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THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021

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16. Abstract

The new high strength, heat treatable aluminum alloy 2021 has been evaluated by Manufacturing Research and Technology Division employing sheet and plate (0.063 to 0.50" (0.16-1.27cm) thick) from the first lot of plant-fabricated material. Tensile properties were determined for tempers produced by the manufacturer and after subjection to extensive thermal processing over the temperature range from 315°F (430°K) for artificial aging, up to 995°F (808°K) for solution heat treatment, and cooled at various rates. Tensile tests confirm high strengths in the heat treated and aged temper, -T8E31*, as produced by the manufacturer and, -T62, as produced in our studies.

*Now designated -T81

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*Now designated -T81

THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021

SUMMARY

Mechanical property data have been determined on sheet and plate of this new aluminum alloy in tempers produced by the manufacturer and after various thermal treatments that might be contemplated in a fabricating shop during manufacture of structural parts. The alloy develops high strength in the heat treated and aged temper. 2021 is quench sensitive and is responsive to other thermal and mechanical processing conditions such that specific recommended procedures are essential. Specific fabricating procedures will be required in the shop to assure satisfactory processing and production of high performance structures. No unusual problems are anticipated in introducing this new, high strength, heat treatable aluminum alloy into a reputable aircraft or aerospace shop. Some preliminary familiarization tests should be expected to fill in the learning curve as with any new material. This high-copper containing alloy may be viewed in general terms as a modified 2219-type having strengths equivalent to 2014 but improved weldability and resistance to stress corrosion cracking. Aluminum alloy 2021 shows promise for consideration for use in high strength structures.

INTRODUCTION

Aluminum Alloy 2021 was developed under NASA/MSFC Contract NAS8-5452, "Development of a High Strength Aluminum Alloy, Readily Weldable in Plate Thicknesses, and Suitable for Application at -423°F (20°K)". The new alloy offers a desirable combination of properties (Refs. 1, 2, 3 & 4) for space vehicle structures, i.e., strength equivalent to 2014-T6, about the same cryogenic toughness, but with improved resistance to stress corrosion cracking compared to 2014-T6 and weldability similar to 2219 with greater weld strength.

The basic composition of 2021 is similar to 2219 with small additions of cadmium (Cd) and tin (Sn). These alloying elements increase tensile properties above those for 2219 and affect other behavior characteristics but apparently do not degrade good weldability. Strengths of 2021 are not dependent upon cold work prior to aging to develop maximum values, hence strengths attained after complete heat treatment by the user may be equivalent to those developed by the manufacturer.

PURPOSE

The purpose of the work accomplished in MR&T Division, as described in this report, was to determine mechanical properties of the new alloy in the annealed (-0) and heat treated (-T8E31)* tempers as produced by the manufacturer and to determine response of the alloy to various thermal treatments that might be contemplated in a fabricating shop in applying the material to structural use.

MATERIAL AND PROCEDURE

Sheet and plate employed in this evaluation were samples from the first lots of material produced in the manufacturer's plant. Tensile test data were supplied by the manufacturer (Alcoa) for these -0 and -T8E31* tempers respectively (Table I). MSFC performed tensile tests on selected gages of sheet and plate as received. The major portion of our work however consisted of thermal treatment evaluation to determine the response of the material to various thermal treatments over the temperature range from solution heat treating on down to artificial aging or precipitation heat treatment.

RESULTS AND DISCUSSION

Evaluation of thermal treatment response of 2021 aluminum alloy sheet and plate show that:

1. Strengths increase with increasing solution heat treating temperature of 975 to 995°F (797-808°K). Maximum strengths developed were 80 ksi (56.2 kg/mm^2) TS, 73 ksi (51.3 kg/mm^2) YS with 5% El for sheet (-T62 Temper). See Table II (IIa), Figure 1.

(Manufacturer recommends a temperature of 985 $\pm$ 10°F, 802 $\pm$ 5°K).

2. Solution heat treating time of 1 hour soak at 985°F (802°K) for .063" (.16 cm) and .125" (.32 cm) sheet and 2 hrs. soak at 985°F (802°K) for .500" (1.27 cm) plate appear adequate on the basis of mechanical properties. See Table III (IIIa), Figures 3 & 4.

(Manufacturer recommends a minimum soaking time of 1 hr. and 2 hrs. respectively for these gages).

*Now designated -T81

3. Strengths decrease with decreasing quench rate in the order: cold water, liquid nitrogen (LN_2), boiling water and fan cooled. See Table II (IIa), Figure 2.

(Manufacturer recommends rapid quenching in cold water).

4. Quench sensitivity is greater for plate than for sheet. For the LN_2 quench, the tensile strength of the 0.5" (1.27 cm) plate $\simeq$ the yield strength of the 0.063" (0.16 cm) sheet, while for cold water quench, the tensile strength of the plate was higher than ($>$) the yield strength of the sheet. See Table II (IIa), Figure 2.

5. Strengths vary little with artificial aging temperatures of 315 to 335°F (430 - 441°K) for aging times of 16 to 24 hours. See Table III (IIIa), Figure 5.

(Manufacturer recommends aging at 325°F (436°K). The time at temperature depends on thickness, i.e., 16 hrs. for .063" (.16 cm) and 24 hrs. for .50" (1.27 cm) thick).

6. Reheating -T8E31 sheet and plate at 400°F (477°K) lowers strengths slightly, however, increasing reheating temperature to 750°F (672°K) followed by air cooling decreases strengths progressively. See Table IV (IVa), Figures 6 & 7.

7. Increasing reheating time from 5 min. to 30 min. for temperatures of 400 - 850°F (477 - 727°K), or up to 2 hrs. for 750°F (672°K), followed by air cooling has a relatively minor effect on further decreasing strengths of the original -T8E31 material. See Table IV (IVa), Figures 6 & 7.

8. Slow cooling in the furnace to 500°F (533°K) from reheating temperatures of 650 to 850°F (616 - 727°K) appreciably lowers strengths and increases % elongation of original -T8E31 material. Tensile strength was lowered more than yield strength. See Table IV (IVa), Figures 6 & 7.

9. Reheating -T8E31 temper material at 750°F (672°K) for 2 hrs. followed by slow cooling to 500°F (533°K) results in essentially completely annealed strengths. See Table IV (IVa), Figure 8.

(Manufacturer recommends (for complete annealing) heating at 775°F (686°K) for 2 - 3 hrs. and slow cooling at a rate of about 50°F (30°K) per hour down to 500°F (533°K). This is the same annealing practice used for alloys 2014, 2024 and 2219.)

10. Reheating -O temper sheet at temperatures of 400 - 550°F (477 - 561°K) had little effect on strengths. Higher reheating temperatures, 650 - 850°F (616 - 727°K), result in increased strengths when followed by air cooling but little change in strength when furnace cooled. See Table IV (IVa), Figure 9.

Variations in the high strengths obtained from one heat treating test to another (cf. Tables II & III) indicate that 2021 alloy material is responsive to variables in handling and hence suggest that thermal processing should be closely controlled in order to produce consistent strength and other properties.

A rerun of the quench rate evaluation test (Table II) shows reasonable consistency in values within the test. The improved elongation for the .063" (.16 cm) sheet compared with the previous test data confirms the suspicion that cold work introduced by flattening the warpage after quenching may adversely affect elongation. The improved strengths obtained in the rerun of slowly quenched .500" (1.27 cm) thick plate indicate that close control of processing can noticeably influence resultant properties. The quench sensitivity of alloy 2021 is readily shown by the strengths plotted in Figure 2. Quench rate also would be expected to influence corrosion behavior. The manufacturer's recommendation of "rapid quenching in cold water" appears to be well founded for alloy 2021.

Artificial aging at a temperature of 325°F $\pm$ 10°F (436°K $\pm$ 3°K) for periods of 16 to 24 hours produces relatively little variation in strengths for .063" (.16 cm) sheet and .500" (1.27 cm) plate. As shown in Figure 5, the tensile strength and elongation of sheet are generally higher than plate while the yield strength of the two gages may be comparable. Even though strengths may be relatively unaffected by these variations in aging, corrosion behavior might be readily affected by the aging procedure employed. Generally it is recognized that overaging aluminum alloys is associated with improved corrosion behavior. Thus the recommended thermal treatment is usually a compromise to provide a useful combination of strengths, corrosion behavior and other desired characteristics.

Cold work such as introduced by flattening or stretching between quenching and aging may affect (lower) strength and corrosion behavior of alloy 2021. A pre-aging treatment is employed in making the -T81 temper. This might be considered if any thought is given to forming 2021 in the "-W" temper shortly after quenching. Refer to Alcoa's Green Letter for further discussion concerning intermediate cold work, preaging and aging and refer directly to the manufacturer for the optimum practice based on the latest tests especially for heavy gage material.

CONCLUSIONS

These initial tests show that the new aluminum alloy 2021: (1) develops high strengths in the heat treated and aged temper, (2) is sensitive to quench rate and other processing conditions, and (3) shows promise for consideration for use in high strength structural components.

RECOMMENDATIONS

The new aluminum alloy 2021 should be evaluated on a more comprehensive basis considering all aspects of fabrication in order to provide realistic data for actual use of the material.

Consideration should be given to 2021 as a potential replacement for aluminum alloy 2014 on the basis of improved weldability and improved resistance to stress corrosion cracking and for 2219 on the basis of improved strength as shown below for various temperatures.

Alloy and Temper	Room Temperature			-320°F (77°K)			400°F (477°K)		
	TS ksi (kg/mm^2)	YS ksi (kg/mm^2)	El %	TS ksi (kg/mm^2)	YS ksi (kg/mm^2)	El %	TS ksi (kg/mm^2)	YS ksi (kg/mm^2)	El %
2219-T87	69 (48.5)	57 (40.1)	10	*83 (58.4)	61 (42.9)	15	34 (23.9)	25 (17.6)	20
2014-T651	70 (49.2)	60 (42.2)	13	80 (56.2)	53 (37.3)	28	16 (11.2)	13 (9.1)	35
2021-T81	73 (51.3)	63 (44.3)	9	91 (64.0)	75 (52.7)	10	32 (22.5)	28 (19.7)	23

* -T81 orig.

REFERENCES

1. Alcoa Green Letter, Aluminum Alloy 2021, dated April 1968.

2. Iron Age, dated June 27, 1968, Page 72, "Alloy 2021: Another Step Ahead?"

3. Metalworking News, dated December 23, 1968, Page 10, "Alcoa Develops Alloy for Rocket Structure".

4. Metal Progress, April 1969, Pages 7 - 8, "Two New Cryogenic Alloys Look Promising in Tests".

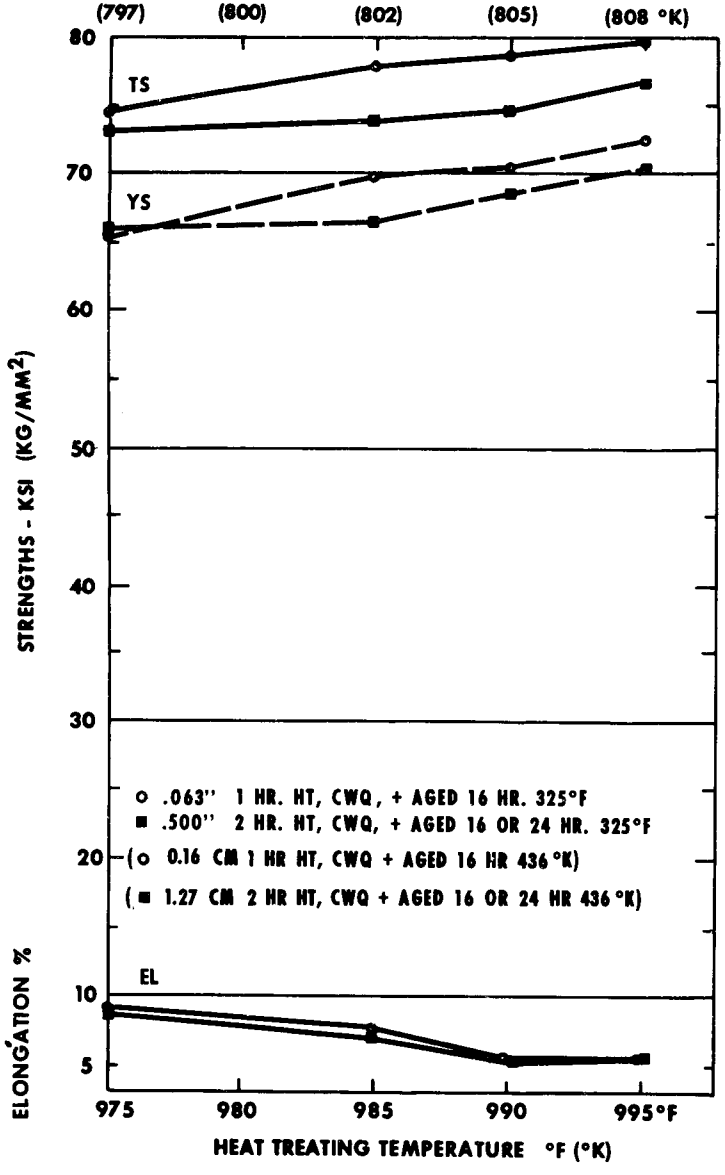

FIGURE 1 EP 5095 HEAT TREATING TEMPERATURE VS STRENGTHS OF 2021-T62 FROM -O SHEET & PLATE

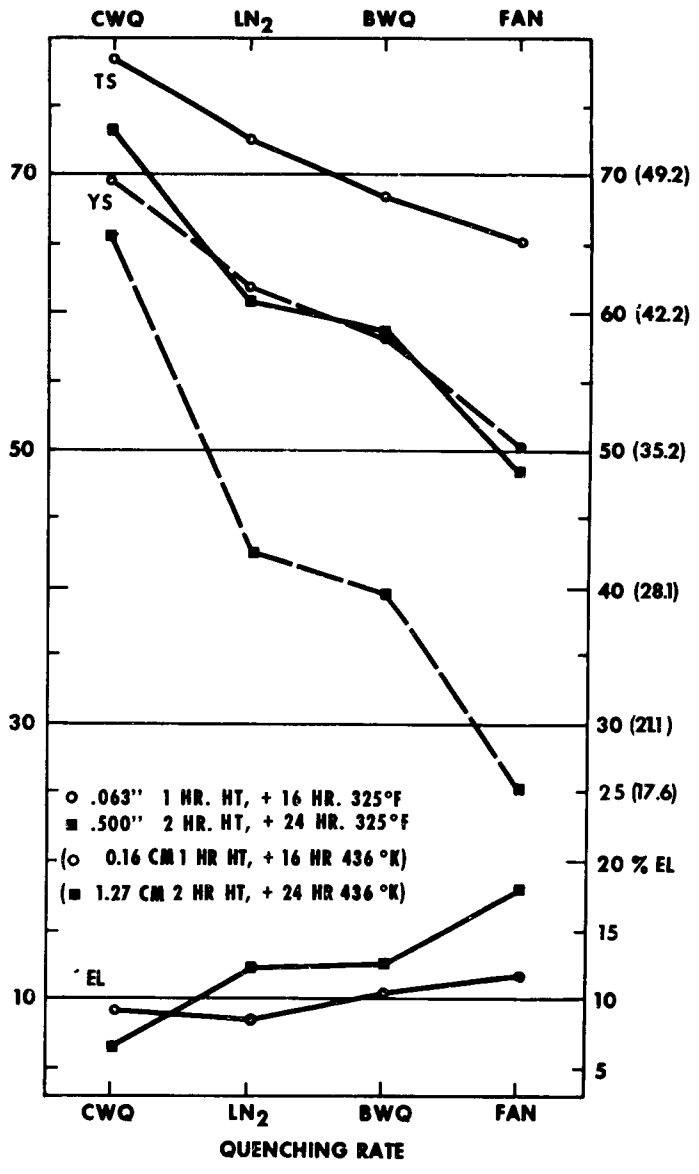

FIGURE 2 EP 5095 QUENCH RATE FROM 985°F (802 °K) VS STRENGTHS OF 2021-T62 FROM -O

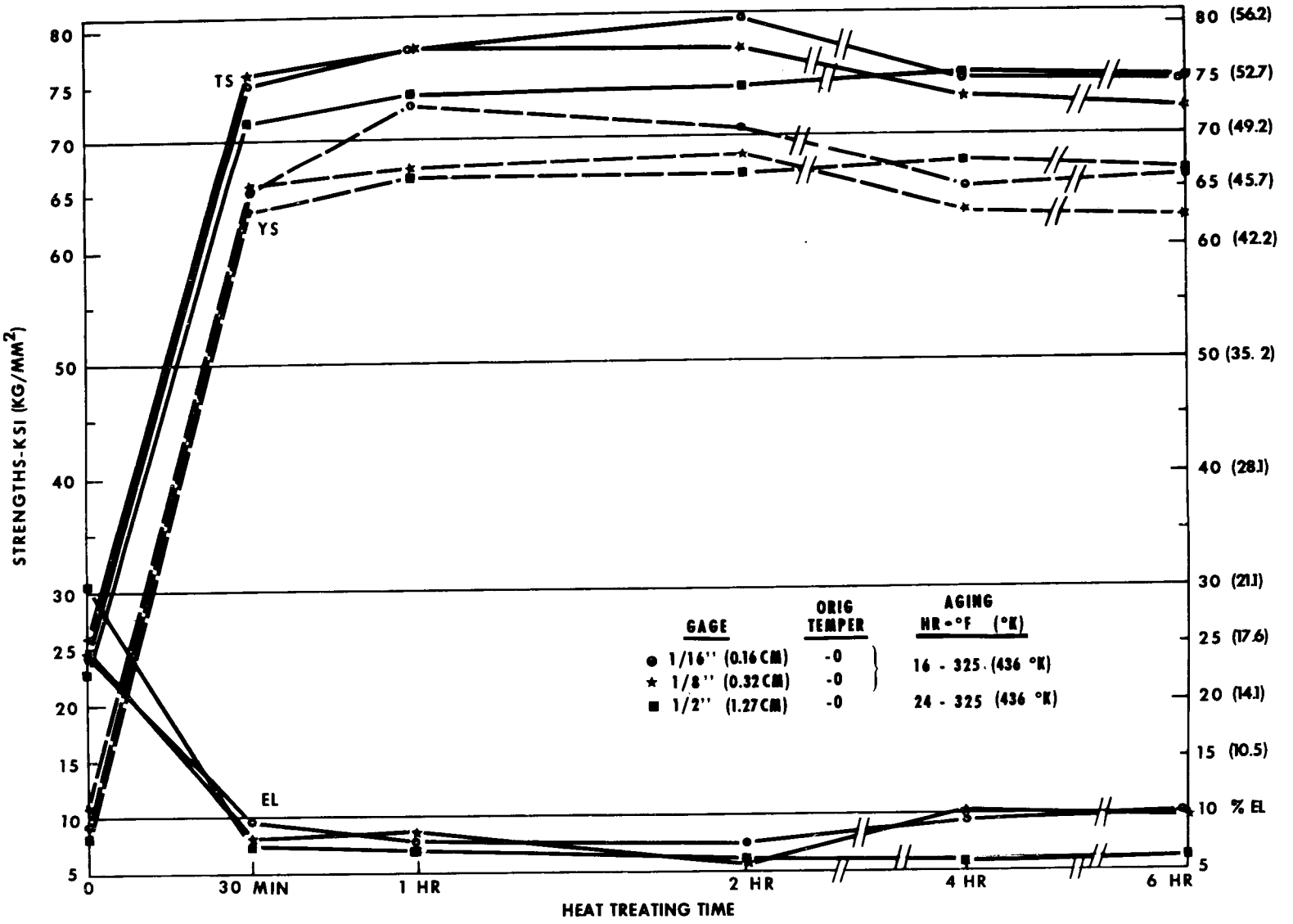

FIGURE 3 EP 5095 HEAT TREATING TIME AT 985°F(802 °K)VS STRENGTHS OF 2021-T62 FROM -0 SHEET & PLATE

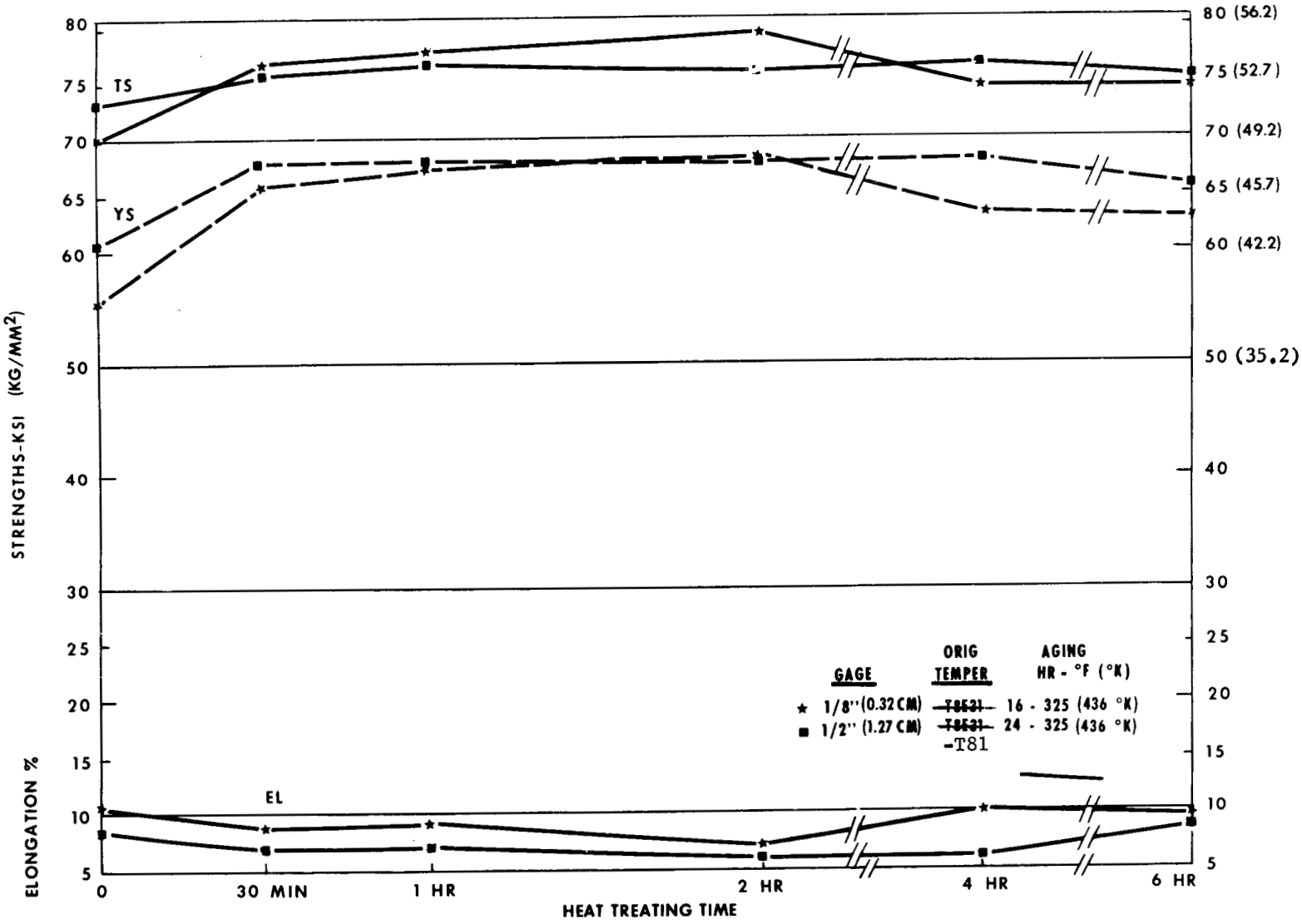

FIGURE 4 EP 5095 HEAT TREATING TIME AT 985°F (802 °K) VS STRENGTHS OF 2021-T62 FROM ~~-T8E31-~~ SHEET & PLATE -T81

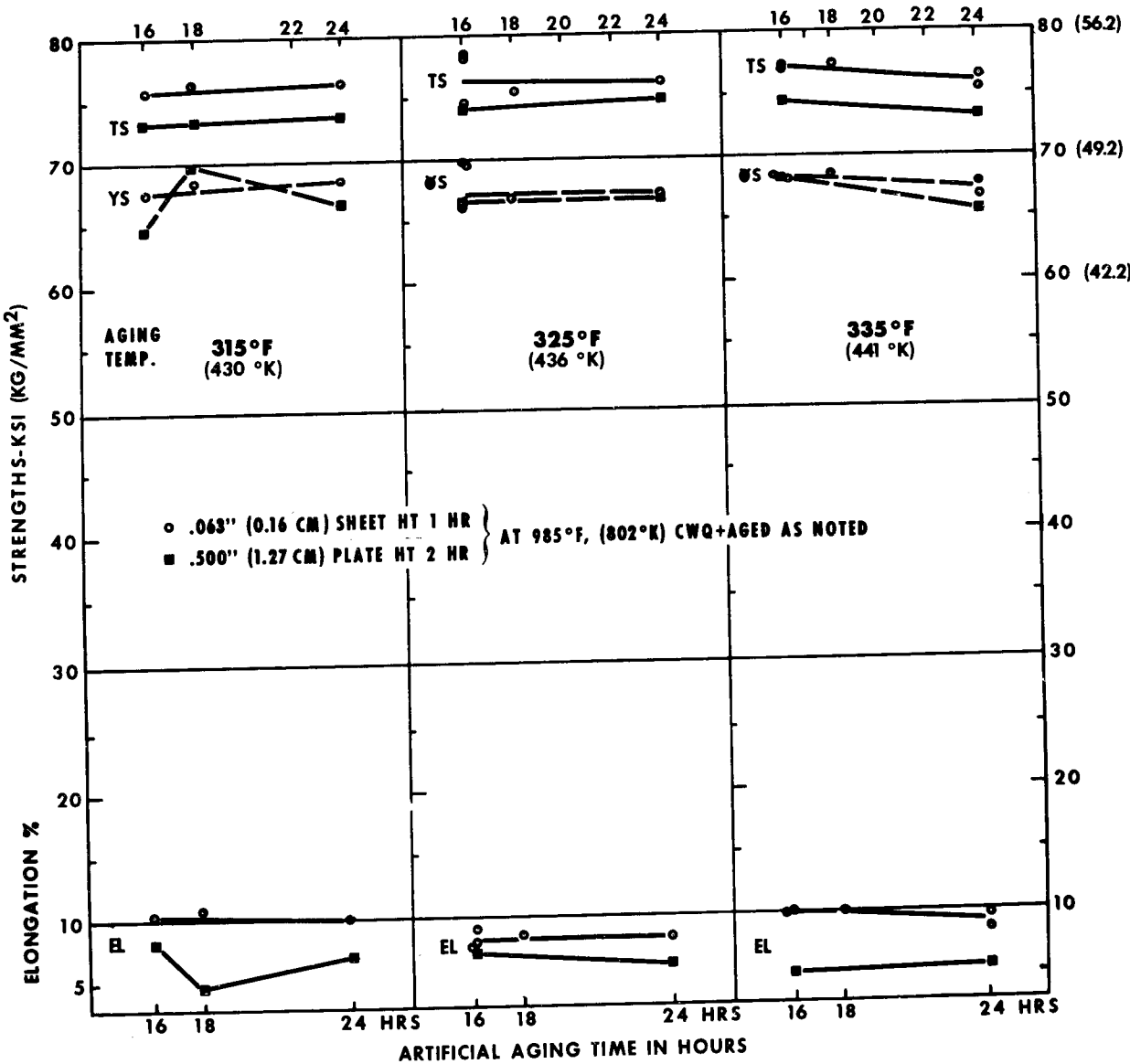

FIGURE 5 EP 5095 ARTIFICIAL AGING TEMPERATURE & TIME VS STRENGTHS OF 2021-T62 FROM-O SHEET & PLATE

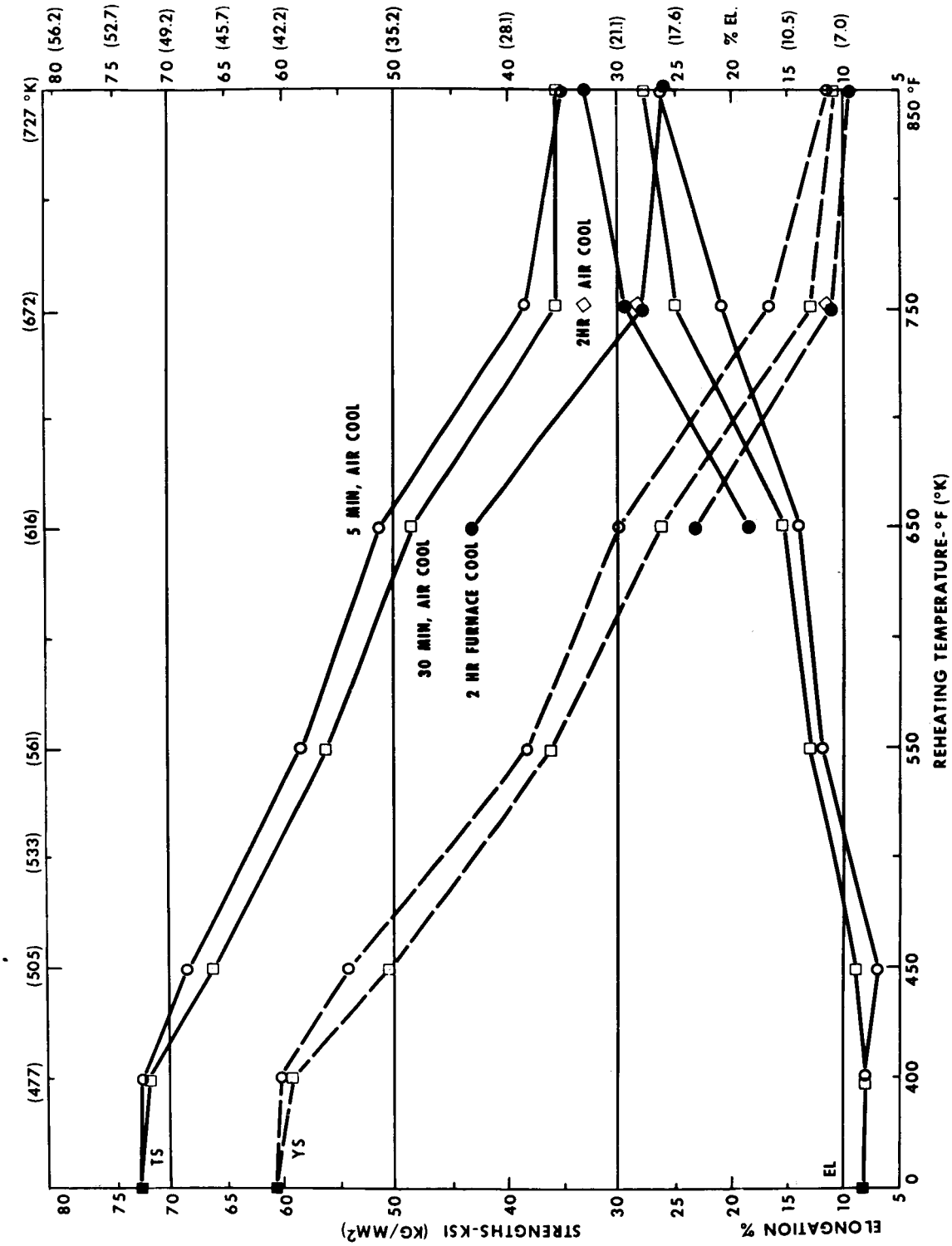

FIGURE 6 EP 5095 REHEATING TEMPERATURE VS STRENGTHS OF 2021~~-T6511~~, 1/2" (1.27CM) PLATE
-T81

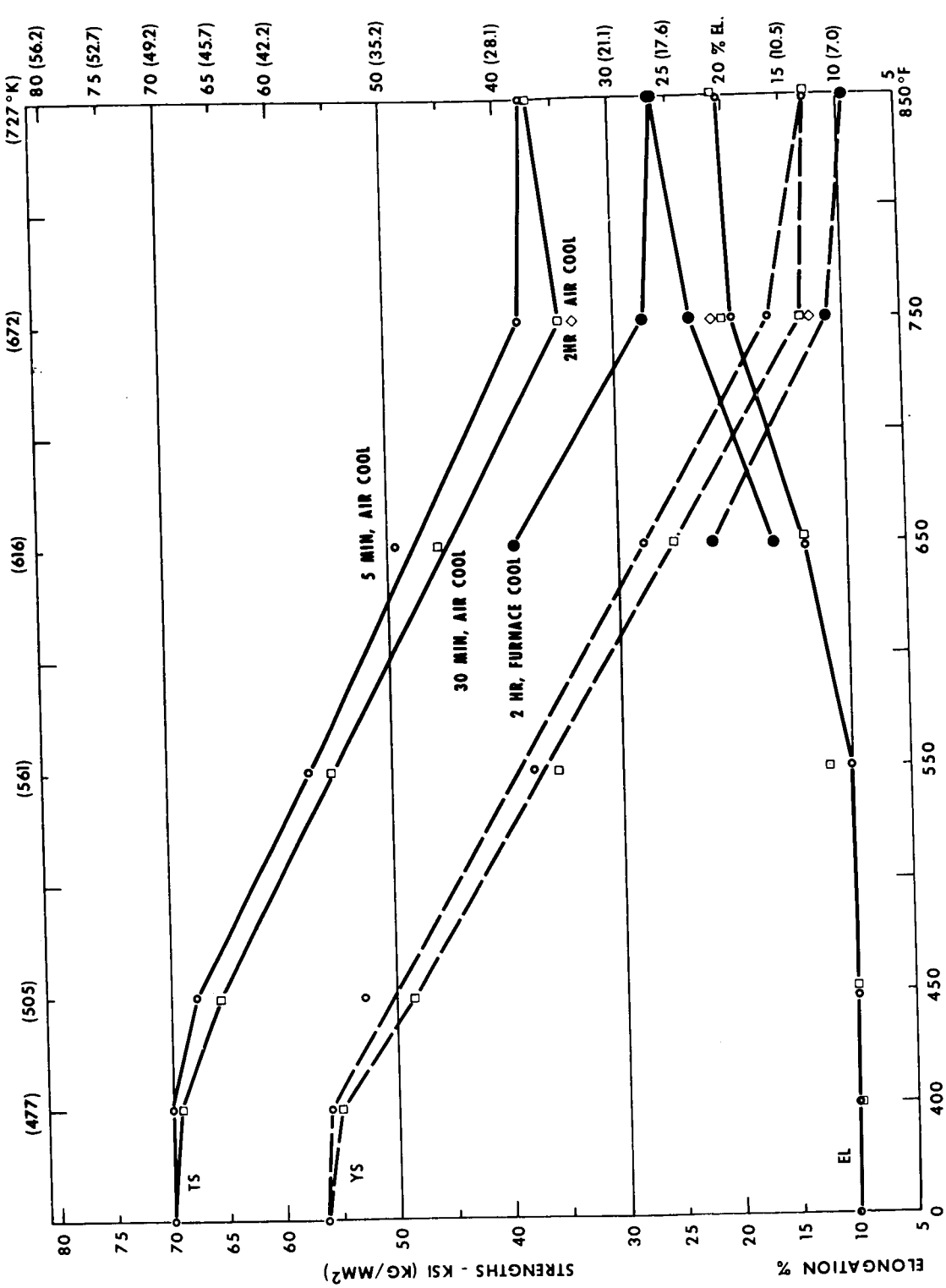

FIGURE 7 EP 5095 REHEATING TEMPERATURE VS STRENGTHS OF 2021 ~~T8531~~-T81, 1/8" (0.32 CM) SHEET

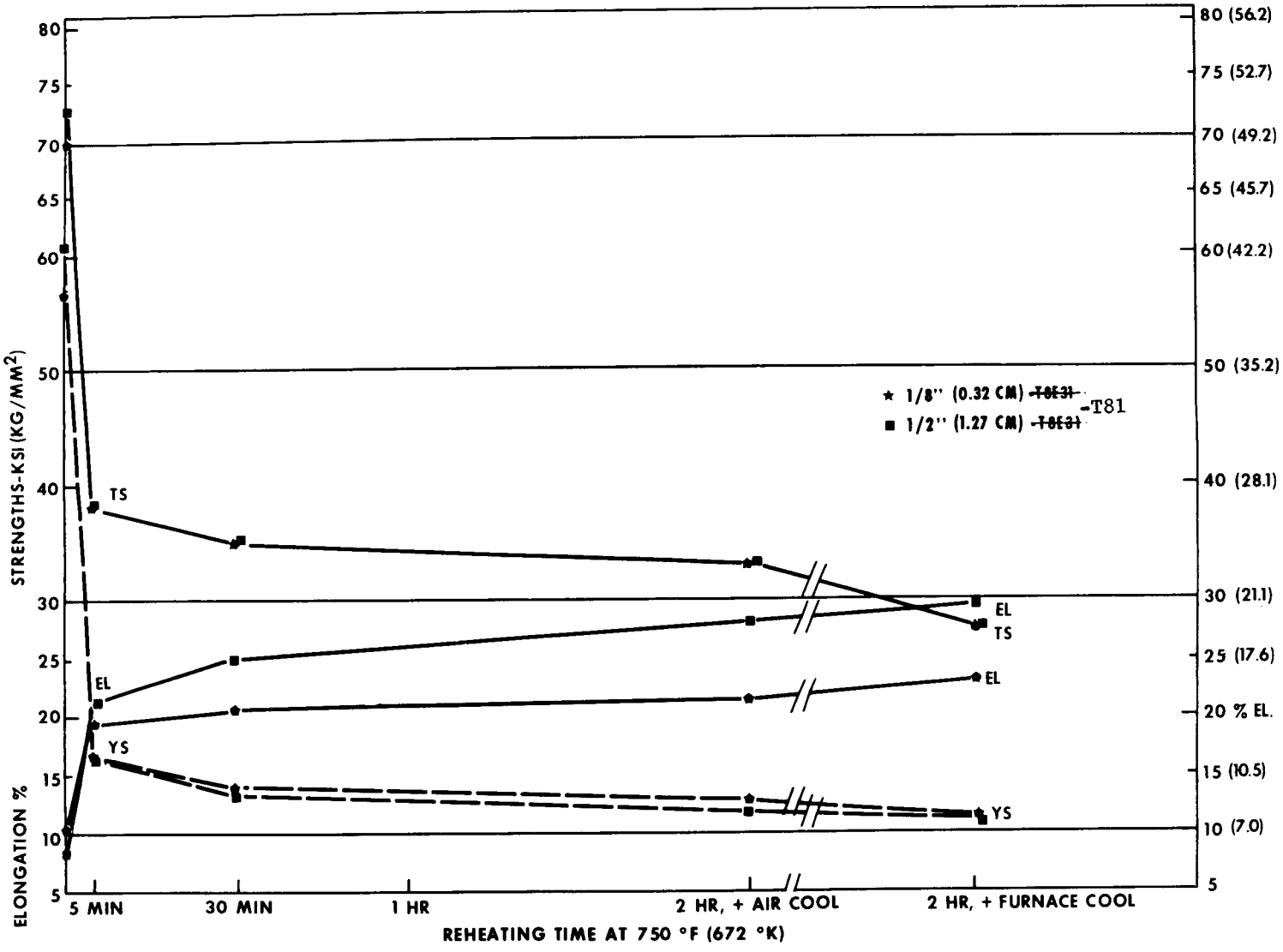

FIGURE 8 EP 5095 REHEATING TIME AT 750°F & (672 °K) COOLING RATE VS STRENGTHS OF ~~T6E31~~ -T81 SHEET & PLATE

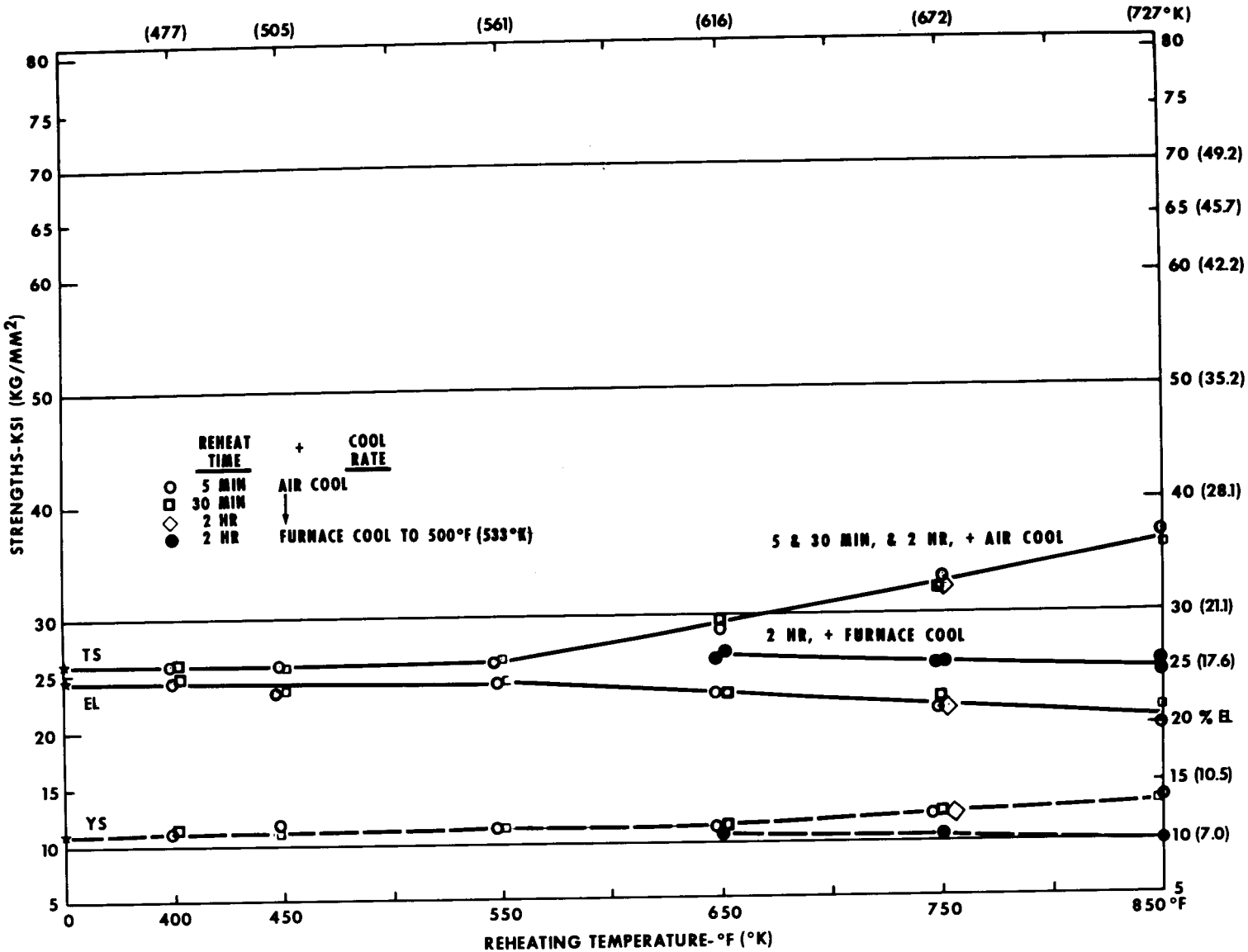

FIGURE 9 EP 5095 REHEATING TEMPERATURE VS STRENGTHS OF 2021-O, 1/8" (0.32 CM) SHEET

THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021
Manufacturer's Tensile Data vs. MSFC Tensile Test Data

TABLE I - EP 5095

Material Received From Manufacturer				Manufacturer's Tests			MSFC Tests As Received			MSFC Tests -T62 as re HT at MSFC		
Dimensions	No. Pcs.	Lot No.	Original Temper	TS ksi(kg/mm^2)	YS ksi(kg/mm^2)	EL %	TS ksi(kg/mm^2)	YS ksi(kg/mm^2)	EL %	TS ksi(kg/mm^2)	YS ksi(kg/mm^2)	EL %
.064 X 24 X 48" (.16 X 61 X 122cm)	4	326545*	-0	25(17.6)	9 (6.3)	25	24(16.9)	10 (7.0)	24	78(54.8)	70(49.2)	7
										78(54.8)	73(51.3)	7
.125 (.32cm)	4	326399*		25(17.6)	11 (7.7)	23	26(18.3)	11 (7.7)	24	78(54.8)	67(47.1)	9
.500 (1.27cm)	4	325600*		22(15.5)	8 (5.6)	29	23(16.2)	8 (5.6)	30	75(52.7)	69(48.5)	5
										75(52.7)	67(47.1)	6
.064 X 36 X 96" (.16 X 91 X 249cm)	2	638-244	~~-T8E31~~ -T81	73(51.3)	61(42.9)	9	------	------	--	------	------	--
.125 (.32cm)	2	107-556		72(50.6)	59(41.5)	9	70(49.2)	57(40.1)	10	78(54.8)	67(47.1)	10
.250 (.64cm)	2	638-257		75(52.7)	67(47.1)	9	------	------	--	------	------	--
.500 (1.27cm)	1	638-231		75(52.7)	66(46.4)	6	73(51.3)	61(4.29)	8	76(53.4)	68(47.8)	7
	1	638-235		76(53.4)	69(48.5)	4						
1.000 (2.54cm)	2	638-221		75(52.7)	67(47.1)	6	------	------	--	------	------	--

*Alcoa Research Lab. identification, other material (-T8E31)** from Alcoa Davenport Plant.

Chemical Composition of Al Alloy 2021

	Cu	Mn	Zr	V	Cd	Sn	Ti	Mg	Zn	Si	Fe
nominal	6.3	0.3	0.18	0.10	0.15	0.05	0.06				
limits	5.8-6.8	.20-.40	.10-.25	.05-.15	.05-.20	.03-.08	.02-.10	.02 max.	.10 max.	.20 max.	.30 max.

** Now designated -T81

THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021
Heat Treating Temperature and Quenching

Table II - EP 5095

Material Gage	Original Temper	HT Time	TS ksi	YS ksi	EL %	TS ksi	YS ksi	EL %	TS ksi	YS ksi	EL %	TS ksi	YS ksi	EL %
Solution Heat Treating Temperature and Time vs. Strength of -T62 Temper 2021														
			975°F(797°K)			985°F(802°K)			995°F(808°K)					
.063" (.16 cm)	-0	1 hr	74.5	65.4	9.1	78.0	69.8	7.5	79.7	72.8	5.5	—	—	—
		2 hrs	73.0	65.5	7.6	72.1	62.5	9.5	79.7	72.0	7.5	—	—	—
.500" (1.27 cm)	-0	2 hrs	73.2	66.0	8.5	74.0	66.5	7.1	76.5	70.3	5.3	—	—	—
		4 hrs	72.8	65.7	7.2	75.3	69.7	4.4	76.8	70.3	5.7	—	—	—
All Specimens	{quenched in cold water (after solution heat treating per procedures noted above), aged 4 days at room temperature + 16 hours at 325°F(436°K).													
Quench Rate vs. Strength of -T62 Temper 2021														
			Cold Water Quench			Liquid Nitrogen Q.			Boiling Water Q.			Fan Cooled		
.063" (.16 cm)	-0	1 hr	78.7	70.4	5.3	72.8	61.8	8.4	72.1	61.3	4.5	63.8	46.7	8.7
		2 hrs	73.4	66.5	4.8	74.0	64.2	5.0	75.6	66.4	5.0	64.7	48.9	8.1
.500" (1.27 cm)	-0	2 hrs	74.8	68.8	5.2	60.8	42.4	12.3	~~40.5~~	~~15.4~~	~~19.9~~	~~44.9~~	~~18.3~~	~~20.0~~
		4 hrs	74.5	69.7	3.7	61.3	42.6	11.9	57.9	36.5	11.9	~~42.6~~	~~15.8~~	~~22.2~~
All Specimens	{solution heat treated at 990°F(805°K), quenched as noted above, aged 4 days at room temperature + {16 hrs. at 325°F(436°K) for .063"(0.16cm) sheet; 24 hrs. at 325°F(436°K) for .500"(1.27cm) plate													
.063" (.16 cm)	-0	1 hr	78.4	69.6	9.0	—	—	—	68.6	58.1	10.5	65.0	50.2	11.5
		2 hrs	76.0	67.2	9.3	—	—	—	69.7	57.6	9.9	61.3	47.1	11.5
.500" (1.27 cm)	-0	2 hrs	73.2	65.8	6.6	—	—	—	58.6	39.4	12.9	48.2	25.1	18.0
		4 hrs	72.5	64.8	7.0	—	—	—	58.9	40.8	12.5	46.7	24.3	16.7
{solution heat treated at 985°F(802°K), quenched as noted above, aged 1-4 hrs. at room temperature + {16 hrs. at 325°F(436°K) for .063" (0.16cm) sheet; 24 hrs. at 325°F(436°K) for .500" (1.27cm) plate														

THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021
Heat Treating Temperature and Quenching

Table IIa - EP 5095

Material Gage	Original Temper	HT Time	TS kg/mm²	YS kg/mm²	EL %	TS kg/mm²	YS kg/mm²	EL %	TS kg/mm²	YS kg/mm²	EL %	TS kg/mm²	YS kg/mm²	EL %
Solution Heat Treating Temperature and Time vs. Strength of -T62 Temper 2021														
			797°K			802°K			808°K					
0.16 cm	-0	1 hr	52.0	45.7	9	54.8	49.2	7	56.2	51.3	5	---	---	---
		2 hrs	51.3	45.7	8	50.6	43.6	9	56.2	50.6	7	---	---	---
1.27 cm	-0	2 hrs	51.3	46.4	8	52.0	46.4	7	53.4	49.2	5	---	---	---
		4 hrs	51.3	46.4	7	52.7	49.2	4	54.1	49.2	6	---	---	---
All Specimens	{quenched in cold water (after solution heat treating per procedures noted above), aged 4 days at room temperature + 16 hours at 436°K.													
Quench Rate vs. Strength of -T62 Temper 2021														
			Cold Water Quench			Liquid Nitrogen Q.			Boiling Water Q.			Fan Cooled		
0.16 cm	-0	1 hr	55.5	49.2	5	51.3	43.6	8	50.6	42.9	4	45.0	33.0	9
		2 hrs	51.3	46.4	5	52.0	45.0	5	53.4	46.4	5	45.7	34.4	8
1.27 cm	-0	2 hrs	52.7	48.5	5	42.9	29.5	12	~~28.1~~	~~10.5~~	~~20~~	~~31.6~~	~~12.7~~	~~20~~
		4 hrs	52.0	49.2	4	42.9	30.2	12	40.8	25.3	12	~~30.2~~	~~11.2~~	~~22~~
All Specimens	{solution heat treated at 805°K, quenched as noted above, aged 4 days at room temperature + {16 hrs. at 436°K for 0.16 cm sheet / 24 hrs. at 436°K for 1.27 cm sheet													
0.16 cm	-0	1 hr	54.8	49.2	9	---	---	---	48.5	40.8	10	45.7	35.2	11
		2 hrs	53.4	47.1	9	---	---	---	49.2	40.8	10	42.9	33.0	11
1.27 cm	-0	2 hrs	51.3	46.4	7	---	---	---	41.5	27.4	13	33.7	17.6	18
		4 hrs	50.6	45.7	7	---	---	---	41.5	28.8	12	33.0	16.9	17
{solution heat treated at 802°K, quenched as noted above, aged 1 -4 hrs. at room temperature + {16 hrs. at 436°K for 0.16 cm sheet / 24 hrs. at 436°K for 1.27 cm sheet														

THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021
Heat Treating Time and Aging

TABLE III - EP 5095

Material Gage	Original Temper	Heating Time	TS ksi	YS ksi	EL %	TS ksi	YS ksi	EL %	TS ksi	YS ksi	EL %
Solution Heat Treating Time vs. Strength of -T62 Temper 2021											
		Solution H.T. 985°F(802°K)	.063"(0.16cm) Sheet			.125"(0.32cm) Sheet			.500"(1.27cm) Plate		
	-0	------	24.3	9.6	24.3	25.9	11.3	24.5	22.6	7.9	30.5
		30 min	75.0	65.8	9.3	75.8	66.2	8.0	72.0	63.8	7.5
		1 hr	78.0	73.3	7.3	78.0	67.4	8.8	74.3	66.5	7.0
(See Columns)		2 hr	80.8	71.2	7.5	77.8	68.6	5.5	74.7	66.8	6.0
		4 hr	75.2	65.4	9.5	73.6	63.4	10.4	75.5	67.6	5.5
		6 hr	74.9	65.9	10.0	72.5	62.6	9.8	75.0	66.8	6.0
	-~~T8E31~~	------	----	----	----	70.0	56.6	10.3	72.9	60.9	8.3
	-T81	30 min	----	----	----	77.1	66.4	9.4	76.2	68.1	7.0
		1 hr	----	----	----	78.0	67.5	9.6	76.5	68.7	7.0
(See Columns)		2 hr	----	----	----	79.4	68.7	7.3	75.9	68.3	6.7
		4 hr	----	----	----	74.7	63.7	10.0	76.7	68.4	6.6
		6 hr	----	----	----	74.8	63.3	9.8	75.2	66.8	8.0

All specimens {solution heat treated at 985°F (802°K), quenched in cold water, aged 4 days at room temperature + {16 hours at 325°F (436°K) for .063" (0.16cm) & .125"(0.32cm) sheet; 24 hours at 325°F (436°K) for .500" (1.27cm)plate

Artificial Aging Temperature and Time vs. Strength of -T62 Temper 2021

		Aging	315°F(430°K)			325°F(436°K)			335°F(441°K)		
						*78.4	69.6	9.0			
.063"(0.16cm)	-0	16 hr	*75.8	67.5	10.3	*74.7	66.0	8.0	*76.9	68.0	9.9
						78.0	69.8	7.5	79.5	70.0	6.0
						78.0	73.3	7.3			
		18 hr	*76.7	68.3	10.9	*75.6	66.9	8.4	*77.5	68.4	10.0
			80.3	72.0	4.5						
		24 hr	*76.6	68.3	10.0	*76.1	67.2	8.2	*75.2	66.6	9.5
									76.4	67.4	8.3
.500"(1.27cm)	-0	16 hr	73.3	64.7	8.0	74.0	66.5	7.1	74.2	68.1	5.0
		18 hr	73.3	69.7	4.8	----	----	----	----	----	----
		24 hr	73.8	66.7	7.0	74.7	66.8	6.0	73.2	65.7	5.5
						74.8	68.8	5.2			

All specimens {solution heat treated at 985°F (802°K)(1 hr for .063"(0.16cm) sheet, 2 hr for .500"(1.27cm) plate), aged 4 days at room temperature + artificially aged per procedures noted above *aged ~~4~~ hrs.

THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021
Heat Treating Time and Aging
TABLE IIIa - EP 5095

Material Gage	Original Temper	Heating Time	TS kg/mm²	YS	EL %	TS kg/mm²	YS	EL %	TS kg/mm²	YS	EL %
Solution Heat Treating Time vs. Strength of -T62 Temper 2021											
		Solution H.T. 802°K	0.16cm Sheet			0.32cm Sheet			1.27cm Plate		
	-0	----	16.9	7.0	24	18.3	7.7	24	16.2	5.6	30
	↓	30 min	52.7	46.4	9	53.4	46.4	8	50.6	45.0	7
		1 hr	54.8	51.3	7	54.8	47.1	9	52.0	46.4	7
(See Columns)		2 hr	56.9	49.9	7	54.8	48.5	5	52.7	47.1	6
		4 hr	52.7	45.7	9	52.0	44.3	10	52.7	47.8	5
	↓	6 hr	52.7	46.4	10	50.6	44.3	10	52.7	47.1	6
	~~-T8E31~~ -T81	----	----	----	----	49.2	40.1	10	51.3	42.9	8
		30 min	----	----	----	54.1	46.4	9	53.4	47.8	7
		1 hr	----	----	----	54.8	47.1	10	53.4	48.5	7
(See Columns)		2 hr	----	----	----	55.5	48.5	7	53.4	47.8	7
		4 hr	----	----	----	52.7	45.0	10	54.1	47.8	7
	↓	6 hr	----	----	----	52.7	44.3	10	52.7	47.1	8
All specimens	{solution heat treated at 802°K, quenched in cold water {aged 4 days at room temperature + {16 hours at 436°K for 0.16cm and 0.32cm {24 hours at 436°K for 1.27cm plate										
Artificial Aging Temperature vs. Strength of -T62 Temper 2021											
		Aging	430°K			436°K			441°K		
0.16cm	-0	16 hr	*53.4	47.1	10	*54.8	49.2	9			
						*52.7	46.4	8	*54.1	47.8	10
						54.8	49.2	7	55.5	49.2	6
						54.8	51.3	7			
		18 hr	*54.1	47.8	11	*53.4	47.1	8	*54.1	47.8	10
			56.2	50.6	4						
	↓	24 hr	*54.1	47.8	10	53.4	47.1	8	*52.7	47.1	9
									53.4	47.1	8
1.27cm	-0	16 hr	51.3	45.7	8	52.0	46.4	7	52.0	47.8	5
		18 hr	51.3	49.2	5	----	----	----	----	----	----
	↓	24 hr	52.0	47.1	7	52.7	47.1	6	51.3	46.4	5
						52.7	48.5	5			
All specimens	{solution heat treated at 802°K (1 hr for 0.16cm sheet, 2 hr for 1.27cm plate), quenched in cold water, {aged 4 days} at room temperature + artificially aged per procedures noted above *aged~4 hrs}										

THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021
Reheating Temperature, Time and Cooling Rate
TABLE IV - EP 5095

Reheating Temperature, Time and Cooling Rate vs. Strength of -O and -T8E31 Temper 2021

Material Gage	Original Temper	Reheating Temp.	Cooling Rate	TS ksi	YS ksi	EL %	TS ksi	YS ksi	EL %	TS ksi	YS ksi	EL %	TS ksi	YS ksi	EL %
				5 Min., + Air Cool			30 Min., + Air Cool			2 Hour, + Air Cool			2 Hour, + Furnace Cool to 500°F(533°K)		
.125" (0.32cm)	-O	°F (°K)	----	(25.9	11.3	24.5)									
		400(477)	Air Cool*	25.9	11.6	24.5	26.0	11.8	24.9	----	----	----	----	----	----
		450(505)	↓	26.1	11.7	23.2	25.7	11.3	23.7	----	----	----	----	----	----
		550(561)	↓	26.3	11.3	24.1	26.5	11.3	24.5	----	----	----	----	----	----
		650(616)	AC* or Fce†	28.8	11.4	23.0	29.6	11.5	23.0	----	----	----	26.4	11.1	26.9
		750(672)	↓	33.0	12.3	21.8	32.2	12.2	23.0	32.4	12.2	21.8	26.1	10.4	26.0
		850(727)	↓	36.9	13.9	20.0	36.2	13.4	21.9	----	----	----	25.5	10.0	24.8
.125" (0.32cm)	~~-T8E31~~ -T81	°F (°K)	----	(70.0	56.6	10.3)									
		400(477)	Air Cool*	70.0	56.0	10.0	69.2	55.1	9.7	----	----	----	----	----	----
		450(505)	↓	67.8	52.9	9.9	65.6	48.5	10.0	----	----	----	----	----	----
		550(561)	↓	57.4	37.8	10.1	55.4	35.6	12.1	----	----	----	----	----	----
		650(616)	AC* or Fce†	49.5	27.8	13.8	45.7	25.1	13.9	----	----	----	39.2	21.9	16.5
		750(672)	↓	38.5	16.5	19.5	34.9	13.8	20.5	33.4	12.9	21.4	27.6	11.6	23.4
		850(727)	↓	37.9	13.1	20.5	37.2	13.0	20.9	----	----	----	26.5	9.6	26.3
.500" (1.27cm)	~~-T8E31~~ -T81	°F (°K)	----	(72.9	60.9	8.3)									
		400(477)	Air Cool*	72.5	60.1	7.9	72.1	59.0	7.9	----	----	----	----	----	----
		450(505)	↓	68.7	54.1	7.0	66.5	50.4	9.1	----	----	----	----	----	----
		550(561)	↓	58.4	38.1	12.0	56.5	36.6	13.0	----	----	----	----	----	----
		650(616)	AC* or Fce†	51.6	30.0	14.2	48.6	26.7	15.5	----	----	----	43.0	22.9	18.8
		750(672)	↓	38.6	16.4	21.1	35.3	13.2	25.0	33.5	11.7	28.0	27.8	11.2	29.5
		850(727)	↓	35.1	11.6	26.8	35.6	11.3	27.6	----	----	----	26.6	9.4	32.8

All Specimens reheated at temperatures for times noted above,
* air cooled after removal from furnace at reheating temp. or
† furnace cooled to 500°F (533°K) at ~50°(27°K) per hour, removed from furnace at 500°F(533°K) and air cooled

THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021
REHEATING TEMPERATURE, TIME AND COOLING RATE
TABLE IVa - EP 5095

Reheating Temperature, Time and Cooling Rate vs. Strength of -0 and -T8E31 Temper 2021

Material Gage	Original Temper	Reheating Temp.	Cooling Rate	TS kg/mm²	YS	EL %	TS kg/mm²	YS	EL %	TS kg/mm²	YS	EL %	TS kg/mm²	YS	EL %
				5 Min., + Air Cool			30 Min., + Air Cool			2 Hour, + Air Cool			2 Hour, + Furnace Cool to 533°K		
0.32cm	-0	----	----	(18.3	7.7	24)									
		477°K	Air Cool*	18.3	8.4	24	18.3	8.4	25	----	----	----	----	----	----
		505		18.3	8.4	23	18.3	7.7	24	----	----	----	----	----	----
		561		18.3	7.7	24	18.3	7.7	24	----	----	----	----	----	----
		616	AC* or Fce†	20.4	7.7	23	21.1	7.7	23	----	----	----	18.3	7.7	27.0
		672		23.2	8.4	22	22.5	8.4	23	22.5	8.4	22	18.3	7.0	26.0
		727		26.0	9.8	20	25.3	9.1	22	----	----	----	17.6	7.0	25.0
0.32cm	~~-T8E31~~	----	----	(49.2	40.1	10)									
	-T81	477°K	Air Cool*	49.2	39.4	10	48.5	38.7	10	----	----	----	----	----	----
		505		47.8	37.3	10	46.4	33.7	10	----	----	----	----	----	----
		561		40.1	26.7	10	38.7	25.3	12	----	----	----	----	----	----
		616	AC* or Fce†	34.4	19.7	14	32.3	17.6	14	----	----	----	27.4	15.5	16
		672		26.7	11.2	19	24.6	9.8	20	23.2	9.1	21	19.7	8.4	23
		727		26.7	9.1	20	26.0	9.1	21	----	----	----	18.3	7.0	26
1.27cm	~~-T8E31~~	----	----	(51.3	42.9	8)									
	-T81	477°K	Air Cool*	50.6	42.2	8	50.6	41.5	8	----	----	----	----	----	----
		505		48.5	38.0	7	46.4	35.2	9	----	----	----	----	----	----
		561		40.8	26.7	12	39.4	26.0	13	----	----	----	----	----	----
		616	AC* or Fce†	36.6	21.1	14	34.4	19.0	15	----	----	----	30.2	16.2	19
		672		27.4	11.2	21	24.6	9.1	25	23.2	8.4	28	19.7	7.7	29
		727		24.6	8.4	27	25.3	7.7	28	----	----	----	19.0	6.3	33

All Specimens - reheated at temperatures for times noted above,
* air cooled after removal from furnace at reheating temp. or
† furnace cooled to 533°K at ~27° per hour, removed from furnace at 533°K and air cooled

APPROVAL

THERMAL TREATING STUDIES ON NEW ALUMINUM ALLOY 2021

by

M W Brennecke

M. W. Brennecke

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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