REVISED: MARCH 1968

NONFERROUS ALLOYS

J. G. SESSLER

Mg
2 Th
0.8 Mn

HM 21 A

1. GENERAL

HM21A is one of a recently developed series of heat treatable magnesium alloys containing thorium and manganese as hardeners. It is available in the form of sheet, plate and forgings for service at temperatures up to 700F. Sheet and plate in the T8 condition are superior to HK31A-H24 for short time service above 550F and, at lower temperatures for long time service. Sheet and plate in the T81 condition are superior to HM21A-T8 at temperatures up to 600F and are comparable with HM21A-T8 at 600F and above. Forgings in the T5 condition offer the best combination of properties for magnesium alloys in the temperature range of 500 to 700F. This alloy can be readily welded and it is free from stress cracking.

1.01 Commercial Designation

HM21A

1.02 Alternate Designation

None

1.03 Specifications

Table 1.03

TABLE 1.03

Source	(4) (5)	
Alloy	HM21A	
Form and Condition	AMS	U.S. Government
Sheet and Plate - T8 Condition	4390D	Mil-M-8917 (a)
Sheet and Plate - T81 Condition	4383	-
Forgings - T5 Condition	4363A	-
Forgings	-	QQ-M-40b (b)

(a) Military specification
(b) Federal specification

1.04 Composition

Table 1.04

TABLE 1.04

Source	(4)	
Alloy	HM21A	
	Percent	
	Min	Max
Thorium	1.5	2.5
Manganese	0.45	1.1
Impurities		
each	-	0.10
total	-	0.30
Magnesium	Balance	

1.05 Heat Treatment

1.051 Sheet and plate are heat treated to T8 condition or T81 condition by the producer of the alloy. Its' favorable properties of T8 sheet and plate are obtained by cold work between solution treating and aging. The T81 condition is obtained by modifications at the rolling mill of the basic T8 condition material, (Ref 8).

1.052 Forgings. Age F condition (as forged) to T5 condition 450F, 16 hours.

1.06 Hardness

1.061 Hardness of T5 forgings. At RT 53-62 RE (2). 67 RE (14).

1.062 This alloy hardens fully on heat treating in all commercial section sizes.

1.07 Forms and Conditions Available

1.071 Sheet and plate are available in the full commercial range of sizes in the T8 condition but are limited to the thickness range of 0.125 to 0.312 inch in the T81 condition.

1.072 Forgings are available in all commercial sizes and generally are in the T5 condition.

1.08 Melting and Casting Practice

1.081 Magnesium melting practice for ingots comprises alloying and melting in iron pots under flux and continuous casting of ingots up to about 28 inches diameter.

1.09 Special Considerations

1.091 Alloys containing thorium require dust and fume control to prevent radiation poisoning. Normal dust control for fire hazard during grinding is satisfactory. Welding requires local exhaust of the fumes.

1.092 AEC license is required for fabrication and application of this alloy.

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range. Solidus temp: 1121F
Liquidus temp. 1202F,
(Ref 8)(Ref 16).

2.012 Phase changes. Alloy is subject to precipitation.

2.013 Thermal conductivity.
At RT. 79.2 Btu ft per (hr sq ft F).
At 600F. 81.7 Btu ft per (hr sq ft F),
(Ref 8).

2.014 Thermal expansion, Figure 2.014.

2.015 Specific heat, Figure 2.015.

2.016 Diffusivity, Figure 2.016

2.02 Other Physical Properties

2.021 Density. 0.642 lb per cu in
1.776 gr per cu cm,
(Ref 10)(Ref 15).

2.022 Electrical resistivity, Figure 2.022.

2.023 Magnetic properties. Alloy is non-magnetic.

2.024 Emissivity.

2.025 Damping capacity, Figure 2.025.

2.026 Ignition temperature (estimated) 1180 to 1200F, (Ref 8).

2.03 Chemical Properties

(See also AZ31B).

2.031 General. The base metal salt water corrosion resistance of the wrought magnesium thorium alloys is somewhat better than that of other wrought and cast magnesium alloys. HM21A is believed not to be susceptible to stress corrosion. No failures have occured in T8 sheet specimens exposed to a rural environment for over 7 years when stressed to 75 percent of F_{ty}. Surface preparation of these specimens consisted of acetic nitrate pickle plus abrasive cleaning with #100 grit aloxite cloth, (Ref 1) (Ref 15).

2.04 Nuclear Properties

2.041 Alloy is slightly radioactive, equivalent to a watch dial.

2.042 The manganese content and resulting high nuclear cross section make this alloy unsuitable for applications where nuclear shielding is undesirable.

Mg	
2	Th
0.8	Mn

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3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS specified mechanical properties, Table 3.011.

TABLE 3.011

Source	AMS 4390					AMS 4383	AMS 4363A			
Form	Sheet, Plate					Sheet, Plate	Die Forgings	Ring Forgings		
Condition	T8					T81	T5	T5		
Thickness, inch	0.016 to 0.250	0.250 to 0.500	0.500 to 1.000	1.000 to 2.000	2.000 to 3.000	0.125 to 0.312	up to 4.000	All	up to 2.000	over 2.000
Direction							Parallel to Flow	Circum.	Axial	Axial
F_{tu}, min, ksi	33	32	30	30	30	34	33	32	28	26
F_{ty}, min, ksi	18	21	21	21	21	25	25	26	13	10
F_{cy}, min, ksi	15	20	17	15	14	22				
e(2 in), min, percent	6	6	6	6	6	4	3	4	6	6

3.02 Mechanical Properties At Room Temperature

3.021 Tension. See also 3.031.

3.0211 Stress strain diagrams. See 3.0311.

3.0212 Typical mechanical properties of sheet and plate, Table 3.0212.

TABLE 3.0212

Source	(1)				
Alloy	HM21A				
Form	Sheet and Plate				
Condition	T8				
Thickness, inch	0.016 to 0.250	0.250 to 0.500	0.500 to 1.000	1.000 to 2.000	2.000 to 3.000
F_{tu}, ksi L	36	37	35	34	34
T	35	39	37	37	39
min	33	32	30	30	30
F_{ty}, ksi L	28	30	28	25	26
T	24	28	26	27	28
min	18	21	21	21	21
F_{cy}, ksi L	21	24	22	20	18
T	20	25	23	21	20
min	15	20	17	15	14
e(2 in), percent					
L	11	11	12	11	10
T	17	14	17	13	11
min	6	6	6	6	6

3.0213 Minimum design properties for T81 sheet and plate, Table 3.0213.

TABLE 3.0213

Source	(8)	
Alloy	HM21A	
Form	Sheet and Plate	
Condition	T81	
Thickness, inch	0.125 to 0.250	0.250 to 0.312
F_{tu}, ksi, min	33	34
F_{ty}, ksi, min	25	25
e(2 in), percent	4	4
F_{cy}, ksi, min	22	22

3.0214 Average mechanical properties of rolled rings produced from upset blanks, Table 3.0214.

TABLE 3.0214

Source	(9)			
Alloy	HM21A			
Form	Rolled Rings from Upset Blanks			
Condition	T5			
	Orientation	Rolling Reduction 20 Percent	40 Percent	60 Percent
F_{tu}, ksi	Tang	35	39	40
	Axial	34	34	36
	Radial	34	36	36
F_{ty}, ksi	Tang	29	33	34
	Axial	14	18	23
	Radial	13	14	17
e, percent	Tang	9	7	8
	Axial	10	11	9
	Radial	14	15	12
F_{cy}, ksi	Tang	16	18	21
	Axial	15	15	15
	Radial	15	18	22

3.0215 Average mechanical properties of rolled rings produced directly from cast blanks, Table 3.0215.

TABLE 3.0215

Source	(9)			
Alloy	HM21A			
Form	Rolled Rings from Cast Blanks			
Condition	T5			
	Orientation	Rolling Reduction		
		20 Percent	40 Percent	60 Percent
F_{tu}, ksi	Tang	31	34	37
	Axial	28	31	34
	Radial	30	33	33
F_{ty}, ksi	Tang	22	27	30
	Axial	16	20	23
	Radial	12	12	16
e, percent	Tang	2	5	5
	Axial	3	6	5
	Radial	9	12	9
F_{cy}, ksi	Tang	13	15	20
	Axial	13	15	19
	Radial	16	17	22

3.0216 Effect of exposure to elevated temperature on tensile properties of sheet at room temperature, Figure 3.0216.

3.022 Compression, (See Tables 3.01, 3.0212, 3.0213, 3.0214 and 3.0215).

3.023 Impact.

3.0231 Charpy V Notch impact strength of T5 forgings at room temperature. 5.2 ft lbs, (Ref 2).

3.024 Bending.

3.025 Torsion and shear.

3.0251 Room temperature shear properties of T8 sheet and plate, Table 3.0251.

TABLE 3.0251

Source	(1)				
Alloy	HM21A				
Form	Sheet and Plate (a)				
Condition	T8				
Thickness, inches	0.016 to 0.250	0.250 to 0.500	0.500 to 1.000	1.000 to 2.000	2.000 to 3.000
F_{su}, ksi L	25	26	24	24	24
T	24	27	26	26	27
min	21	20	19	19	19

(a) Data given are typical and minimum properties are not guaranteed.

3.026 Bearing.

3.0261 Room temperature bearing properties of T8 sheet and plate, Table 3.0261.

3.027 Stress concentration.

3.0271 Notch properties.

3.0272 Fracture toughness.

3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures

3.031 Tension.

3.0311 Stress strain diagrams.

3.03111 Tensile stress strain curves for sheet in T8 condition, Figure 3.03111.

3.03112 Tensile stress strain curves for sheet in T81 condition, Figure 3.03112.

3.0312 Effect of test temperature on tensile properties of sheet in condition T8, Figure 3.0312.

3.0313 Effect of test temperature on tensile properties of plate in T8 condition, Figure 3.0313.

3.0314 Effect of test temperature on tensile properties of sheet and plate in the T81 condition, Figure 3.0314.

3.0315 Effect of test temperature on tensile properties of forgings, Figure 3.0315.

3.0316 Effects of test temperature and test direction on tensile properties of forgings, Figure 3.0316.

3.0317 Effects of forging temperature and test temperature on tensile properties, Figure 3.0317.

3.0318 Effect of strain rate on tensile properties of sheet at various test temperatures, Figure 3.0318.

3.032 Compression.

3.0321 Compressive stress–strain curves for sheet in T8 condition, Figure 3.0321.

3.0322 Effect of test temperature on compressive yield strength of sheet, Figure 3.0322.

3.0323 Effect of test temperature on compressive yield strength of plate, Figure 3.0323.

3.033 Impact.

3.034 Bending.

3.035 Torsion and shear.

3.0351 Effect of test temperature on shear strength of sheet in T8 condition, Figure 3.0351.

3.0352 Effect of test temperature on shear strength of plate in T8 condition, Figure 3.0352.

3.036 Bearing.

3.0361 Effect of test temperature on bearing properties of sheet in T8 condition, Figure 3.0361.

3.0362 Effect of test temperature on bearing properties of plate in T8 condition, Figure 3.0362.

3.037 Stress concentration.

3.0371 Notch properties.

3.0372 Fracture toughness.

3.038 Combined properties.

Mg
2 Th
0.8 Mn

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TABLE 3.0261

Source	(1)				
Alloy	HM21A				
Form	Sheet and Plate (a)				
Condition	T8				
Thickness, inches	0.016 to 0.250	0.250 to 0.500	0.500 to 1.000	1.000 to 2.000	2.000 to 3.000
(e/d = 1.5)					
F_{bru}, ksi L	55	57	53	52	52
T	53	61	57	57	61
min	47	45	43	43	43
F_{bry}, ksi L	39	42	40	38	36
T	38	43	41	39	38
min	29	35	31	29	27
(e/d = 2.0)					
F_{bru}, ksi L	65	67	63	61	61
T	63	71	67	67	71
min	56	54	52	52	52
F_{bry}, ksi L	39	42	40	38	36
T	38	43	41	39	38
min	29	35	31	29	27

(a) Data given are typical and minimum properties are not guaranteed.

Mg	
2	Th
0.8	Mn

HM 21 A

3.04 Creep and Creep Rupture Properties

3.041 100 hour creep and total strain data for sheet and forgings, Table 3.041.

TABLE 3.041

Source		(1)(2)(10)			
Condition	Test Direction	Test Temp F	100 Hr Strength, ksi Creep 0.1 Percent	Total Strain 0.2 Percent	0.5 Percent
		≤ 0.125 In Sheet			
T8	-	300	14.9	12.0	15.6
	-	400	13.3	11.4	13.5
	-	500	8.0	7.0	9.0
	-	600	5.0	5.0	6.0
	-	700	2.3	2.6	3.3
		1 In Disk Forged at 700F			
T5	-	400	18.0	12.5	19.0
	-	500	12.0	9.5	13.5
	-	600	7.7	7.0	9.0
	-	700	3.7	3.8	5.4
		1 In Disk Forged at 1000F			
T5	-	400	13.8	11.2	15.0
	-	500	12.0	9.0	13.5
	-	600	5.4	5.3	6.6
	-	700	2.6	2.6	2.9
		Production Forgings			
T5	Axial (a)	400	11.0	9.5	12.0
		600	8.0	7.2	8.0
		700	3.1	3.1	3.3
	Trans (a)	400	11.0	9.4	12.0
		600	7.6	6.9	8.2
	Radial (b)	700	3.5	3.5	3.9
		400	13.0	11.0	15.0
		600	6.0	6.0	6.2
		700	3.4	3.2	3.6

(a) Specimens taken from forged wheel.
(b) Specimens taken from forged impeller fin.

3.042 Stresses for 0.1 percent creep strain in 100 hours for sheet, Figure 3.042.

3.043 Isochronous stress strain curves.

3.0431 Isochronous stress strain curves for T8 sheet at 400 to 900F, Figure 3.0431.

3.0432 Isochronous stress strain curves for T81 sheet at 600F, Figure 3.0432.

3.0433 Isochronous stress strain curves for T81 sheet at 700F, Figure 3.0433.

3.0434 Isochronous stress strain curves for T81 sheet at 800F, Figure 3.0434.

3.0435 Isochronous stress strain curves for T81 sheet at 900F, Figure 3.0435.

3.0436 Isochronous stress strain curves for forgings at 400 to 700F, Figure 3.0436.

3.05 Fatigue Properties

3.051 S-N curves for sheet tested at room temperature, 400F and 600F, Figure 3.051.

3.052 S-N curves for smooth and notched specimens from forgings tested at room temperature, Figure 3.052.

3.053 S-N curves for smooth specimens from forgings tested at room temperature, 400F and 600F, Figure 3.053.

3.06 Elastic Properties

3.061 Poisson's Ratio. 0.35. (Ref 10).

3.062 Modulus of elasticity.

3.0621 Effect of test temperature on modulus of elasticity. Figure 3.0621.

3.063 Modulus of rigidity. 2400 ksi. (Ref 10).

4. FABRICATION

4.01 Formability

4.011 General. Magnesium alloys possess excellent formability at elevated temperatures and many operations requiring relatively mild deformation around generous radii (as in bending) can be done at room temperature for HM21A, no significant change in bending radius occurs from room temperature to 500F. Parts requiring bends sharper than can be made at room temperature should be bent at 600 to 800F. In drawing operations the sheet requires die temperatures of 700 to 750F with drawing speeds up to 12 inches per minute. Punch temperatures of 350 to 400F are recommended and generous radii on drawing dies should be employed, (Ref 10)(Ref 15).

4.012 Hot working temperature range. 650 to 800F, (Ref 16).

4.013 Die temperature of electrically heated dies for hot dimpling is 850F, provided that die contact with sheet does not exceed 5 seconds, (Ref 10).

4.014 Suggested bend factors, Figure 4.014.

4.015 Forging of alloy is usually done in closed dies and press forging is the preferred method, (Ref 10).

4.02 Machining and Grinding

4.021 HM21A has excellent machining characteristics. High speed tools are normally suitable but carbide tipped tools are preferred. Very good finish cuts are obtained with diamond tools. Tools must be kept sharp. Dry machining is recommended and compressed air is sometimes used for cooling. If liquid coolant is used, it should be mineral oil, (Ref 10).

4.022 Drilling. General purpose steel drills can be used for holes up to 5 times drill diameter. Speeds can vary from 300 to 2000 fpm with feeds from 0.005 to 0.050 inch per revolution, (Ref 10).

4.023 Milling Turning. Moderate feeds and depth of cut, high cutting speeds, large rake angles and ample chip clearance are desirable, (see reference 10 for more detailed information).

4.024 Grinding. Rough grinding should employ medium to course grain wheels. Dust collection systems (wet type) specifically recommended for magnesium must be used.

4.03 Welding

4.031 General. Alloy exhibits good weldability with practically no tendency toward weld cracking. EZ33A composition is recommended for arc welding. The alloy is also readily spot welded. Detailed information on weldability of this alloy is given in reference 11.

4.04 Heat Treatment

See AZ63A.

4.05 Surface Treatment

4.051 General. Surface treatments for magnesium alloys are many and are used in numerous combinations. They are applied for corrosion protection, electrical resistance or abrasion resistance. Excellent detailed discussions pertaining to surface treatment of magnesium alloys are given in references 6.7 and 10.

Mg	
2	Th
0.8	Mn

HM 21 A

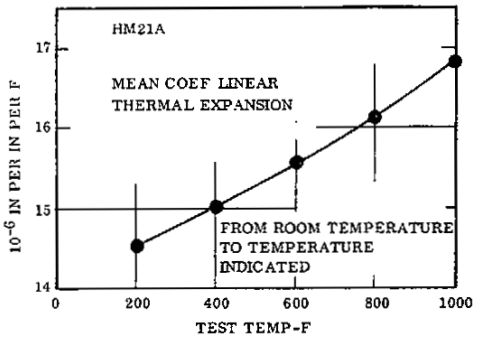

FIG. 2.014 THERMAL EXPANSION.

(8)

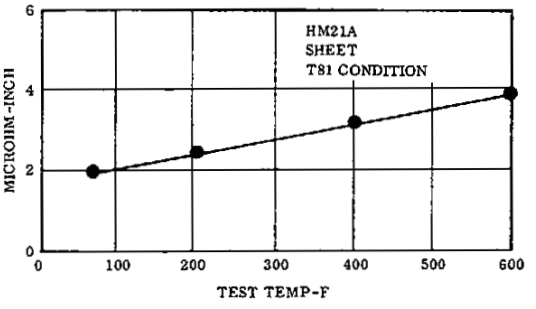

FIG. 2.022 ELECTRICAL RESISTIVITY.

(8)

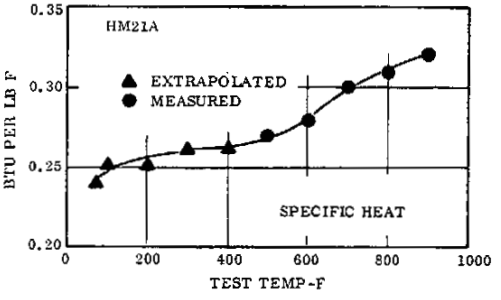

FIG. 2.015 SPECIFIC HEAT.

(10)

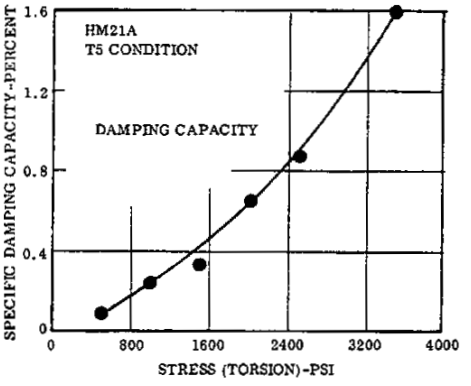

FIG. 2.025 DAMPING CAPACITY.

(14)

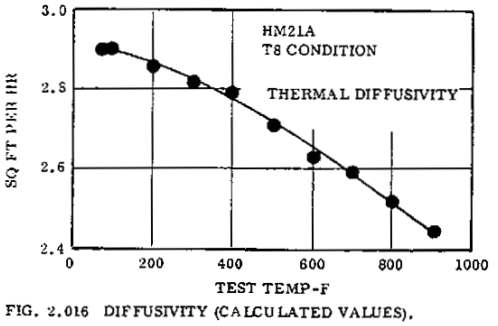

FIG. 2.016 DIFFUSIVITY (CALCULATED VALUES).

(10)

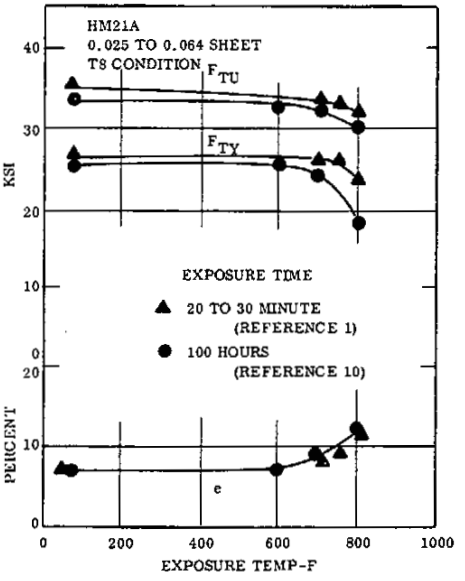

FIG. 3.0216 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF SHEET AT ROOM TEMPERATURE.

(1) (10)

	Mg
2	Th
0.8	Mn

HM 21 A

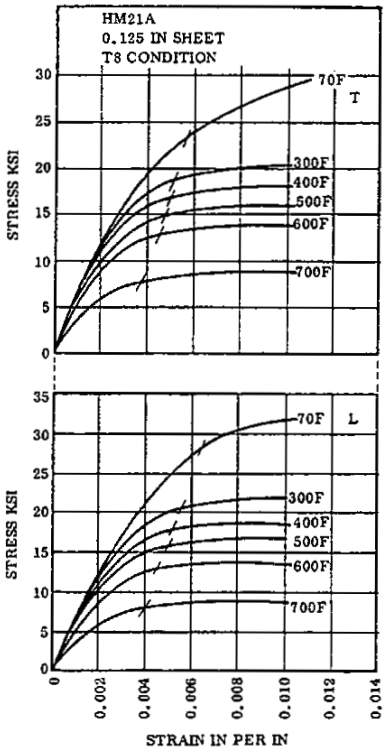

FIG. 3.03111 TENSILE STRESS STRAIN CURVES FOR SHEET IN T8 CONDITION.

(10)

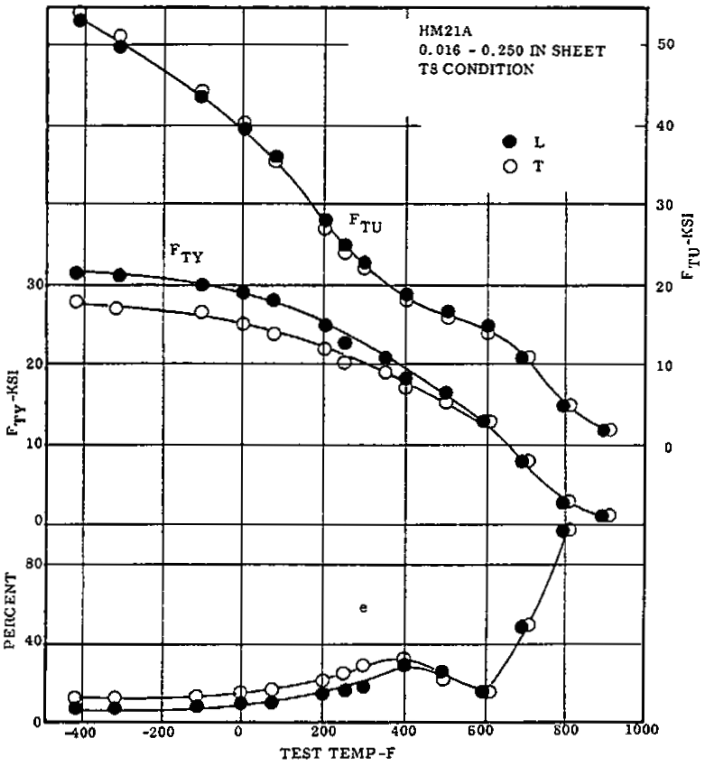

FIG. 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET IN CONDITION T8. (1)

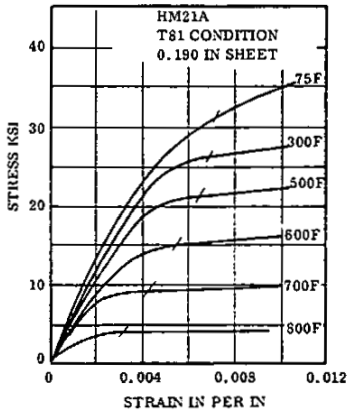

FIG. 3.03112 TENSILE STRESS STRAIN CURVES FOR SHEET IN T81 CONDITION.

(10)

Mg	
2	Th
0.8	Mn

HM 21 A

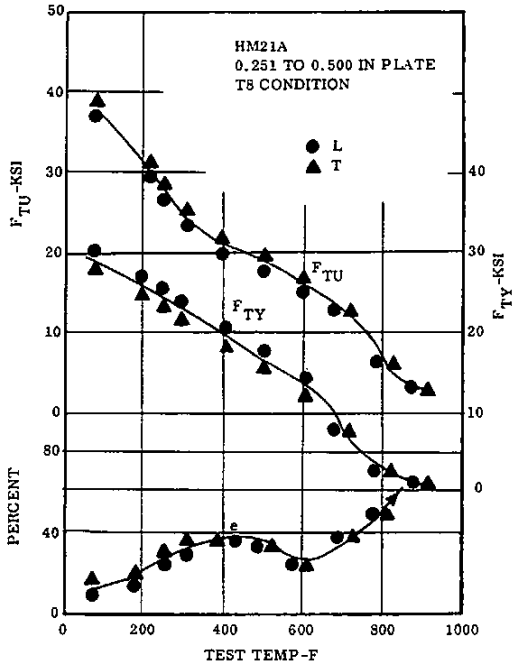

FIG. 3.0313 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF PLATE IN T8 CONDITION. (1)

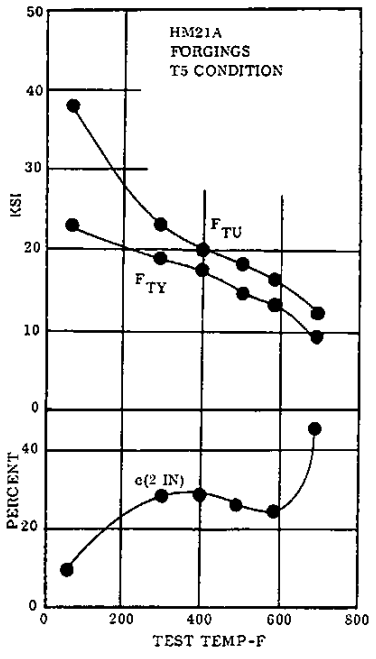

FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF FORGINGS. (10)

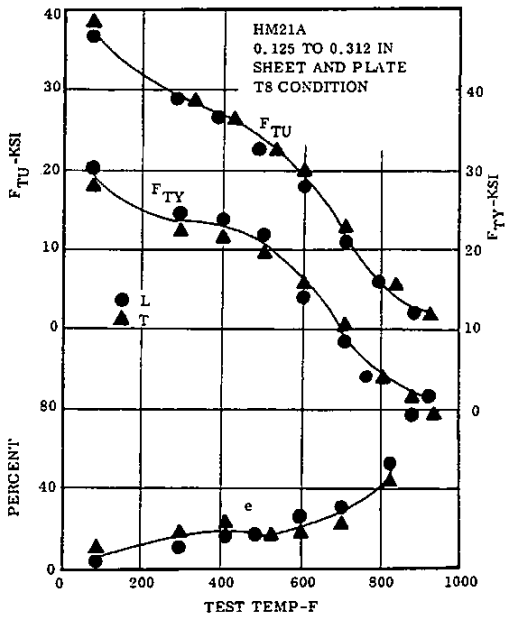

FIG. 3.0314 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET AND PLATE IN THE T81 CONDITION. (8)

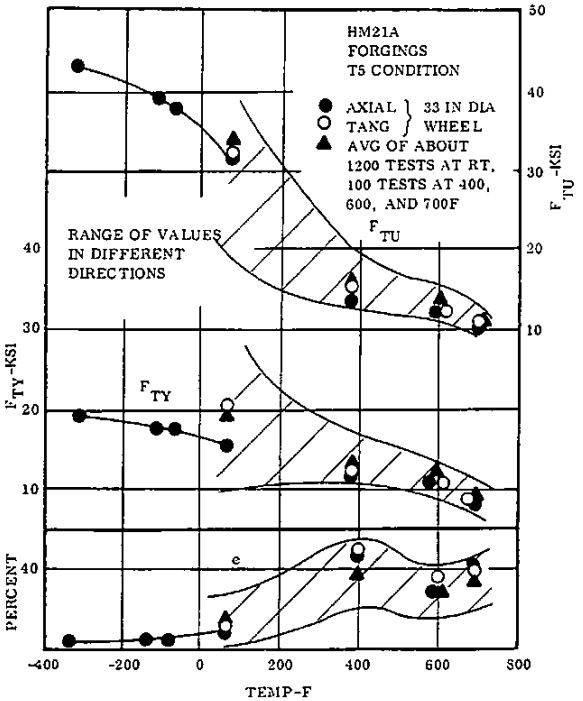

FIG. 3.0316 EFFECTS OF TEST TEMPERATURE AND TEST DIRECTION ON TENSILE PROPERTIES OF FORGINGS.

(2)

	Mg
2	Th
0.8	Mn

HM 21 A

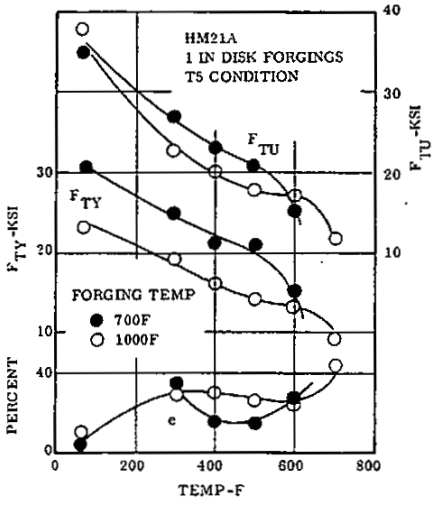

FIG. 3.0317 EFFECT OF FORGING TEMPERATURE AND TEST TEMPERATURES ON TENSILE PROPERTIES.

(2)

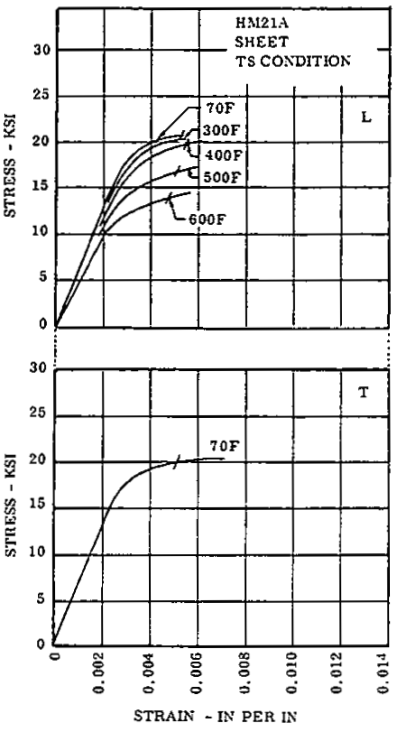

FIG. 3.0321 COMPRESSIVE STRESS-STRAIN CURVES FOR SHEET IN T5 CONDITION.

(10)

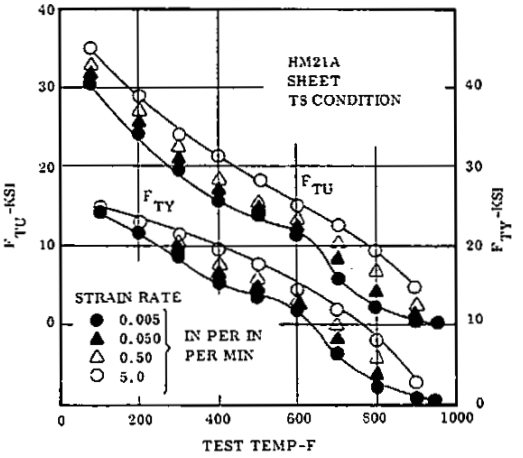

FIG. 3.0318 EFFECT OF STRAIN RATE ON TENSILE PROPERTIES OF SHEET AT VARIOUS TEST TEMPERATURES.

(10)

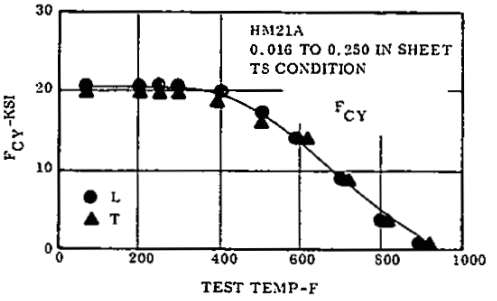

FIG. 3.0322 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF SHEET.

(1)

Mg	
2	Th
0.8	Mn

HM 21 A

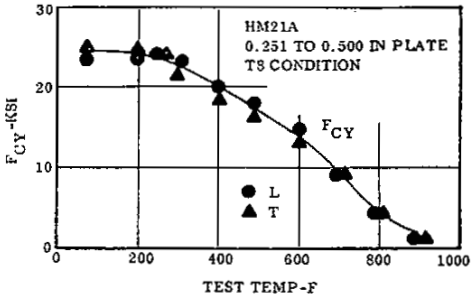

FIG. 3.0323 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF PLATE.

(1)

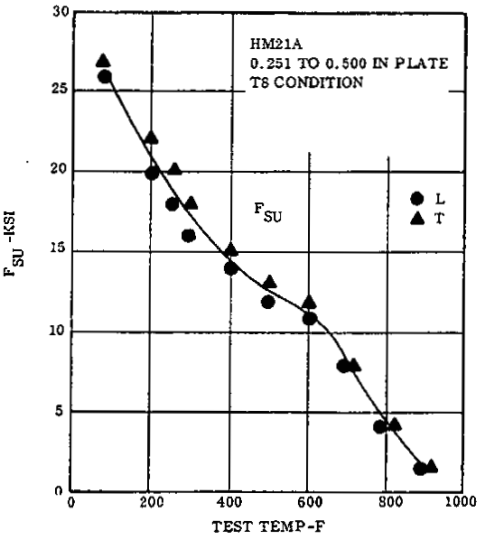

FIG. 3.0352 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF PLATE IN T8 CONDITION.

(1)

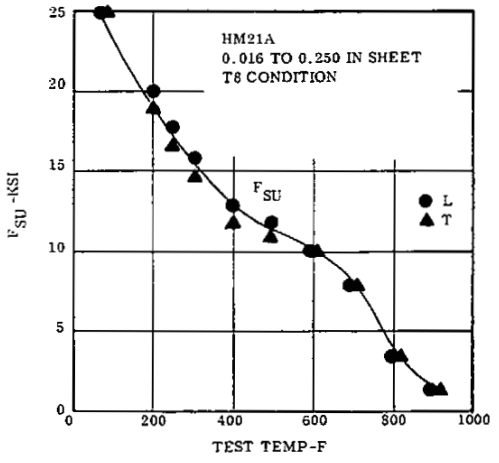

FIG. 3.0351 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF SHEET IN T8 CONDITION.

(1)

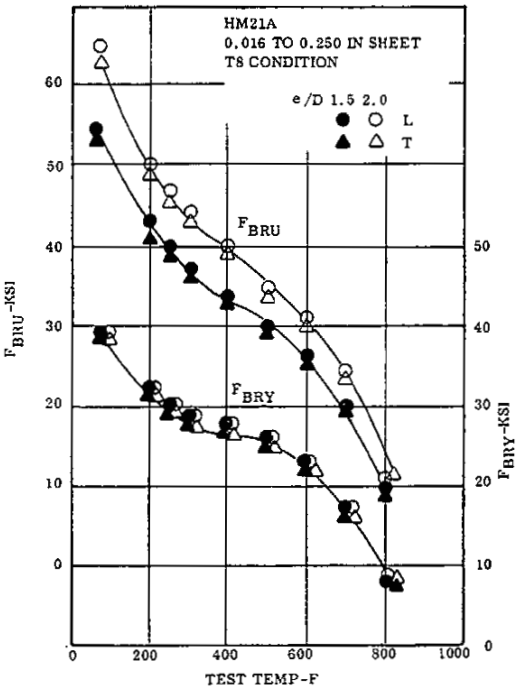

FIG. 3.0361 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF SHEET IN T8 CONDITION.

(1)

Mg
2 Th
0.8 Mn

HM 21 A

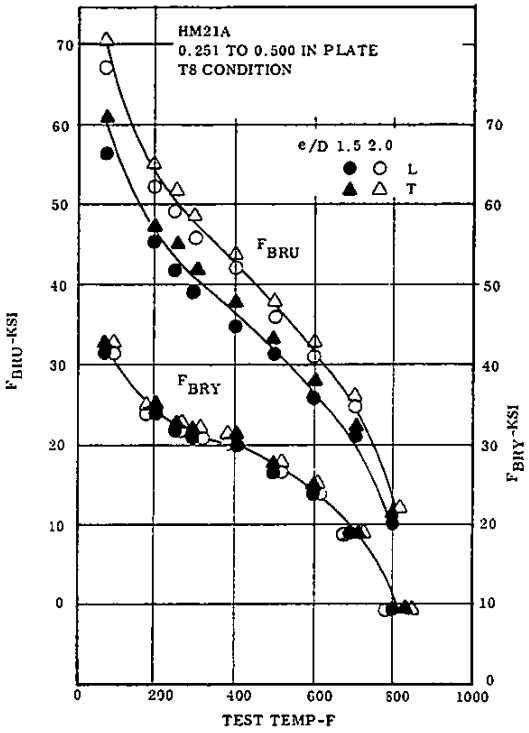

FIG. 3.0362 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF PLATE IN T8 CONDITION.

(1)

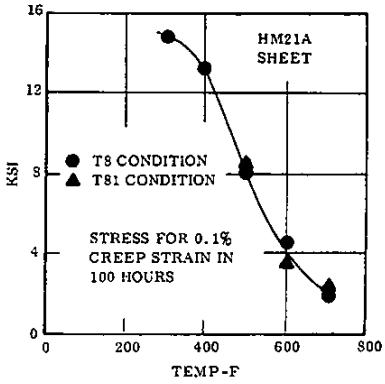

FIG. 3.042 STRESSES FOR 0.1 PERCENT CREEP STRAIN IN 100 HOURS FOR SHEET.

(7)

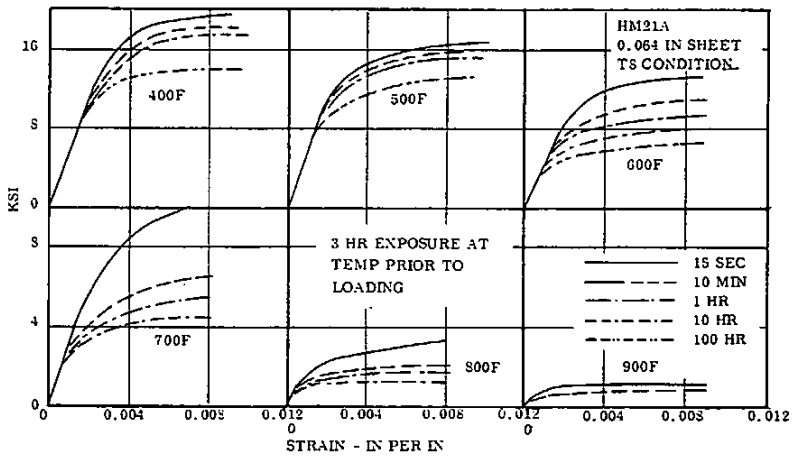

FIG. 3.0431 ISOCHRONOUS STRESS STRAIN CURVES FOR T8 SHEET AT 400 TO 900F.

(10)

	Mg
2	Th
0.8	Mn

HM 21 A

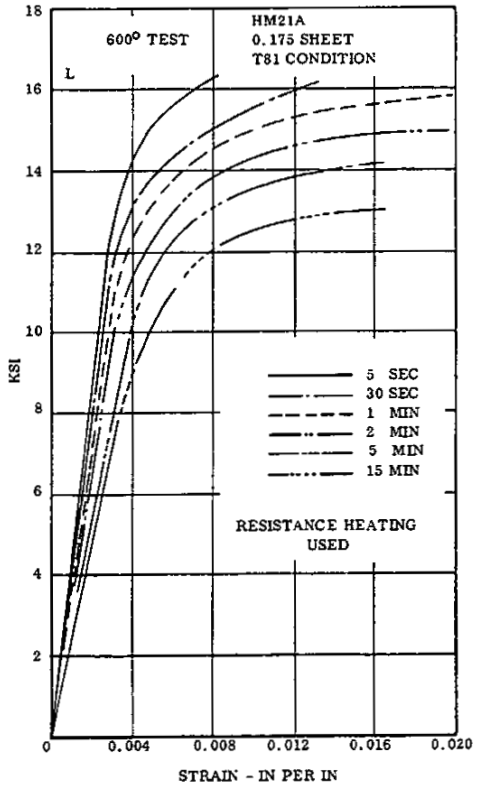

FIG. 3.0432 ISOCHRONOUS STRESS STRAIN CURVES FOR T81 SHEET AT 600F.

(8)

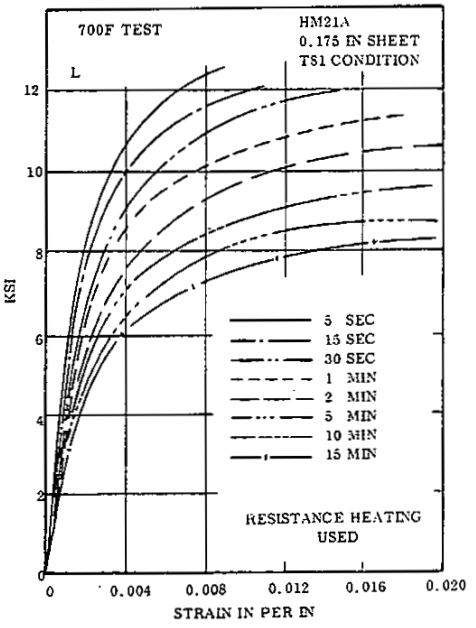

FIG. 3.0433 ISOCHRONOUS STRESS STRAIN CURVES FOR T81 SHEET AT 700F.

(8)

	Mg
2	Th
0.8	Mn

HM 21 A

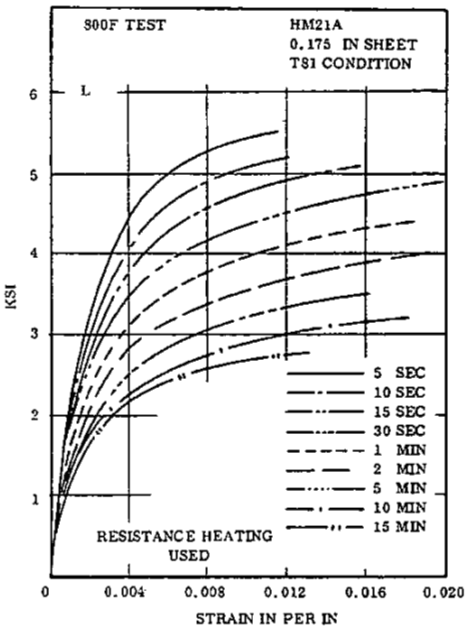

FIG. 3.034 ISOCHRONOUS STRESS STRAIN CURVES FOR T81 SHEET AT 800F.

(8)

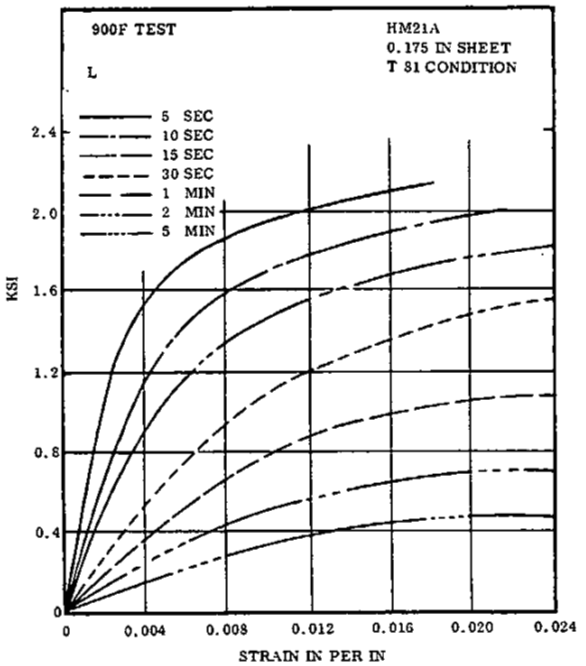

FIG. 3.0435 ISOCHRONOUS STRESS STRAIN CURVES FOR T81 SHEET AT 900F.

(8)

Mg
2 Th
0.8 Mn

HM 21 A

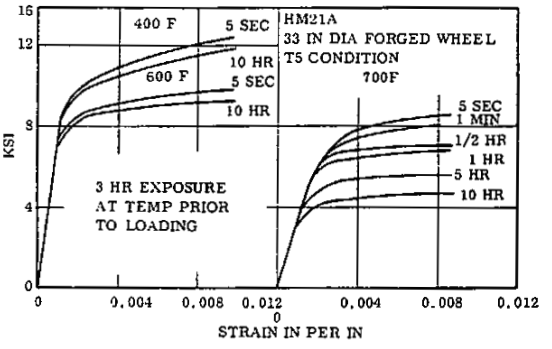

FIG. 3.0436 ISOCHRONOUS STRESS STRAIN CURVES FOR FORGINGS AT 400 TO 700F.

(10)

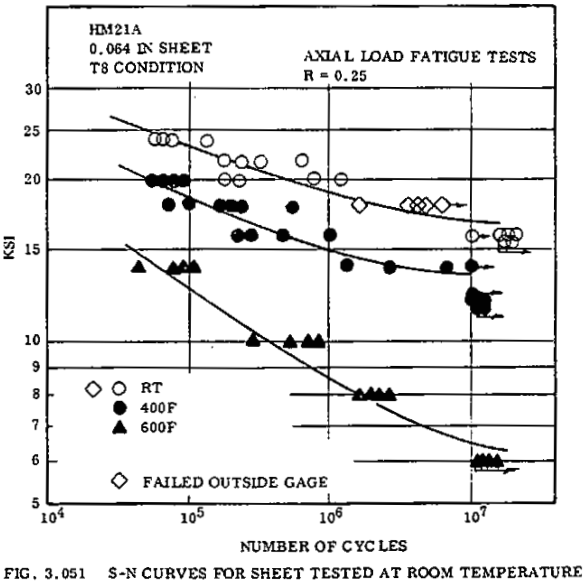

FIG. 3.051 S-N CURVES FOR SHEET TESTED AT ROOM TEMPERATURE, 400F AND 600F.

(1)

Mg	
2	Th
0.8	Mn

HM 21 A

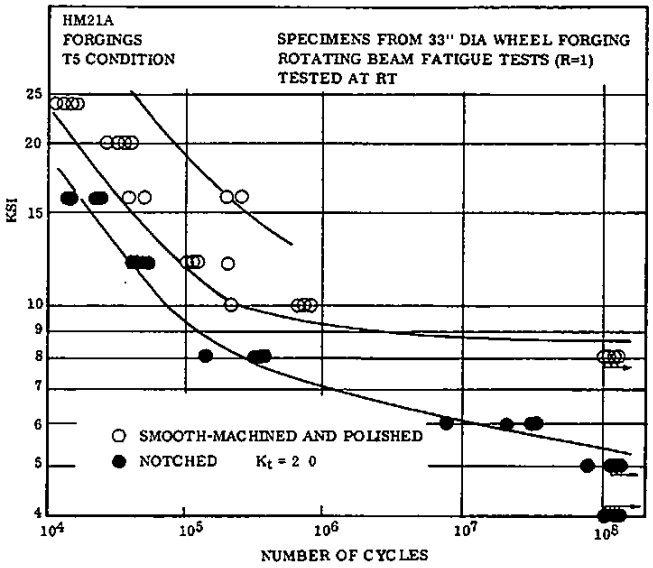

FIG. 3.052 S-N CURVES FOR SMOOTH AND NOTCHED SPECIMENS FROM FORGINGS TESTED AT ROOM TEMPERATURE.
(2)

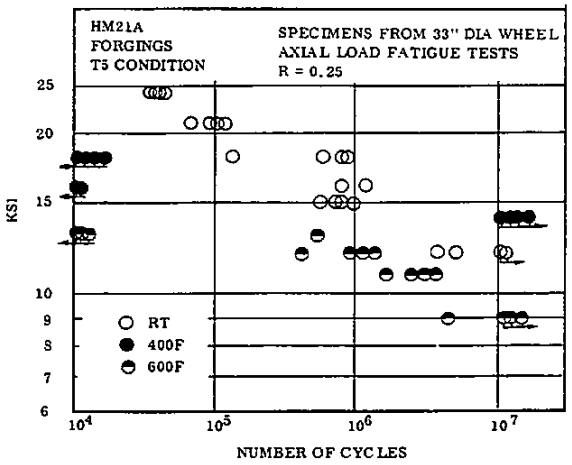

FIG. 3.053 S-N CURVES FOR SMOOTH SPECIMENS FROM FORGINGS TESTED AT ROOM TEMPERATURE, 400F AND 600F.
(2)

	Mg
2	Th
0.8	Mn

HM 21 A

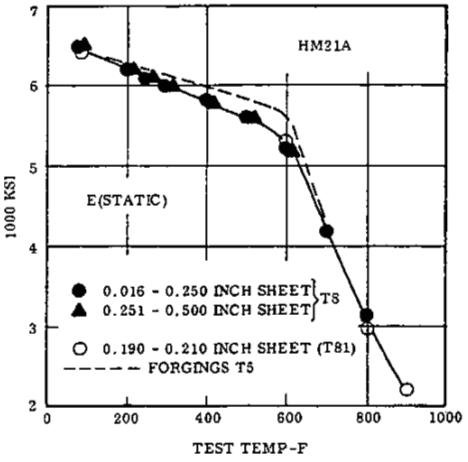

FIG. 3.0621 EFFECT OF TEST TEMPERATURE ON MODULUS OF ELASTICITY.
(1)(2)(10)

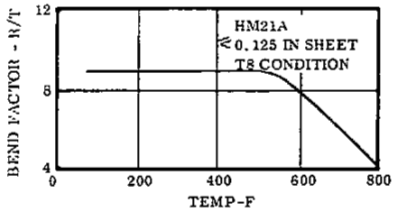

FIG. 4.014 SUGGESTED BEND FACTORS.
(10)

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