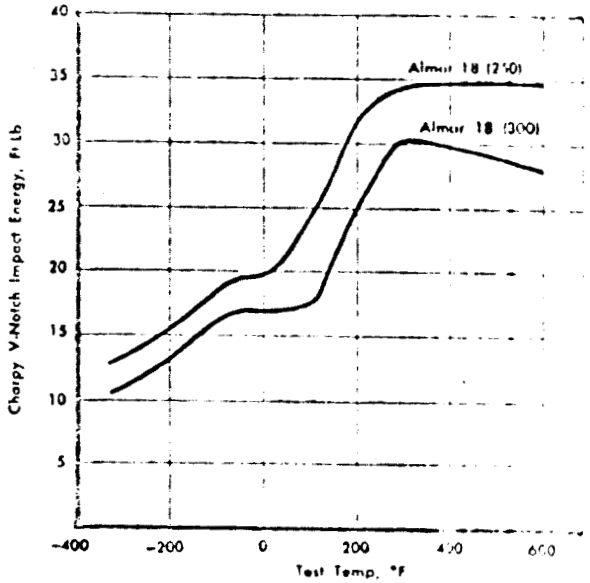


FIGURE 14—Elevated temperature tensile properties of Almar 18 bar stock.

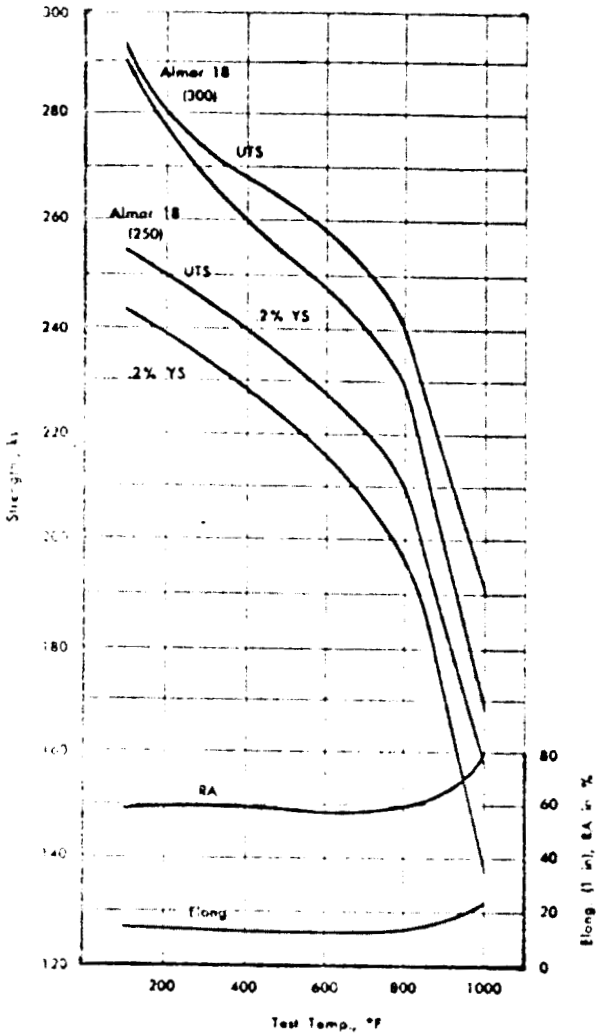


FIGURE 15—Effect of consumable electrode vacuum remelting on short transverse ductility of Almar 18.

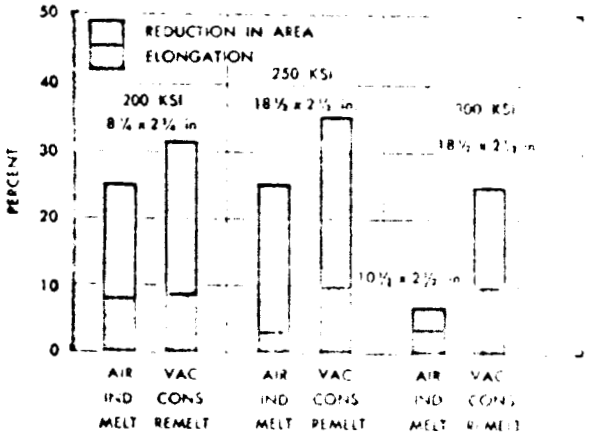
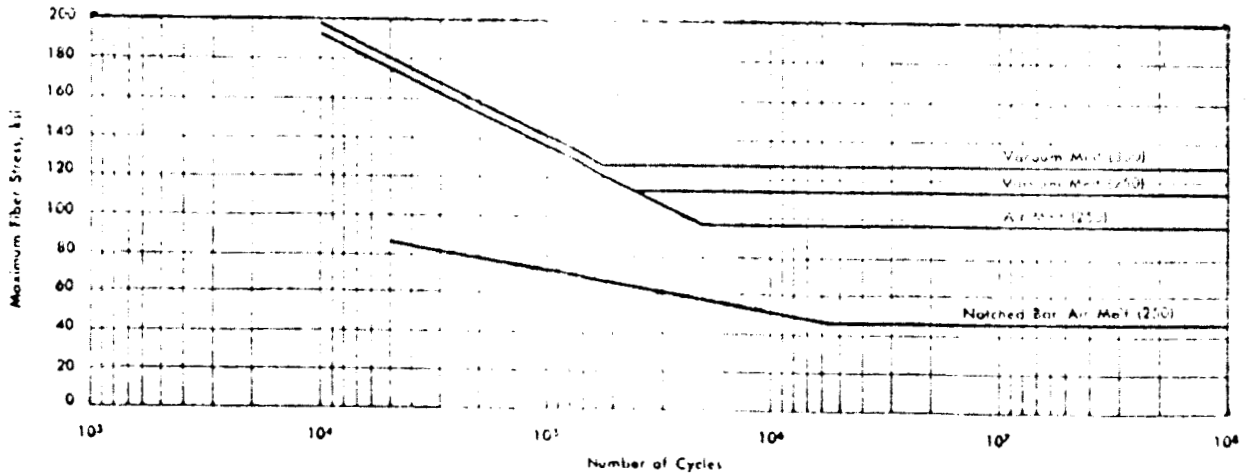


FIGURE 16—Fatigue strength of Almar 18.



2.6 BERYLLIUM COPPER

The strength density ratios of this material are low compared to some of the steels. The material does have other properties which qualify it for cryogenic usage, namely, it is as tough at -423F as it is at room temperature. It also retains its ductility. It would be most appropriate for springs, electrical components, etc.

TABLE I DATE September 28, 1964

ALLOY BERYLLIUM COPPER SHEET THICKNESS 0.008
25 ALLOY

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 0.298 - .297 (3) (1)					
Modulus of Elasticity					
Annealed	Tensile - 1000 psi		60-78		
A (1)	Yield - 1000 psi		28-36		
	Elong. in 2" %		35-60		
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition HT Cold Rolled Age Hardened (2)	Tensile - 1000 psi		199	221	218
	Yield - 1000 psi		177	212	229
	Elong. in 2"		2.5	2.7	3.6
	Bearing - 1000 psi $\frac{e}{D}$ = 2) (3)		205		
	Shear - 1000 psi (3)		104		
Str. to Density Ratio - $\frac{F_{tu}}{}(10^{-5})$			5.94	7.12	7.69
Impact Str. (Charpy), ft. lb.			2.7	4	
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 0.3 (2) .87 .89 .88

Weld-Joint Efficiencies (same and dissimilar metals) Weld prior to age hardening

Resistance to Crack Propagation

Formability Very good

Cleanability

Availability

Cost

Source (1) Brush Beryllium & Beryllium Co.
(2) Data, GD-ERR-AN-400, (3) MIL-HDBK-5

2.7 TITANIUM ALLOYS

Because of the very high strength to density ratios for the materials studied they seem to be excellent candidates for cryogenic structures. With the exception of the commercial production Ti5A-1-2.5 Sn all materials studied were of the extra low interstitial type. It has been found that an oxygen content in excess of 0.03% tends to cause embrittlement at cryogenic temperatures. It must be pointed out also that titanium alloys are not compatible with fluorine.

REVISED DATA

TABLE I

DATE September 2[illegible], 1964

ALLOY TITANIUM COMMERCIALLY PURE AMS - 4902, Ti 45A

SHEET THICKNESS

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. (3) 0.164					
Modulus of Elasticity			(3) 15.5		
Annealed .010 sheet (1)	Tensile - 1000 psi	(3) 36% R.T.	71.9	136	179
	Yield - 1000 psi	26% R.T.	53.8	105	140
	Elong. in 2"		29.2	48	20.3
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi	42% R.T.	(3) [illegible]		
	[illegible]		1.[illegible]	1.06	1.[illegible]
Heat Treated or Cold Worked Condition 50% cold rolled 0.022 sheet (2)	Tensile - 1000 psi	45% (3) anneal R.T.	113	168	199
	Yield - 1000 psi	[illegible] anneal R.T.	96.9	157	174
	Elong. in 2"		6.5	13.7	30.3
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi	[illegible] anneal R.T.			
Str. to Density Ratio - $\frac{F_{tu}}{\sqrt{\ }}$ (10^{-5})			5.91	9.56	11.61
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No (4) unacceptable

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) (2) 1.31 1.19 1.18

Weld Joint Efficiencies (same and dissimilar metals)

Resistance to Crack Propagation

Formability

Cleanability

Availability

Cost

1. [illegible]-AN-400 Evaluation of materials & test methods @ cryogenic temp.
2. [illegible]-AN-257 Development of high strength sheet alloys for cryogenic applic.
3. DMIC report 145, design info on titanium alloys
4. MSFC-MTP-P&VE-M-63-14 Compatability of materials with Lox

TABLE I

DATE September 2[illegible], 196[illegible]

ALLOY TITANIUM SAI-2.5 Sn ELI SHEET THICKNESS

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 0.161-0.164					
Modulus of Elasticity					
Annealed	Tensile - 1000 psi	GD/A 115	127	189	239
0.014 sht	Yield - 1000 psi	105	117	175	225
	Elong. in 2"	155	15.3	18.3	13.0
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
	[illegible]	[illegible]		1.23	1.[illegible]
Heat Treated or Cold Worked Condition	Tensile - 1000 psi	12[illegible]		203	233
	Yield - 1000 psi	118		191	225
5% CR 0.031 sht	Elong. in 2"	10.5		7.0	1.2
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio -	$\frac{\sigma}{\rho}$ (10^{-5})	7.29		11.79	13.88
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No Unacceptable

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)	6.3	1.27	1.19	.95
Weld Joint Efficiencies (same and dissimilar metals)	ASD 90		97	93

Resistance to Crack Propagation

Formability

Cleanability

Availability

Cost

GD/A ERR-AN-400
ASD-TDR-62-258

Figure 7. Notched Tensile Properties vs. Temperature for Three Heats of Ti-5Al-2.5 Sn, GD/A Specification 0-71010

EXTRA LOW IRON & INTERSTITIAL CONTENT

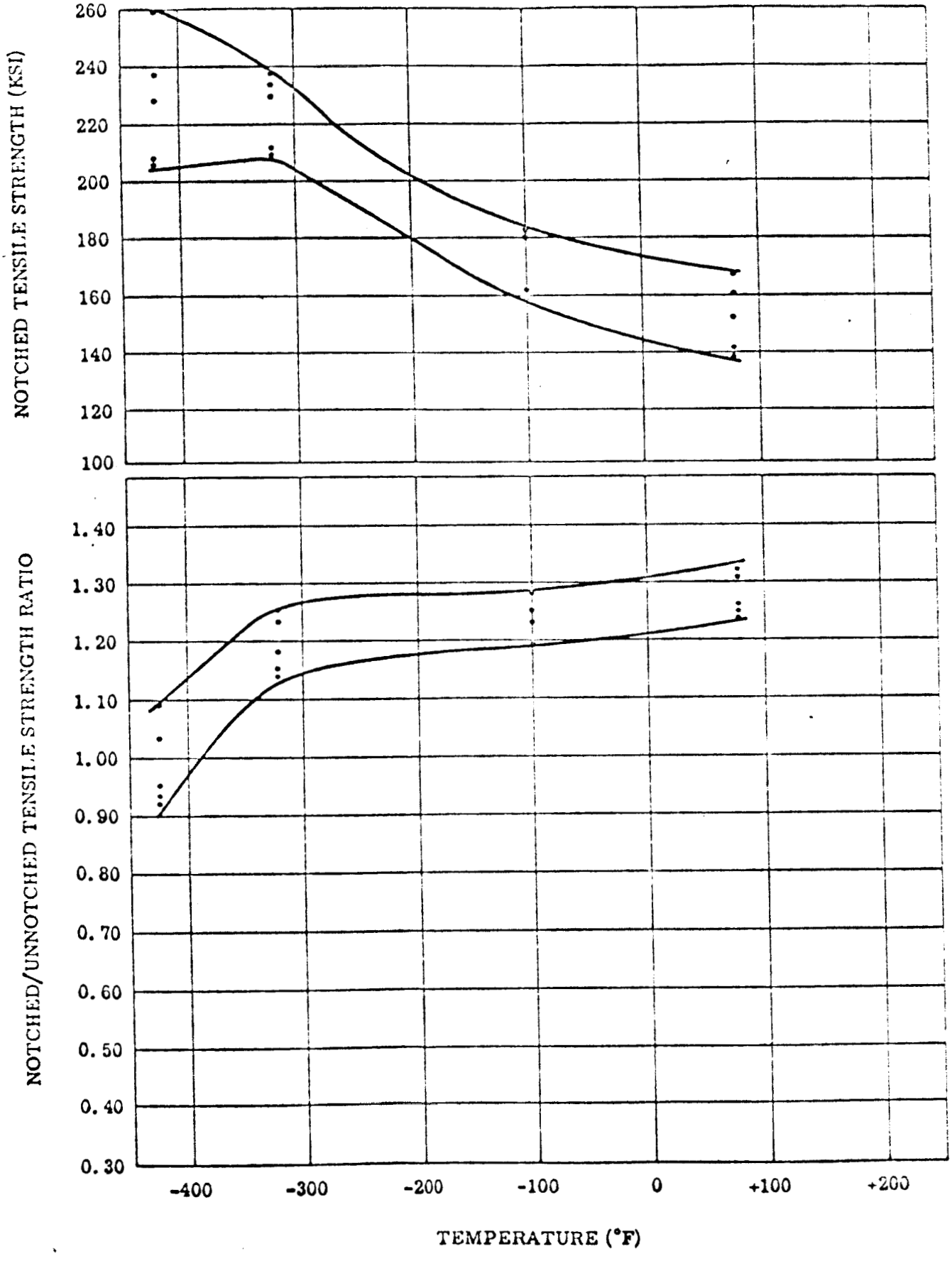
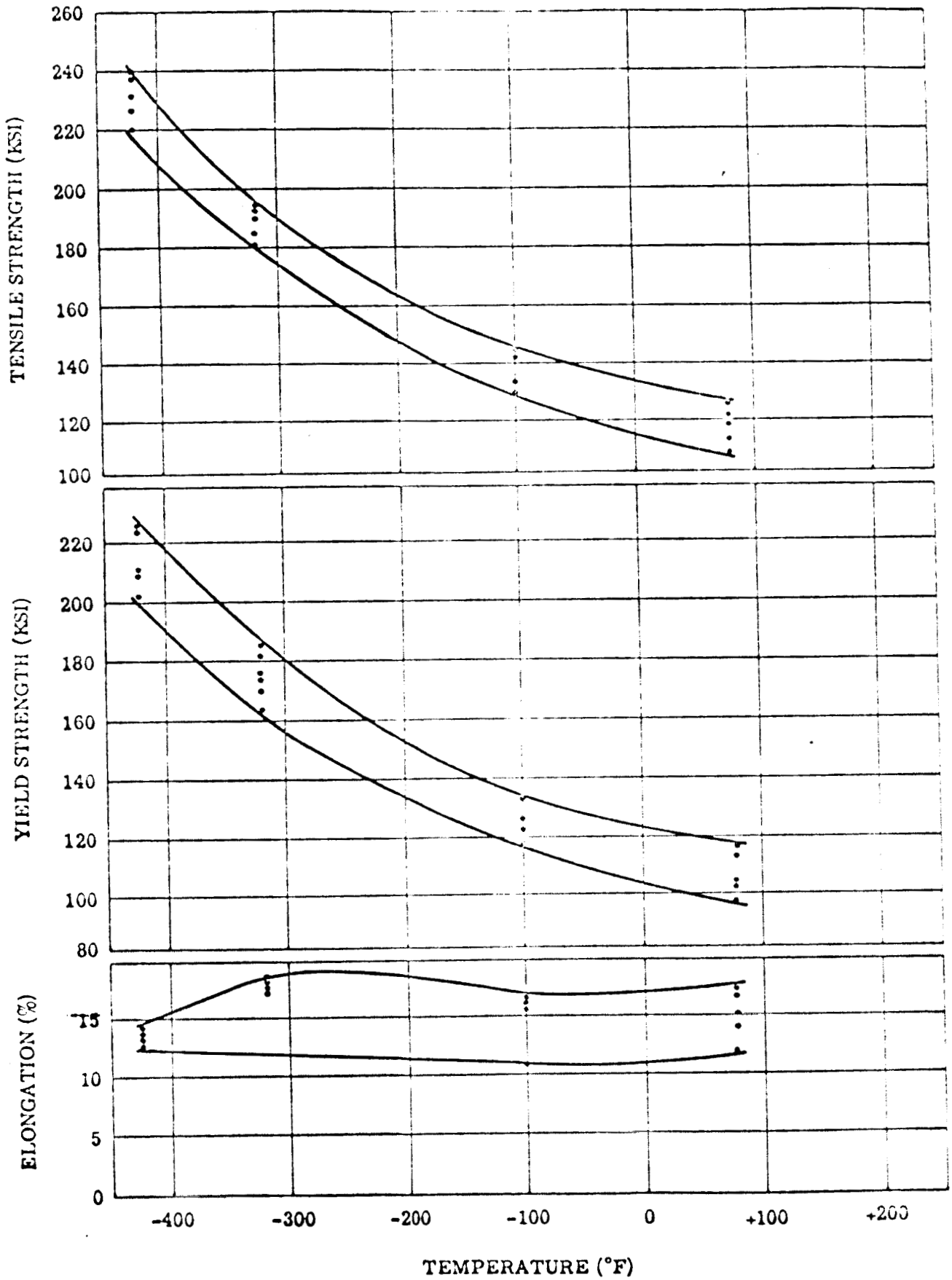


Figure 6. Tensile Properties vs. Temperature - for Three Heats of Ti-5Al-2.5 Sn, GD/A Specification 0-71010



REVISED DATA

TABLE I DATE September 24, 1964

ALLOY TITANIUM 5AL 2.5S Sn SHEET THICKNESS 0.014 - [illegible]
Commercial production Spec AMS [illegible]

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 0.161-0.164					
Modulus of Elasticity		(2) 80% R.T.	15.5(2)	18	17
MillAnnealed	Tensile - 1000 psi	(2) 60% R.T.	(1) 118-141	(1) 196-214	(1) 247-267
	Yield - 1000 psi	R.T.	111-128	184-203	320-[illegible]
	Elong. in 2"		[illegible]-22	12-17	2-15
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)	R.T.	240(2)		
	Shear - 1000 psi	R.T.	[illegible]		
Heat Treated or Cold Worked Condition	Tensile - 1000 psi	(strength not improved by heat treatment)	120-145		237-274
	Yield - 1000 psi		103-125		198-244
20% cold rolled (1)	Elong. in 2"		8-9		4-6
	Bearing - 1000 psi $\frac{e}{D}$ = 2)				
	Shear - 1000 psi				

Str. to Density Ratio - Max.

Impact Str. (Charpy), ft. lb. 14(min)(3)

Fatigue Str. Curves at indicated temps. curves attached

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No (4) unacceptable

Thermal Shock Sensitivity

(1) Notched/Unnotched Tensile Ratio (K_t value) 6.3 C.R 1.22-1.30 [illegible]
annual 1.30 1.1[illegible] [illegible] - .97

(1) Weld Joint Efficiencies (same and dissimilar metals) 99-100 98-100 [illegible]-100

Resistance to Crack Propagation

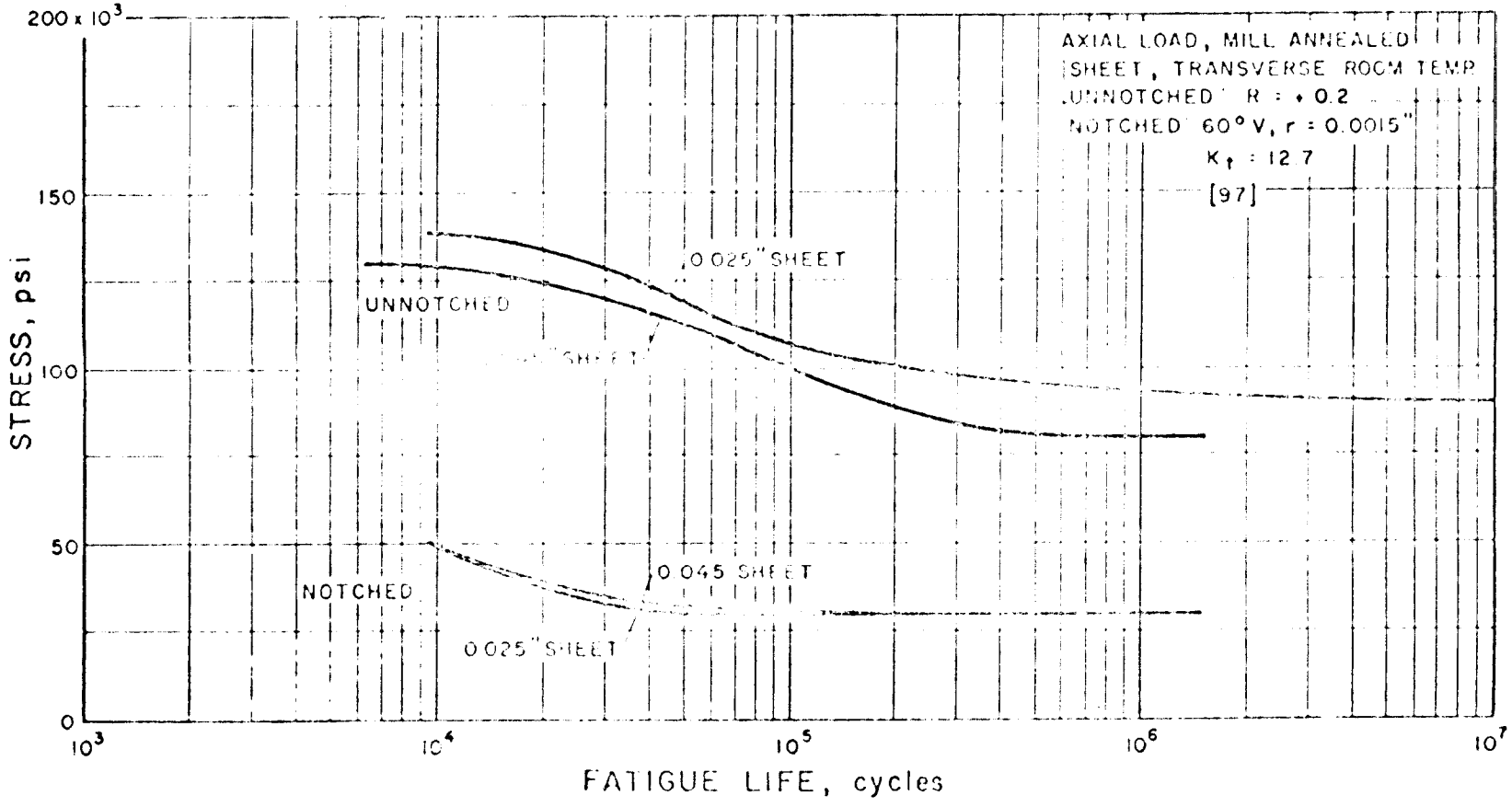
Formability suitable [illegible]-1200F

Cleanability

Availability

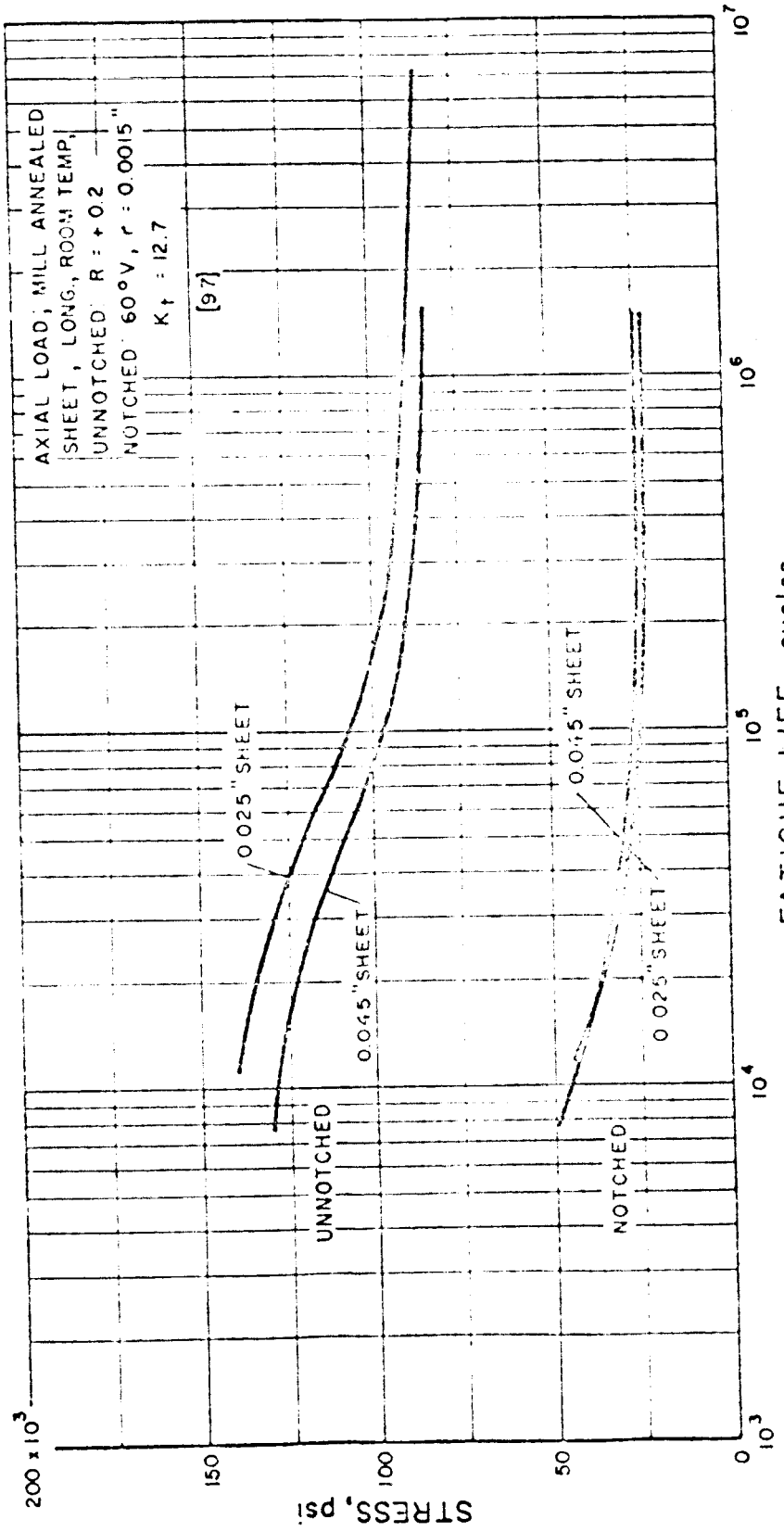
Cost

1. Mech prop of Ti-5Al-2.5Sn Alloy, GE/A
2. DMIC report 145, 10 Jan 61
3. Design News 29 Sept. 61
4. MSFC-MTP-P&VE - M-63-14, Compatability of materials with LOX



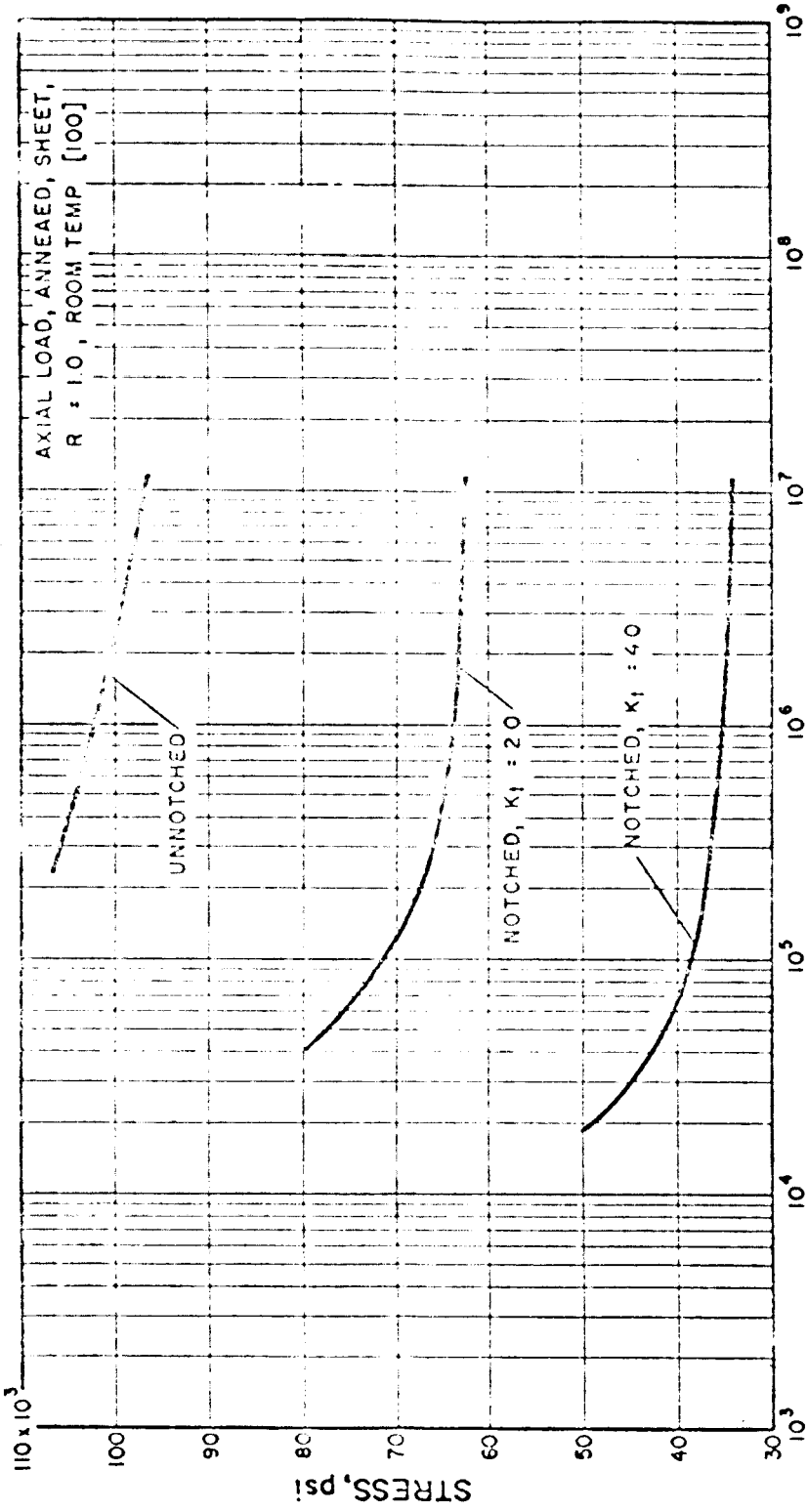
FATIGUE BEHAVIOR OF A-110-AT TITANIUM

F. 1. n - 1



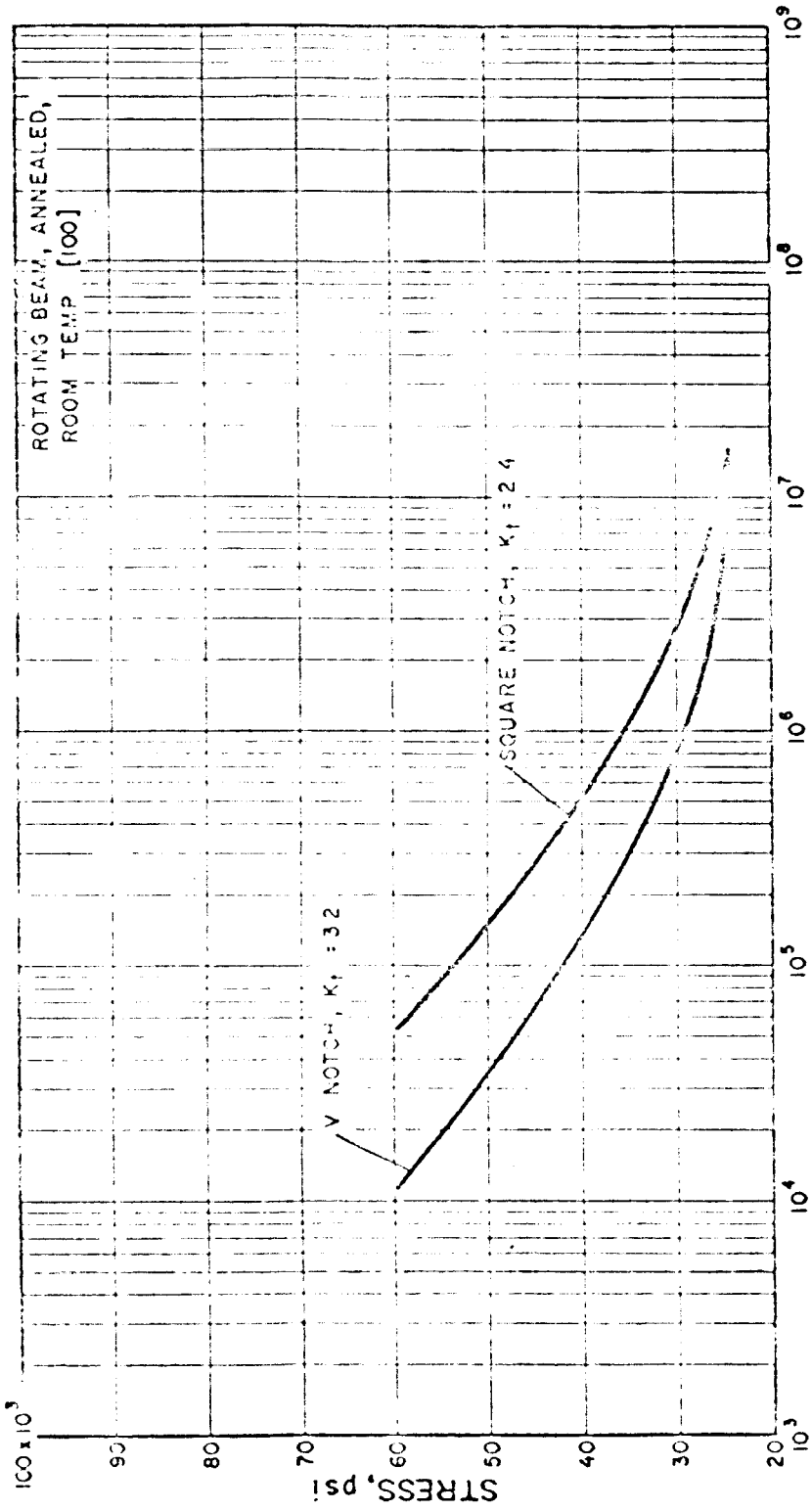
FATIGUE BEHAVIOR OF A-110-AT TITANIUM

F.1.n-2

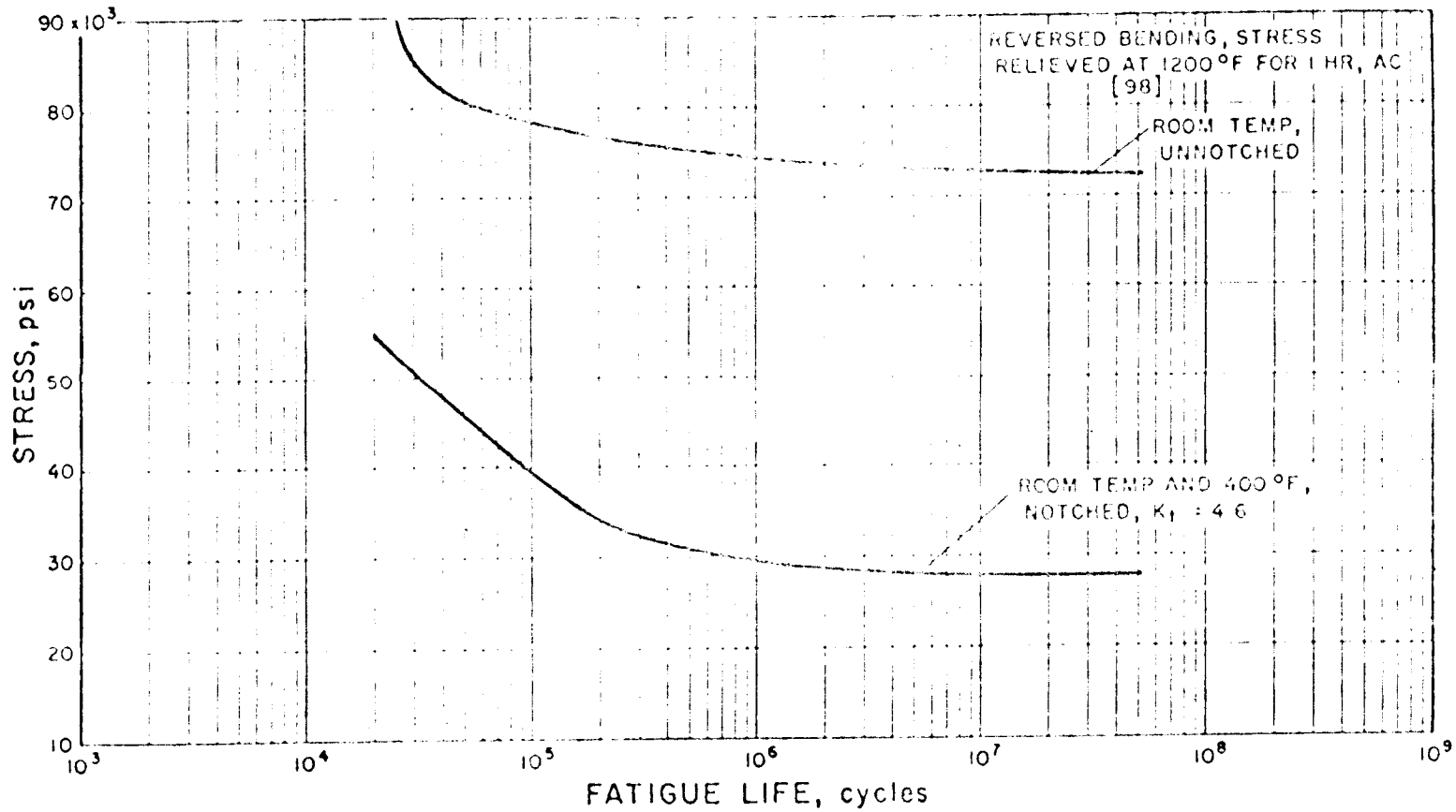


FATIGUE BEHAVIOR OF A-110-AT TITANIUM

F.I.n-3



FATIGUE BEHAVIOR OF A-110-AT TITANIUM



FATIGUE BEHAVIOR OF A-110-AT TITANIUM

REVISED DATA

TABLE I

DATE September 24, 1964

ALLOY TITANIUM 6Al-4V SHEET THICKNESS 0.045

O_2 content 0.15%

Properties of Sheet Material		800°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 0.160-0.163					
Modulus of Elasticity		(4)12	(2) 15.4	(4)16.7	(4) 19.4
MillAnnealed (1) (3)	Tensile - 1000 psi		136-143	218-220	264
	Yield - 1000 psi		127-138	204-210	255
	Elong. in 2"		11-13.5	13.8-17	1.8
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)	201 (2)	144		
	Shear - 1000 psi	53	76		
	Notched-Unnotched Tensile Ratio	[illegible]	[illegible]		
Heat Treated or Cold Worked (3) Condition	Tensile - 1000 psi		[illegible]	265	292
	Yield - 1000 psi		172	232	265
Aged 1660F 6 min W2,1000F-4hr, AC	Elong. in 2"		6.5	5.0	.5
	Bearing - 1000 psi $\frac{e}{D}$ = 2)	245 (5)	320		
	Shear - 1000 psi	78	110		
Str. to Density Ratio - $\frac{F_{tu}}{\gamma}$ (10^{-5})			11.68	14.41	16.47
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps. See curves					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No Unacceptable

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)

Weld Joint Efficiencies (same and dissimilar metals) 1.22 .94 .80

Resistance to Crack Propagation 100 100 100

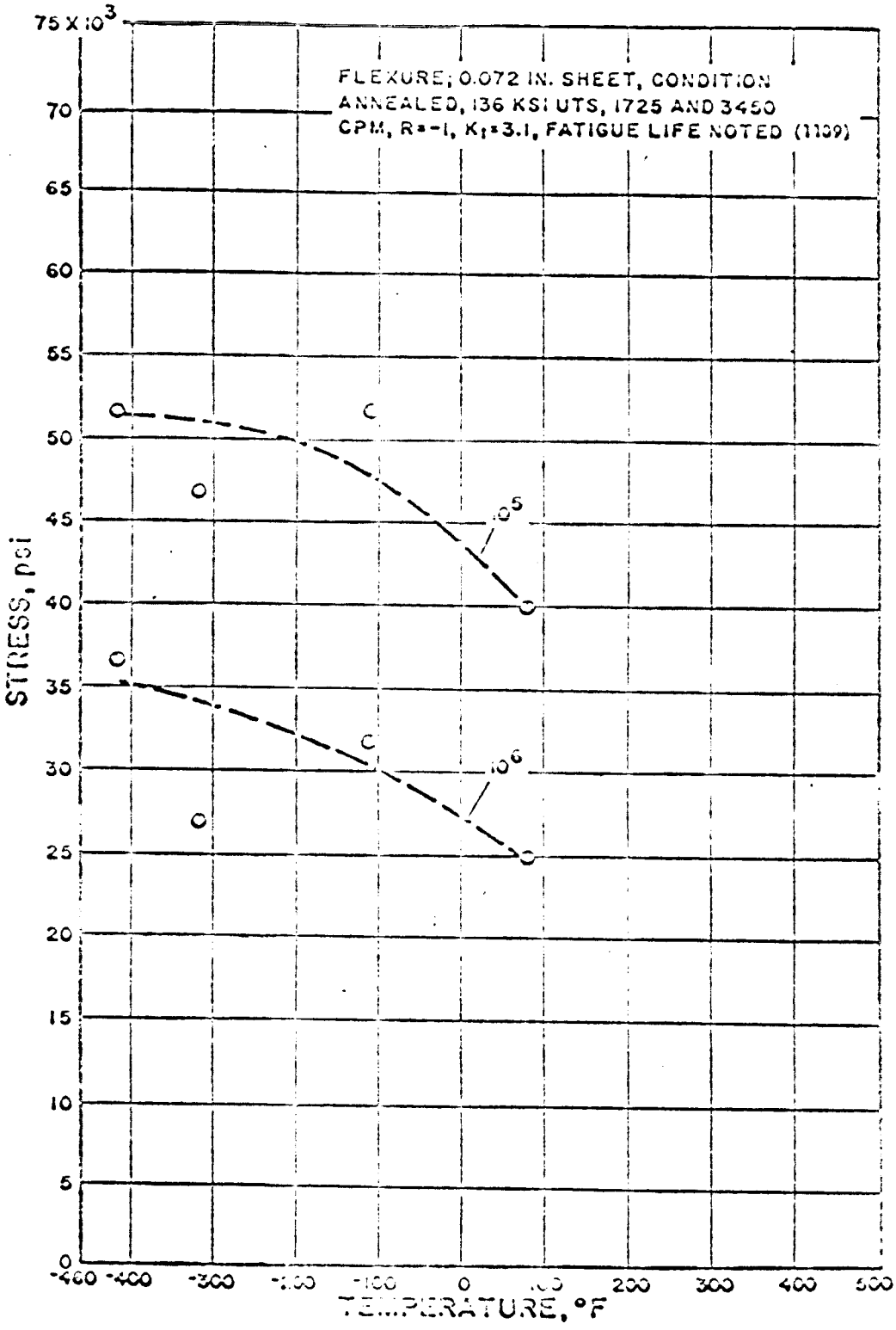
Formability

Cleanability

Availability

Cost

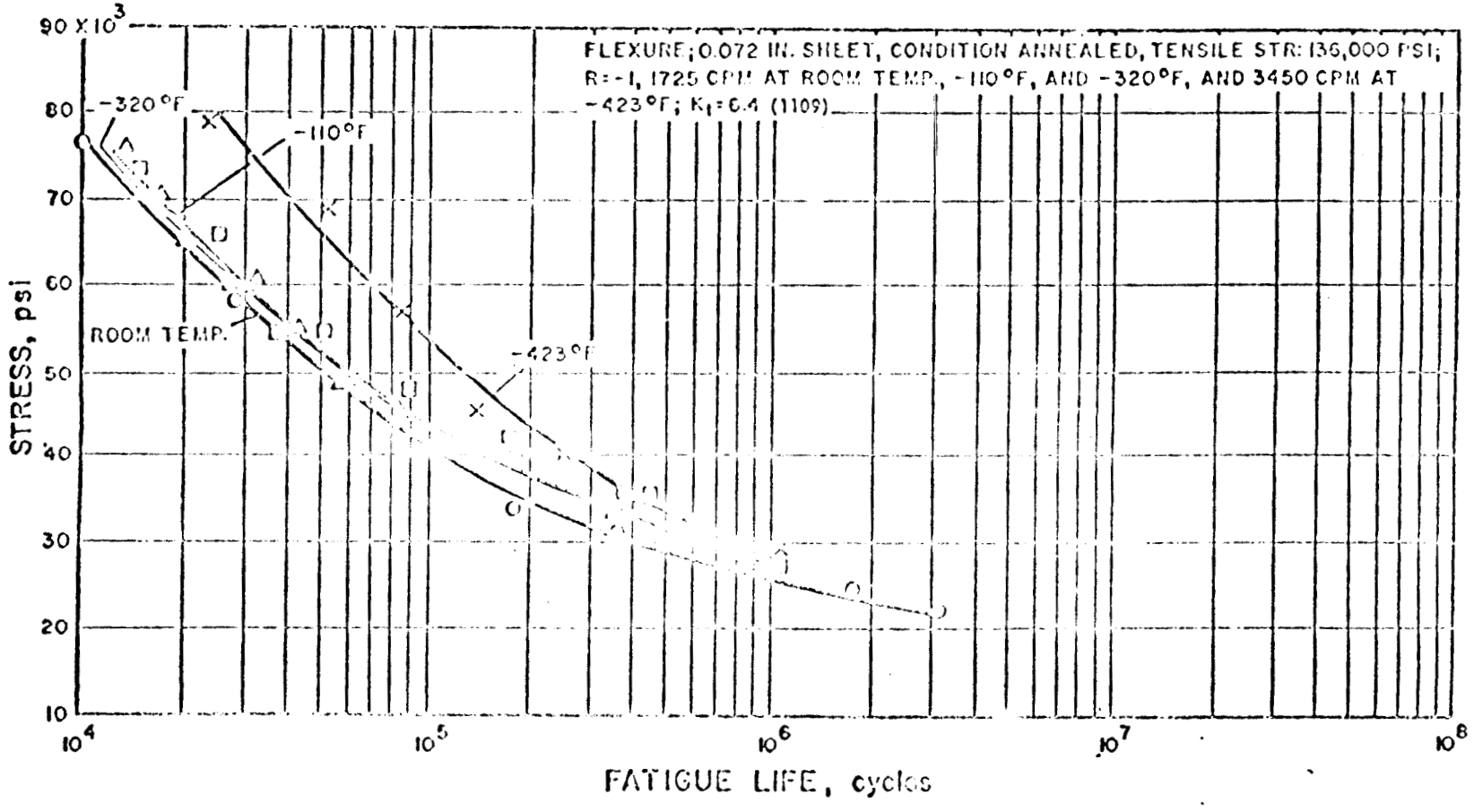
1. ERR-AN-400, GD/A Evaluation of materials & test methods @ cryogenic temp.
2. DMIC report 145, Design info on titanium alloys
3. Air Force materials Laboratory Cryogenic handbook (#QTS 171809)
4. DMIC Memo 61 S. ASD-TDR-62-335 Vol 2a Design Data



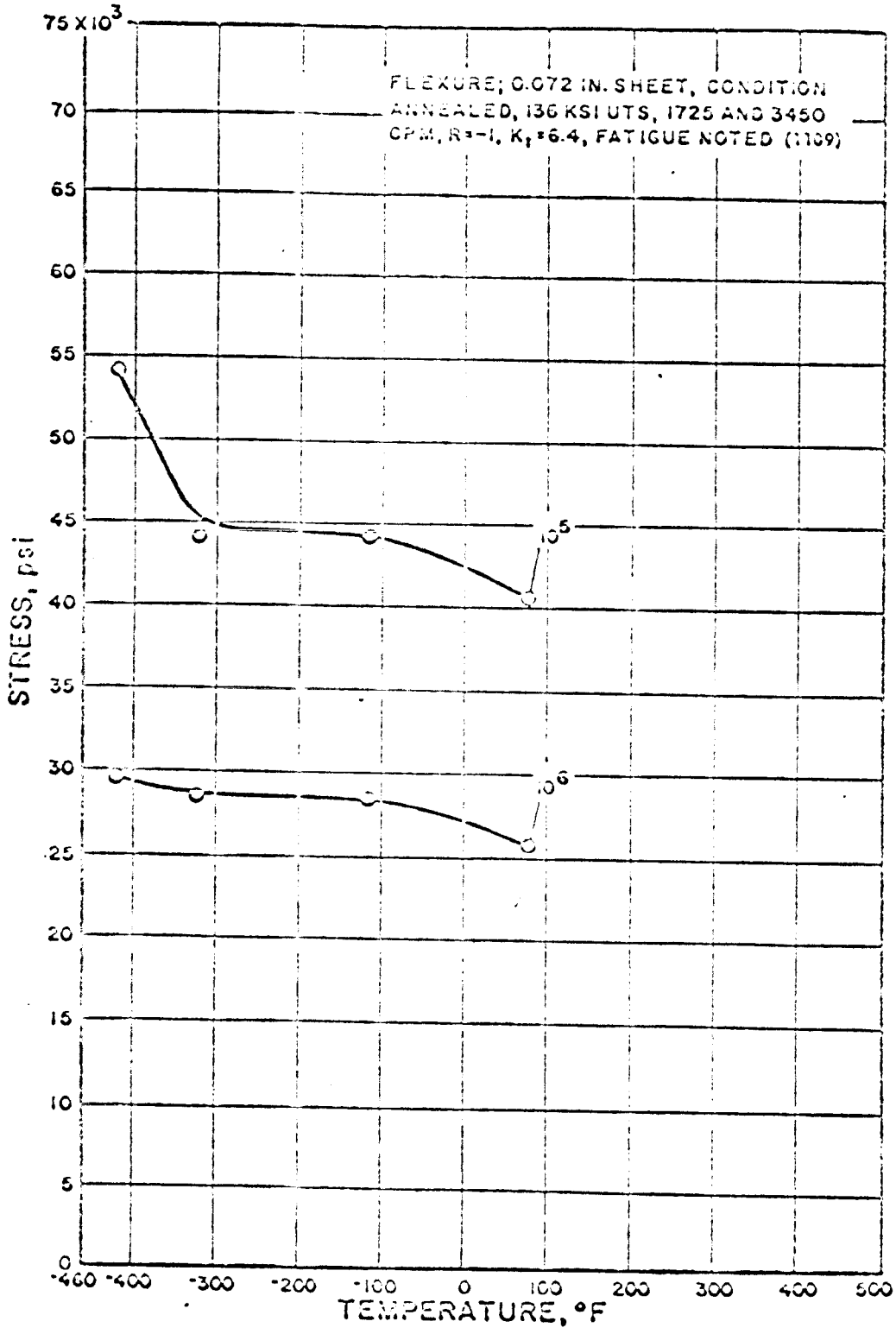
FATIGUE STRENGTH OF 6Al-4V TITANIUM

(10-15-62)

AIR FORCE MATERIALS LABORATORY
CRYOGENIC HANDBOOK (OTS # PB 171309)

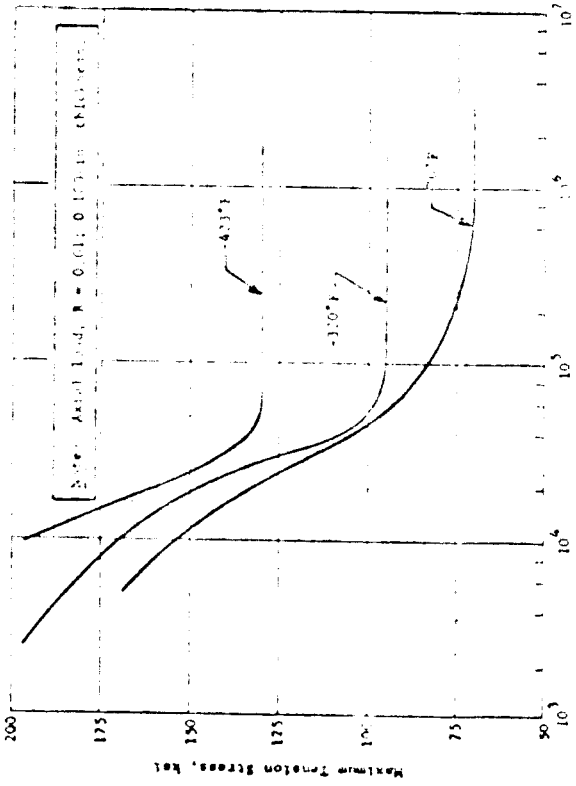


FATIGUE BEHAVIOR OF 6Al-4V TITANIUM



FATIGUE STRENGTH OF 6Al-4V TITANIUM

(10-18-62)



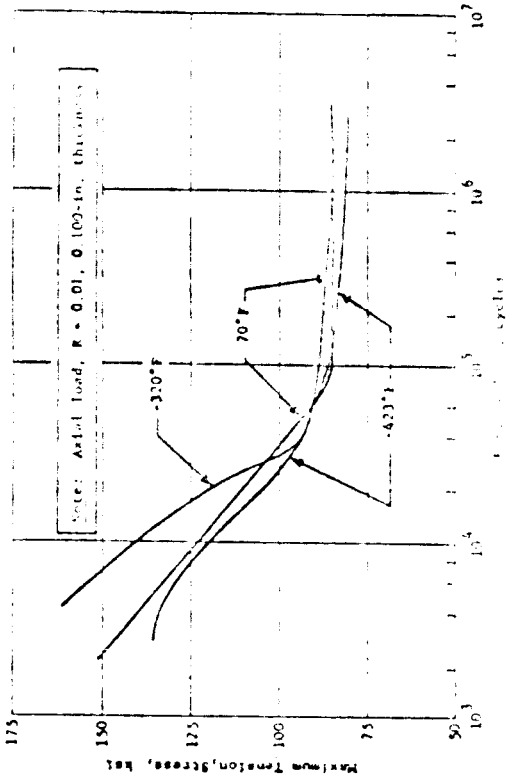


FIG. 7 FATIGUE [illegible]

a. Parent [illegible]

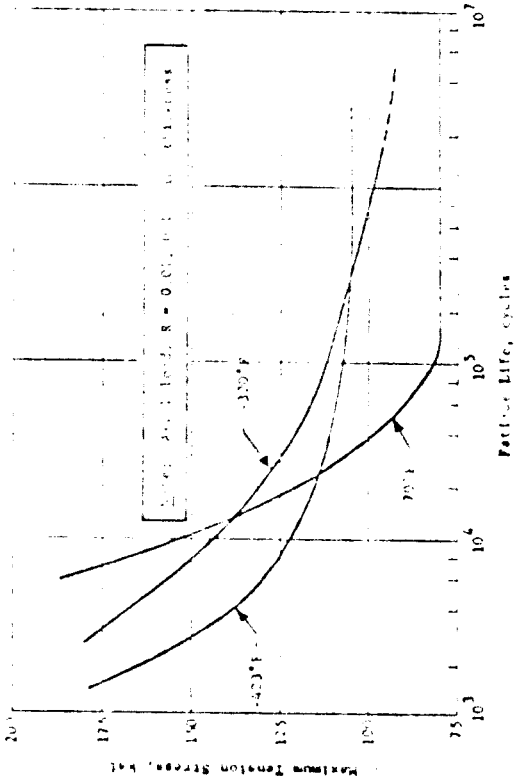
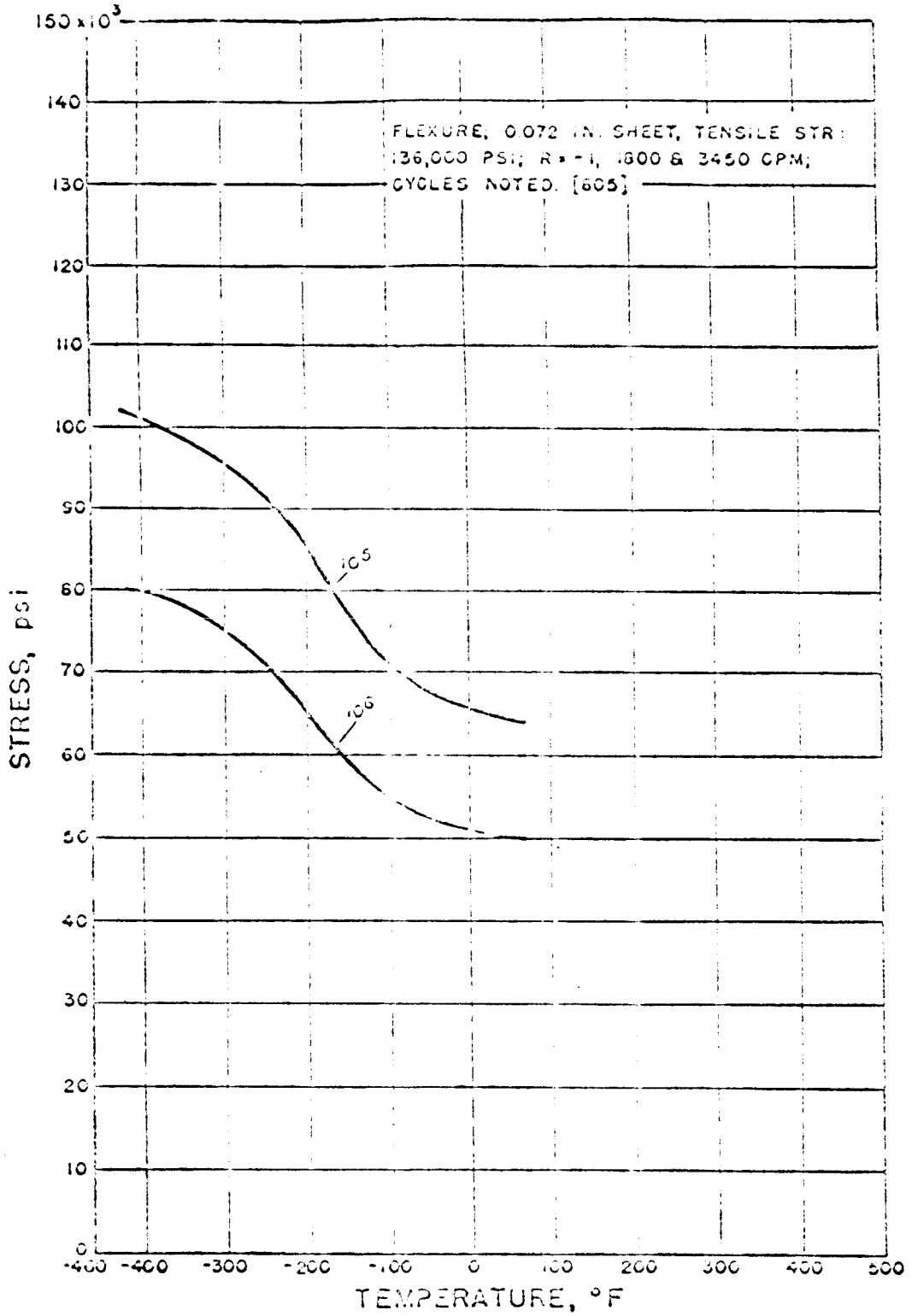
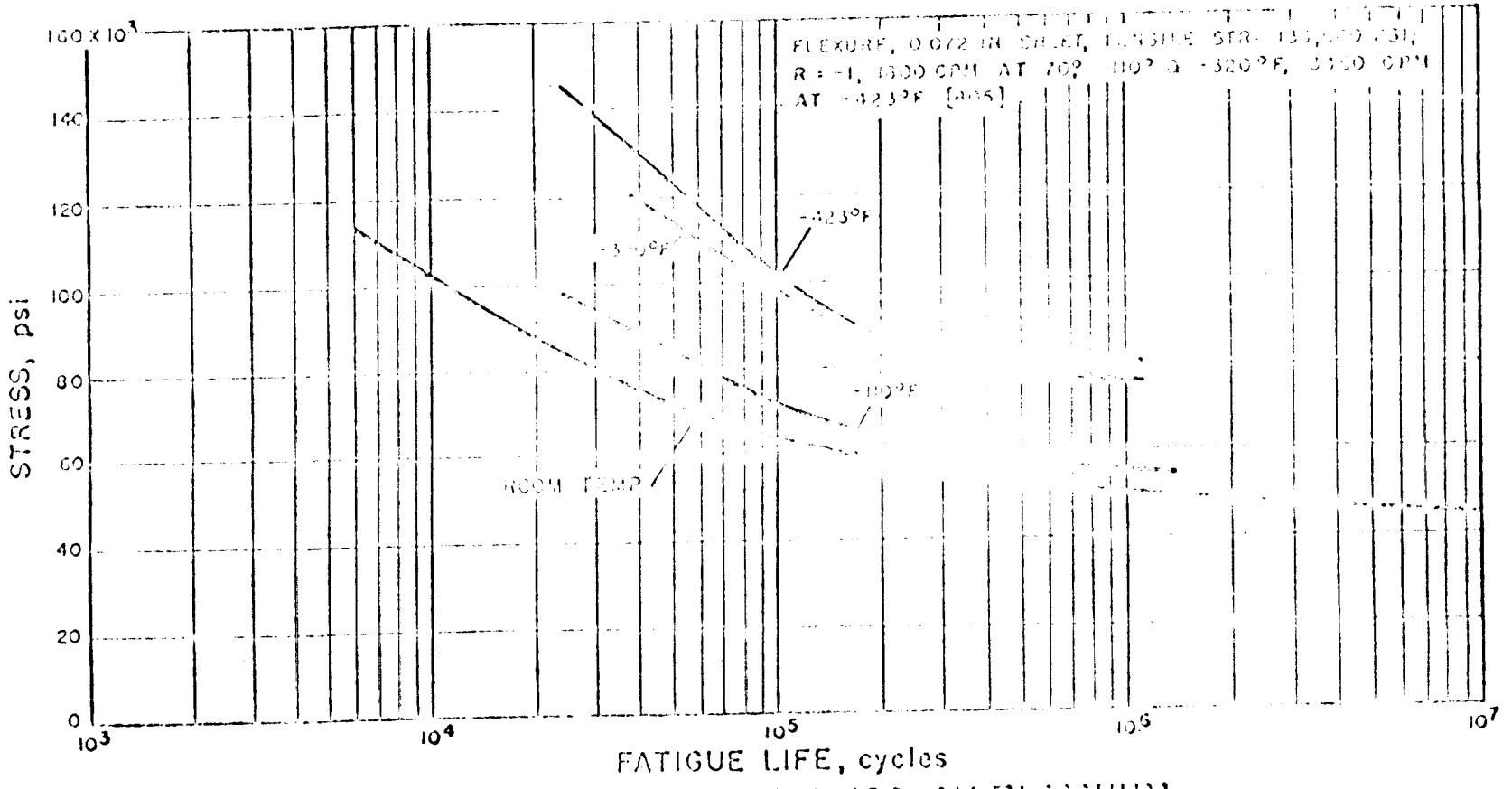


FIG. 8 FATIGUE [illegible] OF PARENT METAL OF [illegible] TITANIUM ALLOY

PAPER C-1
FATIGUE BEHAVIOR
MARTIN CO.



FATIGUE STRENGTH OF C-120-AV TITANIUM



FATIGUE BEHAVIOR OF C-120-AV TITANIUM

Fig. 3.n

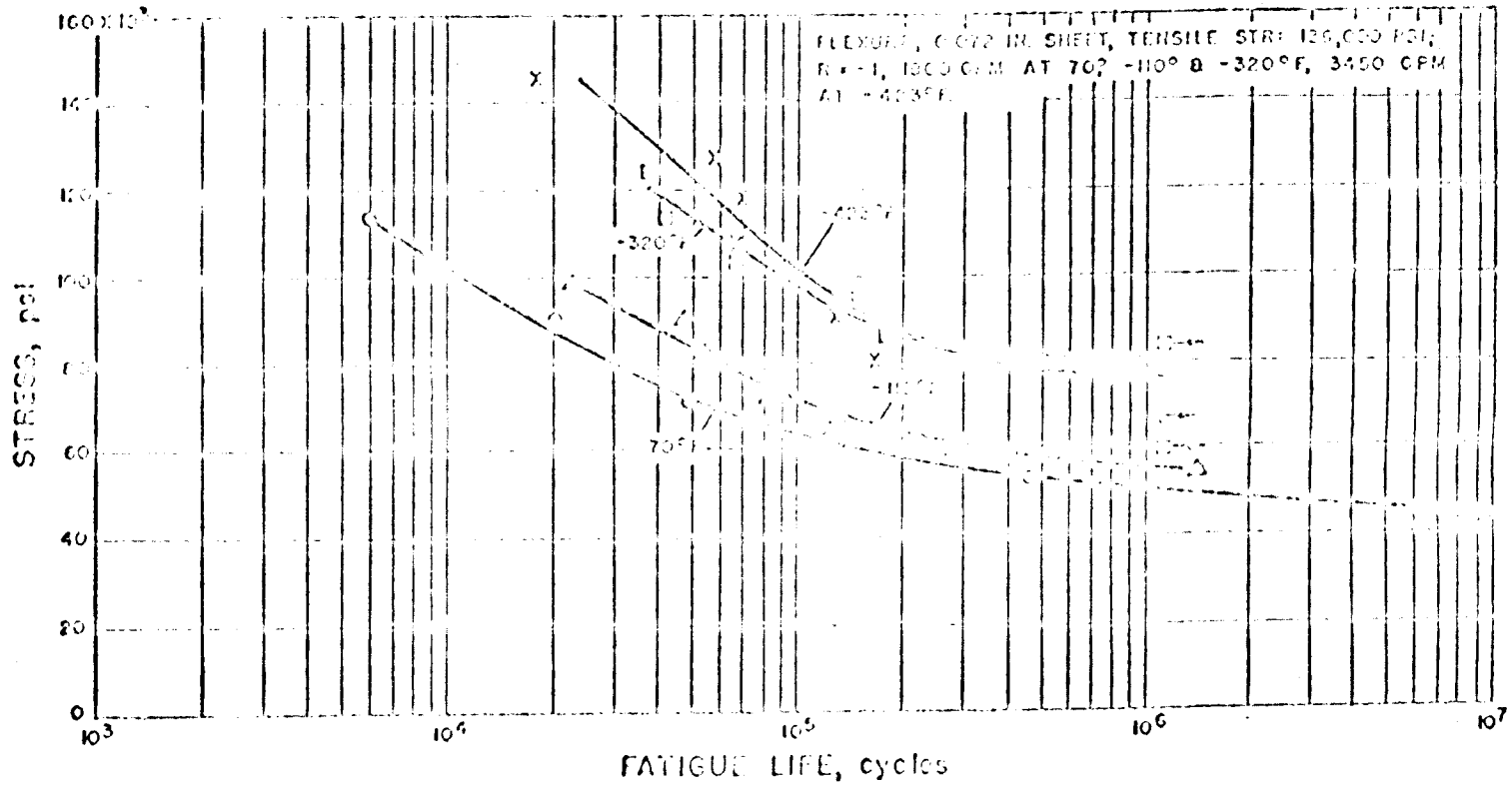


FIGURE 23. UNNOTCHED (K_T = 1) FATIGUE BEHAVIOR OF ANNEALED 6Al-4V TITANIUM

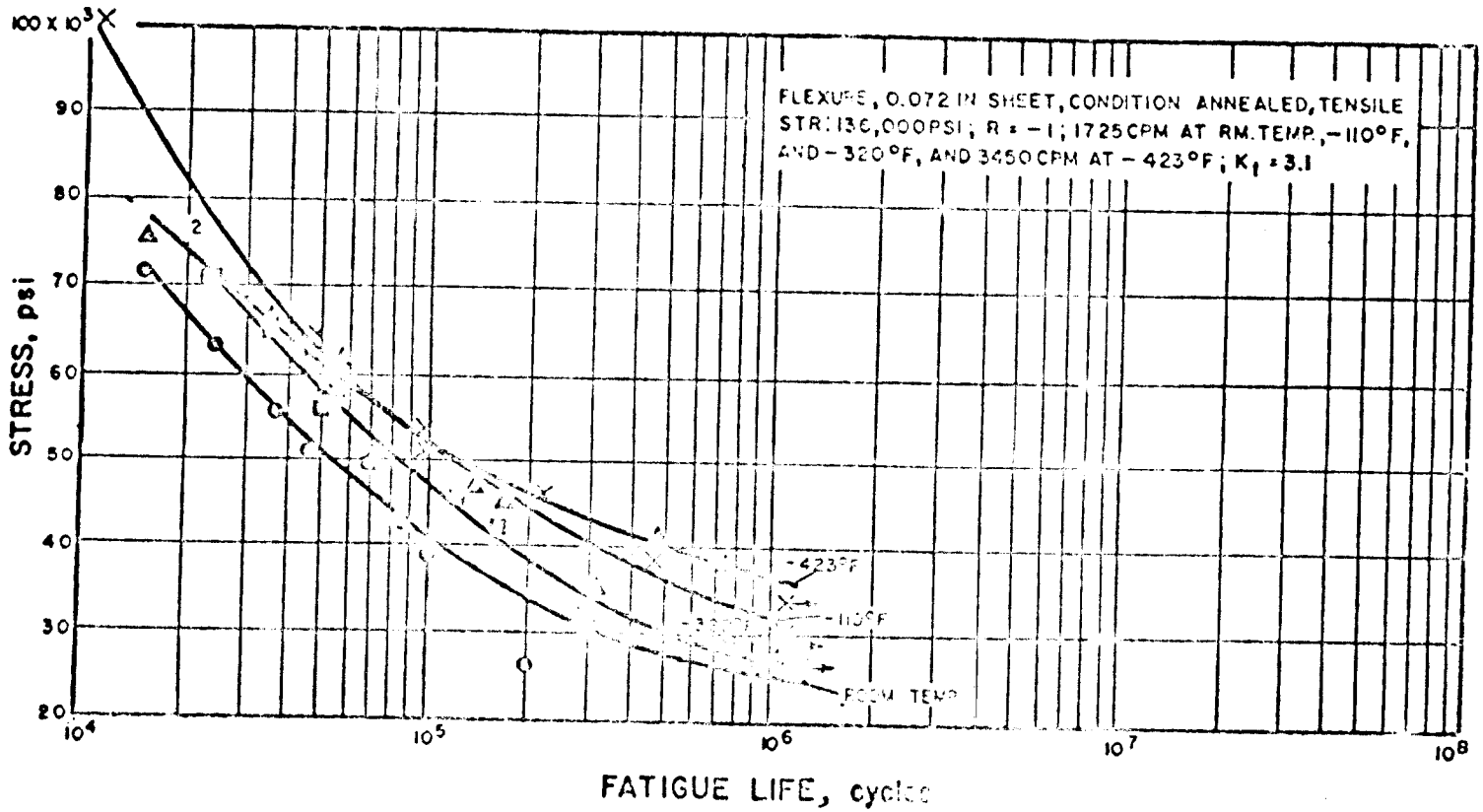


FIGURE 38. NOTCHED (K_T = 3.1) FATIGUE BEHAVIOR OF ANNEALED 6Al-4V TITANIUM

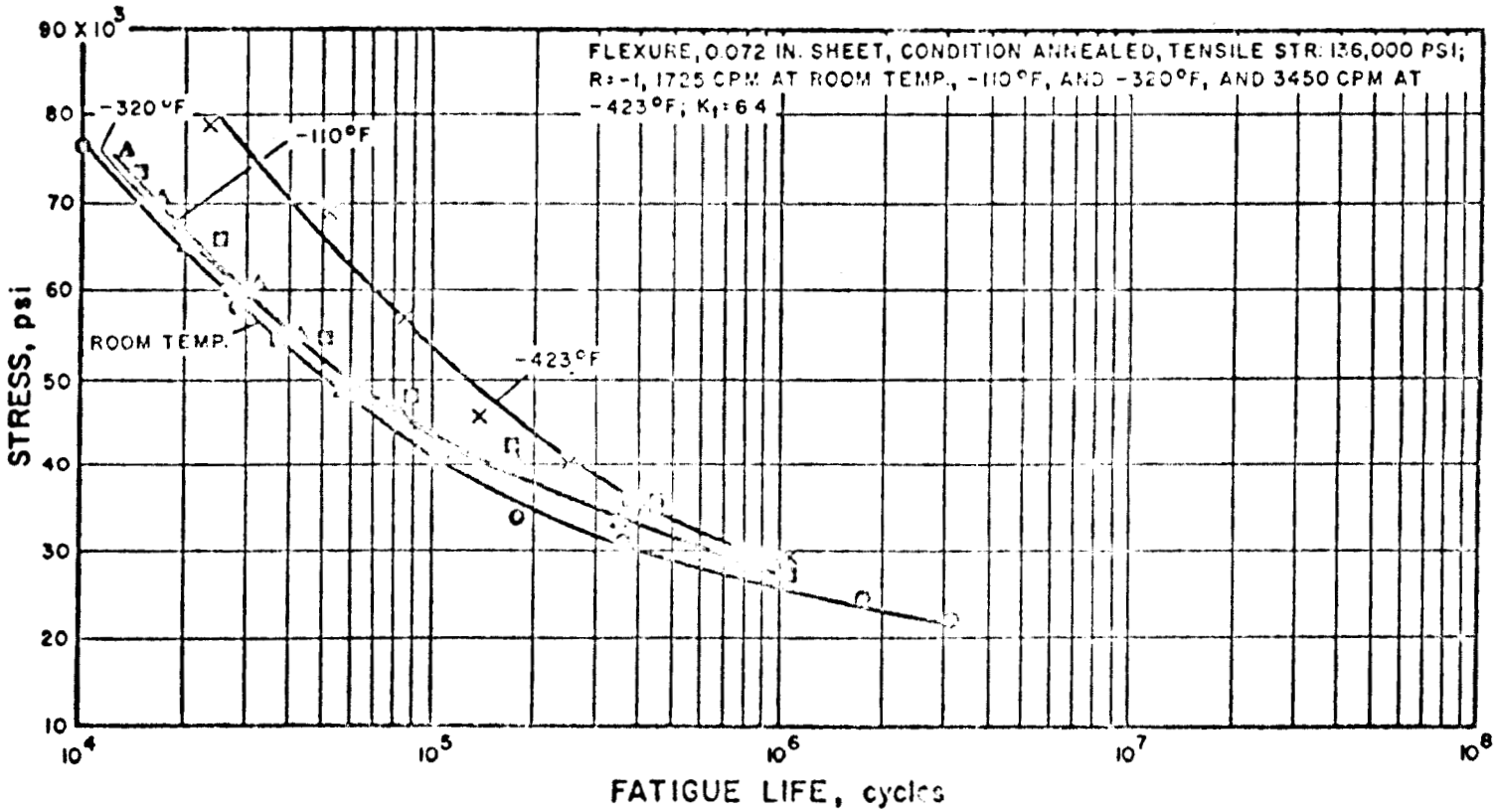


FIGURE 52. NOTCHED (K_T = 6.4) FATIGUE BEHAVIOR OF ANNEALED 6Al-4V TITANIUM

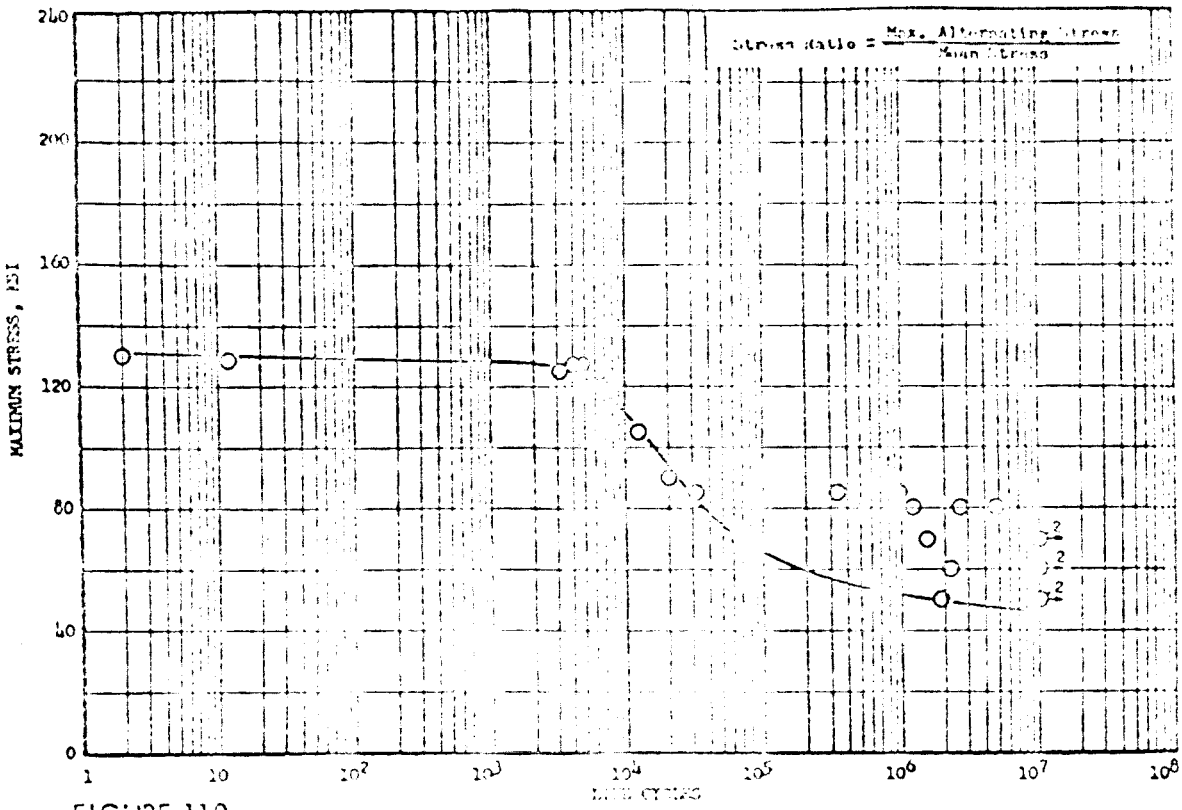


FIGURE 110 – AXIAL LOAD FATIGUE CURVE FOR TI-6Al-4V, 0.063 INCH THICK, AT 800°F WITH A STRESS CONCENTRATION OF 1.0 AND A STRESS RATIO OF 1.0 (REACTIVE METALS HEAT NOS. 31372 AND 32163)

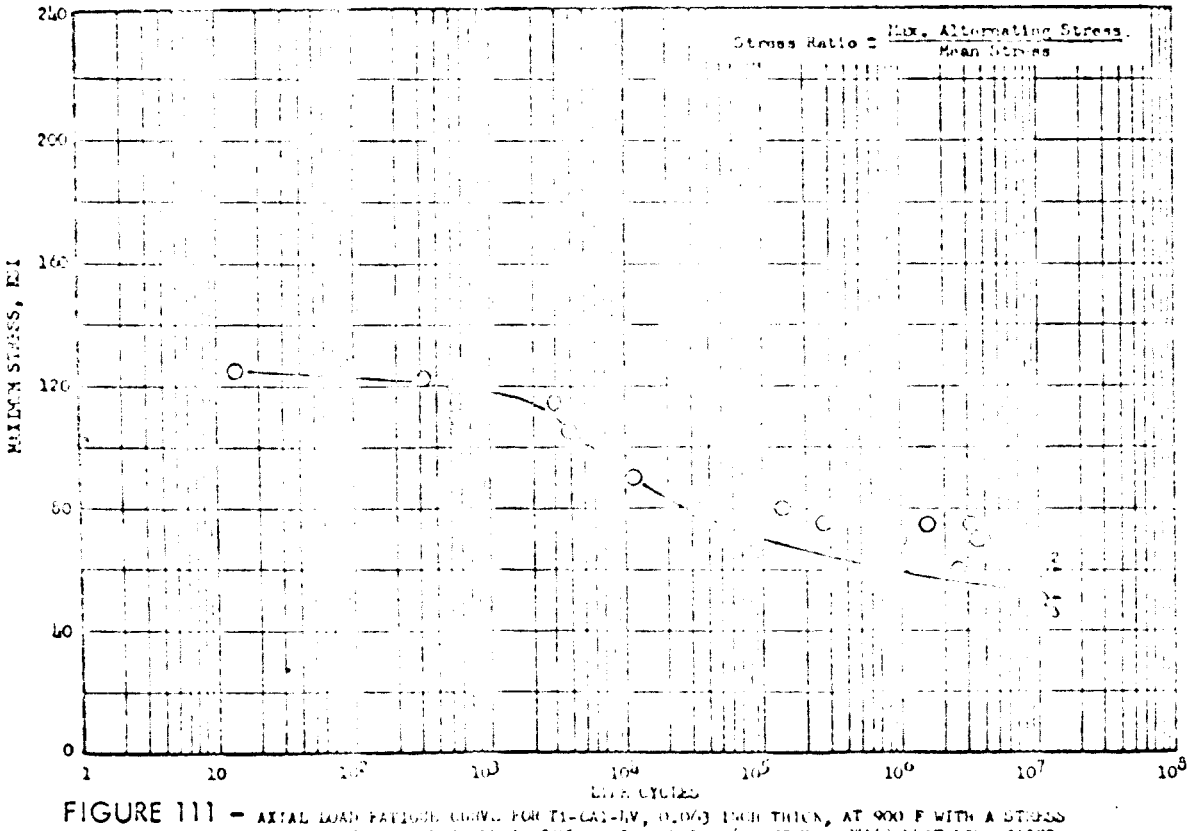


FIGURE 111 – AXIAL LOAD FATIGUE CURVE FOR TI-6Al-4V, 0.063 INCH THICK, AT 900°F WITH A STRESS CONCENTRATION OF 1.0 AND A STRESS RATIO OF 1.0 (REACTIVE METALS HEAT NOS. 31372 AND 32163)

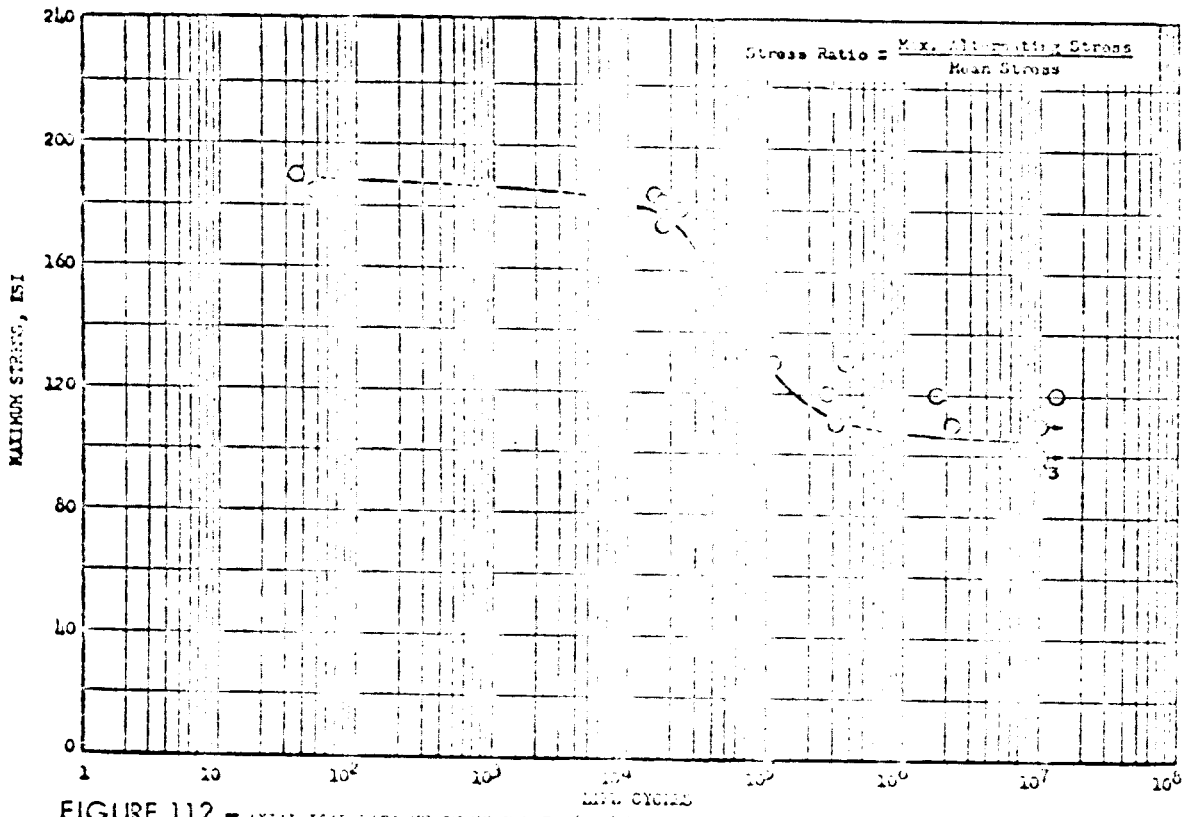


FIGURE 112 - AXIAL LOAD FATIGUE CURVE FOR Ti-(Al-4V, 0.060) INCH THICK, AT ROOM TEMPERATURE WITH A STRESS CONCENTRATION OF 1.0 AND A STRESS RATIO OF 0.3 (REACTIVE METALS HEAT NOS. 31372 AND 32163)

2.8 ALUMINUM ALLOYS

Most aluminum alloys are suitable for cryogenic structures due to their fairly high strength and good weldability. In most cases ductility at low temperatures is also good, as is the strength to density ratio. Notched/unnotched ratios are for the most part in excess of 0.90.

TABLE I DATE _____

ALLOY 201[illegible] T6 ALUM SHEET THICKNESS 0.020 - 1.000,[illegible]

Properties of Sheet Material		500°F	R.T.	-320°F	-423°F
Density, lbs/cu. in. 0.101 (2)					
Modulus of Elasticity X 10^6 (1)					
Annealed	Tensile - 1000 psi		10 27	11.3 39	11.8
(3)	Yield - 1000 psi		14	11.5	
-0	Elong. in 2"		18	36	
	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi		18		
Heat Treated or Cold Worked Condition (1)	Tensile - 1000 psi		71.6	65.5	101
	Yield - 1000 psi		65.2	74.1	83.4
-T6	Elong. in 2"		10	12.4	14.7
0.063 Sht	Bearing - 1000 psi ($\frac{e}{D}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - $\frac{F_{tu}}{\rho}$ (10-[illegible])			[illegible]	7.34	8.25
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value)	6.3(1)	1.[illegible]	1.06	1.02
Weld Joint Efficiencies (same and dissimilar metals)	(1)	77	75	70

Resistance to Crack Propagation

Formability

Cleanability

Availability

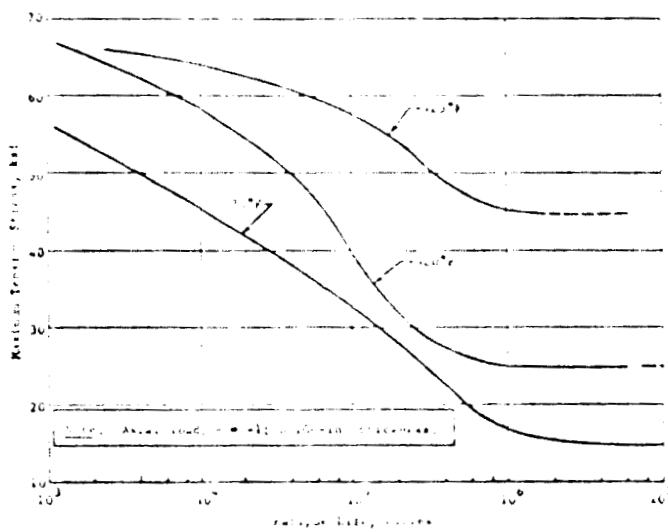
Cost

SOURCE - 1) ASD-TDR-62-258, (2) ALCOA, (3) REYNOLDS

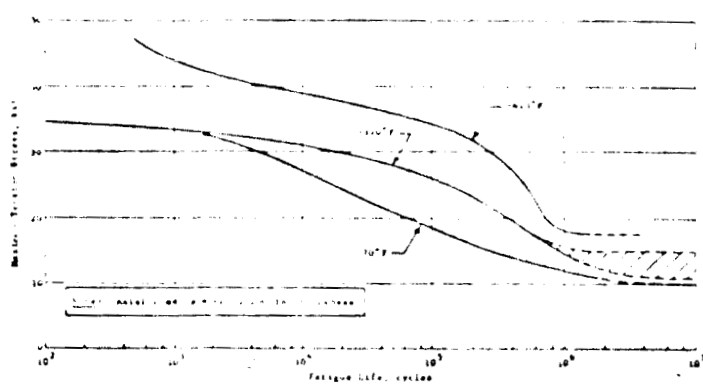
IV. EXPERIMENTAL RESULTS

Fatigue tests were performed to provide stress vs number of cycles to failure (S/N) curves at 70, -320, and -423°F. A stress ratio (R) of -1 was used for all aluminum specimens. The titanium specimens were not sufficiently flat to permit fully reversed stressing and were tested under tension/tension loading at a stress ratio of 0.01. Fatigue tests on welded Ti-13V-11Cr-3Al were not performed.

Fatigue test results are illustrated in Fig. 2 thru 8.



a. Parent Metal



b. Welded Metal

Fig. 2 Fatigue Properties of 2014-T6 Aluminum Alloy

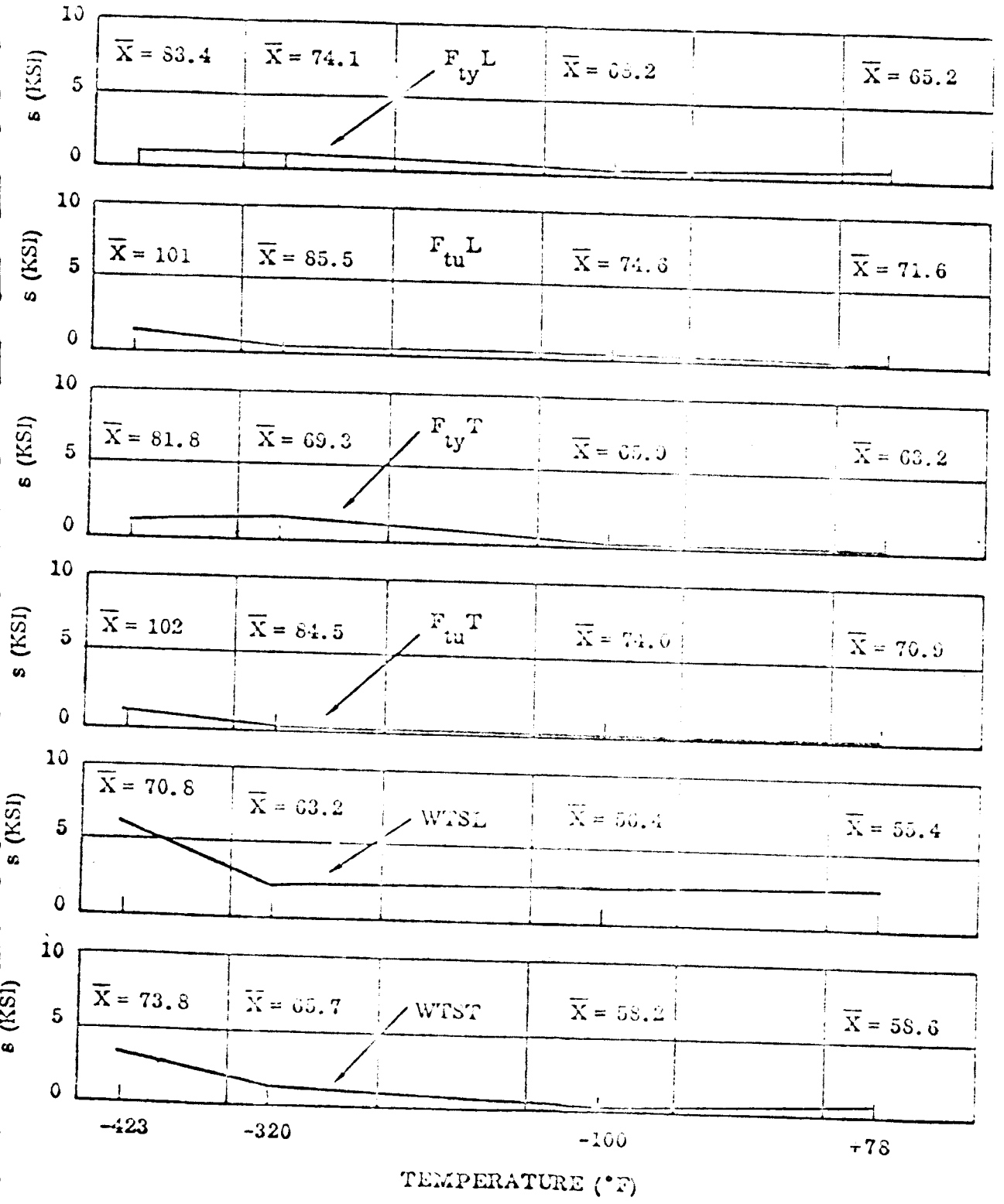


Figure 133. Standard Deviations Versus Temperature (2014-T6 Aluminum Alloy)

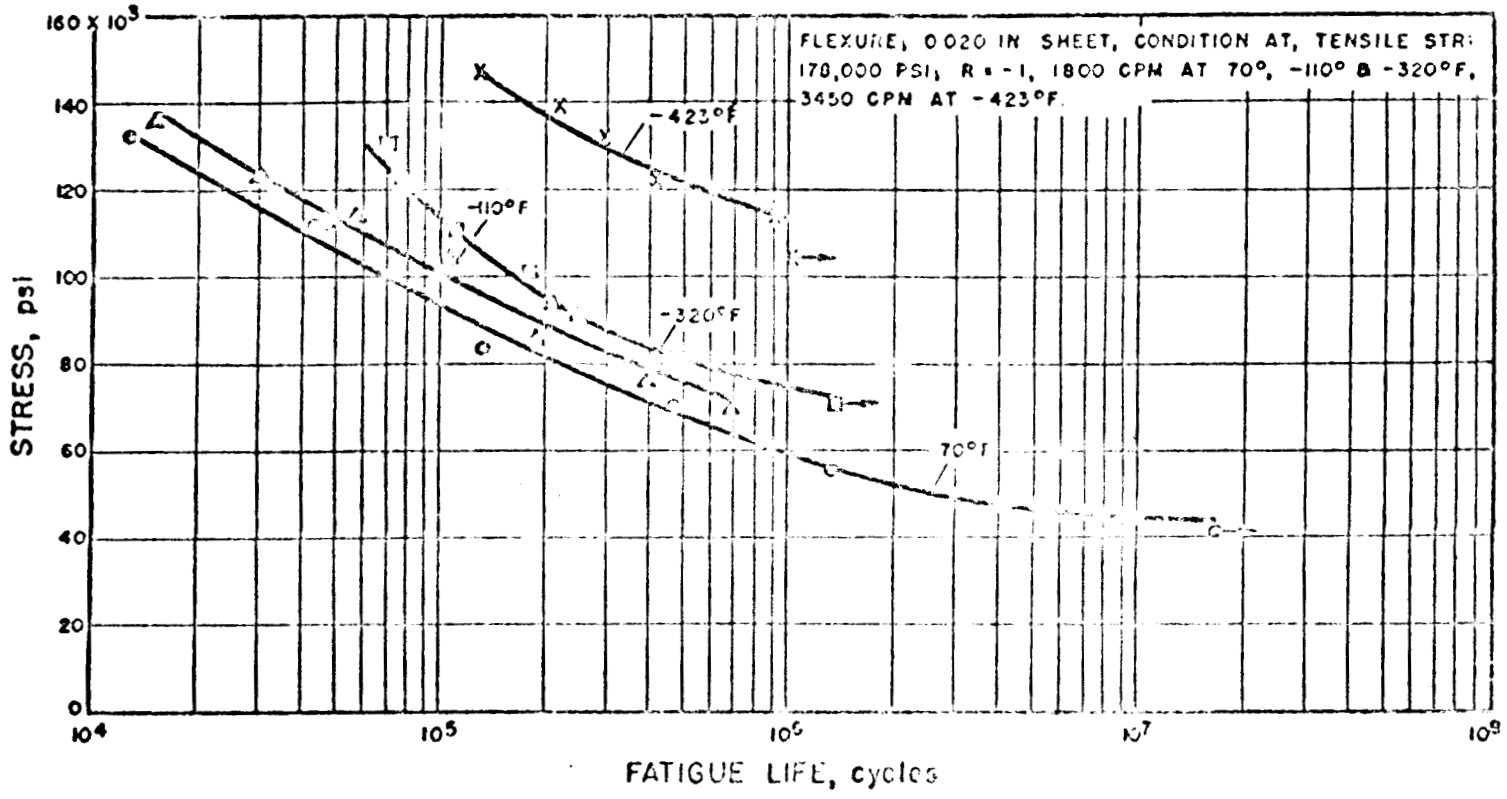


FIGURE 30. UNNOTCHED (K_T = 1) FATIGUE BEHAVIOR OF ANNEALED AND AGE-HARDENED BERYLCO 25 BERYLLIUM-COPPER

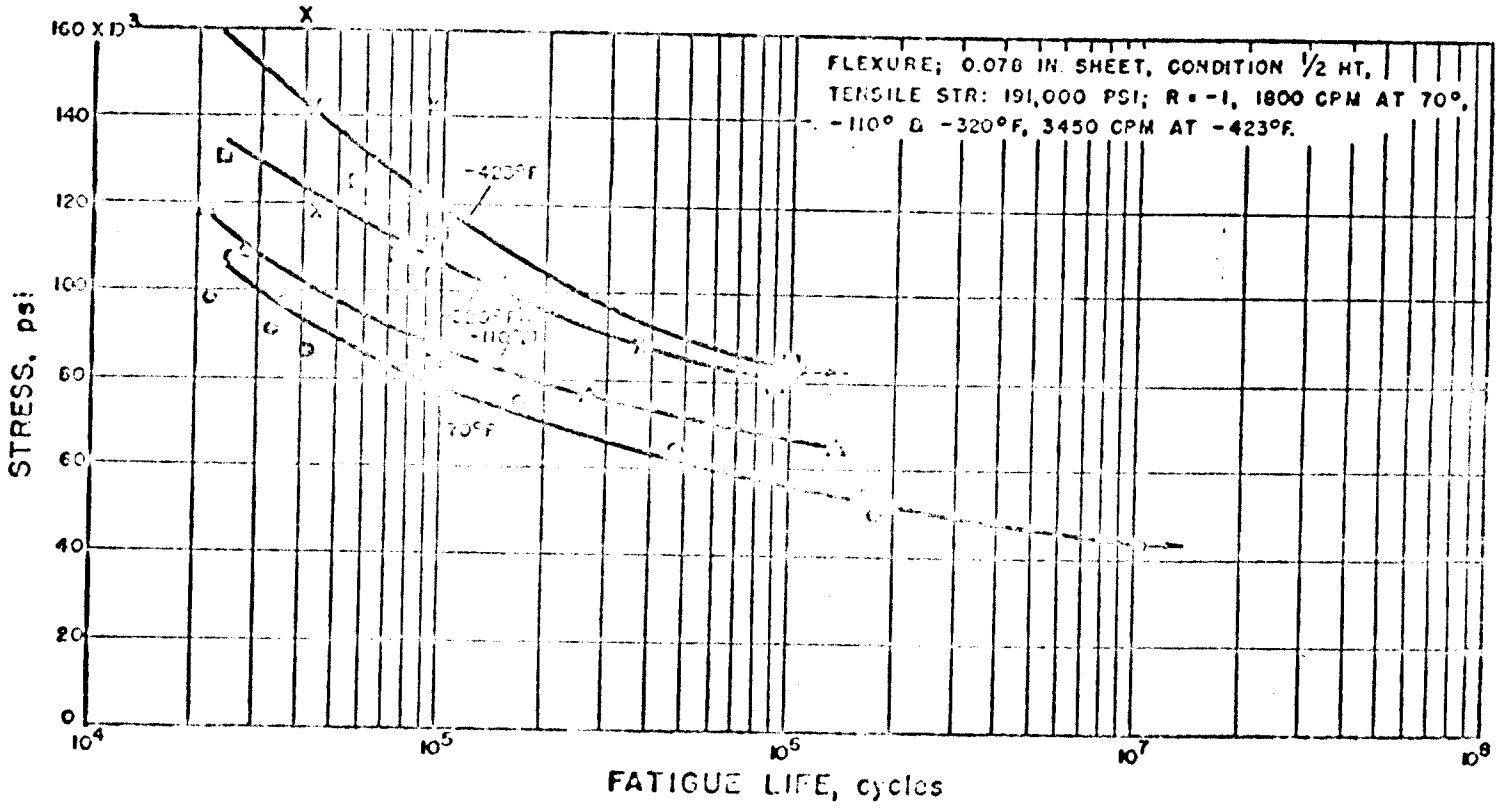


FIGURE 31. UNNOTCHED (K_T = 1) FATIGUE BEHAVIOR OF COLD-ROLLED AND AGE-HARDENED BERYLCO 25 BERYLLIUM-COPPER

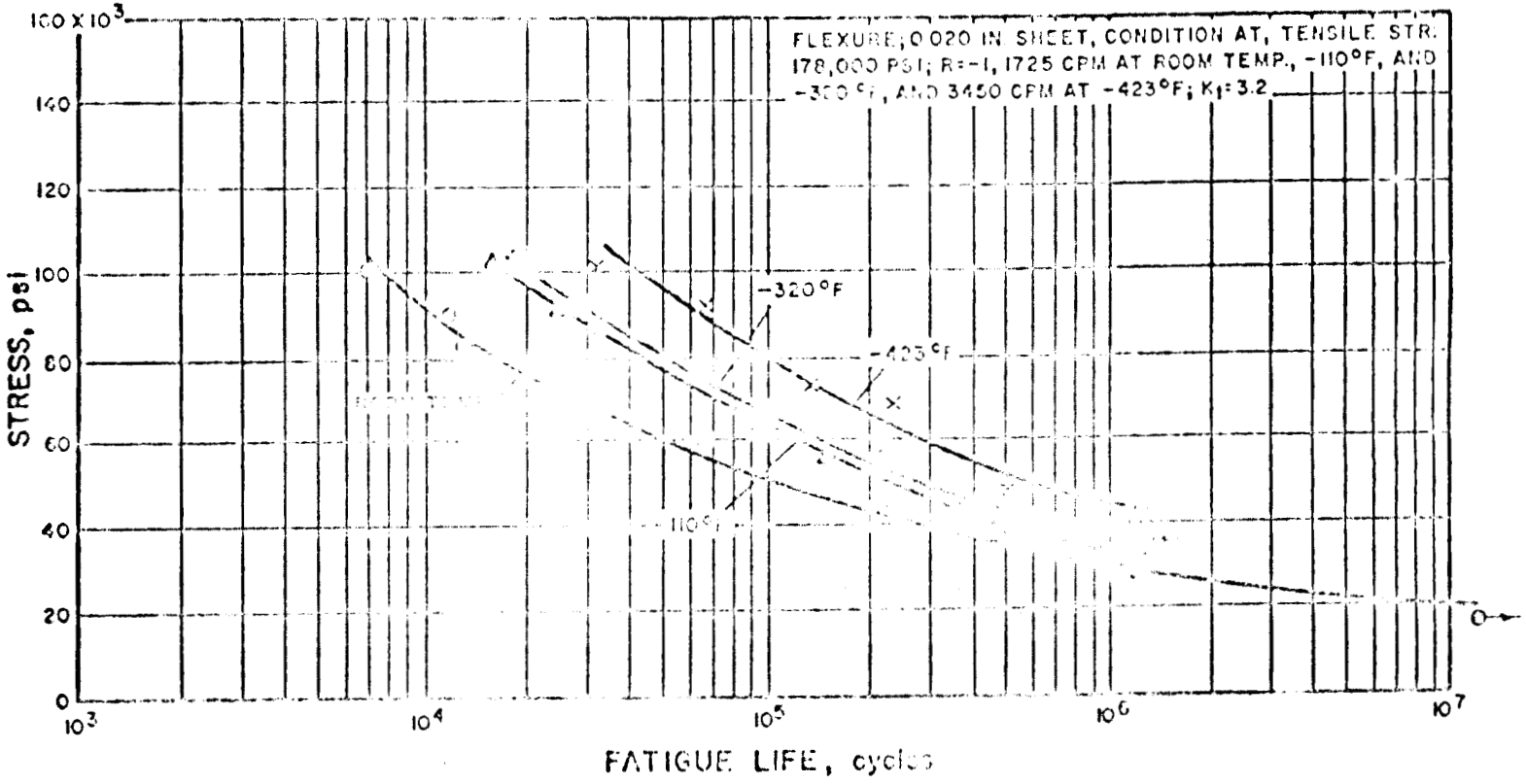


FIGURE 45. NOTCHED (K_T = 3.2 FATIGUE BEHAVIOR OF ANNEALED AND AGE-HARDENED BERYLCO 25 BERYLLIUM COPPER

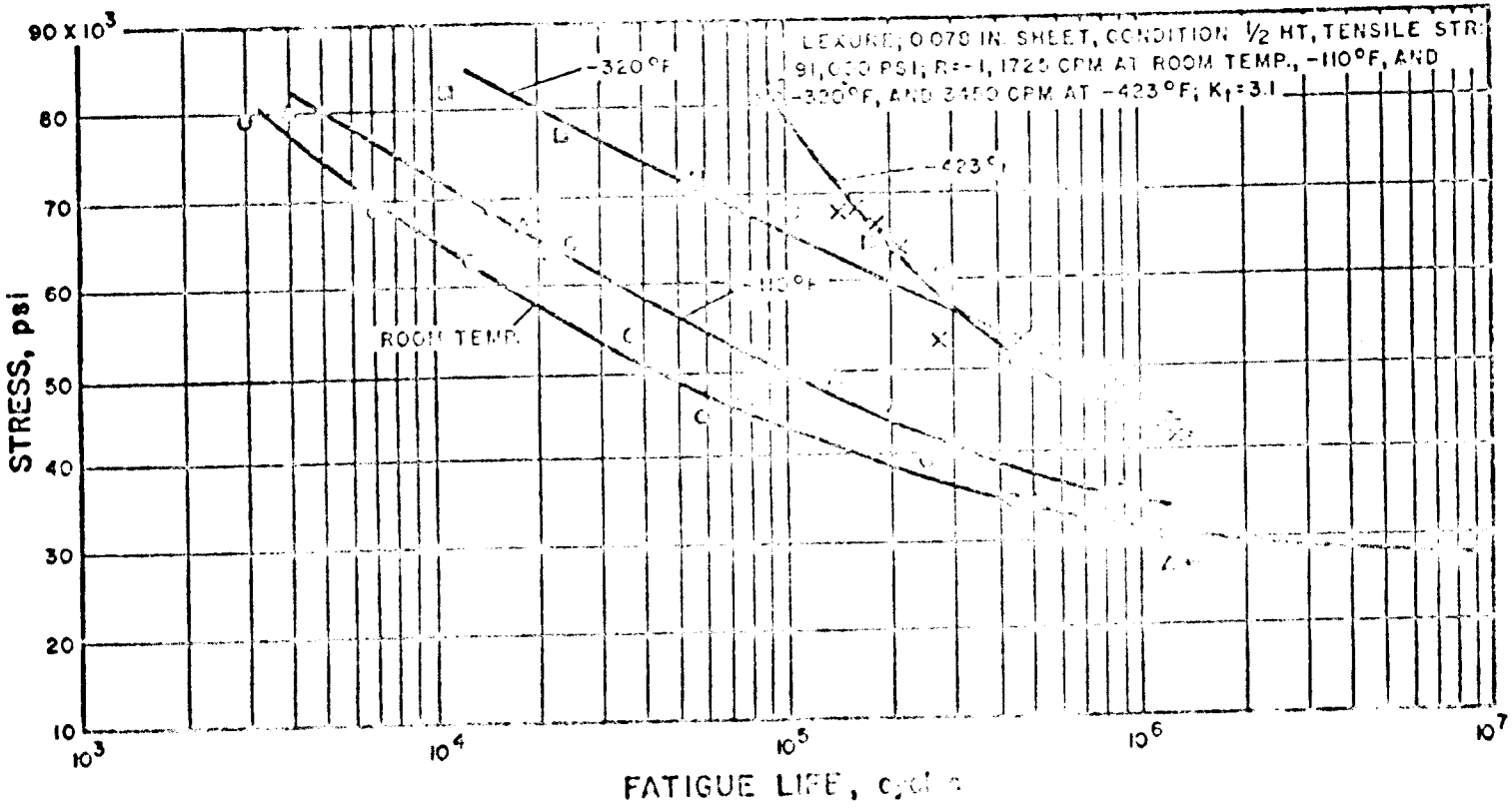


FIGURE 46. NOTCHED (K_T = 3.1) FATIGUE BEHAVIOR OF COLD-ROLLED AND AGE-HARDENED BERYLCO 25 BERYLLIUM-COPPER

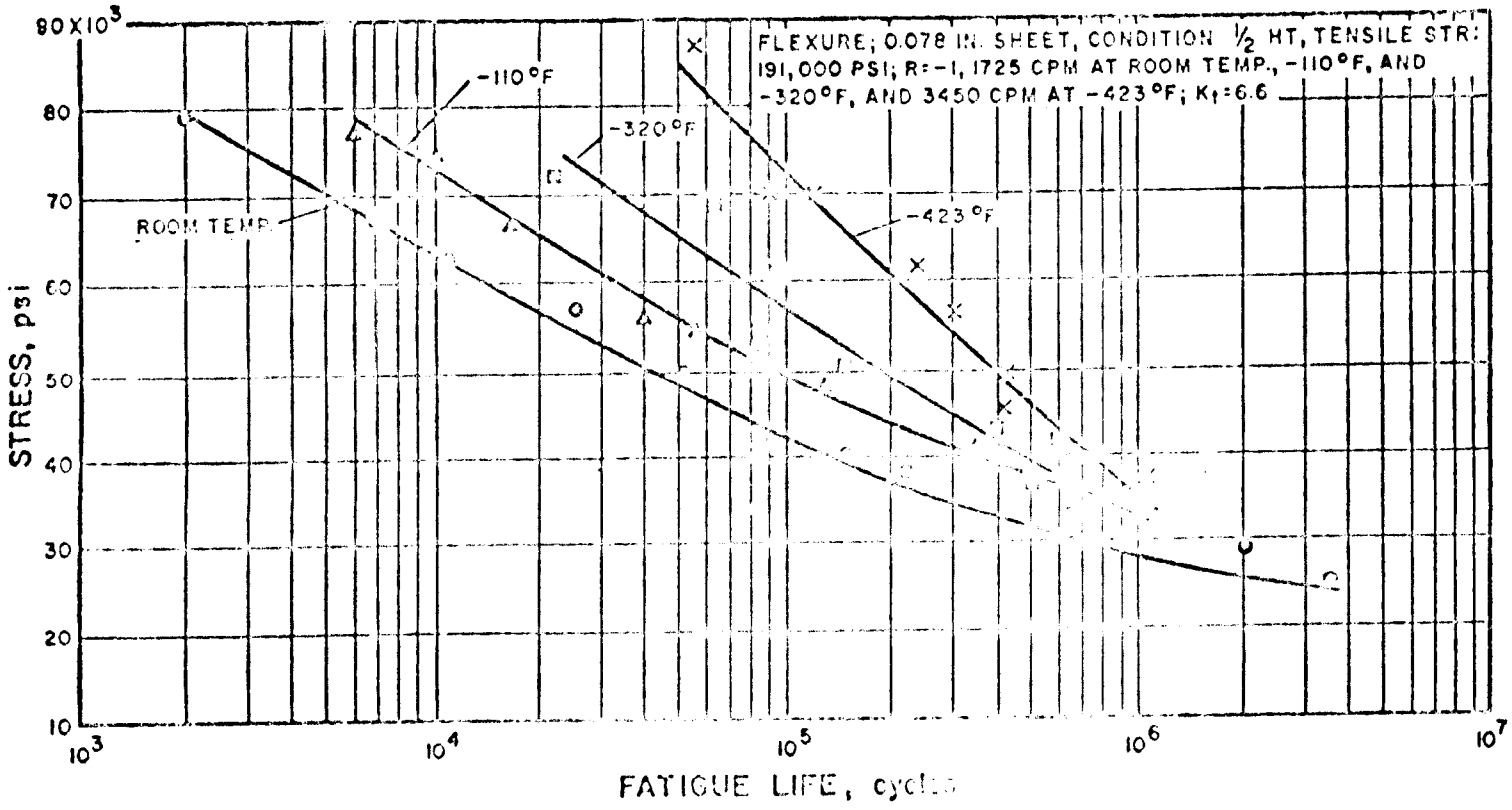


FIGURE 54. NOTCHED (K_T = 6.6) FATIGUE BEHAVIOR OF COLD-ROLLED AND AGE-HARDENED BERYLCO 25 BERYLLIUM-COPPER

[illegible] DATE September 2[illegible], 1964

ALLOY [illegible] ALUM SHEET THICKNESS .125

Properties of Sheet Material		600F	R.T.	-320°F	-423°F
Density, lbs/cu. in. .102-.103(1)					
Modulus of Elasticity T87(1)		7.5	10.6	11.9	12.5
Annealed -0 (1)	Tensile - 1000 psi T		25		
	Yield - 1000 psi T		11		
	Elong. in 2" T		18		
	Bearing - 1000 psi ($\frac{D}{S}$ = 2)				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition T87 (1) .125	Tensile - 1000 psi	[illegible]	[illegible]	[illegible]	102
	Yield - 1000 psi	[illegible]	[illegible]	[illegible]	74
	Elong. in 2"	19	10	13	17
	Bearing - 1000 psi ($\frac{D}{S}$ = 2)				
	Shear - 1000 psi				
Str. to Density Ratio - $\frac{F}{\sqrt{D}}$ (10^{-5})			[illegible]	6.67	7.25
Impact Str. (Charpy), ft. lb.					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No Yes

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) [illegible] (2) [illegible] .97 .92

Weld Joint Efficiencies (same and dissimilar metals)

Resistance to Crack Propagation

Formability

Cleanability

Availability

Cost

SOURCE - (1) ALCOA, (2) GD REPORT, METALS PROGRESS MAR 1963

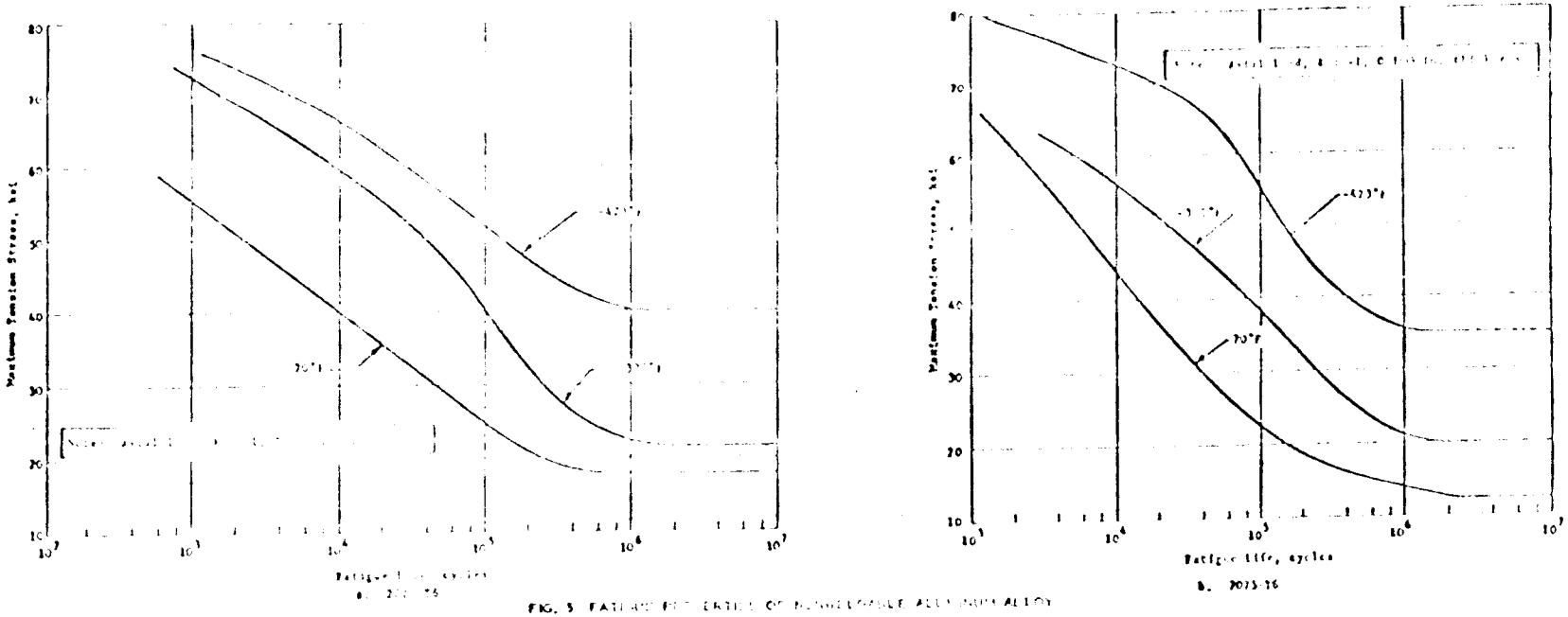


FIG. 5 FATIGUE PROPERTIES OF NONWELDABLE ALUMINUM ALLOY

The nonweldable alloys, 2020-T6 and 7075-T6, exhibited steeper S/N curves than the weldable grades. The 2020-T6 curve at 70°F flattened out after a relatively short number of cycles. The 7075-T6 composition showed a very low room temperature endurance limit. The liquid hydrogen curve was quite steep.

Fracture surfaces of the parent metal fatigue specimens showed typical transgranular fatigue failures, and the 5456-H343 and 7075-T6 specimens showed a laminated appearance. This behavior is typical for the strain-hardened 5456 alloy, even in static tension failures, but is not observed for the 7075 composition in tension.

Fatigue curves for the three welded alloys exhibited very similar shape and strength properties. Endurance limit values varied little.

A review of techniques proposed for curve fitting suggested that insufficient data were available for use with these methods.

In an attempt to compare data obtained for the various alloys, the fatigue properties were reduced to ratios of fatigue strength/tensile strength and fatigue strength/yield strength. This approach permits a comparison of behavior under dynamic conditions with that under static conditions. Table 1 presents the data for fatigue strength properties at 10^4, 10^5, and 10^6 cycles and for the endurance limit compared to tensile properties.

Table 1 Fatigue Strength/Ultimate Strength Ratio for Aluminum Alloys

Material	Temperature, °F	Ultimate Str[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2014-T6 Parent Metal	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]-T87 Parent Metal	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
5456-H343 Parent Metal	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
2020-T6 Parent Metal	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7075-T6 Parent Metal	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2014-T6 Welded	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2219-T87 Welded	70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	-320	[illegible]	[illegible]	[illegible]	13 (0.11)	12 (0.19)
	-423	[illegible]	[illegible]	[illegible]	22 [illegible]	[illegible]
5456-H343 Welded	70	[illegible]	24 [illegible]	16 (0.3[illegible])	[illegible]	[illegible]
	-320	59	29 [illegible]	20 (0.34)	13 (0.22)	[illegible] (0.20)
	-423	55	35 (0.64)	30 (0.54)	21 to 23 (0.38 to 0.42)	18 to 23 (0.33 to 0.42)

The data clearly show the poor behavior of 7075-T6 at all temperatures. The 2020-T6 is similarly lower than the remaining alloys. The three remaining alloys (parent metal condition) are similar at 70°F, with 2219 exhibiting slightly higher properties. At the cryogenic temperatures, 5456-H343 shows the highest dynamic/strength ratio. A comparison of the weld properties shows very similar results for the three alloys at room temperature. At cryogenic temperatures, the 5456 appears to be superior. The results of this analysis can be compared with notch toughness properties to determine whether any trends become apparent. Table 2 compares the fatigue strength to tensile and yield strength ratios with the notch/unnotch strength ratio at various temperatures. The table shows that the 5456-H343 alloy that exhibits an outstanding fatigue strength ratio is rather poor in notch toughness and that the 7075-T6 alloy is poor in both categories.

Table 2 Comparison of Fatigue Strength Ratios with Notch Strength Ratios for Aluminum Alloys

Alloy	Temperature, °F	Fatigue/Yield Ratio	Fatigue/Ultimate Ratio	Notch/Unnotch Ratio*
2014-T6	70	[illegible]	[illegible]	[illegible]
	-320	[illegible]	[illegible]	[illegible]
	-423	[illegible]	[illegible]	[illegible]
2219-T87	[illegible]	[illegible]	[illegible]	[illegible]
	-320	[illegible]	[illegible]	[illegible]
	-423	[illegible]	[illegible]	[illegible]
5456-H343	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
7075-T6	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
	-423	[illegible]	[illegible]	[illegible]

*K_t = [illegible]

The results of two tests performed under tension/tension loading show the effect of stress ratio on fatigue properties. Although insufficient data are presented for a quantitative analysis of the effect, the marked increase in life is apparent. Figure 9 compares 2219-T87 parent metal and 2014-T6 welded properties tested at R = -1 with points obtained for R = 0 at -423°F.

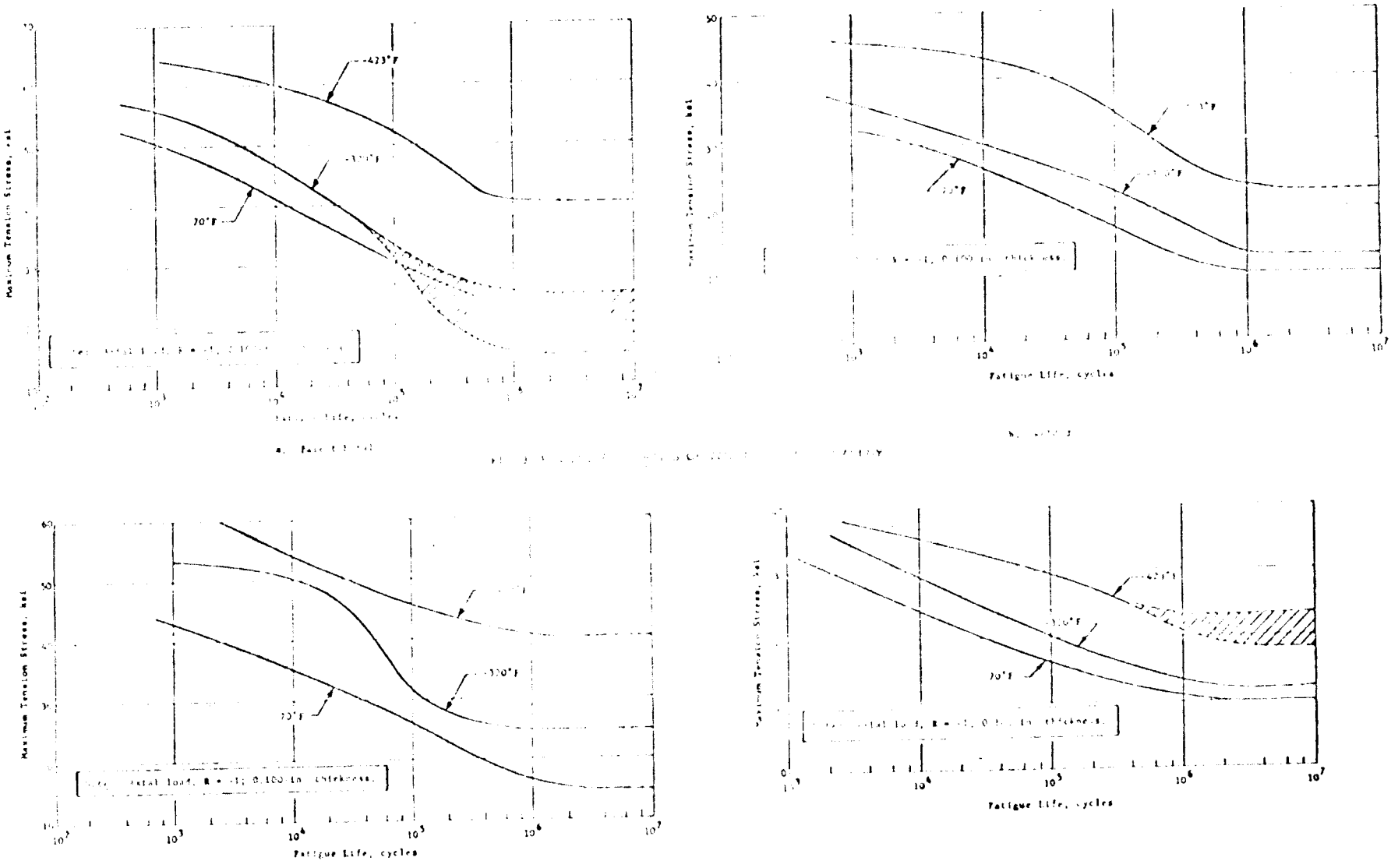


FIG. 4 FATIGUE PROPERTIES OF 5456 H343

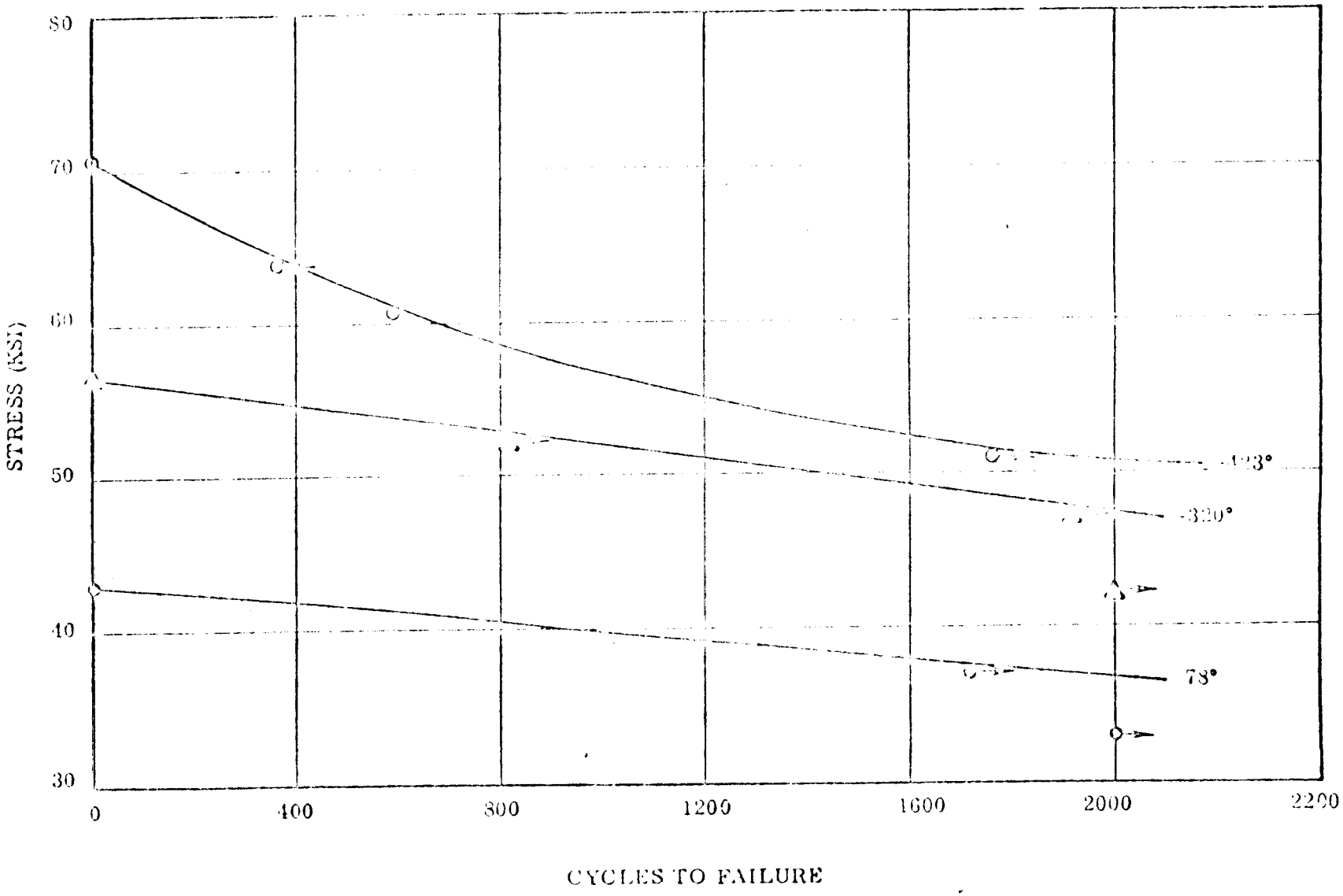


Figure 10[redacted]. N Curve 2219-T81 Aluminum Alloy (Longitudinal Joint No. 1)

[illegible] DATE [illegible]

ALLOY [illegible] SHEET THICKNESS [illegible]

[illegible] of Sheet Material		[illegible]	[illegible]	[illegible]	[illegible]
Density, lbs/cu. in. .0[illegible] (2)					
Modulus of Elasticity (1) X 10^6			10.2	1.1	11.2
Annealed -0 (3)	Tensile - 1000 psi	[illegible]	28	[illegible]	
	Yield - 1000 psi	[illegible]	[illegible]	16	
		[illegible]	[illegible]	50	
	Elong. in 2"				
	Bearing - 1000 psi [illegible]				
	Shear - 1000 psi		[illegible]		
Heat Treated or Cold Worked Condition	Tensile - 1000 psi	[illegible]	[illegible]	[illegible]	[illegible]
	Yield - 1000 psi	[illegible]	[illegible]	[illegible] (1)	[illegible]
-H 38	Elong. in 2"	[illegible]	7	[illegible]	32
.040 (1)	Bearing - 1000 psi [illegible] 2)				
	Shear - 1000 psi				
Str. to Density Ratio - [illegible]			[illegible]	[illegible]	[illegible]
Impact Str. [illegible]					
Fatigue Str. Curves at indicated temp.					

[illegible]

LOX or Liquid Fluorine Sensitivity - Yes or No Yes

Thermal Shock Sensitivity

[illegible] (Ig value) [illegible] (1) [illegible] 1.01 [illegible]

Weld Joint Efficiencies ([illegible] dissimilar metals) [illegible] 75 [illegible]

Resistance to Crack Propagation

Formability

Cleanability

Availability

Cost

SOURCE (3) REYNOLDS (2) ALCOA [illegible] PROP OF SEVERAL 5000 SERIES ALUM ALLOYS ([illegible])

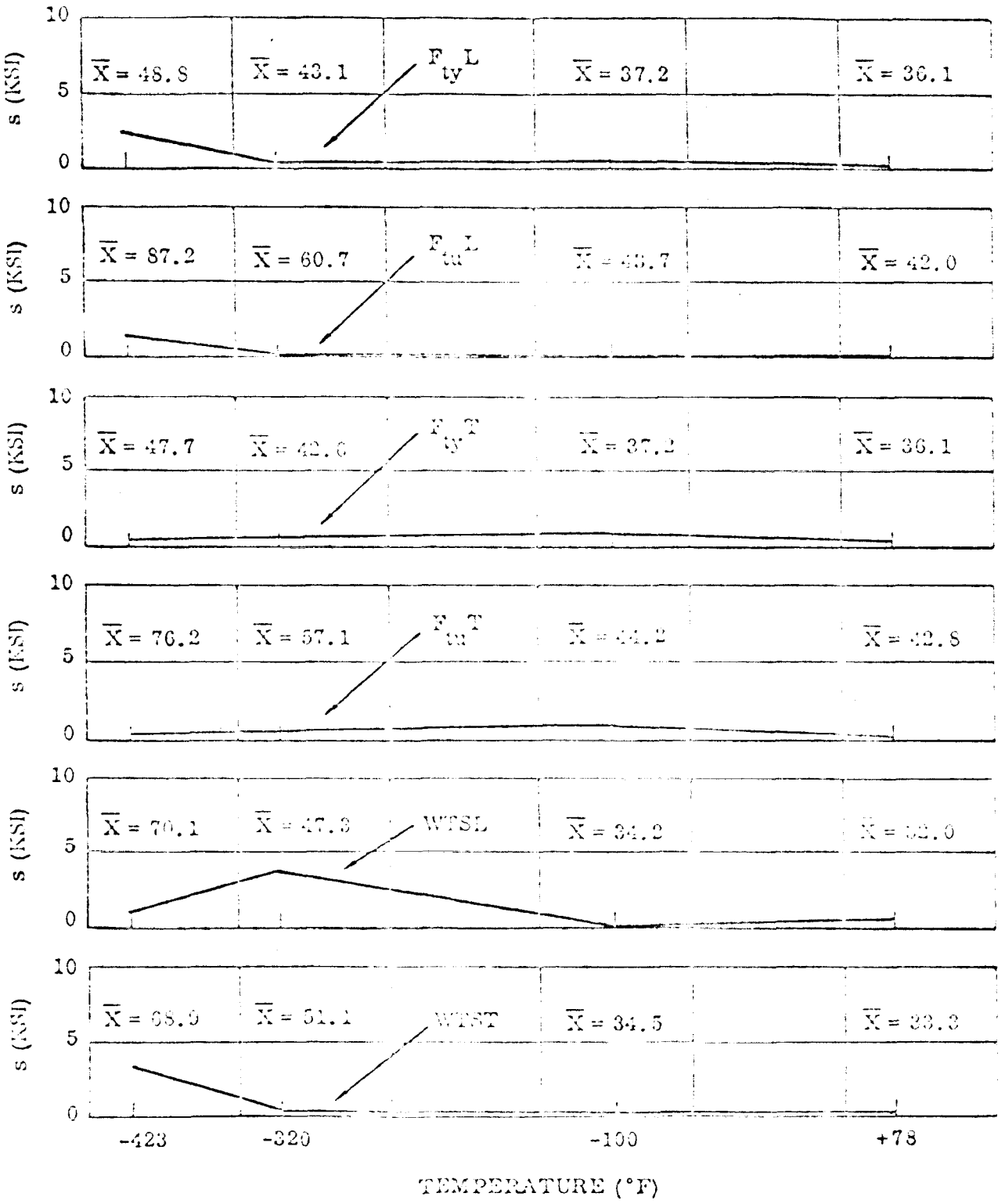


Figure 134. Standard Deviations Versus Temperature (5052-H38 Aluminum Alloy)

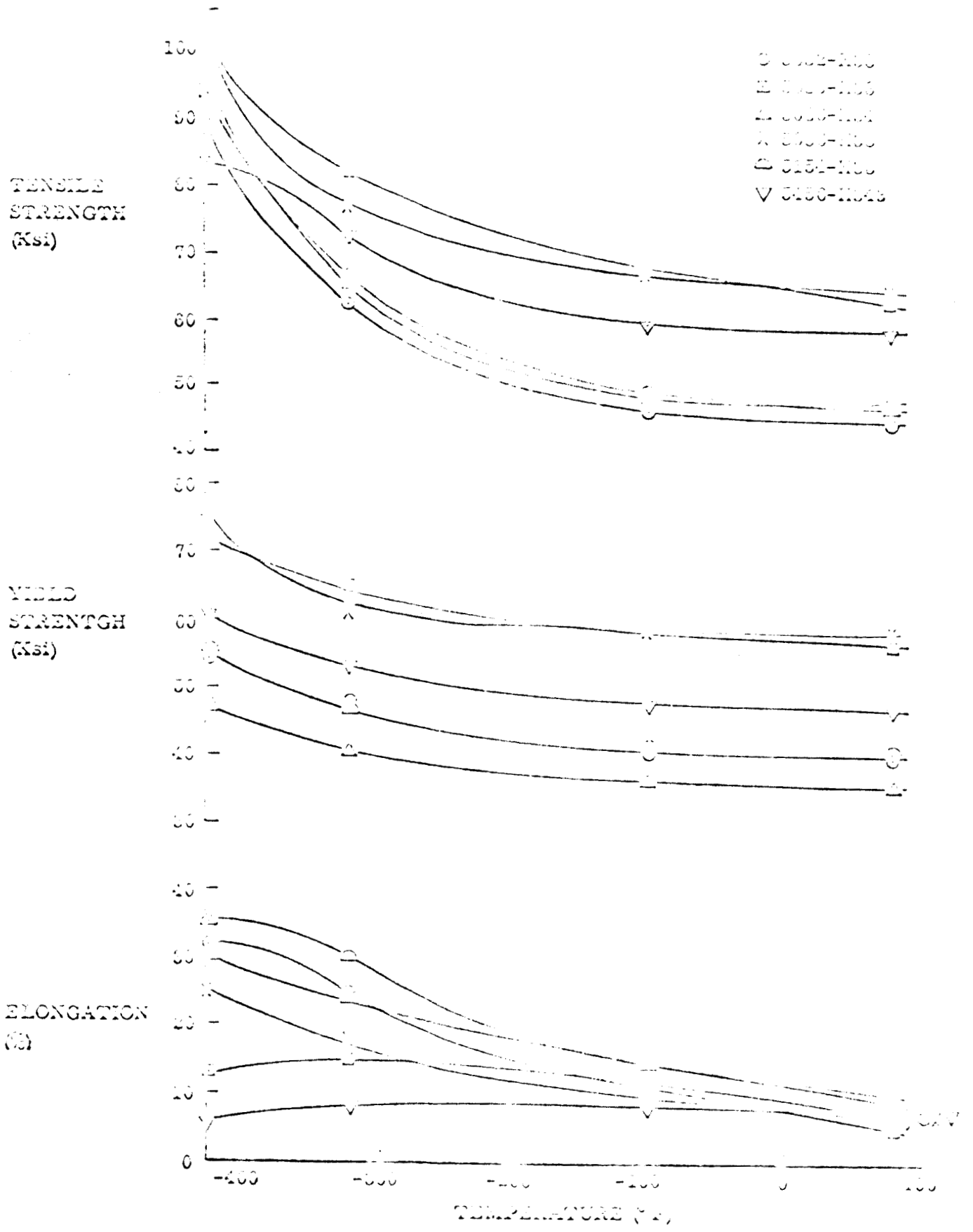

TENSILE
STRENGTH
(Ksi)
YIELD
STRENTGH
(Ksi)
ELONGATION
(%)
100
90
80
70
60
50
40
30
20
10
0
-400
-300
-200
-100
0
100
TEMPERATURE (°F)

Figure 2. [illegible]

TABLE [illegible] DATE [illegible]

ALLOY [illegible] [illegible]

[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Density, lbs/cu. in. .0[illegible](2)					
Modulus of Elasticity X 10^6(1)			10.[illegible]	11.1	1[illegible].0
Annealed	Tensile - 1000 psi	[illegible]		[illegible]	[illegible]
	Yield - 1000 psi	[illegible]	[illegible]	[illegible]	[illegible]
-0 (3)	Elong. in 2"	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible] - 1000 psi ([illegible])				
	[illegible] - 1000 psi		[illegible]		
Heat Treated or Cold Worked Condition	Tensile - 1000 psi	[illegible]	[illegible]	[illegible]	[illegible]
	Yield - 1000 psi	[illegible]	[illegible]	[illegible] (2.	72.5
-[illegible]	Elong. in 2"	[illegible]	[illegible]	[illegible]	1[illegible]
.[illegible]0 (1)	[illegible] - 1000 psi [illegible]				
	Shear - 1000 psi				
Str. to Density Ratio - [illegible]			[illegible]	[illegible]	7.5
Impact Str. ([illegible]), ft. lb.					
Fatigue Str. [illegible]					

[illegible]

LOX or Liquid Fluorine Sensitivity - [illegible]

Thermal Shock Sensitivity

Notch [illegible] Notched Tensile Ratio ([illegible]) [illegible] [illegible] [illegible]

[illegible] Efficiencies ([illegible])

Resistance to Crack Propagation

[illegible]

Cleanability

Availability

Cost

[illegible] (2) [illegible], (3) [illegible]
[illegible]

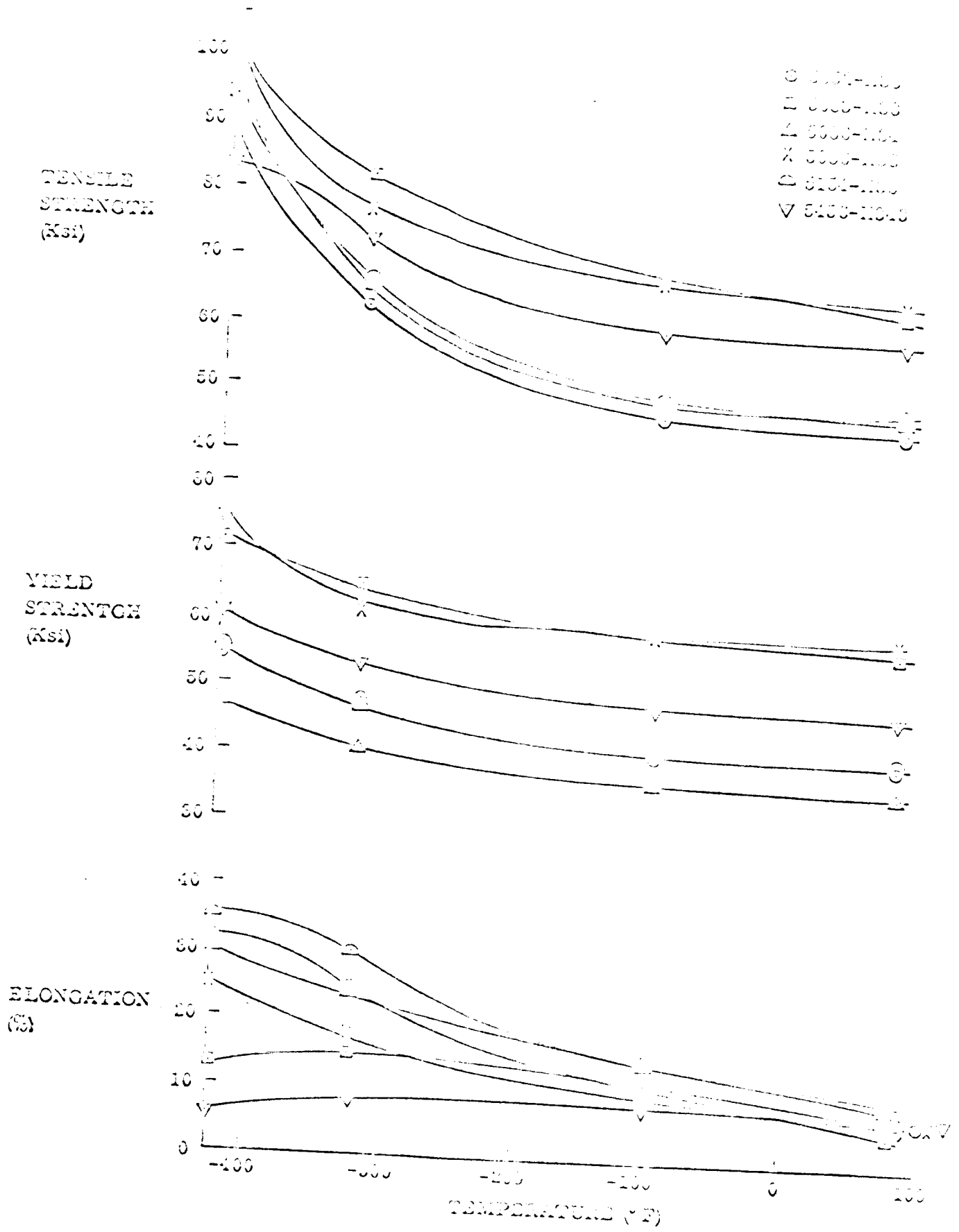

TENSILE STRENGTH (Ksi)
YIELD STRENTGH (Ksi)
ELONGATION (%)
TEMPERATURE (°F)

Figure 1. [illegible]

[illegible] DATE [illegible]

ALLOY [illegible] SHEET THICKNESS

Properties of Sheet Material		[illegible]	[illegible]	-[illegible]	-[illegible]
Density, lbs/cu. in. .098(2)					
Modulus of Elasticity x10^6 (1)			10.3	11.5	12.2
Annealed	Tensile - 1000 psi	[illegible]	33	56	77
-O (3)	Yield - 1000 psi		[illegible]	22	23
	Elong. in 2"	[illegible]	[illegible]	[illegible]	[illegible]
	Bearing - 1000 psi [illegible]				
	Shear - 1000 psi		[illegible]		
Heat Treated or Cold Worked Condition	Tensile - 1000 psi	[illegible]	[illegible]	[illegible]	95.3
	Yield - 1000 psi	[illegible] (1)	[illegible] (1)	[illegible]	47
-H 34	Elong. in 2"	[illegible]	9	[illegible]	30
.040 (1)	Bearing - 1000 psi [illegible]				
	Shear - 1000 psi				
Str. to Density [illegible]			[illegible]	4.25	[illegible]
Impact Str. ([illegible]), [illegible]					
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid [illegible] - [illegible]

Thermal Shock Sensitivity

Notched/Unnotched [illegible] (1)[illegible] .95 [illegible]

Weld Joint Efficiencies ([illegible] Metals)(1)[illegible] 85

Resistance to Crack Propagation

Formability

Cleanability

Availability

Cost

SOURCE (2) ALCOA, REYNOLDS, MECH PROP OF [illegible] 5000 SERIES ALUM ALLOYS (GD), (3) REYNOLDS

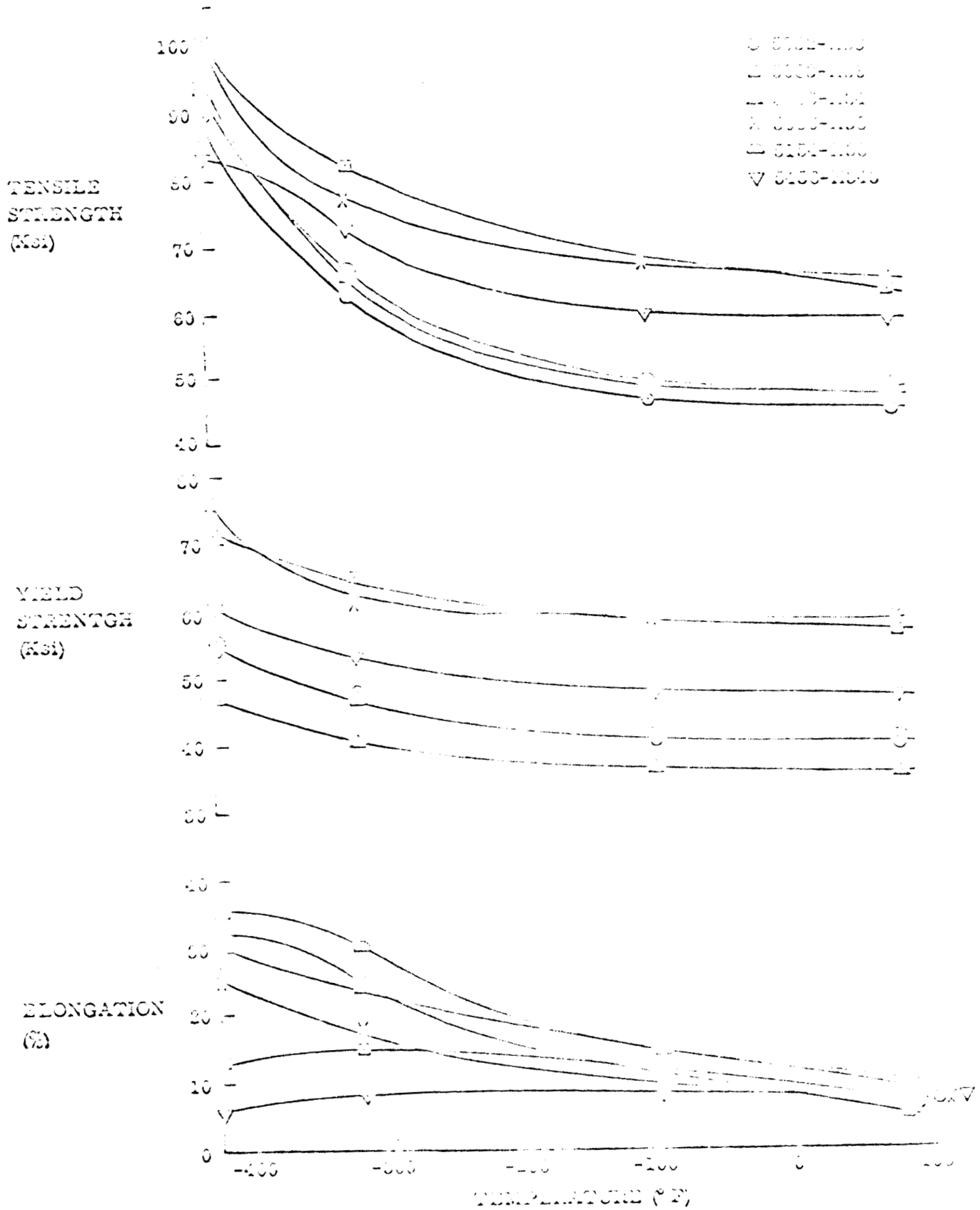


Figure 1. Yield and Tensile Strength (Ksi) and Elongation (%) vs. Temperature (°F) for Several 5000 Series Aluminum Alloys

TABLE I DATE [illegible]

ALLOY [illegible] SHEET THICKNESS [illegible]

[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Density, lbs/cu. in. [illegible] (1)					
Modulus of Elasticity X 10^6 (2)			10.2	11.3	[illegible]
Annealed	Tensile - 1000 psi	[illegible]	[illegible]	[illegible]	
	Yield - 1000 psi		[illegible]	[illegible]	
-0 (3)	Elong. in 2"		[illegible]	[illegible]	
	[illegible] - 1000 [illegible]				
	[illegible] - [illegible]				
[illegible] or Cold Worked Condition	[illegible] - [illegible]		[illegible]	[illegible]	[illegible]
	[illegible] - [illegible]		[illegible]	[illegible]	[illegible]
-[illegible] (2)	Elong. in 2"	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible] - 1000 psi [illegible]				
	[illegible] - [illegible] psi				
Str. to Density [illegible]			[illegible]	[illegible]	[illegible]
Impact Str. ([illegible]), [illegible]					
Fatigue Str. Curves at [illegible]					

Remarks:

LCN or Liquid Nitrogen Sensitivity - [illegible]

Thermal Shock Sensitivity

Notched/Unnotched [illegible] ([illegible]) [illegible] [illegible] [illegible]

Weld Joint Efficiencies ([illegible] and dissimilar metals) [illegible] [illegible] [illegible]

Resistance to Crack Propagation

Formability

Cleanability

Availability

Cost

SOURCE-(1) ALCOA, (2) [illegible] PROP OF SEVERAL [illegible] SERIES ALUM ALLOYS (CS), (3) REYNOLDS

[illegible]

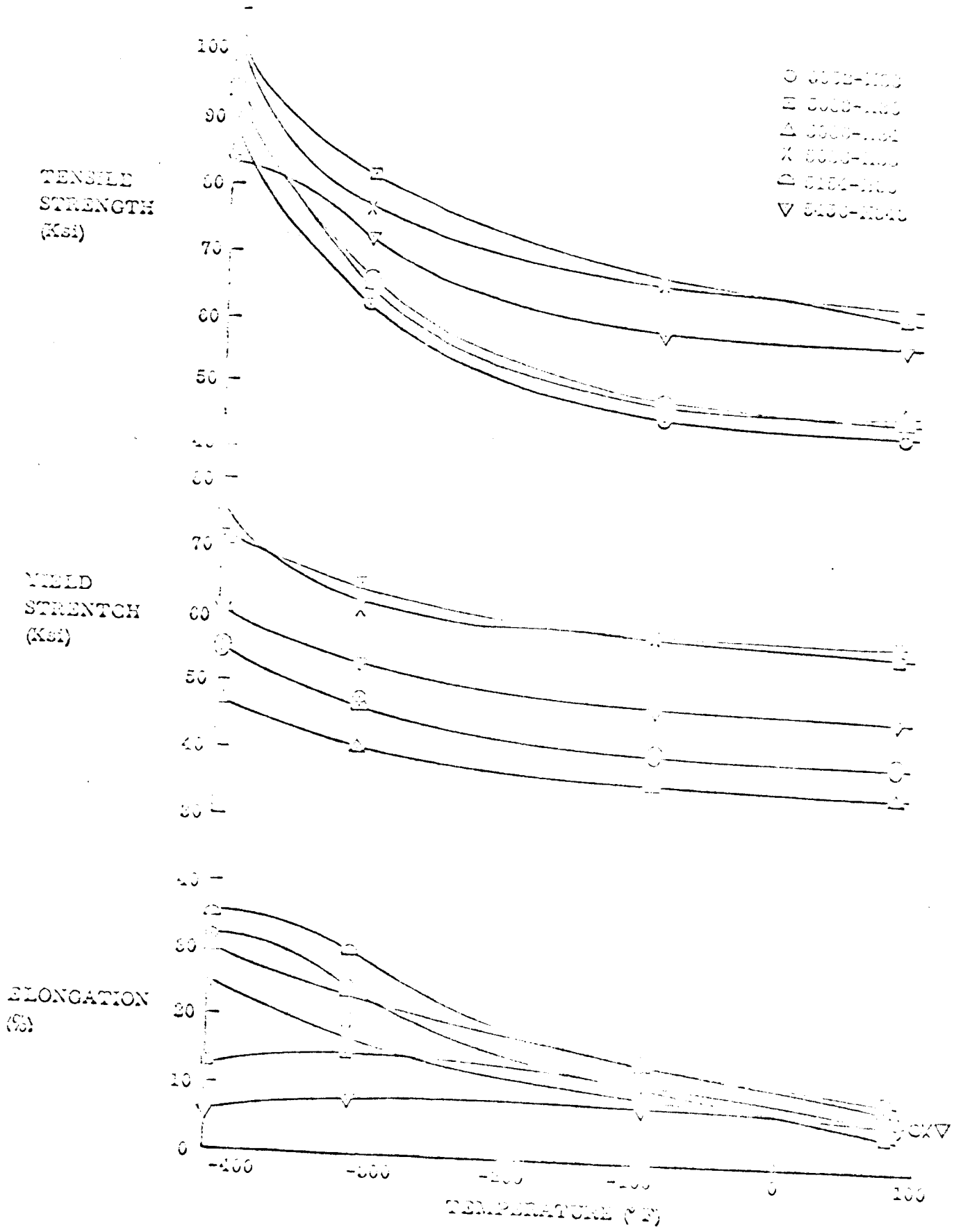


Figure 1. Yield and Tensile Strengths (Ksi) and Elongations (%) vs. Temperature (°F) for Several 5000 Series Aluminum Alloys.

TABLE I DATE [illegible]

ALLOY [illegible] SHEET THICKNESS

Properties of Sheet Material		[illegible]	R.T.	[illegible]	[illegible]
Density, lbs/cu. in. 0.096					
Modulus of Elasticity X10^6 (1)			10.5	[illegible]	11.2
Annealed	Tensile - 1000 psi		[illegible]	[illegible]	
-0 (2)	Yield - 1000 psi		[illegible]	[illegible]	
	Elong. in 2		[illegible]	[illegible]	
	[illegible] - 1000 psi [illegible]				
	[illegible] - 1000 psi				
Heat Treated or Cold Worked Condition [illegible]	Tensile - 1000 psi		[illegible]	[illegible]	[illegible]
	Yield - 1000 psi		[illegible]	[illegible]	[illegible]
[illegible] (1)	Elong. in 2		[illegible]	[illegible]	[illegible]
	[illegible]				
	[illegible]				
Str. [illegible]			[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]					
[illegible]					
[illegible] Sensitivity - [illegible]					
[illegible]					
[illegible] Tensile Ratio ([illegible])			[illegible]		.77
[illegible] Joint [illegible] (Same and [illegible])			[illegible]		.75
[illegible] Crack Propagation					
Formability					
Cleanability					
Availability					
Cost					

(1) SOURCE - ASD-TDR-62-258, (2) REYNOLDS

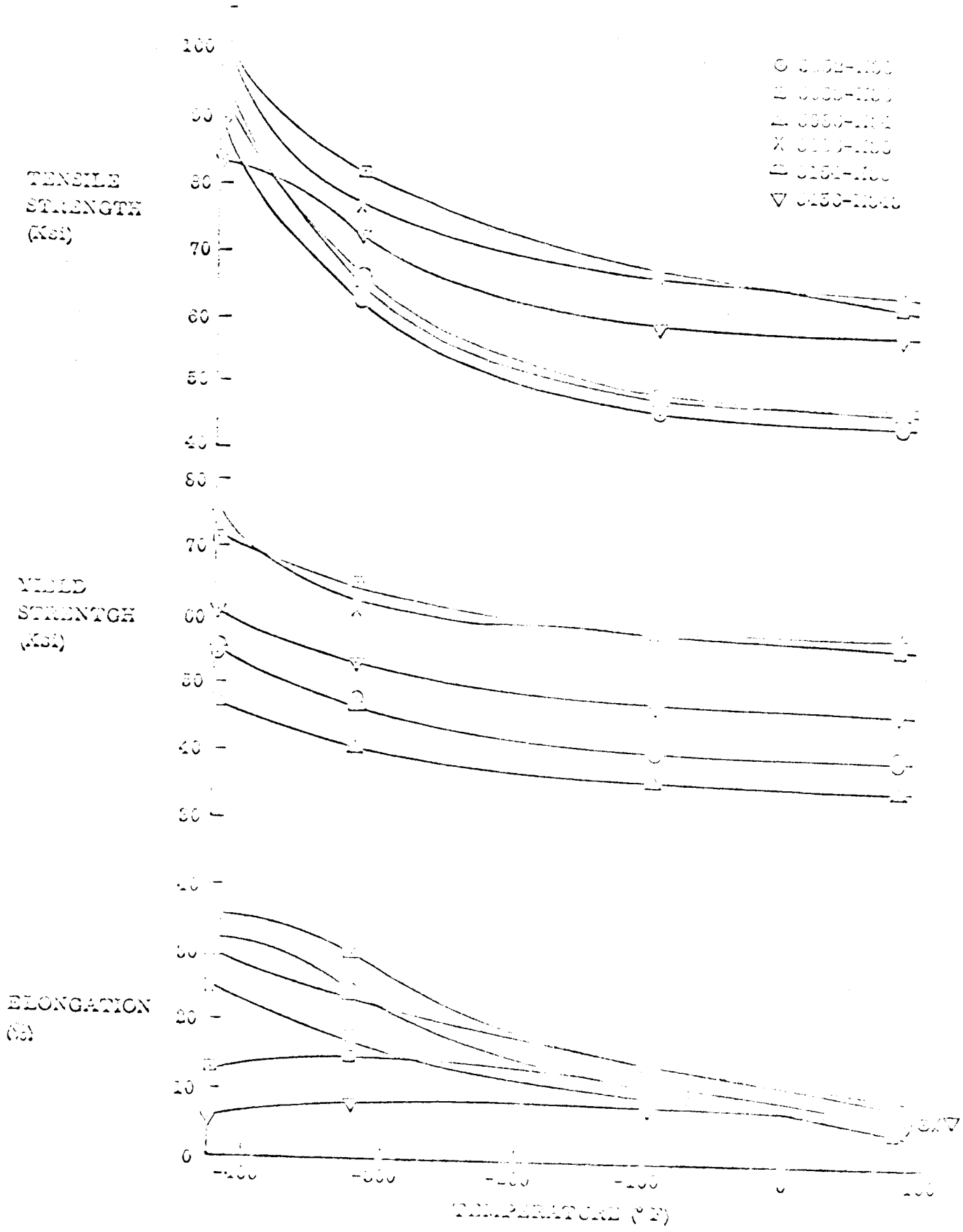


Figure 1. [illegible] Elongation (%) vs. Temperature (°F) for Several 5000 Series Aluminum Alloys.

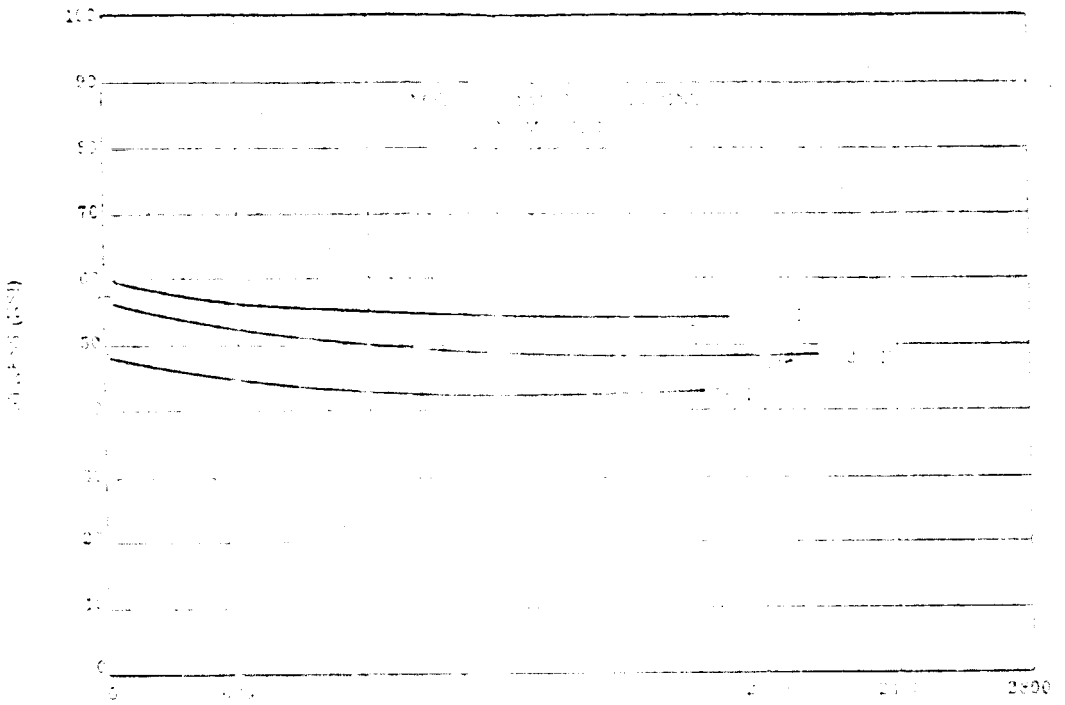


Figure 32. S-N Curve - [illegible] (Transverse - Joint No. 1)

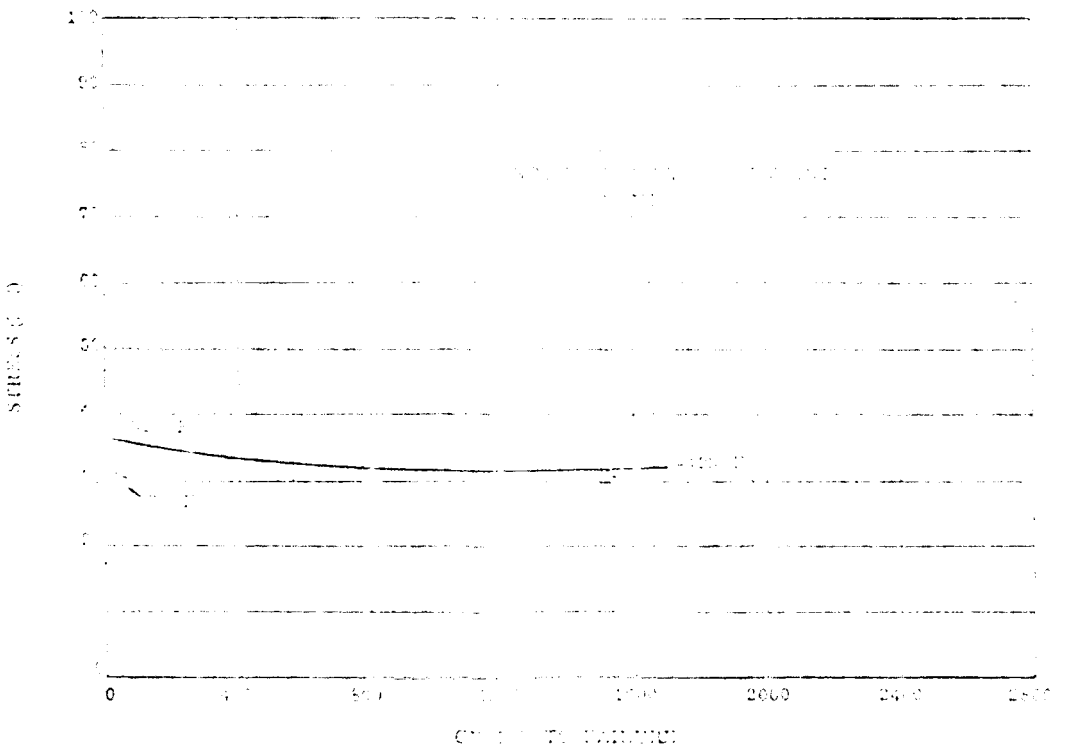


Figure 33. S-N Curve - 5456-[illegible] Alloy (Longitudinal - Joint No. 2)

TABLE I DATE [illegible]

ALLOY [illegible] SHEET THICKNESS

Properties of Sheet Material		[illegible]	R.T.	-320°F	[illegible]
Density, lbs/cu. in. .098 (1)					
Modulus of Elasticity 26 (1)		8	10	11	
Annealed	Tensile - 1000 psi	[illegible]	18	35	[illegible]
	Yield - 1000 psi	[illegible]	8	10	[illegible]
-0	Elong. in 2"	[illegible]	[illegible]	[illegible]	52
	Bearing - 1000 psi [illegible]				
	Shear - [illegible]				
Heat Treated or Cold Worked Condition (3)	Tensile - 1000 psi	[illegible]	[illegible]	[illegible]	[illegible]
	Yield - 1000 psi	[illegible]	[illegible]	[illegible]	[illegible]
-16	Elong. in 2"	[illegible]	[illegible]	[illegible]	23
	Bearing - 1000 psi [illegible]				
	Shear - 1000 psi				
Str. to Density Ratio - [illegible] (10^{-5})			[illegible]	5.23	[illegible]
Impact Str. (Charpy), ft. lbs. (5)			[illegible]	11.5	12
Fatigue Str. Curves at indicated temps.					

Remarks:

LOX or Liquid Fluorine Sensitivity - Yes or No [illegible]

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio (K_t value) 6.3(3) [illegible] 1.00 [illegible]

Weld Joint Efficiencies (same and dissimilar metals)

Resistance to Crack Propagation

Formability

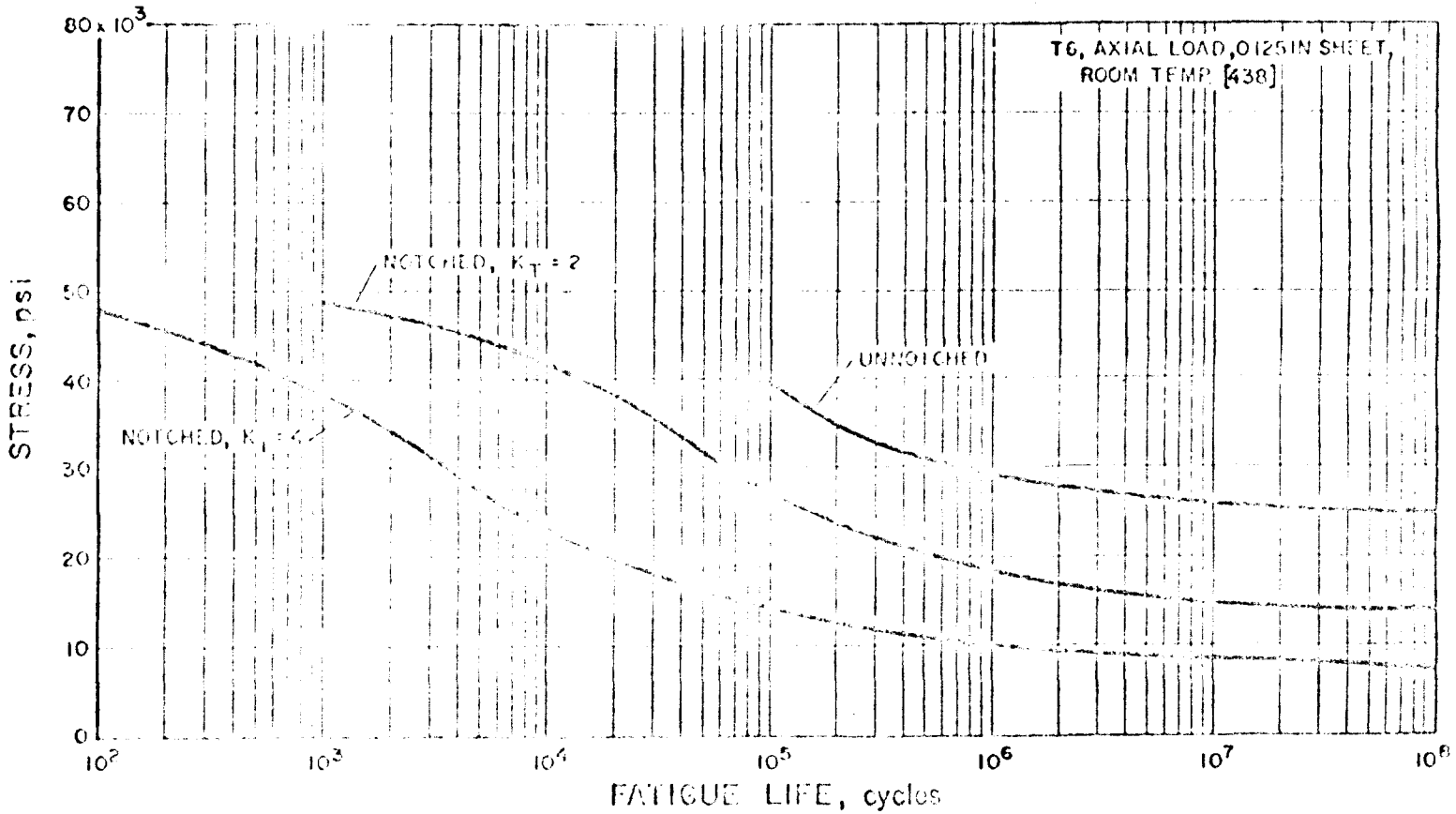
Cleanability

Availability

Cost

SOURCE (1) ALCOA (2) REYNOLDS, (3) [illegible] FOR CRYOGENIC SERVICE [illegible] (4) TB 171809, (5) MONOGRAPH 13

(4) [illegible] MATERIAL DATA HANDBOOK
[illegible]



FATIGUE BEHAVIOR OF 6061 ALUMINUM

A.6.n

[illegible] DATE [illegible]

ALLOY [illegible] SHEET THICKNESS .150

[illegible] of Sheet Material	[illegible]	[illegible]	[illegible]	[illegible]
Density, lbs/cu. in. .0918 (2)				
Modulus of Elasticity				
Annealed	Tensile - 1000 psi			
-0	Yield - 1000 psi			
	Elong. in 2"			
	Bearing - 1000 psi ($\frac{D}{D}$ = 2)			
	Shear - 1000 psi			
Heat Treated or Cold Worked Condition (1)	Tensile - 1000 psi	[illegible]	79.3	[illegible]
	Yield - 1000 psi	[illegible]	[illegible]	70.5
To .150	Elong. in 2"	15.3	[illegible]	22
	Bearing - 1000 psi ($\frac{D}{D}$ = 2)			
	Shear - 1000 psi			
Str. to Density Ratio - $\frac{F}{D}$ (10^{-5})		[illegible]	[illegible]	7.13
Impact Str. (Charpy), ft. lb. 1.5 [illegible] (2)		55.5	71.3	
Fatigue Str. Curves at indicated temps.				

Remarks

LOX or Liquid Fluorine Sensitivity - [illegible]

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio ([illegible]) .3(1)1.15 1.02 [illegible]

Weld Joint Efficiencies (same and [illegible] metals)

Resistance to Crack Propagation

Permeability

Cleanability

Availability

Cost

SOURCE(1) G.D. -ERR-AN-400(2) KAISER [illegible]

TABLE I DATE [illegible]

ALLOY [illegible] ALUM SHEET THICKNESS

Properties of Sheet Material		[illegible]	R.T.	-[illegible]°F	-[illegible]°F
Density, lbs/cu. in. .101(1)					
Modulus of Elasticity(T6)		[illegible]	10.5(1)	11 (1)	12.5 (1)
Annealed	Tensile - 1000 psi	[illegible]	33	50	
	Yield - 1000 psi	[illegible]	15	17	
-0 (2)	Elong. in 2"	[illegible]	17	22	
	Bearing - 1000 psi ([illegible])				
	Shear - 1000 psi				
Heat Treated or Cold Worked Condition	Tensile - 1000	[illegible]	[illegible]	[illegible]	[illegible]
	Yield - 1000 psi (2)	[illegible]	[illegible] (3)	[illegible] (3)	100
-T6	Elong. in 2"	[illegible]	[illegible]	[illegible]	8
.025	Bearing - 1000 psi [illegible]				
	Shear - 1000 psi	[illegible]	[illegible]		
Str. to Density Ratio - [illegible] (10^{-5})			[illegible]	[illegible]	[illegible]

Impact Str. ([illegible]), ft. lb.

Fatigue Str. [illegible] at indicated temps.

[illegible]

LOX or Liquid Fluorine Sensitivity - [illegible]

Thermal Shock Sensitivity

Notched/Unnotched Tensile Ratio ([illegible]) [illegible] [illegible] [illegible]

Weld Joint Efficiencies (same and dissimilar [illegible])

Resistance to Crack Propagation

Formability Inferior to 202[illegible]-0, [illegible]

Cleanability

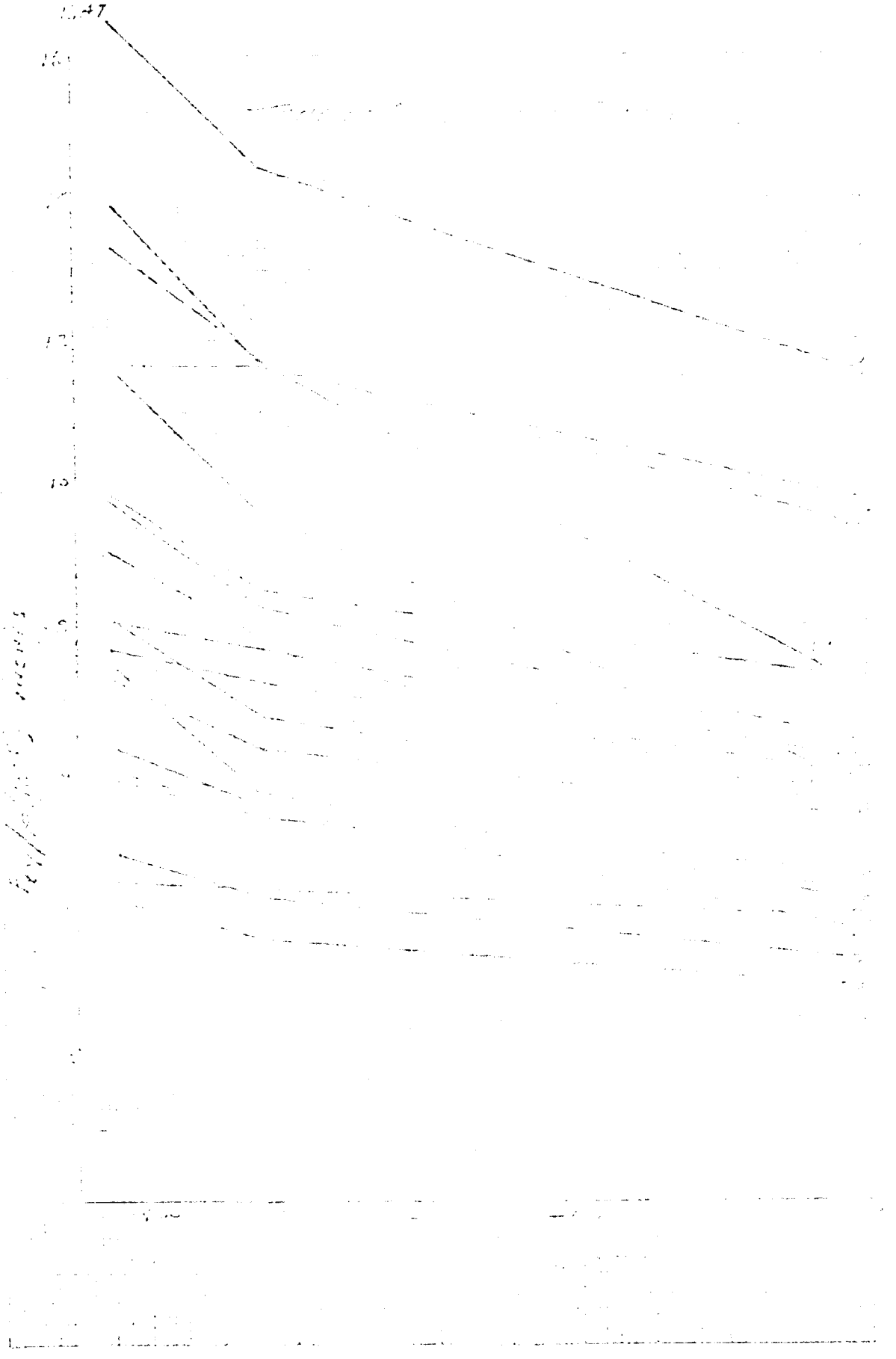
Availability All Forms

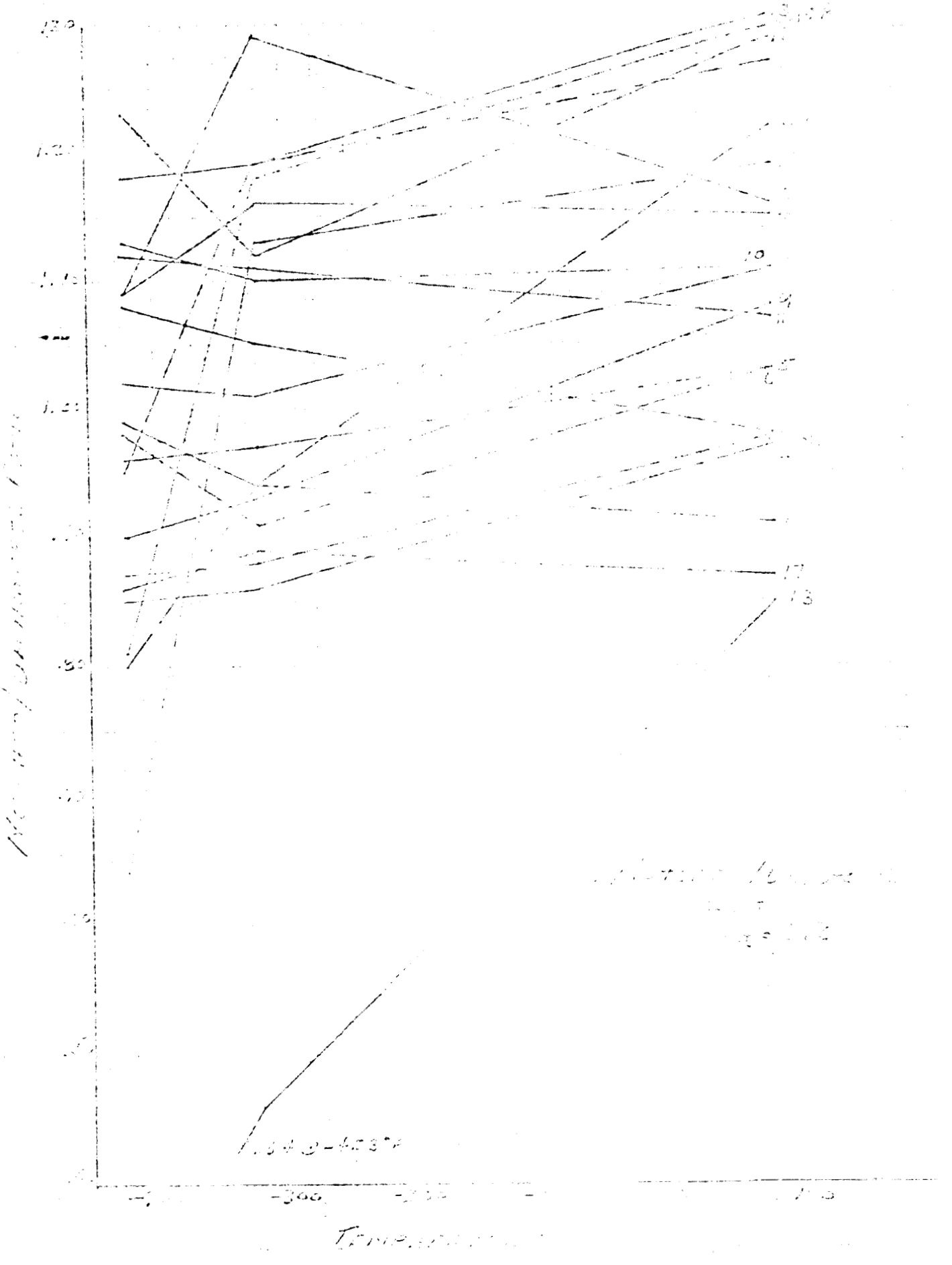
Cost

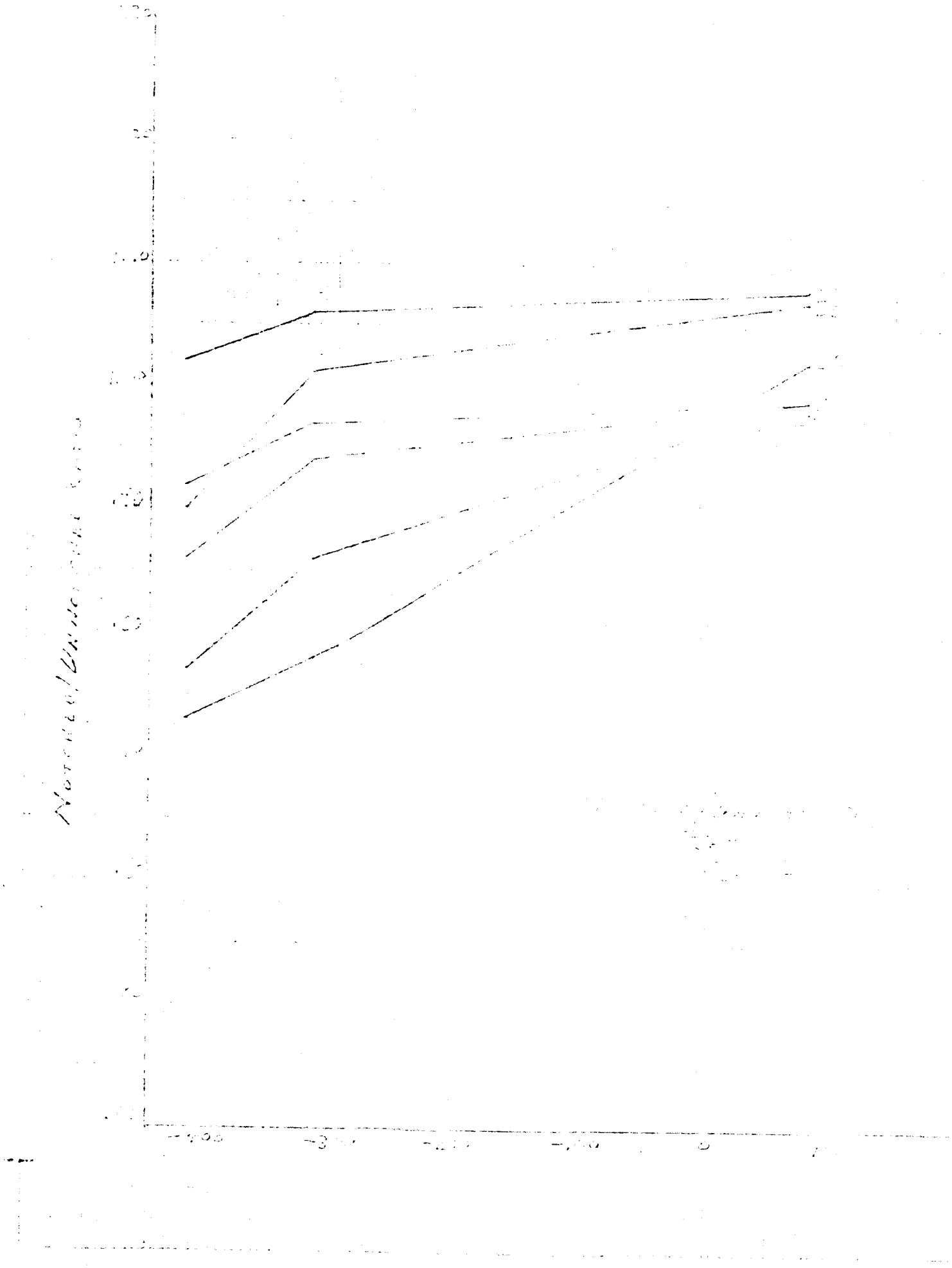
SOURCE (1) ALCOA, (2) REYNOLDS, (3) PROPERTIES OF 7000 SERIES ALUM ([illegible])

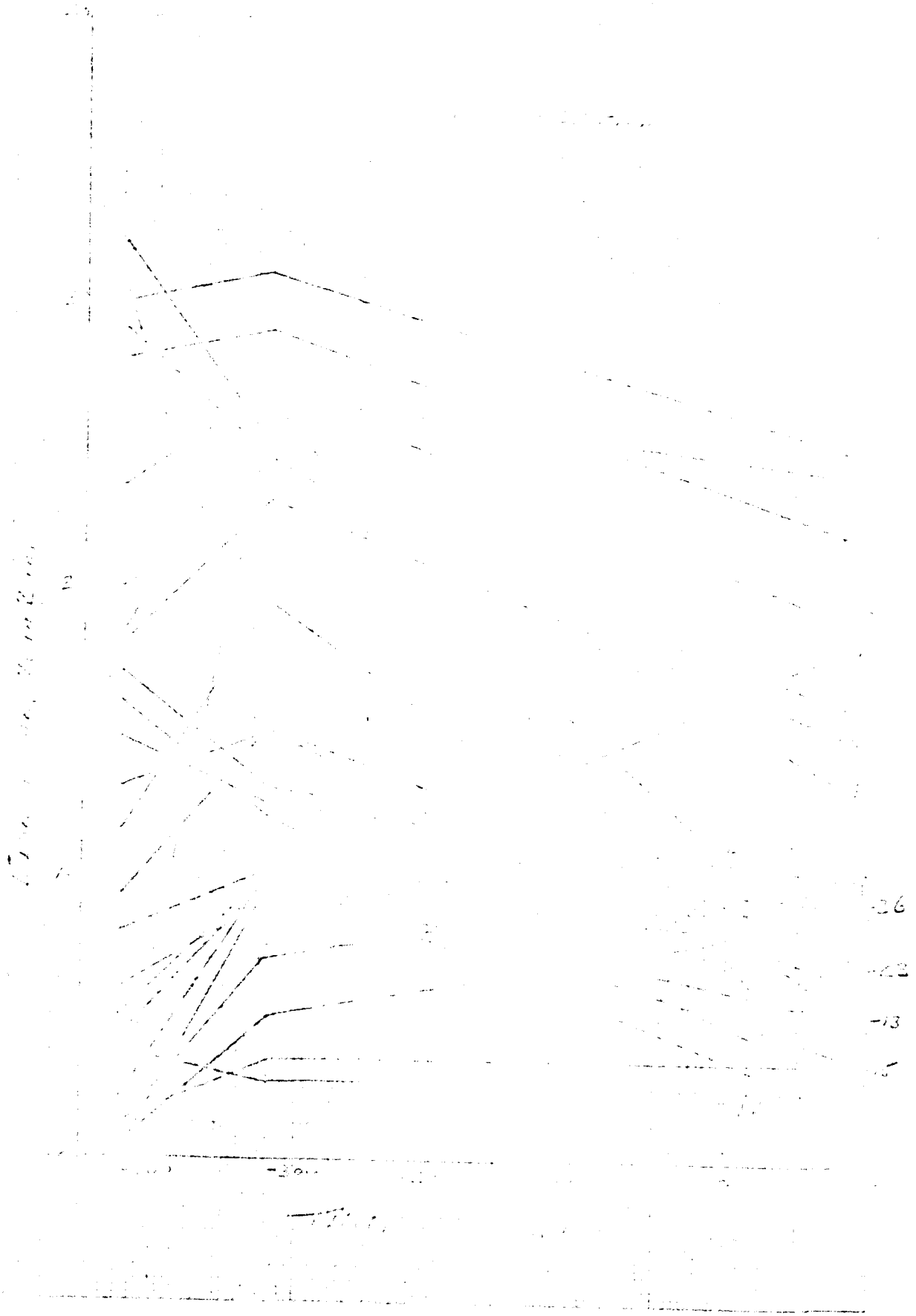
KEY TO GRAPHS

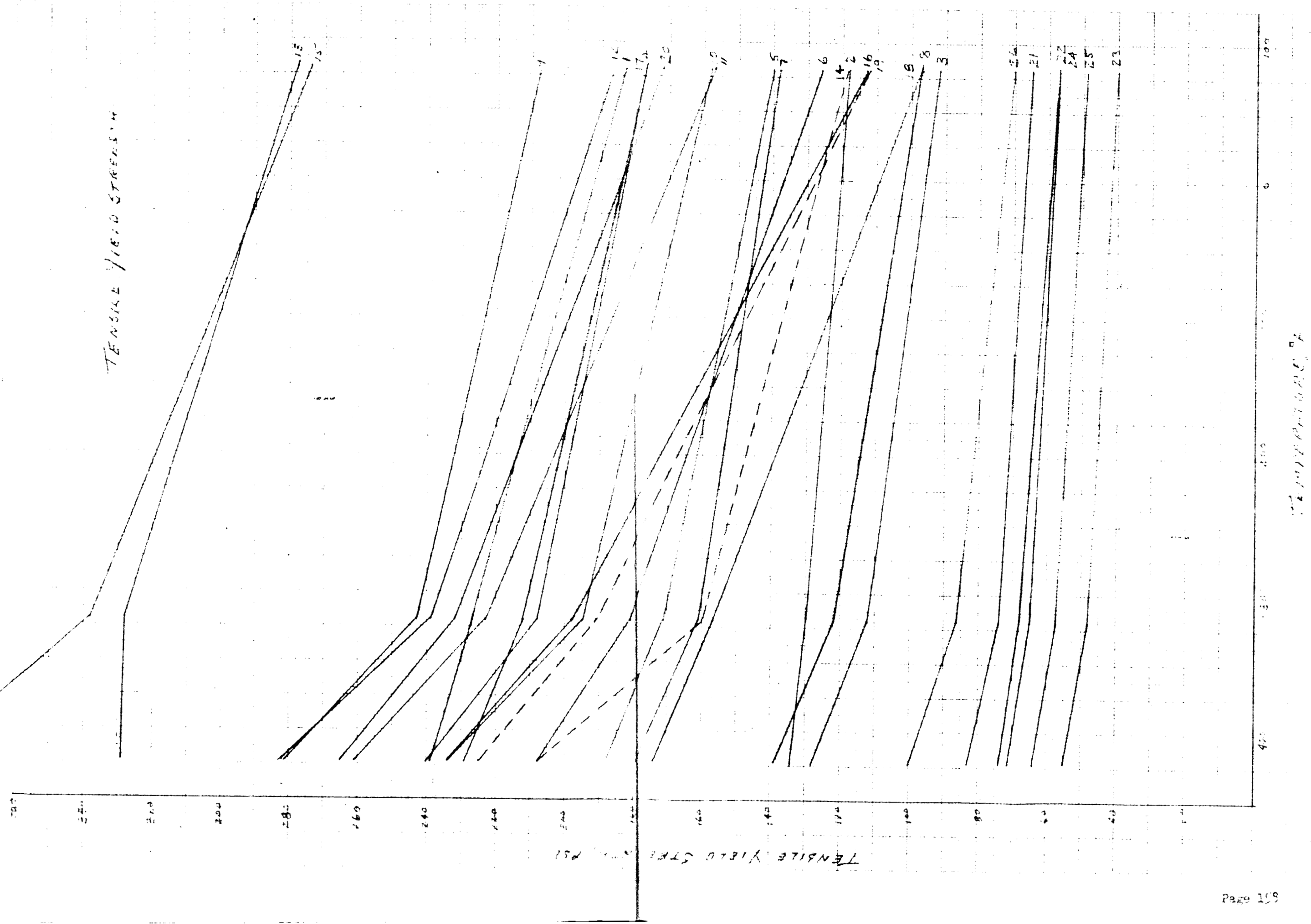
CODE NO	MATERIAL	CONDITION	TYPE
1	INCONEL 718	Aged & 20% CR	.031 Sht
2	INCONEL X-750	Aged @ 1300°-20hr A.C.	0.063 Sht
3	K-MONEL	Aged 1080-1100 -16 hr	0.020 Sht
4	HASTELLOY B	40% CR	0.011 Sht
5	HASTELLOY C	20% CR & AGED 1100°-16Hr	0.034 Sht
6	HAYNES 25(L605)	20% CR	0.010 Sht
7	RENE 41	Aged 1950°-30min AC+1400°-16hr AC	0.020 Sht
8	A-286	Aged 1800°-30min AC+1325°-16hr AC	0.016 Sht
9	301 S.S.	60% C.R.	Sht
10	304 HLC SS	50% C.R.	0.012 Sht
11	310 S.S.	75% C.R.	0.020 Sht
12	321 S.S.	35% C.R. -[illegible]	0.003 Sht
13	AM355 S.S.	[illegible] 1[illegible]0°	0.032 Sht
14	9% NISTEEL(ASTM -A353)	[illegible] 1650°&1450° 1050°F Temp	Bar
15	18% Ni STEEL (MARAGING)	Aged 900°-3 hrs A.C.	0.070 Sht
16	18% Ni STEEL (MARAGING)	SOLUTION ANNEALED	0.070 Sht
17	[illegible] 25	Cold Rolled & Age Hardened (HT)	0.028 Sht
18	[illegible] (Commercially [illegible])	Ti45A 50% Cold Rolled	0.022 Sht
19	TITANIUM 5A1-2.5 [illegible]	5% C.R.	0.031 Sht
19A	"	Commercial Production Annealed	
20	TITANIUM 6A1-4V (O_2 0.15%)	Aged 1600° 5 min, WQ,1000F 4hr A.C.	
21	[illegible] ALUMINUM	T6	0.[illegible] Sht
22	[illegible] ALUMINUM	T67	0.125 Sht
23	5052 ALUMINUM	[illegible]	0.040 Sht
24	5083 ALUMINUM	[illegible]	0.050 Sht
25	5456 ALUMINUM	[illegible]	0.063 Sht
26	7075 ALUMINUM	T6	0.025 Sht










TENSILE YIELD STRESS
TENSILE YIELD STRESS

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APPENDIX B

WELDING AND FORMING EVALUATION FOR Ti5Al2.5Sn R-64112

SOLAR

A DIVISION OF INTERNATIONAL HARVESTER COMPANY

RESEARCH MEMORANDUM

2200 PACIFIC HIGHWAY, SAN DIEGO, CALIFORNIA

R-64112

September 29, 1964

TO: H. T. Mischel
cc: J. V. Long/W. A. Compton
File (PJV)

FROM: P. J. Valdez
Research Engineer - Ext 793

APPROVED: J. W. Welty
Chief Metallurgist - Ext 765

SUBJECT: NASA CONTRACT: IMPROVING & DEVELOPING METHODS FOR THE FORMING OF BELLOWS. (MECHANICAL PROPERTIES EVALUATION)

Reference: RFE 9/23/64, EWO 6011343

Two important properties that need be known in forming and shaping a material are its resistance to plastic flow (strength) and its ductility. The first mentioned property determines the size of machinery needed for the forming operation, the second determines the maximum allowable deformation a material can experience without fracturing. Factors affecting ductility are:

- Temperature
- Crystal Structure
- Prior processing
- Strain Rate

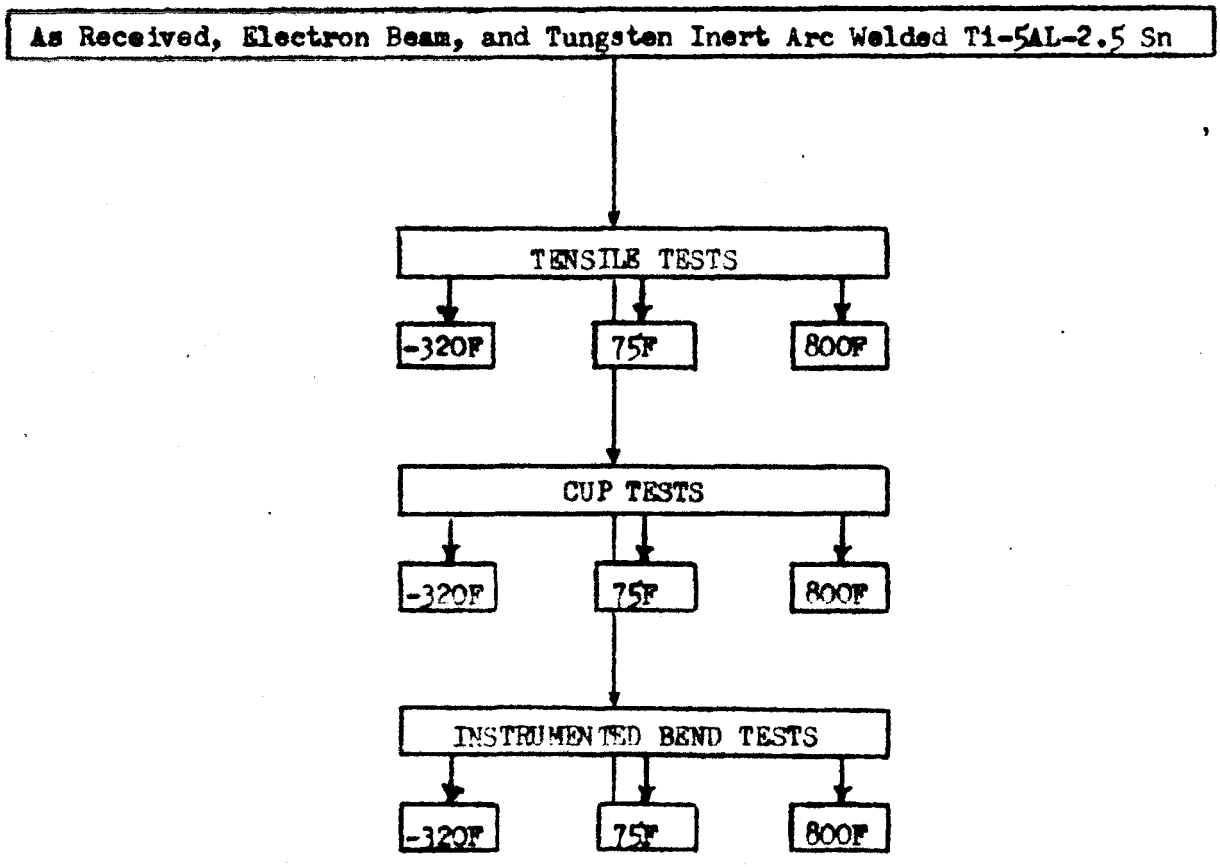
Many laboratory tests have been devised to measure ductility with the objective of simulating fabricating conditions. The most common methods are: measurement of reduction in area and elongation in tension tests, measurement of number of twists to fracture in a torsion test, measurement of depth on cup tests, and measurement of angle of bending upon appearance of first visible crack in bend tests.

The present evaluation will include tensile tests, bend ductility tests, and cup tests from -320 to 800F on titanium alloy A-110AT (Ti-5AL-2.5Sn) of both electron beam and tungsten inert arc welds in the following conditions:

- As welded (Weld to be transverse to direction of rolling on all specimens)
- As welded and stress relieved 15 Min at 1200F
- As welded, stress relieved at 1200F, planished, annealed at 1500F for 30 minutes.

A minimum of (2) two specimens will be tested in each condition at each test temperature. The technical data evolved from research, development, and advancement of capability will be used to assist in obtaining optimum design and process data, manufacturing techniques, and in process control criteria. Scope of the present program is shown in Figure 1.

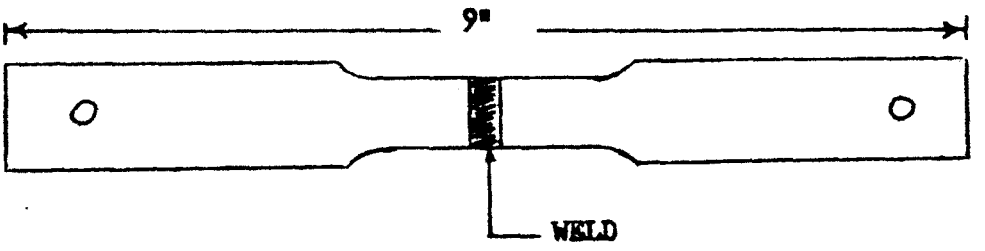
FIGURE I



TEST SPECIMENS

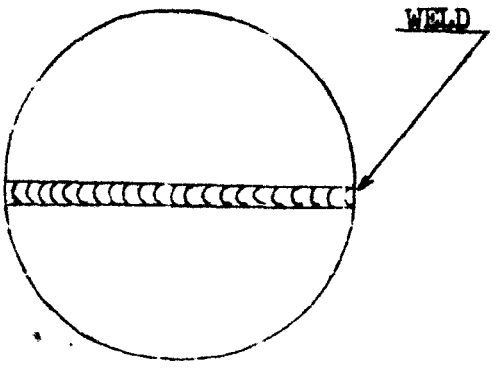
Tensile test specimen to be used in the present investigation will be of the single pin standard flat type (Fig. 2). The weld zone of the welded specimens will be located at the mid-span of the reduced section.

FIGURE 2



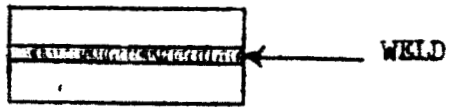
Cup test specimens will be sheared to 1.8 inch diameter with the weld located in the mid-section of the disc, (Figure 3).

FIGURE 3



Bend test specimens (Fig. 4) will sheared to .500" x 1.00" with the weld centered and parallel to the length of the specimen. Thus, in testing, the axis of the bending radius will be normal to the direction of the weld so that fusion zone, the heat affected zone, and the parent material will all experience the same angle of bend.

FIGURE 4



EQUIPMENT

The Ti-5AL-2.5Sn alloy will undoubtedly require specialized equipment and artificial environments to perform testing, fabrication, joining, in-process control and inspection operations. Studies in this area will be concerned with developing the requirements, justifications and specifications for this equipment.

PLV:jhw

APPENDIX C

CRYOGENIC FORMING MECHANISM PROPOSAL

AEROSPACE MANUFACTURING

Manufacturing Development Proposal for Forming at Cryogenic Temperatures

Sales Order 6-1616-7

National Aeronautics and Space Administration

For Design, Fabrication and Testing Services Leading To
Optimum Pressurization and Propellant Feed Ducting Systems

Investigating Team

G. F. Hoff, Jr. - Production Engineer
W. L. Potts - Project Planner
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Consultants

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Consultants

Written by:

D. W. Tank
Project Planner

Approved by:

W. E. Dickinson
Project Manager - Aerospace

September 25, 1964

A. Assignment

Aerospace Manufacturing was requested to perform preliminary study to determine a forming technique at -320° utilizing liquid nitrogen. Such assignment was requested by H. Mischel, Project Engineer, under Engineering Work Order 6501340. The request asked for -

- Manufacturing approaches.
- Facilities.
- Tooling.
- Schematic drawings and photographs of the proposed system.

B. Discussion

LH_2 forming experiences in Aerospace Manufacturing have been limited to information contained in technical publications and in-plant discussions from time to time in the past several months. It is considered by Manufacturing to be a significant advancement in the "state of the art". It is recognized that careful handling in forming of this type is mandatory, therefore safety factors regarding the manufacturing portions of the project of the project were given special consideration.

Four major areas of activity have been reviewed -

- Facilities.
- Tooling.
- Manufacturing approach.
- Safety factors.

Facilities

The Solar developed bellows forming press now in operation in Department 17 (Aircraft Bellows) has been selected for the development. The facility is loaded approximately 40% at the present time, which provides us with ample time for this task. The facility has the features deemed necessary for the test program, such as capability of repeating to close tolerances and economical to tool.

The proposed forming process is such that materials are not drawn through or over any die surface. During the forming operation, the die moves with the material which has been pre-set to produce a convolution of a calculated elongation, therefore minimizing or eliminating die marks in the drawn area.

The facility is isolated in the bellows forming department and is not near a main traffic aisle thus helpful regarding the safety aspects of the machine. Supporting facilities, such as precision shears, welders, sizing equipment, etc., are in the adjacent area. The attached photograph illustrates the facility and the accessibility to observing forming operation.

Tooling

A 3" diameter, one convolution bellows has been established for first approach. With this established approach, the tool design can be minimized by using a tabulated type of design currently existing. Tooling materials must be similar to formed specimen material thus minimizing shrinkage differentials. This also considers ordinary steels are extremely brittle at cryogenic temperatures. Materials considered for tools are Inco X, Inconel 286 and, in some areas, Type 321. The upper and lower dies will be 6" in diameter insulated from the press base. A vacuum jacketed container will surround the lower die and be of sufficient depth to cover upper die during the pre-form and forming cycles (Operation 3 in Manufacturing Plan). Adjustable set blocks will be necessary to control die openings (Operation 2 in Manufacturing Plan). Tools will be capable of producing samples at room temperatures and sub-zero temperatures with no modification except in the areas of pressure sealing.

Manufacturing Approach

As previously stated, the bellows will be a one convolution type. Material gages from .008 through .020 range requiring a low forming pressure. The proposed method of obtaining pre-form and forming pressures is to introduce a pre-determined quantity of LN_2 inside the tube. Gas from the LN_2 (Operation 3 in Manufacturing Plan) will be regulated at the desired pressure. It should be noted that only bellows requiring low forming pressure can be produced in this manner due to safety hazards. Standard manufacturing approaches for dimensional control are as shown in the attached photographs.

Manufacturing Plan

Basic operations will be to shear, weld and size precision cylinders of the various materials to be tested. Welds will be radiographic inspected as required. Samples will be formed at both room temperatures and sub-zero -320°.

1. Place tube in die base.
2. Lower top die to set blocks.
3. Introduce LN_2 to cavity around dies. Hold until stabilized.
4. Pour pre-determined amount of LN_2 inside tube to be formed.
5. Form primary bulge.
6. Hold pressure in cavity.
7. Finish form convolution.
8. Remove form dies.

Operations #3 and #4 will be omitted when forming room temperature specimen.

Safety

The working side of the facility will be protected by swinging door of Plexiglass. Possibly some stainless steel wire mesh will be utilized. Just prior to forming, the LN_2 in the open container will be drawn off. This will eliminate the possibility of LN_2 being blown throughout the area in the event of part rupture.

Development Costs

Tentative costs for the program are based on preliminary information obtained from the engineering directives and manufacturing investigations.

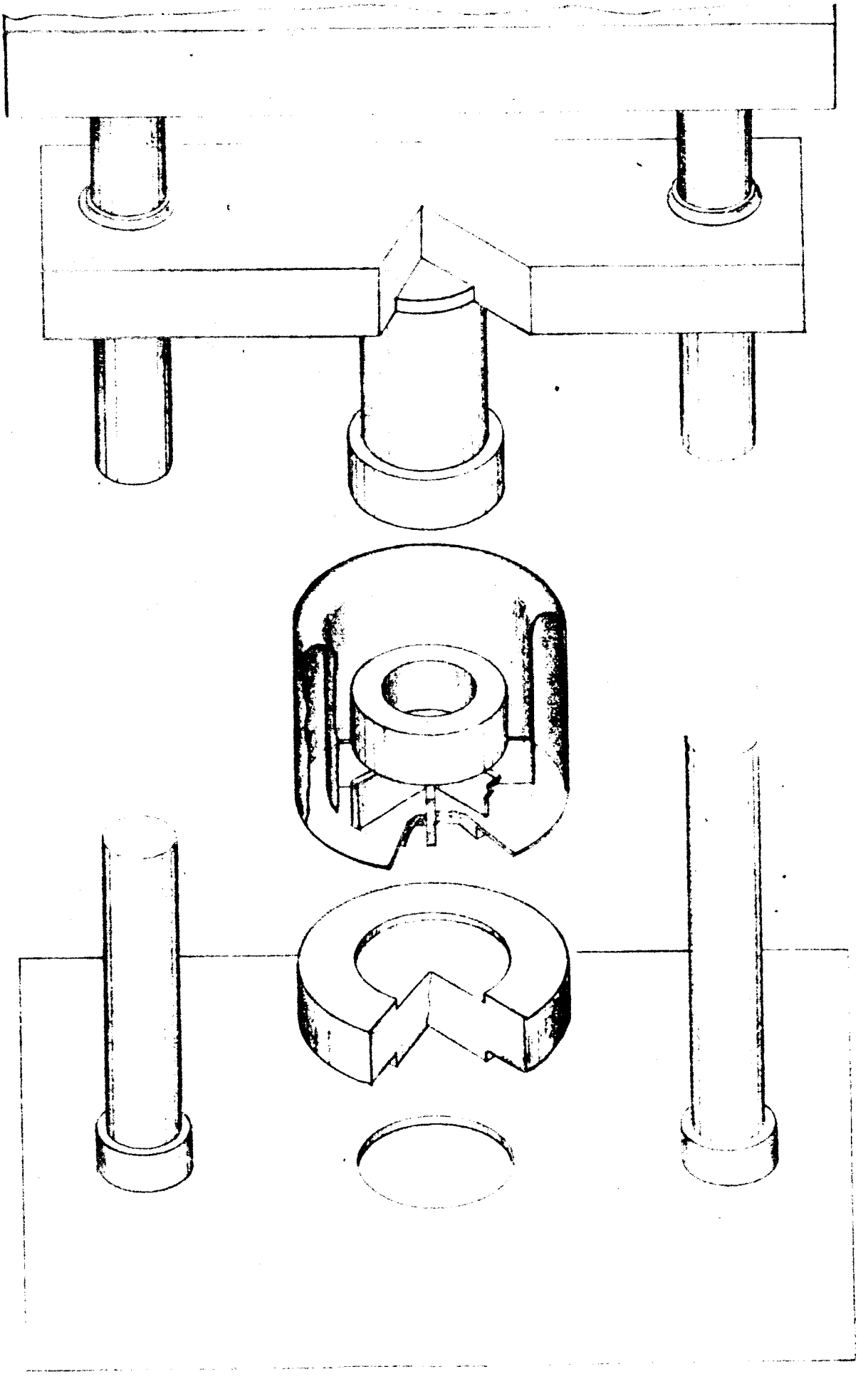
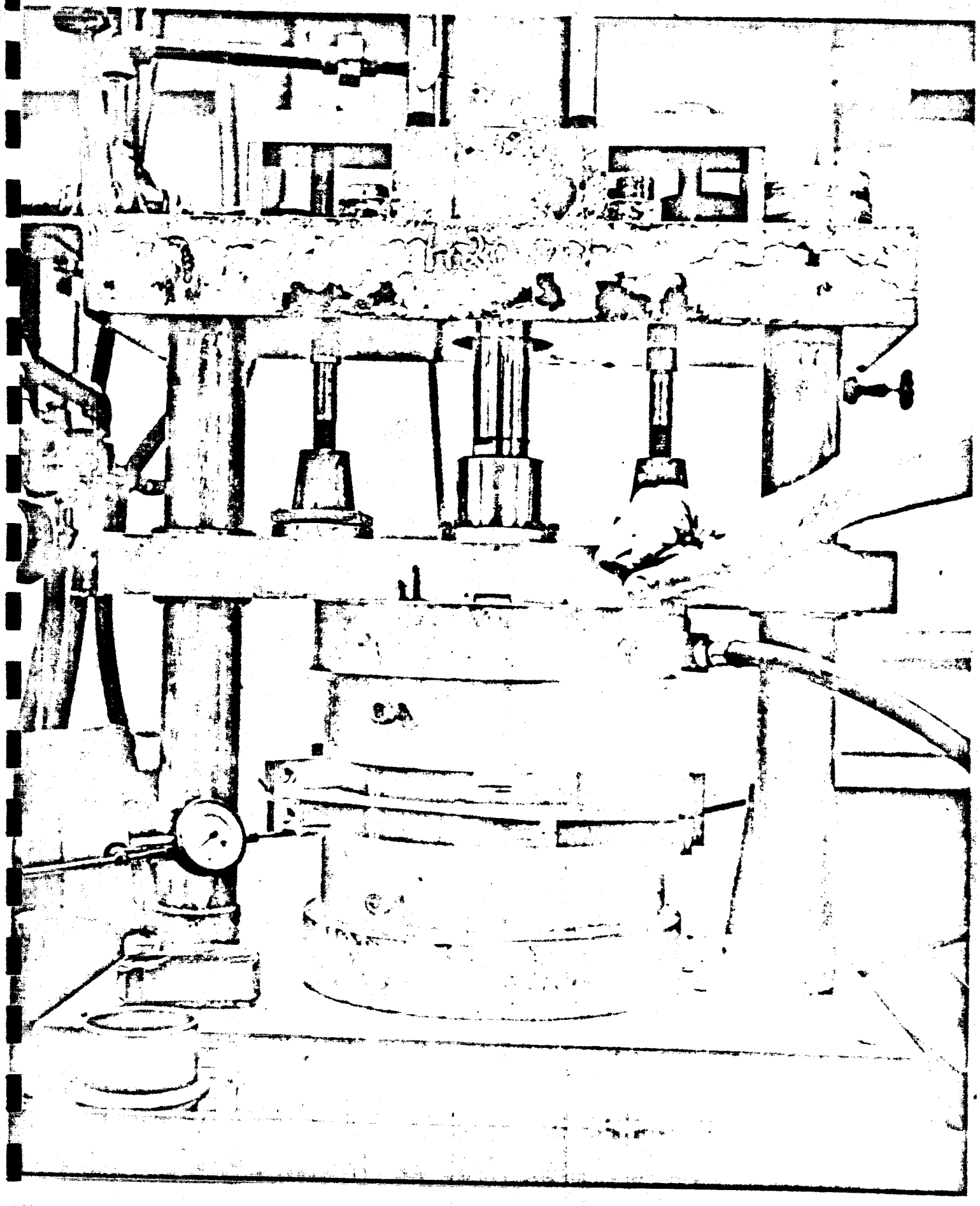
a. Preparation of samples, machine set up and forming operations at room temperature.	22 hours per sample
b. Preparation of samples, machine set up and forming operations at -320° formed samples.	36 hours per sample

It is considered per previous discussions that material for a and b above will be furnished by Engineering. Manufacturing Engineering will require 120 hours to finalize the basic plan, generate tooling requirements and maintain surveillance of development work in process. Tooling approaches are estimated to cost 350 hours for tools and proofing operations and $600 for materials.

Summation

Since LN_2 forming is a new concept, the approach and suggested techniques of the Investigating Team will possibly require modification as experience is gained. To minimize variables, an established approach to bellows forming was chosen. Records will be kept of all activities and progress reports will be presented after each major phase of the project is completed.

WED/mar



CRYOGENIC FORMING MACHINE SET-UP