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NONFERROUS ALLOYS

1. **GENERAL**
 This austenitic nickel base alloy, with a nominal 25 percent chromium content, possesses excellent high temperature strength and oxidation and carburization resistant properties to 2200F. It is readily formed and welded by all welding techniques in general usage. Forming and machining may be performed on this material in the same manner as on the conventional austenitic stainless steels. It is available in all wrought forms including weaving wire, expanded metal, and perforated sheet. Tests involving boiling 42 percent magnesium chloride solution and also polythionic acid at room temperature failed to induce stress-corrosion cracking in RA-333. Its 45 percent nominal nickel content enables RA-333 to show excellent resistance to sigma phase formation. It has a low coefficient of expansion in comparison to other nickel-chromium high temperature alloys. It has seen use in numerous turbine component parts.

1.01 Commercial Designation
 RA-333

1.02 Alternate Designations
 None.

1.03 Specifications
 1.031 AMS specifications, Table 1.031.

TABLE 1.031

AMS	Form
5717B	Bars, Forgings, and Rings
5593A	Sheet and Plate

1.04 Composition
 Table 1.04.

TABLE 1.04

Source	AMS (1)(2)		(3)		(4)		
	Min	Max	Min	Max	Min	Max	Nominal
Carbon	-	0.08	-	0.08	-	0.08	0.05
Manganese	-	2.00	-	2.00	-	2.00	1.50
Phosphorous	-	0.030	-	0.03	-	0.030	0.015
Sulfur	-	0.030	-	0.03	-	0.030	0.015
Silicon	0.75	1.50	0.75	1.50	0.75	1.50	1.25
Chromium	24.00	27.00	24.0	27.0	24	27	25
Nickel	44.00	47.00	44.0	47.0	44	47	45
Molybdenum	2.50	4.00	2.5	4.0	2.50	4.00	3
Cobalt	2.50	4.00	2.5	4.0	2.50	4.00	3
Tungsten	2.50	4.00	2.5	4.0	2.50	4.00	3
Iron	Balance		Balance		Balance		18
Copper	-	0.50	-	0.50	Controlled Low		-
Tin	-	0.025	-	0.025	Controlled Low		-
Lead	-	0.025	-	0.025	Controlled Low		-

1.05 Heat Treatment
 1.051 Mill anneal. 2050F ± 50F, rapid air cool or water quench.
 1.052 Solution treat. 2200F ± 50F, rapid air cool or water quench.

1.06 Hardness
 1.061 This alloy is basically a nonhardenable austenitic alloy. However, a slight increase in hot-hardness in the temperature range 1400F-1800F has been noted upon solution treating and aging at 1350F for 16 hours. AMS 5593A and AMS 5717B stipulate that sheet, strip, plate, bars, forgings, and rings shall have Rockwell B hardness not higher than 95 or equivalent.
 1.062 This alloy can be hardened by cold working.

1.07 Forms and Conditions Available
 1.071 The alloy is available in a full commercial range of sizes for sheet, strip, plate, bar, billets, wire, pipe, forgings, expanded metal, and perforated metal.
 1.072 Wrought products are available in the mill annealed condition.

1.08 Melting Practice
 Electric furnace air melted.

1.09 Special Considerations

2. **PHYSICAL AND CHEMICAL PROPERTIES**

2.01 Thermal Properties
 2.011 Melting range. 2420-2465F (4).
 2.012 Phase changes. The alloy is austenitic at all temperatures.
 2.0121 Time-temperature-transformation diagrams.
 2.013 Thermal conductivity, Figure 2.013.
 2.014 Thermal expansion, Figure 2.014.
 2.015 Specific heat, 0.11 Btu per (lb F) (32-212) (4).
 2.016 Thermal diffusivity.

2.02 Other Physical Properties
 2.021 Density. 0.298 lb per cu in (4).
 2.022 Electrical resistivity, Figure 2.022 (4).
 2.023 Magnetic properties. Magnetic permeability, annealed B-H at 200H-1.004.
 2.024 Emittance.
 2.025 Damping capacity.

2.03 Chemical Properties
 2.031 Corrosion resistance of this alloy compares favorably with other chromium-molybdenum-tungsten containing nickel base alloys. Tests in boiling 42 percent magnesium-chloride solution and also in polythionic acid-at-room-temperature failed to induce stress-corrosion cracking in this alloy.
 2.032 Intergranular corrosion.
 2.033 Oxidation resistance up to 2250F is very good. The oxidation rate in inches per year penetration (IPY) after holding 1000 hours in the 1800-2250F temperature range was found to be very small. Its resistance to neutral and reducing atmospheres at temperatures up to 2200F is also very good. Under oxidizing conditions, the alloy develops a scale which does not spall off.
 2.034 Thousand hour oxidation rate loss for alloy in the 1800-2250F temperature range, Figure 2.034 (5).

2.04 Nuclear Properties

3. **MECHANICAL PROPERTIES**

3.01 Specific Mechanical Properties
 3.011 AMS specified mechanical properties, Table 3.011.

TABLE 3.011

Source	(1) (2)	
	Alloy RA-333	
Form	Sheet, Plate, Strip	Bars, Forgings, and Rings
Condition	Annealed (2000F + 50F)	
Thickness	All thickness (Elongation requirements not applying to sheet and strip under 0.020 inch)	All
F _{TU} , Max - ksi	120	120
F _{TY} , Min - ksi	-	35
e(2 in or 4D)		
Min - percent	30	30

3.02 Mechanical Properties at Room Temperature
 3.021 Tension.
 3.0211 Stress-strain diagrams.

	Ni
25	Cr
18	Fe
3	Mo
3	W
3	Co
1.25	Si

RA-333

	Ni
25	Cr
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3	Mo
3	W
3	Co
1.25	Si

RA-333

- 3.0212 Typical mechanical properties at room temperature for sheet, plate, and bar, Table 3.0212.

Source	(4)
Alloy	RA-333
Form	Sheet, Plate, Bar
Condition	Annealed
F _{tu} , - ksi	100
F _{ty} , - ksi	50
e(2 in) - percent	50
RA - percent	57

- 3.022 Compression.
3.0221 Stress-strain diagrams.
3.023 Impact.
3.024 Bending.
3.025 Torsion and shear.
3.026 Bearing.
3.027 Stress concentration.
3.0271 Notch properties.
3.0272 Fracture toughness.
3.028 Combined properties.

- 3.03 Mechanical Properties at Elevated Temperatures
3.031 Tension.
3.0311 Stress-strain diagrams.
3.0312 Effect of test temperature on tensile properties of bar, mill annealed, Figure 3.0312.
3.0313 Effect of test temperature on tensile properties of solution treated bar, Figure 3.0313.
3.0314 Effect of aging on tensile properties of bar at elevated temperatures, Table 3.0314.

Source	(6)				
Alloy	RA-333				
Form	Bar Samples				
Condition	Solution Treated (2200F, 1/2 hour) WQ plus aged 1350F, 16 hours, AC				
Data	Tensile Properties				
Aged	Test Temp F	F _{tu} ksi	F _{ty} ksi	e (percent)	RA (percent)
yes	1400	62.6	39.8	47.5	49.8
yes	1600	35.7	32.5	49.1	61.5
yes	1800	19.6	18.1	27.4	37.1
no	1400	61.9	40.9	48.1	56.4
no	1600	36.8	34.0	65.7	65.3
no	1800	19.6	17.1	74.1	63.5

ASTM grain size 3-5(7). All samples from same heat.

- 3.032 Compression, Table 3.032

Source	(8)	
Alloy	RA-333	
Form	Bar Stock	
Data	Compressive Yield Properties	
Condition	Temperature - F	F _{ty} ksi (a) (b)
Mill annealed 2050F, 1/2 hr. WQ	1400	31.6
Same	1600	27
Same	1800	14.3
Solution Treated 2200F, 1/2 hr., WQ	1400	31.8
Same	1600	30.8
Same	1800	16.5
Solution treated 2200F, 1/2 hr., WQ and aged 1350F, 16 hrs., AC	1400	37.3
Same	1600	29.6
Same	1800	16.9

(a) Speed of testing, strain pace 0.005 inch per inch per minute to yield point.
(b) Each figure obtained from averaging three determinations, each from a different heat.

- 3.0321 Stress-strain diagrams.
3.033 Impact.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.0372 Fatigue toughness.
3.038 Combined properties.

- 3.04 Creep and Creep Rupture Properties
3.041 1 percent total strain curves for bar at 1400, 1600, and 1800F, Figure 3.041.
3.042 2 percent total strain curves for bar at 1400, 1600, and 1800F, Figure 3.042.
3.043 Creep rupture curves for bar at 1400-1800F, Figure 3.043.
3.044 Minimum creep curves for bar at 1400-2100F, Figure 3.044.
3.045 Creep rupture properties for two different heats, for bar, Table 3.045.

Source	(9)	
Alloy	RA-333	
Form	Bar	
Condition	Mill annealed 2050F, 1/2 hr. WQ	
Test Temperature, F, and Load - ksi	Rupture Time - Hours	
	Heat A	Heat B
1400, 20	86.7	80.9
1600, 10	34.9	88.8
1800, 3.3	114.5	149.6

- 3.0451 Creep rupture properties for two different heats, solution treated for bar, Table 3.0451.

Source	(9)	
Alloy	RA-333	
Form	Bar	
Condition	Solution treated 2200F, 1/2 hr. WQ	
Test Temperature, F, and Load - ksi	Rupture Time - Hours	
	Heat A	Heat B
1400, 24	57.4	30.1
1600, 10	332.5	137.5
1800, 6	41.8	65.4

- 3.0452 Creep rupture properties for solution treated and aged bar, Table 3.0452.

Source	(9)	
Alloy	RA-333	
Form	Bar	
Condition	Solution treated 2200F, 1/2 hr., WQ + Aged 1350F - 16 hr., AC	
Test Temperature, F, and Load - ksi	Rupture Time - Hours	
	Heat A	
1400, 20	164.4	
1600, 10	392.9	
1800, 4.6	203.2	

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3.05 Fatigue Properties3.06 Elastic Properties

- 3.061 Poisson's ratio.
 3.0611 Poisson's ratio at room temperature - 0.315.
 3.062 Modulus of elasticity.
 3.0621 Modulus of elasticity at room and elevated temperatures, Figure 3.0621.
 3.063 Modulus of rigidity.
 3.064 Tangent modulus.

4. FABRICATION

4.01 Formability

- 4.011 General. Forming is usually done at room temperature where the alloy possesses good ductility. Power requirements are approximately equal to those used on austenitic stainless steels. Annealing may be necessary after each stage of a forming operation. Ductility may be restored by annealing at 1900-1950F, holding only long enough to assure uniform temperature and rapidly air cooling (heavier sections may be water quenched).
 4.012 Forging. Starting temperature of 2100-2150F should be employed. The finishing temperature should not be less than 1900F. RA-333 has a narrow hot working range and care should be exercised. Heating must be carried out in a low sulfur air or inert atmosphere.

4.02 Machining and Grinding

- 4.021 Machining should be accomplished with heavy tools, slow speeds and deep cuts to minimize work hardening. Recommended speeds are about 40 percent of those used for screw machine stock (B1112). A sulfur base cutting fluid is suggested. Carbide and high speed tools are suggested for most cutting operations.

- 4.022 High speed steel tools for lathe or turning operations should be ground to:

6-10°	back rake
5-8°	side clearance
8-10°	front clearance
8-14°	cutting edge angle
10-15°	lead angle

It is suggested that carbide tipped tools have smaller angles than high speed steel tools (3).

4.03 Welding

- 4.031 General. This alloy can be welded by most fusion welding procedures including metallic-arc, GTA, GMA, and submerged arc methods. Welding surface preparation is necessary in that the welding surface must be thoroughly cleaned and free of scale.

- 4.032 GTA is used in welding thin sections and on joints that require frequent interruption of the arc where the elimination of flux chipping may result in considerable labor savings.

GMA welding results in much faster deposition and deep penetration. A good recovery of welding wire is achieved. Arcing characteristics are good and sound deposits with freedom from cracking can be obtained, even under highly restrained conditions. The weld deposits are comparable to the base metal in strength, oxidation resistance, and resistance to absorption of carbon and nitrogen. Forming can be performed within normal limits after welding. Welding with coated electrodes can be performed on this alloy using AC-DC titanium coated electrodes.

- 4.033 The following precautions should be kept in mind when using electrodes:

- Keep arc length as short as possible.
- Fill in starts and craters to minimize cracking.
- Avoid weaving to minimize undercutting.
- Do not preheat the parent metal prior to welding.
- Use a power source of not more than 300 amps maximum (current should be kept at the lowest value that will maintain a steady, stable arc).

- 4.034 RA-333 is welded to itself and dissimilar metals using RA-333 filler wire or RA-333-70 electrodes.

4.04 Heat Treatment

- 4.041 All traces of cutting fluid should be removed, prior to heat treating to avoid pickup of sulfur.
 4.042 Heating and heat treatment should be carried on in an inert or sulfur-free air atmosphere.

4.05 Surface Treatment

- 4.051 Pickling of this alloy is generally performed in molten caustic baths such as a sodium hydride bath followed by water quenching and acid dipping. Due to the high alloy content of this material, conventional stainless steel pickling liquors do not result in proper cleaning or scale removal.

	Ni
25	Cr
18	Fe
3	Mo
3	W
3	Co
1.25	Si

RA-333

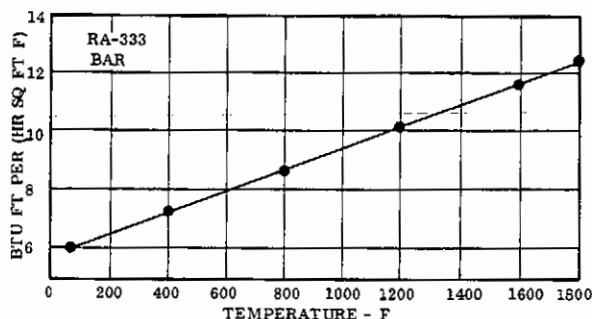


FIG. 2.013 THERMAL CONDUCTIVITY.

(4)

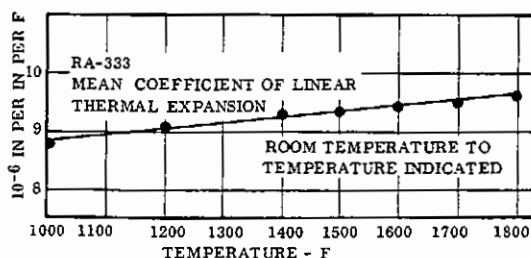


FIG. 2.014 THERMAL EXPANSION.

(4)

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	Ni
25	Cr
18	Fe
3	Mo
3	W
3	Co
1.25	Si

RA-333

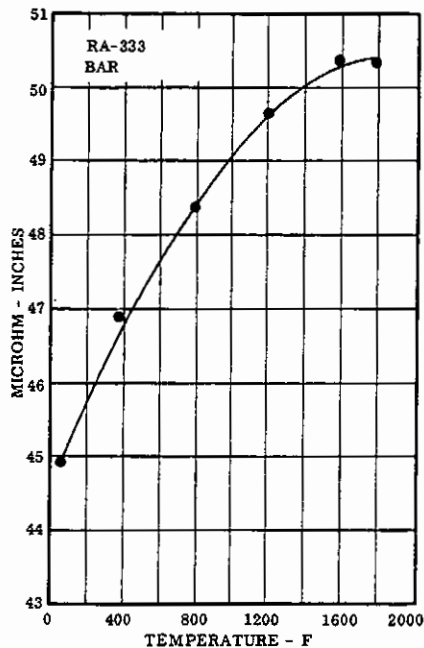


FIG. 2.022 ELECTRICAL RESISTIVITY. (4)

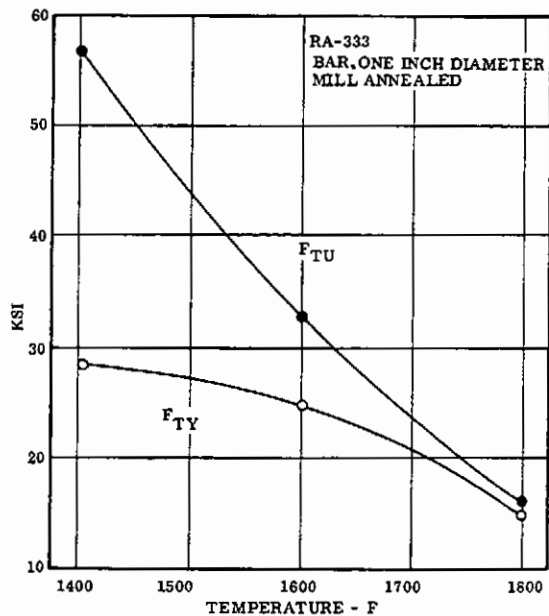


FIG. 3.0312 EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF MILL ANNEALED BAR. (4)

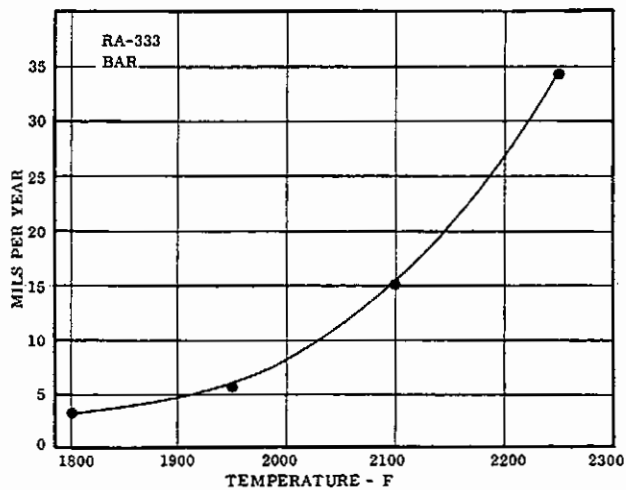


FIG. 2.034 THOUSAND HOUR OXIDATION RATE (AIR ATMOSPHERE). (5)

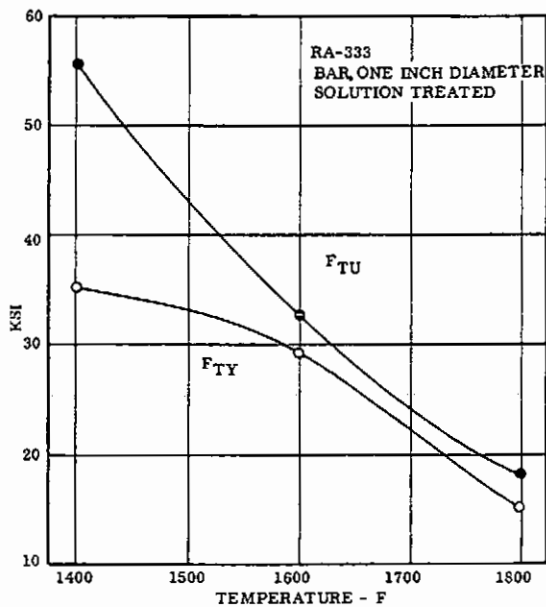


FIG. 3.0313 EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED BAR. (4)

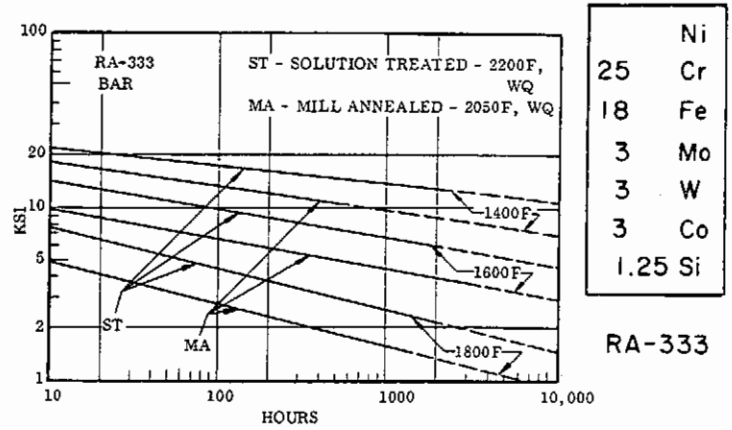


FIG. 3.042 TWO PERCENT TOTAL STRAIN CURVES FOR MILL ANNEALED AND SOLUTION TREATED BAR AT 1400F TO 1800F. (4)

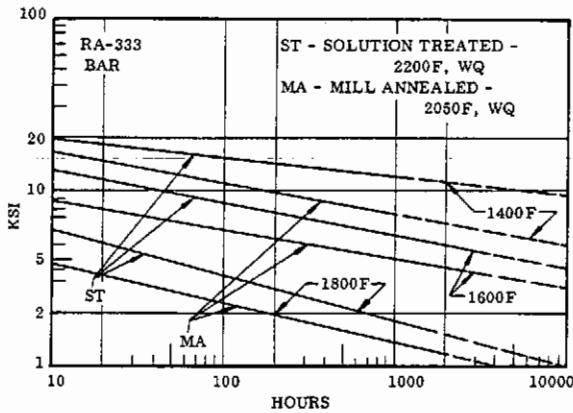


FIG. 3.041 ONE PERCENT TOTAL STRAIN CURVES FOR MILL ANNEALED AND SOLUTION TREATED BAR AT 1400F TO 1800F. (4)

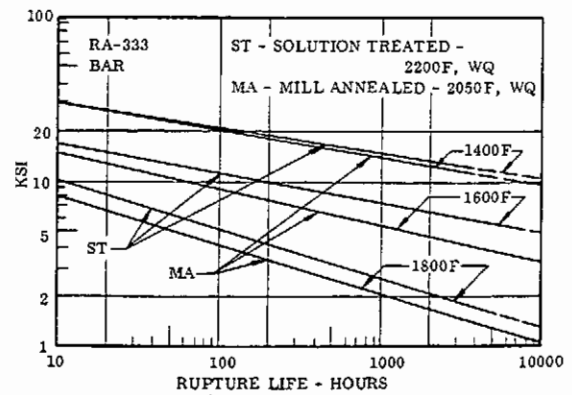


FIG. 3.043 CREEP RUPTURE CURVES FOR MILL ANNEALED AND SOLUTION TREATED BAR AT 1400F TO 1800F. (4)

	Ni
25	Cr
18	Fe
3	Mo
3	W
3	Co
1.25	Si

RA-333

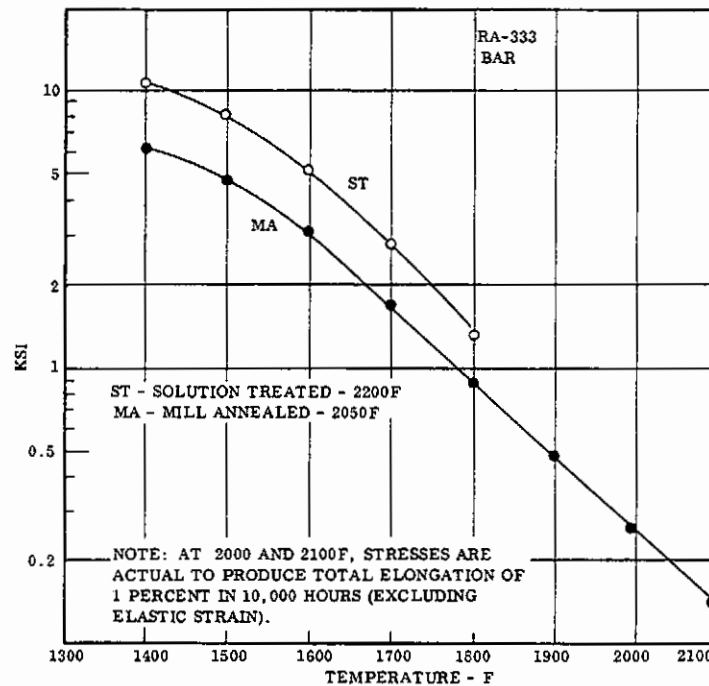


FIG. 3.044 0.0001 PERCENT PER HOUR MINIMUM CREEP RATE CURVE FOR MILL ANNEALED AND SOLUTION TREATED BAR. (4)

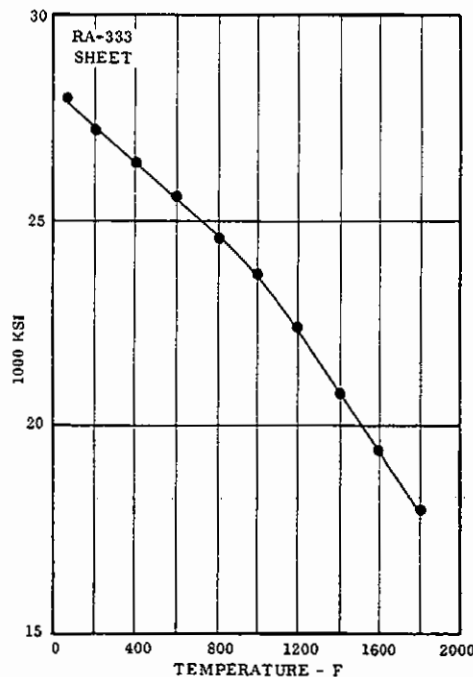


FIG. 3.0621 MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES (DYNAMIC DETERMINATION). (4)

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