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Report No. 8926-140

Material - Aluminum - 2014-T6, 2024-T6 and 2024-T86 Alloys

Effect of Elevated Temperatures on Mechanical Properties

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Abstract:

Tension tests conducted with 2014-T6 aluminum alloy billet and 0.050 and 0.125 inch thick 2024-T6 and 2024-T86 aluminum alloy sheet at room temperature and after heatings of 300, 370 and 425°F for 1/2, 10 and 100 hours showed, within the time limits expressed, the time independence of the mechanical properties of the alloys studied at temperatures up to 300°F. At temperatures in excess of 300°F., time-dependence in the mechanical properties of the alloys asserted itself.

Reference: Giuntoli, A., Bergstedt, P. W., Turner, H. C., "Aluminum Alloys - Mechanical Properties at Room and Elevated Temperature After Various Thermal Exposures," General Dynamics/Convair Report MP 58-077, San Diego, California, 9 January 1959 (Reference attached).

STRUCTURES & MATERIALS LABORATORIES

CONVAIR
A DIVISION OF GENERAL DYNAMICS CORPORATION
SAN DIEGO

REPORT MP 58-077
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TITLE

REPORT NO. MP 58-077

ALUMINUM ALLOYS -- MECHANICAL PROPERTIES AT ROOM AND ELEVATED TEMPERATURE AFTER VARIOUS THERMAL EXPOSURES

MODEL: REA 7038

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INTRODUCTION:

Of the so-called high strength aluminum alloys in current usage, only the copper-base (2000 series) materials possess appreciable resistance to deterioration of mechanical properties at elevated temperature. The zinc-base alloys are more vulnerable due to lower aging-temperature characteristics.

To investigate temperature and exposure-time effects upon the mechanical properties of some selected 2000-series alloys, the program described below was evolved.

OBJECT:

To determine the room temperature and elevated temperature mechanical properties of bare 2024-T6 and -T86 aluminum alloy sheet, 0.050" and 0.125" thick, and 2014-T6 aluminum alloy billet after exposure for 1/2, 10, and 100 hrs. at 300°F., 370°F., and 425°F.

CONCLUSIONS:

1. 300°F. exposures had only slight effects upon the room temperature tensile properties of the alloys tested.

2. A sharp reduction in tension yield and ultimate occurred as the exposure temperature was raised and held for the longer time intervals.

3. Tests at temperature revealed a similar sharp decrease in tensile strength as the temperatures exceeded 300°F.

MATERIALS:

All of the test materials were procured from Convair supplies except the bare 2024-T86. Since only clad 2024-T86 sheet is ordinarily stocked, the bare material was obtained from Alcoa by special order.

The 2024-T6 materials were prepared from 2024-T3 flat sheets which were re-solution heat treated and artificially aged in accordance with MIL-H6088a. Recent changes in Military and Convair Specifications now require a longer aging time than the 6 1/2 hours used here.

TEST SPECIMENS:

An 8 inch long tensile specimen with a 1/2" x 2 1/4" gauge section was used for all tension tests of sheet materials. The samples had a shoulder width of 1 1/4" and were initially drilled to accommodate 3/8" D. loading pins. Subsequent bearing failures necessitated increasing the hole-size to 9/16" D. (The use of the specimen configuration shown in Report No. 57-995-6 is recommended for all sheet materials in excess of .040" gauge when doublers are not employed.)

TEST SPECIMENS: (Continued)

A sub-size, standard, round tensile specimen with a 1/4" D. x 1 1/4" gauge section was used for tension tests of the 2014-T6 billet.

Compression specimens, 1" x 3 1/16", were used for all of the materials. Billet samples were machined to a thickness of 1/8".

Shear samples, 1" x 4" approximately, were employed for tests of the flat sheet materials, and a 1/4" D. x 1 1/2" long cylinder was used for shear tests of the 2014-T6 billet.

All specimens were cut with the long dimension parallel to the grain direction of the material.

TEST PROCEDURE:

Quadruplicate tensile and triplicate compression and shear specimens (in the final machined condition) were exposed in a recirculating-air furnace for 1/2, 10, or 100 hours at 300°, 370°, or 425°F. At the time of actual test, specimens were held at temperature for 5 minutes before loading was begun.

All testing was performed in a Tinius-Olsen, 12,000 lb. capacity, universal testing machine. A portable recirculating-air furnace, placed in the testing machine, served as the heat source. The top and bottom of the furnace had suitable openings to admit pull-rods or test fixtures.

For room temperature tension and compression tests, strain was measured with a standard Tinius-Olsen S-1 Atcotran extensometer. To withstand the effects of elevated temperature testing, the coil of the extensometer was replaced with a type suitable for service up to 500°F.

No elevated-temperature compression test jig was available at the time work was in progress on this program. Consequently, considerable difficulty was encountered in the attempt to produce reliable data at temperature using the room-temperature equipment.

Similarly, shear testing was attempted on an experimental basis; unequal load distribution proved to be disastrous in its effects.

RESULTS:

The room temperature tensile properties after the various exposure treatments are shown in Table I. The properties at temperature, after similar exposures, are shown in Table II.

The data from Table I are graphically plotted in Figures 1 through 5, and the at-temperature values of Table II are presented in Figures 6 through 9.

RESULTS: (Continued)

Unfortunately, the shear test results were useless. Duplicate specimens often exhibited a variation in excess of 15,000 psi. The difficulty was traced to faulty load distribution but too late to salvage an appreciable quantity of results without a complete re-sampling.

A shifting load-column also contributed to the dubious compression test results of Table II. However, equipment is now available in the laboratory to check these results should such tests seem worthy of attention.

DISCUSSION OF RESULTS:

Exposure treatments up to 100 hrs. at 300°F. had little effect upon the tensile properties at room temperature. Above 300°F. the effects of the longer-term exposures (10 hrs. and 100 hrs.) became clearly evident. The 2024-T86 curves (Figures 3 and 4) may be smoother in appearance due to the continuous relief of cold work; the -T6 materials, on the other hand, show a tendency to harden very markedly and erratically before over-age softening occurs.

(Since the points were too widely separated in the regions of greatest change, the curves of Figures 1 through 9 were drawn in rather arbitrary fashion. Interpolation is neither intended nor suggested.)

Tension results at elevated temperature exhibited much the same pattern with a very rapid deterioration in properties when the temperature exceeded 300°F. The 2024-T86 curves for yield and ultimate strength reductions were approximately parallel throughout the range of the test (Figures 8 and 9) while the ultimate strength losses were greater than the yield strength losses for the -T6 sheet until the 300°F. temperature was surpassed (Figures 6 and 7).

Similar elevated temperature test results could not be obtained for the 2014-T6 billet material since a satisfactory extensometer was not available for the 0.252 D. tensile specimens.

Inadequate compression jigs and eccentric loading are believed to have caused the peculiar compression test results reported in Table II. The modulus vagaries apparent from the stress-strain curves and the poor correlation with tension yield values emphasize the inaccuracy of these results.

Shear test results were judged unworthy of mention. The flat-shear jig employed here might conceivably yield reproducible results if a satisfactory system were developed to prevent eccentric loading.

NOTE: The data from which this report was prepared are recorded in Materials and Processes Laboratory Notebook No. 910.

TABLE I - ROOM TEMPERATURE MECHANICAL PROPERTIES OF .050" SHEET AND 0.125" SHEET OF 2024-T6 AND 2024-T86 AND 2014-T6 BILLET AFTER EXPOSURE TO VARIOUS TEMPERATURES FOR VARIOUS LENGTHS OF TIME

EXPOSURE CONDITIONS		2024-T6 (0.050 SHEET)				2024-T6 (0.125 SHEET)				2024-T86 (0.050 SHEET)				2024-T86 (.125 SHEET)				2014-T6 (BILLET)		
TIME (HRS)	TEMP (°F)	.2% FTY KSI	FTU KSI	ELONG % IN 2"		.2% FTY KSI	FTU KSI	ELONG % IN 2"		.2% FTY KSI	FTU KSI	ELONG. % IN 2"		.2% FTY KSI	FTU KSI	ELONG % IN 2"		.2% FTY KSI	FTU KSI	ELONG. % IN 1"
NONE	NONE	52.5	70.5	14.0		58.6	72.0	13.0		70.7	75.4	6.5		74.2	76.6	8.0		64.8	73.7	13.0
		51.8	70.3	13.5		59.1	71.8	13.0		71.9	75.9	6.5		73.1	76.0	8.0		64.3	72.7	11.0
		52.1	70.4	13.7	AVE.	58.9	71.9	13.0	AVE.	71.3	75.6	6.5	AVE.	73.6	76.3	8.0	AVE.	64.5	73.2	12.0
½	300	53.7	71.5	15.0		58.1	72.4	14.0		70.1	74.7	7.5		73.6	76.3	7.5		63.8	72.1	11.0
		52.2	70.0	15.0		60.0	72.6	14.5		70.1	74.7	7.0		73.4	76.1	8.0		63.2	70.3	10.0
		52.9	70.7	15.0	AVE.	59.0	72.5	14.2	AVE.	70.1	74.7	7.2	AVE.	73.5	76.2	7.7	AVE.	63.5	71.2	10.5
10	300	54.9	71.3	15.0		58.3	72.7	14.0		70.0	75.0	6.5		74.4	78.0	8.0		65.1	74.0	11.0
		53.2	70.8	15.5		56.4	72.9	12.5		70.4	75.0	6.5		73.8	76.4	8.0		65.0	72.9	12.0
		54.0	71.0	15.2	AVE.	57.3	72.8	13.2	AVE.	70.2	75.0	6.5	AVE.	74.1	77.2	8.0	AVE.	65.0	74.6	11.5
100	300	54.9	70.4	13.5		60.3	71.7	12.5		68.2	73.9	7.5		70.8	75.2	8.5		64.6	71.8	12.0
		54.6	70.4	13.5		61.1	71.6	12.5		67.7	73.1	7.5		70.9	75.4	8.0		63.9	71.3	12.0
		54.7	70.4	13.5	AVE.	60.7	71.6	12.5	AVE.	68.0	73.5	7.5	AVE.	70.8	75.3	8.2	AVE.	64.2	71.5	12.0
½	370	51.6	69.0	14.0		57.8	71.6	13.0		70.0	74.8	6.5		72.3	76.6	8.0		62.7	71.6	11.0
		51.2	69.2	14.0		58.8	71.5	12.5		69.0	73.8	6.5		73.0	75.9	7.5		62.8	71.3	12.0
		51.4	69.1	14.0	AVE.	58.3	71.5	12.7	AVE.	69.5	74.3	6.5	AVE.	72.9	76.2	7.7	AVE.	62.7	71.5	11.5
10	370	57.1	69.0	10.0		59.3	66.5	10.0		66.4	73.0	6.5		67.6	73.2	7.5		63.2	70.6	10.0
		56.4	67.8	9.0		56.5	67.0	9.0		65.8	72.4	7.5		68.6	74.0	8.0		62.5	70.5	11.0
		56.7	68.4	9.5	AVE.	57.9	66.7	9.5	AVE.	66.1	72.7	7.0	AVE.	68.1	73.6	7.7	AVE.	62.8	70.5	10.5
100	370	45.9	58.0	8.0		47.0	59.6	8.0		59.9	68.8	7.5		61.7	70.2	8.5		57.6	66.3	11.0
		45.8	57.5	6.0		48.2	59.7	10.0		59.1	67.7	7.5		60.2	68.7	9.0		57.0	[illegible]	[illegible]
		45.8	57.7	7.0	AVE.	47.6	59.6	9.0	AVE.	59.5	68.2	7.5	AVE.	60.9	69.4	8.8	AVE.	57.3	66.0	10.5
½	425	53.7	67.2	10.5		54.6	65.8	9.0		64.2	71.5	7.0		66.2	72.6	8.5		60.2	67.8	10.0
		55.2	67.1	7.5		54.3	65.5	9.0		64.2	71.0	7.5		66.6	72.9	8.5		60.2	68.3	12.0
		54.4	67.1	9.0	AVE.	54.5	65.6	9.0	AVE.	64.2	71.2	7.2	AVE.	66.4	72.7	8.5	AVE.	60.2	68.0	11.0
10	425	43.9	57.3	7.5		47.0	59.4	9.5		55.2	65.6	8.0		55.0	66.4	9.0		49.9	62.2	10.0
		43.7	57.1	7.5		46.6	58.9	9.0		54.0	64.4	8.0		55.9	66.3	9.0		50.3	63.0	11.0
		43.8	57.2	7.5	AVE.	46.8	59.1	9.3	AVE.	54.6	65.0	8.0	AVE.	55.4	65.9	9.0	AVE.	50.1	62.6	10.5
100	425	39.3	54.5	9.0		41.0	56.2	10.0		45.6	58.8	8.0		43.8	57.8	10.0		33.2	50.6	13.0
		38.7	54.1	9.5		40.1	56.2	10.5		44.8	58.0	8.0		43.6	57.6	8.5		32.5	49.7	13.0
		39.0	54.3	9.2	AVE.	40.5	56.2	10.2	AVE.	44.2	58.4	8.0	AVE.	43.7	57.7	9.2	AVE.	32.8	50.1	13.0

TABLE II - ELEVATED TEMPERATURE MECHANICAL PROPERTIES OF 0.050" AND 0.125" 2024-T6 AND 2024-T86 SHEET AND COMPRESSION YIELD STRENGTH OF 2014-T6 BILLET AFTER EXPOSURE TO VARIOUS TEMPERATURES AND TIMES.

TEST	EXPOSURE		2024-T6 (0.050 SHEET)				2024-T6 (0.125 SHEET)				2024-T86 (0.050 SHEET)				2024-T86 (0.125 SHEET)					2014-T6 (BILLET)
TEMP	CONDITIONS		.2% Fcy	.2% Fty	Ftu	ELONG	.2% Fcy	.2% Fty	Ftu	ELONG	.2% Fcy	.2% Fty	Ftu	ELONG	.2% Fcy	.2% Fty	Ftu	ELONG		.2% Fcy
°F	TIME (HR)	TEMP (°F)	KSI	KSI	KSI	% in 2"	KSI	KSI	KSI	% in 2"	KSI	KSI	KSI	% in 2"	KSI	KSI	KSI	% in 2"		KSI
ROOM	NONE	NONE	57.9	52.5	70.5	14.0	61.6	58.6	72.0	13.0	70.4	70.7	76.4	6.5	75.2	74.2	76.6	8.0		67.9
TEMP			57.9	51.8	70.3	13.5	61.4	59.1	71.8	13.0	72.0	71.9	75.9	6.5	75.1	73.1	76.0	8.0		67.9
CONTROL			57.9	52.1	70.4	13.7	61.5	58.9	71.9	13.0	71.8	71.3	75.6	6.5	75.1	73.6	76.3	8.0	AVE.	67.9
300	½	300	57.5	48.2	62.2	16.0	62.0	52.7	61.5	16.5	69.7	61.3	62.8	10.0	72.6	63.7	66.3	10.0		67.1
			57.0	49.4	62.3	18.0	61.8	53.3	61.7	14.5	70.1	61.3	68.2	12.0	73.3	65.3	64.9	10.0		67.2
			57.2	48.8	62.2	14.0	61.9	53.0	61.6	15.5	69.4	61.3	63.0	11.0	72.9	64.5	65.6	10.0	AVE.	67.1
300	10	300	58.8	49.4	62.8	14.0	60.4	53.1	61.5	14.0	71.0	61.1	63.1	9.5	71.7	63.6	66.2	10.5		
			58.6	49.8	62.3	17.5	59.9	52.8	61.5	14.0	67.6	59.5	62.0	9.5	71.8	64.2	65.8	10.5		
			58.7	49.6	62.5	15.7	60.1	52.9	61.5	14.0	69.3	60.3	62.5	9.5	71.8	63.9	66.0	10.5	AVE.	
300	100	300	57.1	51.4	61.3	7.5	59.2	50.6	56.8	15.0	67.6	56.8	61.2	9.5	67.4	61.6	64.3	12.0		
			57.8	50.9	58.5	10.5	59.5	50.3	56.0	15.0	65.8	58.4	61.7	11.5	69.3	60.7	63.1	12.0		
			57.4	51.1	60.4	9.0	59.3	50.4	56.4	15.0	66.7	57.6	61.4	10.5	68.3	61.1	63.7	12.0	AVE.	
370	½	370	56.7	46.2	53.4	14.0	56.5	49.6	56.0	12.0	65.9	55.6	57.3	10.0	60.1	57.6	59.2	12.5		60.2
			58.6	46.2	53.6	12.5	56.5	49.4	55.3	14.0	68.9	52.5	55.4	11.0	62.3	58.6	59.9	10.5		61.6
			57.7	46.2	53.5	13.2	56.5	49.5	55.6	13.0	67.4	54.0	56.3	10.5	61.2	58.1	59.5	11.5	AVE.	60.9
370	10	370	56.1	46.1	51.0	10.5	51.3	46.0	49.2	16.0	60.0	51.2	55.1	10.0	57.7	52.2	55.7	10.0		
			56.4	45.1	50.0	10.0	52.8	46.8	50.0	11.5	59.9	50.0	53.5	11.5	56.9	53.6	56.0	10.0		
			56.2	45.6	50.5	10.2	52.0	46.4	49.6	14.3	59.9	50.6	54.3	10.7	57.3	52.9	55.8	10.0	AVE.	
370	100	370	44.9	40.2	43.1	11.0	45.4	38.6	42.1	16.5	57.8	47.3	50.8	11.0	58.1	48.8	49.9	12.0		53.6
			43.7	37.0	41.1	13.5	45.9	38.5	42.5	14.0	58.5	46.5	49.8	11.0	56.9	48.0	52.5	10.0		55.2
			44.3	38.6	42.1	12.2	45.6	38.5	42.3	15.2	58.1	46.9	50.3	11.0	57.5	48.4	51.3	11.0	AVE.	54.4
425	½	425	56.0	39.4	42.2	12.0	52.7	38.6	41.8	19.0	58.2	45.9	49.9	11.0	57.3	44.6	48.0	16.0		
			54.3	38.3	40.9	12.5	56.1	38.7	40.7	20.0	58.4	44.3	47.1	13.5	59.5	45.7	48.8	14.5		
			55.1	38.8	41.5	12.2	54.4	38.6	41.2	19.5	58.3	45.1	48.5	12.2	58.4	45.1	48.4	15.7	AVE.	
425	10	452	43.6	32.7	35.9	12.5	43.3	33.5	35.9	16.5	52.8	40.0	42.9	11.0	52.8	41.1	43.0	16.0		
			48.0	33.3	35.9	16.5	43.5	33.1	36.6	16.0	52.7	38.1	41.7	13.0	51.7	40.0	43.2	14.5		
			42.9	33.0	35.9	14.5	43.4	33.3	36.2	16.2	52.7	39.0	42.3	13.0	52.3	40.5	43.1	15.7	AVE.	
425	100	425	42.2	30.5	34.3	14.5	39.1	29.0	33.0	15.0	44.8	33.9	36.3	15.0	43.3	32.4	35.1	15.5		
			42.2	29.4	32.9	16.0	38.7	29.7	33.4	18.0	44.1	30.8	34.0	16.0	42.8	32.7	36.0	14.5		
			42.2	29.5	33.6	15.2	38.9	29.3	33.2	16.5	44.4	32.8	35.1	15.5	43.0	32.3	36.6	15.0	AVE.	

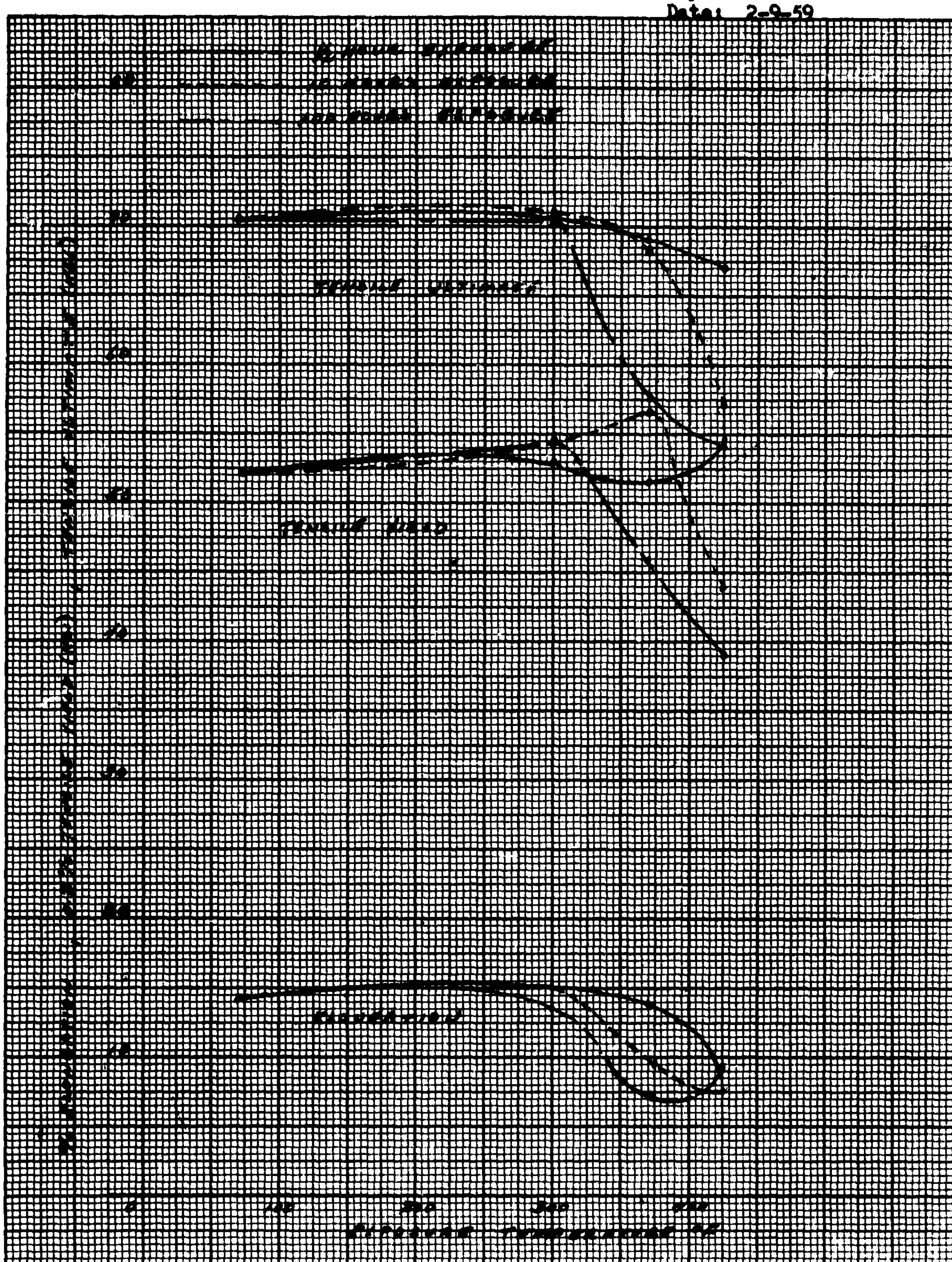

FIG 1 – EFFECT OF EXPOSURE TIME AND TEMPERATURE ON THE MECHANICAL PROPERTIES OF [illegible] ALUMINUM TESTED AT ROOM TEMP.

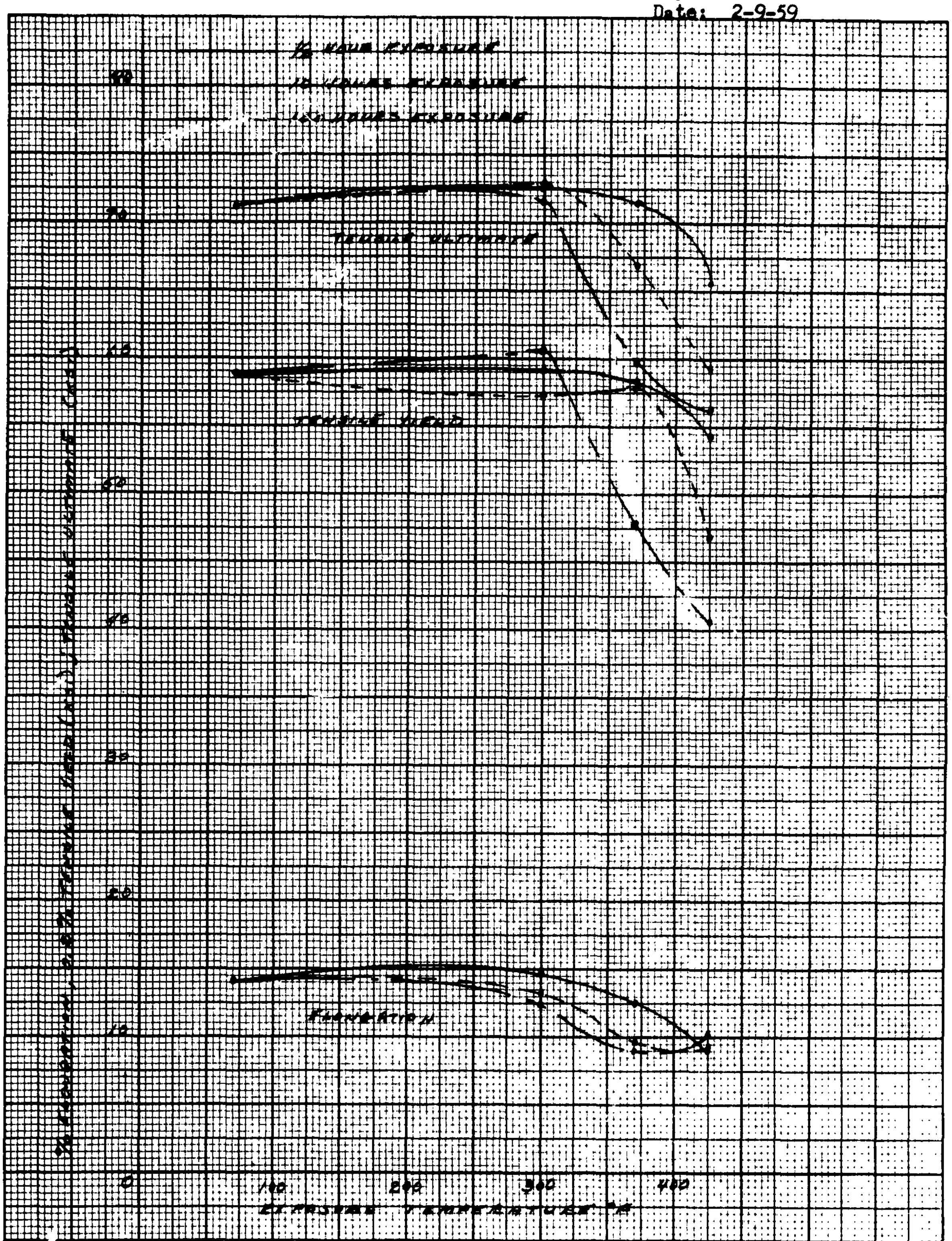

FIG 2 - EFFECT OF EXPOSURE TEMPERATURE AND TIME ON THE MECHANICAL PROPERTIES OF 0.125" CLAD SHEET 2024-T3 ALUMINUM TESTED AT ROOM TEMP.

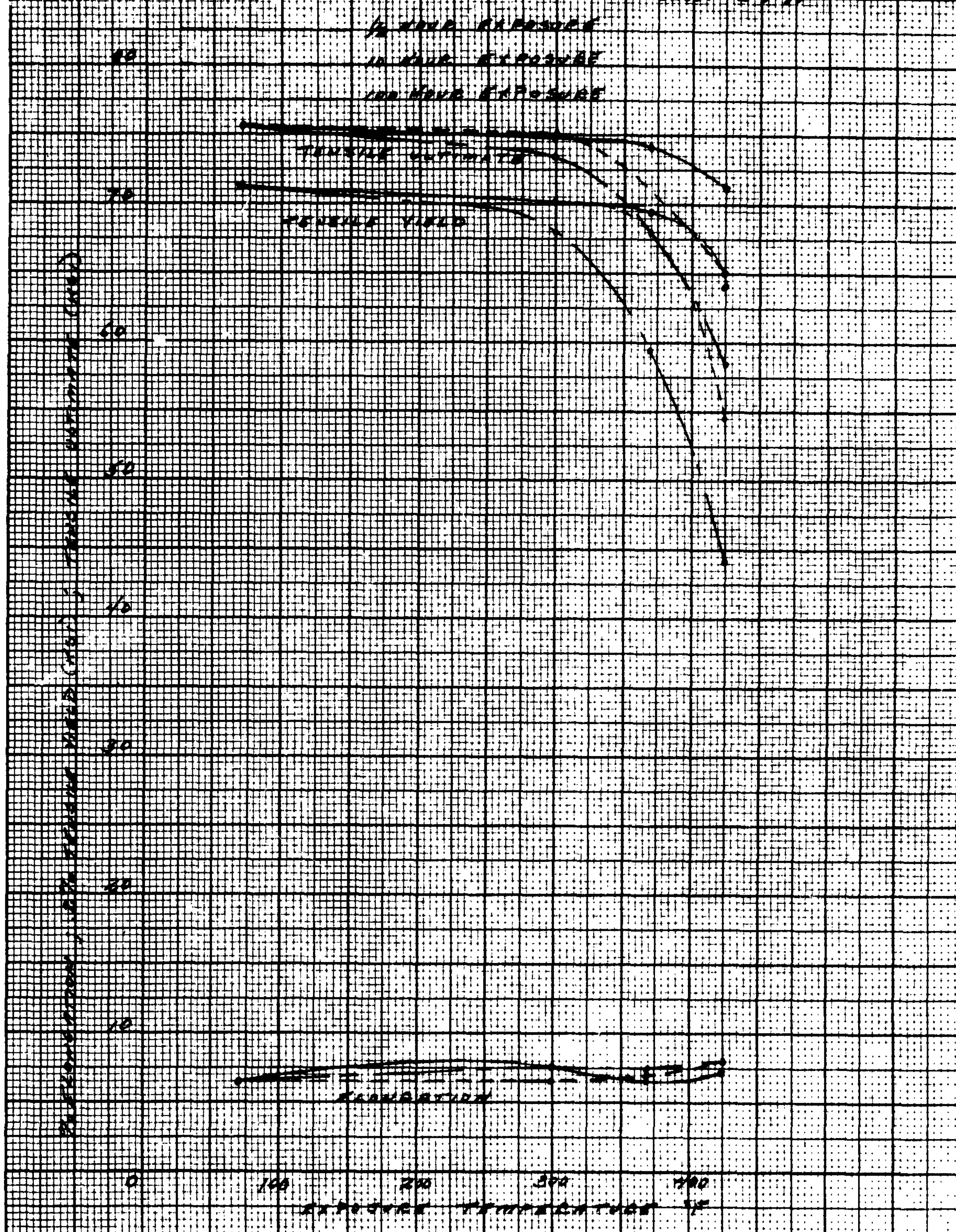

FIG. 3 - EFFECT OF EXPOSURE TEMPERATURE AND TIME ON THE MECHANICAL PROPERTIES OF 0.050" [illegible] BARE 2024-T86 ALUMINUM TESTED AT ROOM TEMP.

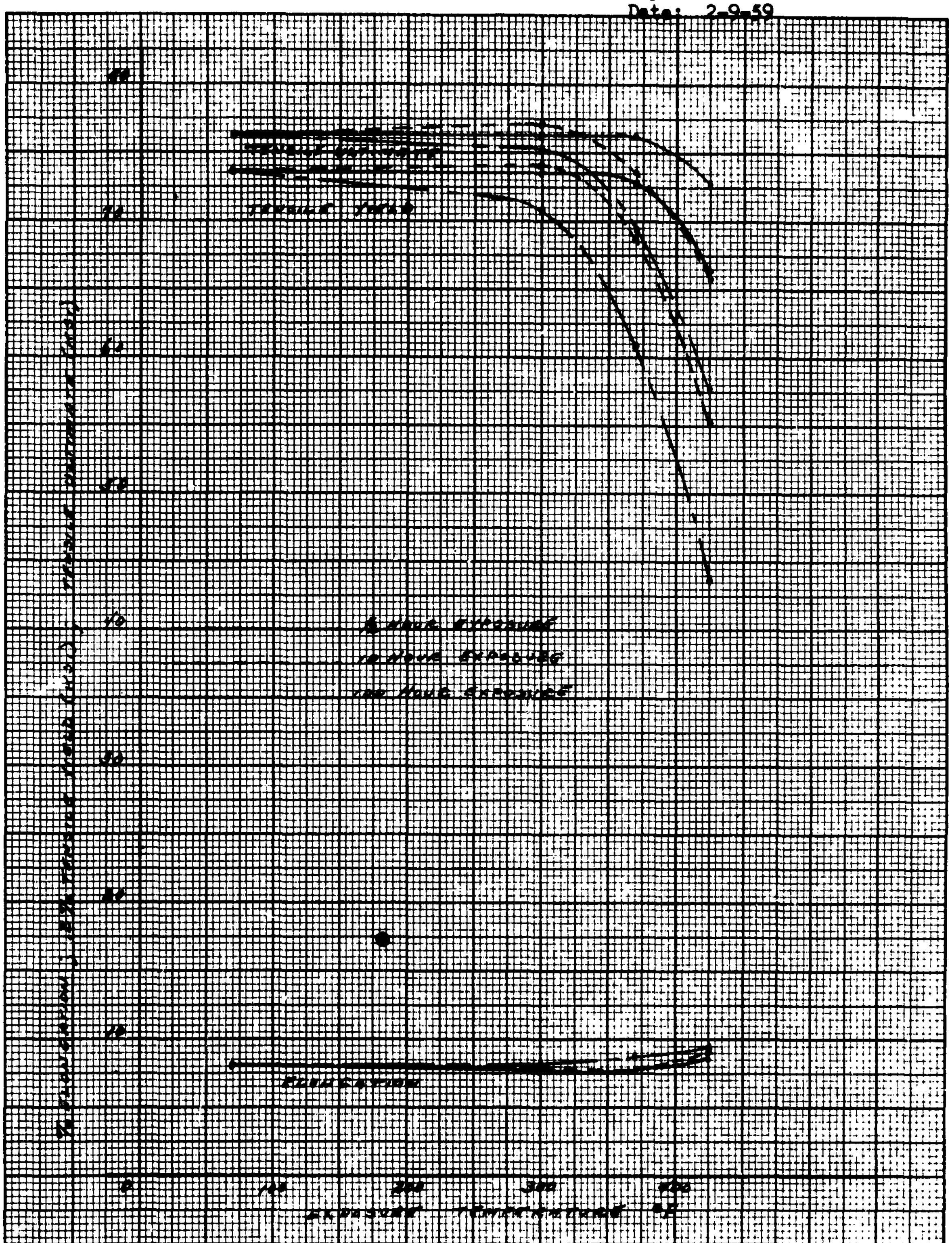

FIG 4 - EFFECT OF EXPOSURE TEMPERATURE AND TIME ON THE MECHANICAL PROPERTIES OF "BIRD" CAGE BASE 2024-T86 ALUMINUM TESTED AT ROOM TEMP.

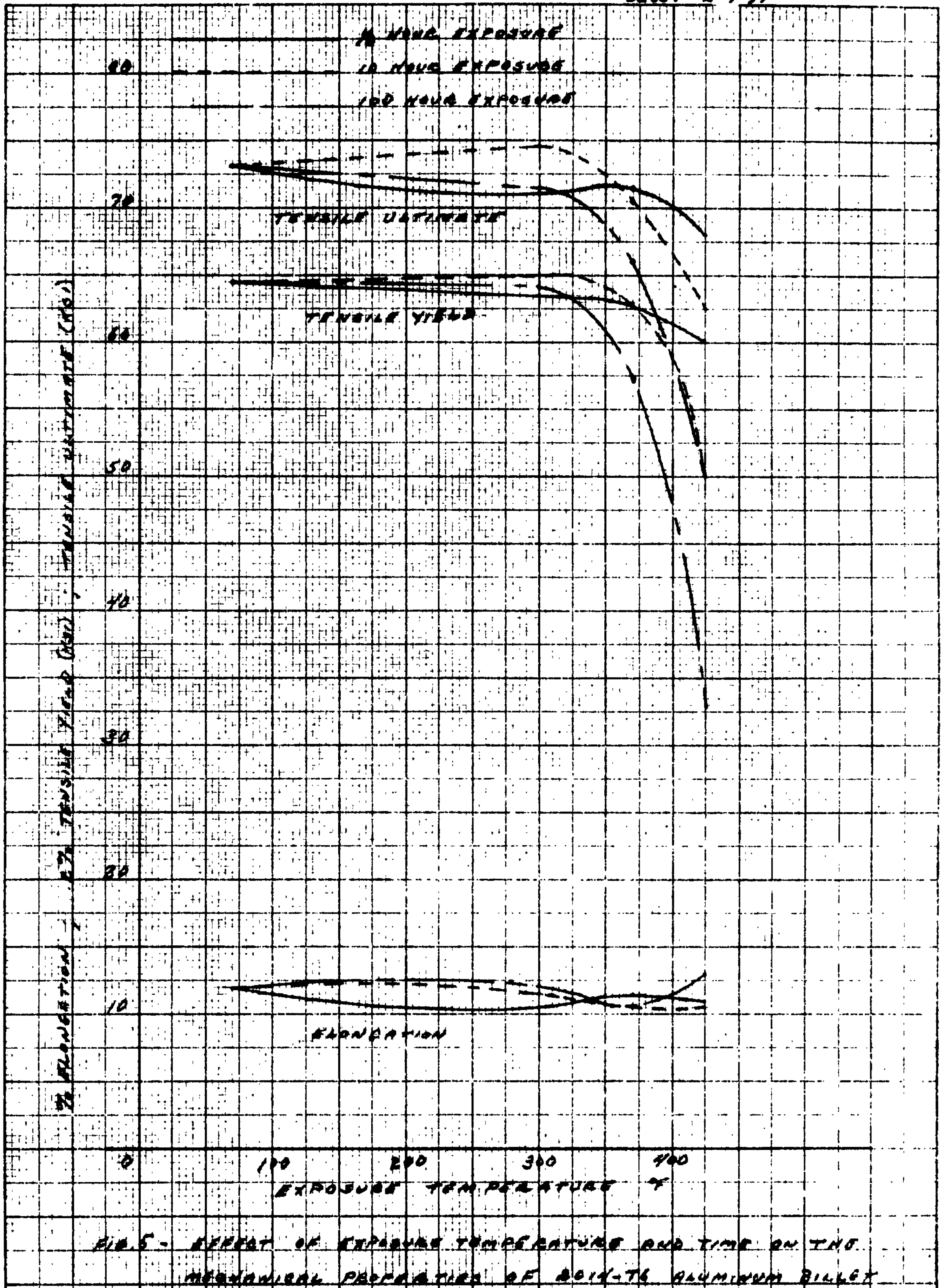

FIG. 5 - EFFECT OF EXPOSURE TEMPERATURE AND TIME ON THE MECHANICAL PROPERTIES OF 2014-T6 ALUMINUM BILLET TESTED AT ROOM TEMP.

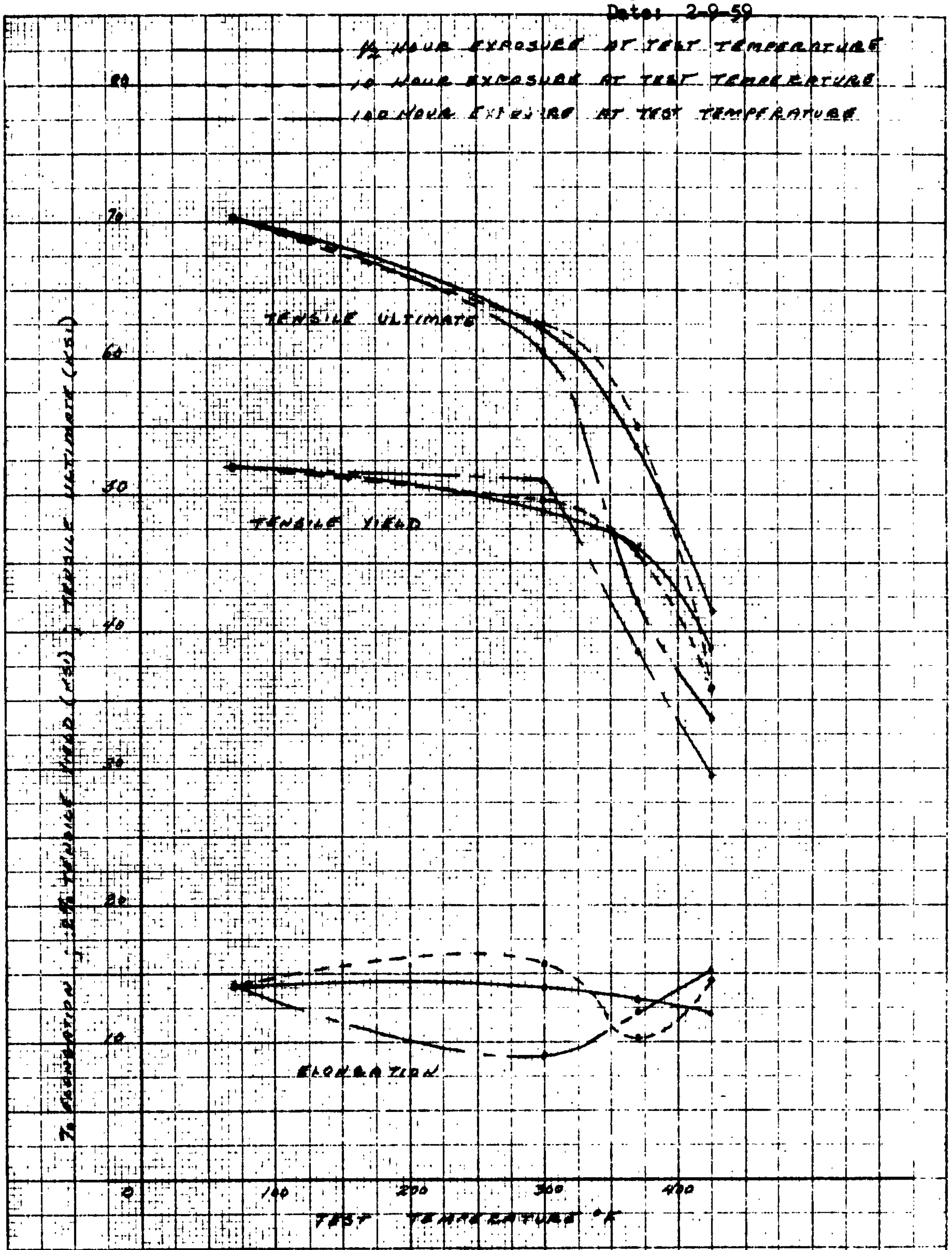

FIG 6 - EFFECT OF ELEVATED TEMPERATURE, EXPOSURE TEMPERATURE, AND TIME ON THE MECHANICAL PROPERTIES OF 0.050" GAGE BARE 2024-T6 ALUMINUM

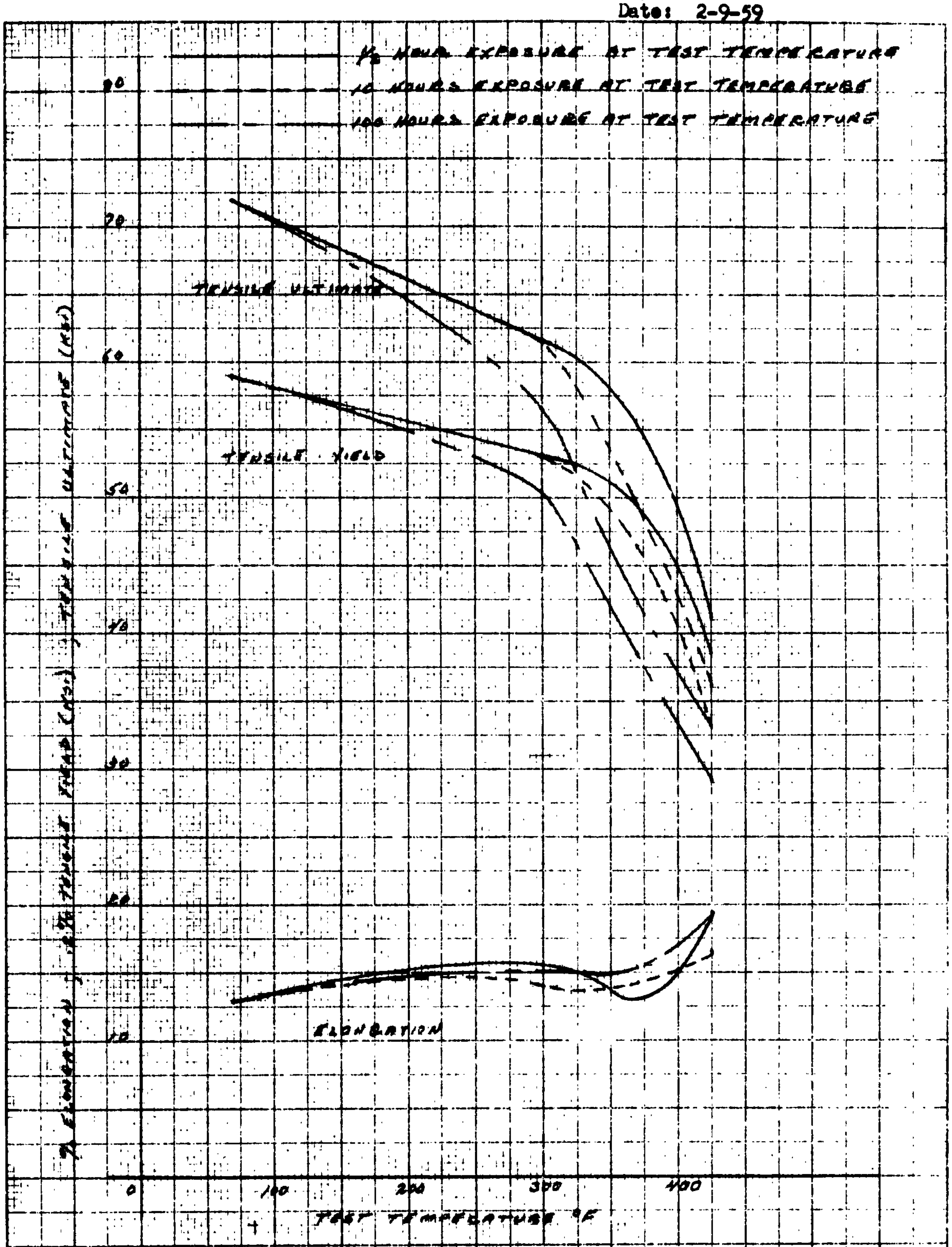

FIG. 7- EFFECT OF ELEVATED TEMPERATURE, EXPOSURE TEMPERATURE, AND TIME ON THE MECHANICAL PROPERTIES OF 0.125" GAGE BARE 2024-T6 ALUMINUM

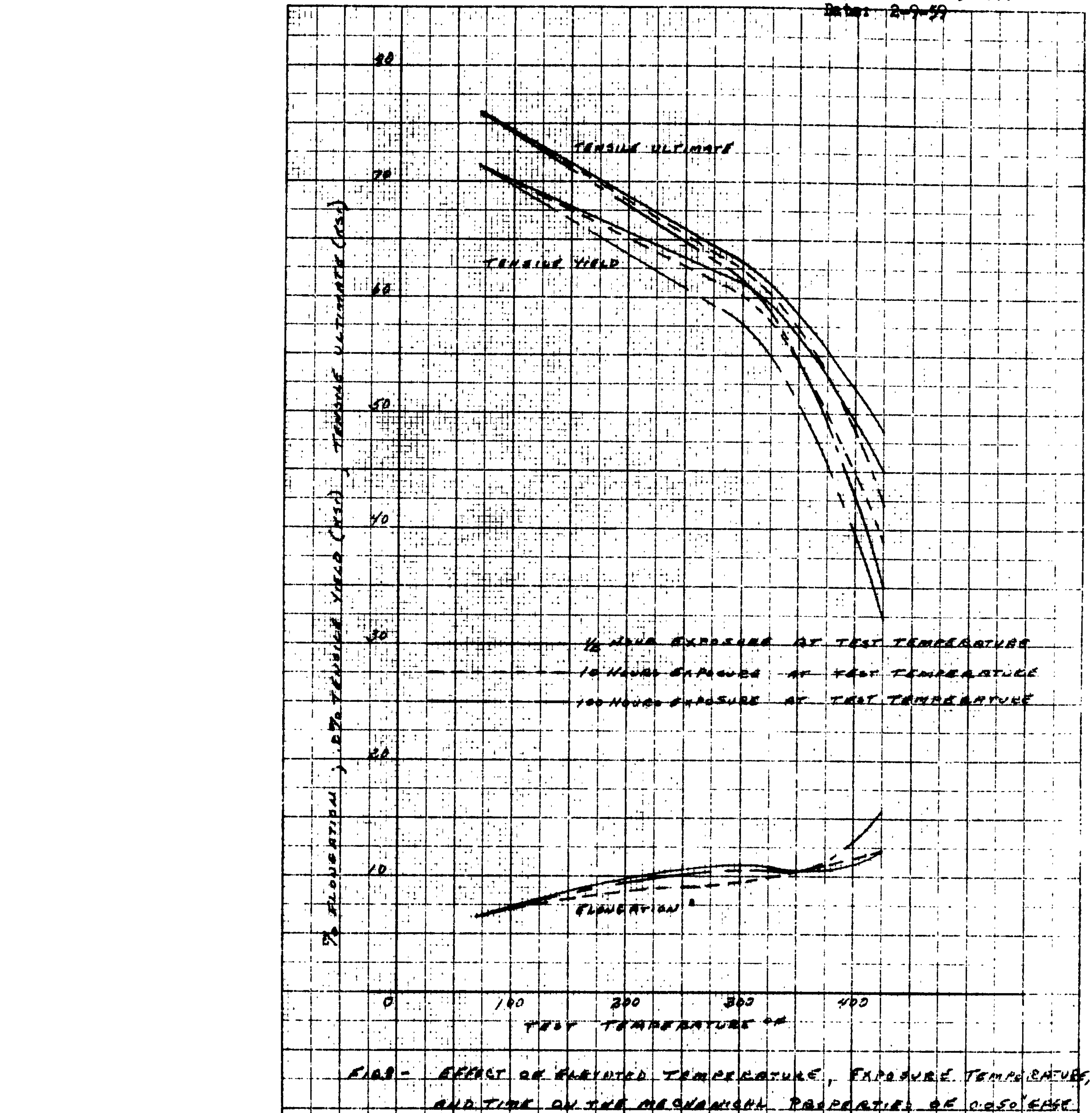

FIG 8 - EFFECT OF ELEVATED TEMPERATURE, EXPOSURE TEMPERATURE, AND TIME ON THE MECHANICAL PROPERTIES OF 0.050" EASE 2024-T86 ALUMINUM

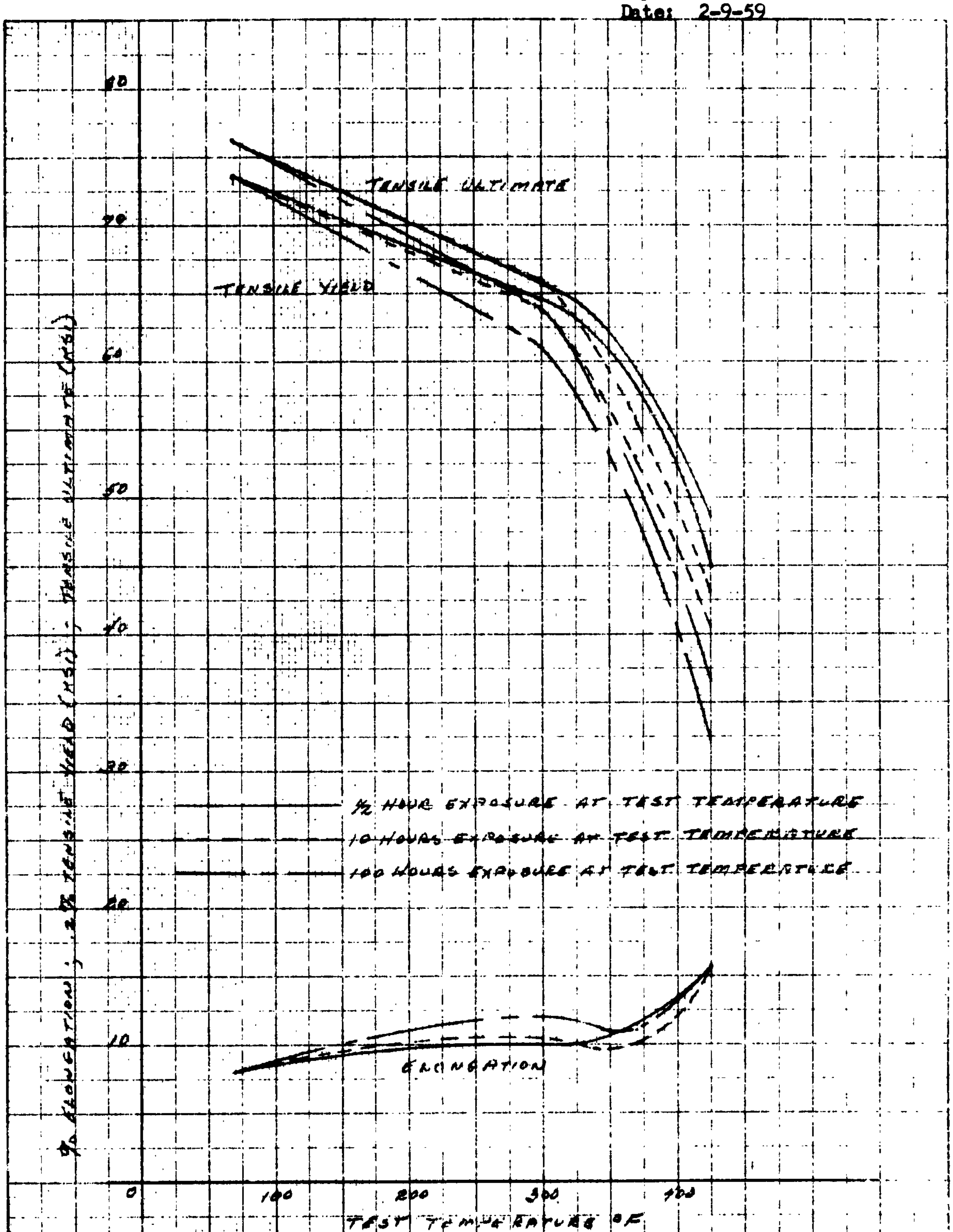

FIG. 9 - EFFECT OF ELEVATED TEMPERATURE, EXPOSURE TEMPERATURE, AND TIME ON THE MECHANICAL PROPERTIES OF 0.125" BARE 2024-T86 ALUMINUM