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STATUS REPORT ON THE BASIC MECHANICAL PROPERTIES OF ADVANCED TEST REACTOR ALUMINUM ALLOYS

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ABSTRACT

This memorandum reports the present results from a program aimed at obtaining the necessary mechanical property data for the fuel element materials proposed for the Advanced Test Reactor. Short-time tensile properties at room and elevated temperatures are given for the X-8001, modified X-8001, and 6061 aluminum alloys in the annealed condition. The isochronous stress-strain curves for the X-8001 alloy at 500 and 600°F also are presented.

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STATUS REPORT ON THE BASIC MECHANICAL PROPERTIES OF ADVANCED TEST REACTOR ALUMINUM ALLOYS

INTRODUCTION

The Advanced Test Reactor (ATR) is a high-flux water-moderated and light water-cooled reactor. The circular segment fuel element consists of 19 curved fuel plates.

The fuel plates are Al-U_3O_8 fuel dispersion clad with an aluminum alloy. The aluminum alloys considered in the final conceptual design[1] for the ATR fuel elements were the 1100, X-8001, X-8002, 6061, M-257, and M-430 aluminum alloys. The materials most feasible for the fuel element cladding are the 6061 and X-8001 alloys, based on the mechanical properties, corrosion resistance, and fabricability data available at this time.

The final selection between these two alloys will be based upon the corrosion and basic mechanical property data now being generated in testing programs at the Oak Ridge National Laboratory (ORNL).

In general, the ATR basic material testing program at ORNL has been established to supply to the designers: (1) the creep and short-time uniaxial tensile properties of X-8001 and composite fuel plates in the form of stress-strain curves; (2) dynamic modulus values of the alloys as a function of temperature; and (3) a literature review of the fatigue properties of the alloys.

This report serves as a mode of disseminating mechanical property data available at this time to those personnel participating in ATR test programs which require the use of such mechanical property data.

EXPERIMENTAL PROCEDURE

The specimens utilized on the mechanical property program were prepared from 0.125-in.-thick sheet by machining. The composition of the alloys is given in Table 1.

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[1] D. R. deBoisblanc, The Advanced Test Reactor – ATR Final Conceptual Design, IDO-16667.

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Table 1. Composition of Aluminum Alloys Under Investigation

Element	Wt % for Alloys		
	6061	X-8001	Modified X-8001
Ni	-	1.19	0.93
Si	0.60	0.06	0.003
Ti	-	-	0.11
Fe	-	0.48	0.53
Mg	1.00	-	-
Cu	0.25	260 ppm	-
Cr	0.25	-	-
Al	Balance	Balance	Balance

All specimens designated by a suffix, 0, were annealed 2 hr at 775°F in air and furnace cooled prior to testing to ensure removal of prior cold working.

The short-time tensile properties were obtained using a 10,000-lb-capacity Baldwin Universal testing machine. The cross-head speed was 0.05 in./min. The load-elongation curves were autographically recorded utilizing an extensometer arrangement on the specimens.

The time-dependent deformation data were obtained using constant load tests and an extensometer arrangement.

RESULTS

The tensile properties of the X-8001-0, modified X-8001-0, and 6061-0 aluminum are given in Table 2 as a function of temperature. Data[2] from Allis Chalmers Research Laboratory are given in Table 3 for comparison purposes.

The stress-strain curves for the X-8001 aluminum at 70, 400, 500, and 600°F are given in Figs. 1 and 2. The modulus values obtained from these data are given in Table 2.

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[2] Dean A. Nehrig, Nuclear Power Department, Allis Chalmers, personal communication, August 22, 1961.

Table 2. Mechanical Properties of Several Aluminum Alloys in the Annealed Condition

Test Temp. (°F)	Yield Strength, psi			Ultimate Tensile Strength, psi			% Elongation at Rupture			Modulus Values 10^{-6} psi		
	6061-0	X8001-0	Mod. X8001-0	6061-0	X8001-0	Mod. X8001-0	6061-0	X8001-0	Mod. X8001-0	6061-0	X8001-0	Mod. X8001-0
RT	8,480	5,025	5,555	20,130	15,635	14,270	23	37	36	10.08	10.4	-
400	7,900	3,810	4,880	15,310	6,165	6,735	30	46	58	-	9.8	-
500	6,815	3,100	3,455	7,630	4,220	4,545	50	61	66	-	8.1	-
600	5,345	2,435	2,815	5,490	2,735	3,365	47	73	63	-	7.0	-

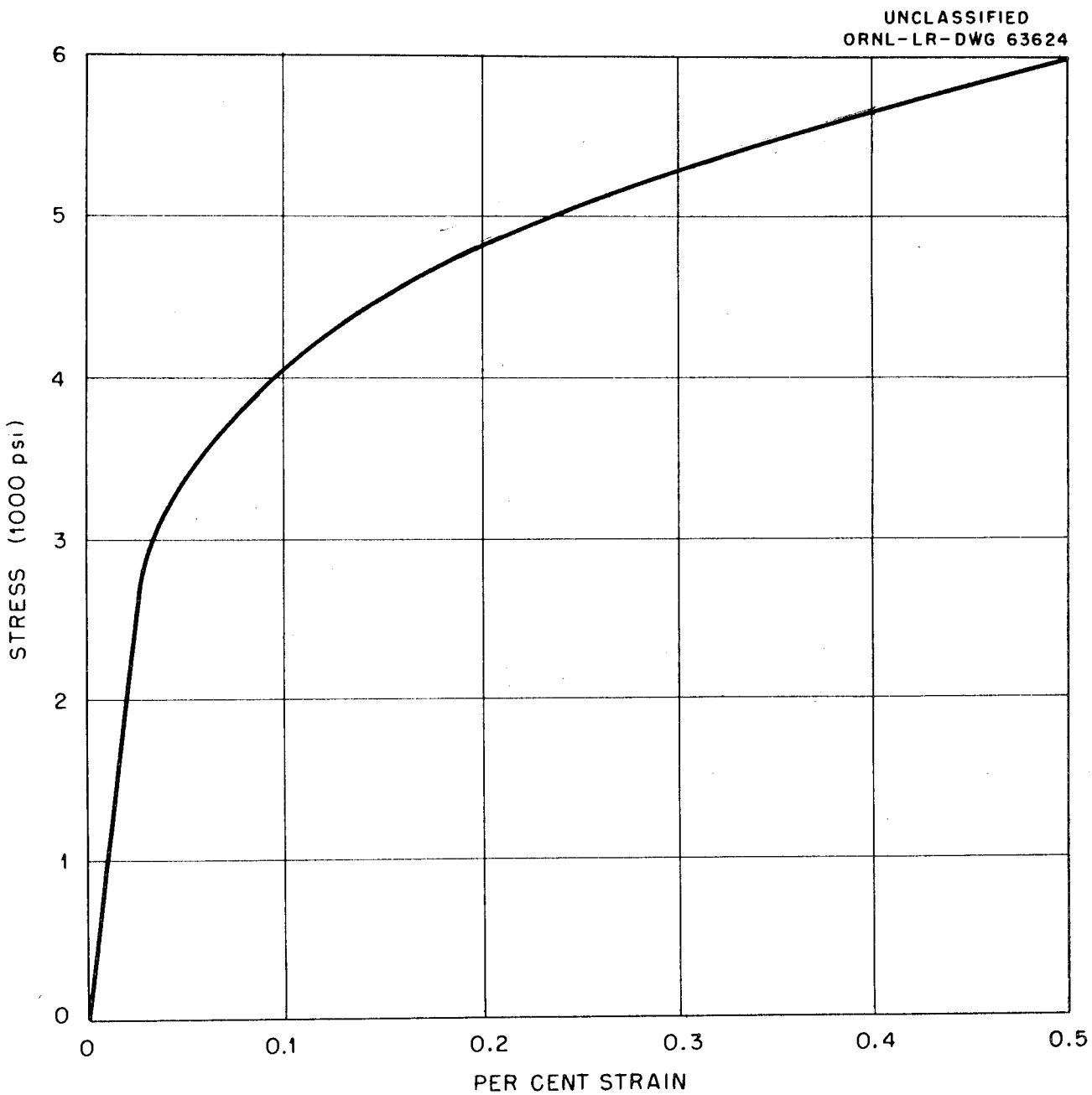

Fig. 1. Stress-Strain Tensile Curve for Aluminum Alloy X-8001-O Tested at Room Temperature.

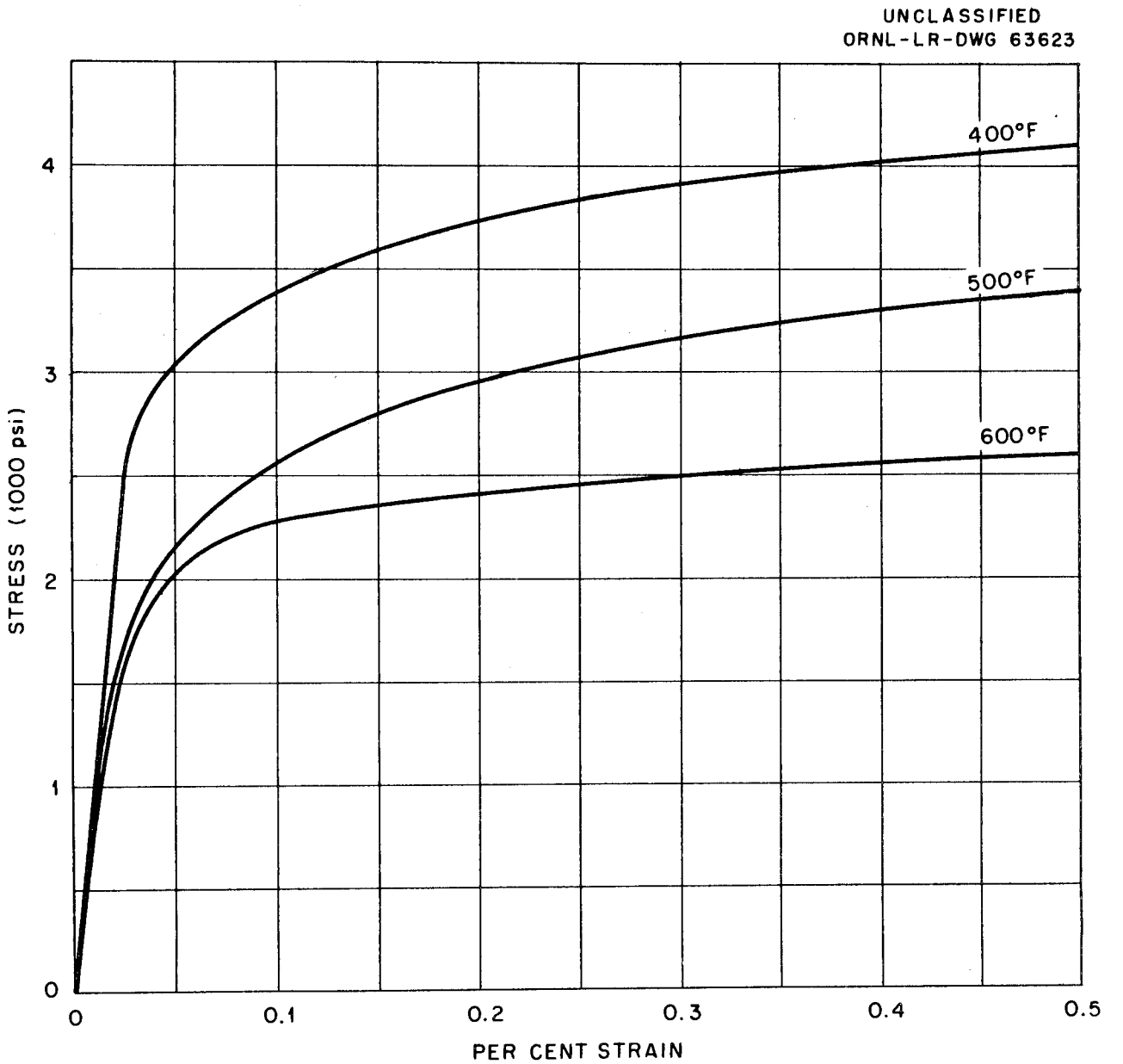

Fig. 2. Stress-Strain Tensile Curve for Aluminum Alloy X-8001-0 Tested at Elevated Temperature.

Table 3. Mechanical Properties of X-8001 Aluminum

Temp. (°F)	Yield Strength x 10^{-3} psi			Ultimate Tensile Strength x 10^{-3} psi		
	Plate	Tube	Rod	Plate	Tube	Rod
70	7.75	7.39	5.05	20.7	15.5	14.1
500			3.02	6.9	7.5	6.2
600			2.40	5.9	6.2	4.6

The isochronous stress-strain curves available at this time for the X-8001-O alloy are shown in Figs. 3 and 4.

DISCUSSION

It is noted that the strength of both the X-8001 and modified X-8001 aluminum in the annealed condition is considerably lower than that of the 6061 aluminum alloy in the annealed condition. One possible method of increasing the strength of the X-8001 system is to cold work the alloy. R. S. Kemper and K. F. Powell[3] have investigated the effect of fabrication variables on the mechanical properties of this alloy. The work of Kemper and Powell indicates: (1) that 10% cold work does not reduce the ductility below tolerable limits but substantially increases the room-temperature yield strength of the X-8001 alloy; (2) a reduction in yield strength of the cold-worked material occurs during annealing due to recovery and recrystallization; and (3) a small increase in yield strength may occur after many hours of annealing which can be attributed to strain aging. Table 4 shows the short-time tensile properties of the alloys at room temperature after 10% cold work and an exposure to elevated temperature for various times. These data indicate that the recovery and recrystallization process in the nonstressed material is not significant at temperatures less than 392°F at 1000 hr. The data in Table 5 indicate that 10% cold work does

[3] R. S. Kemper and K. F. Powell, Mechanical Properties of Aluminum Alloy M-388: Effect of Fabrication Variables, HW-54364 (Jan. 6, 1958).

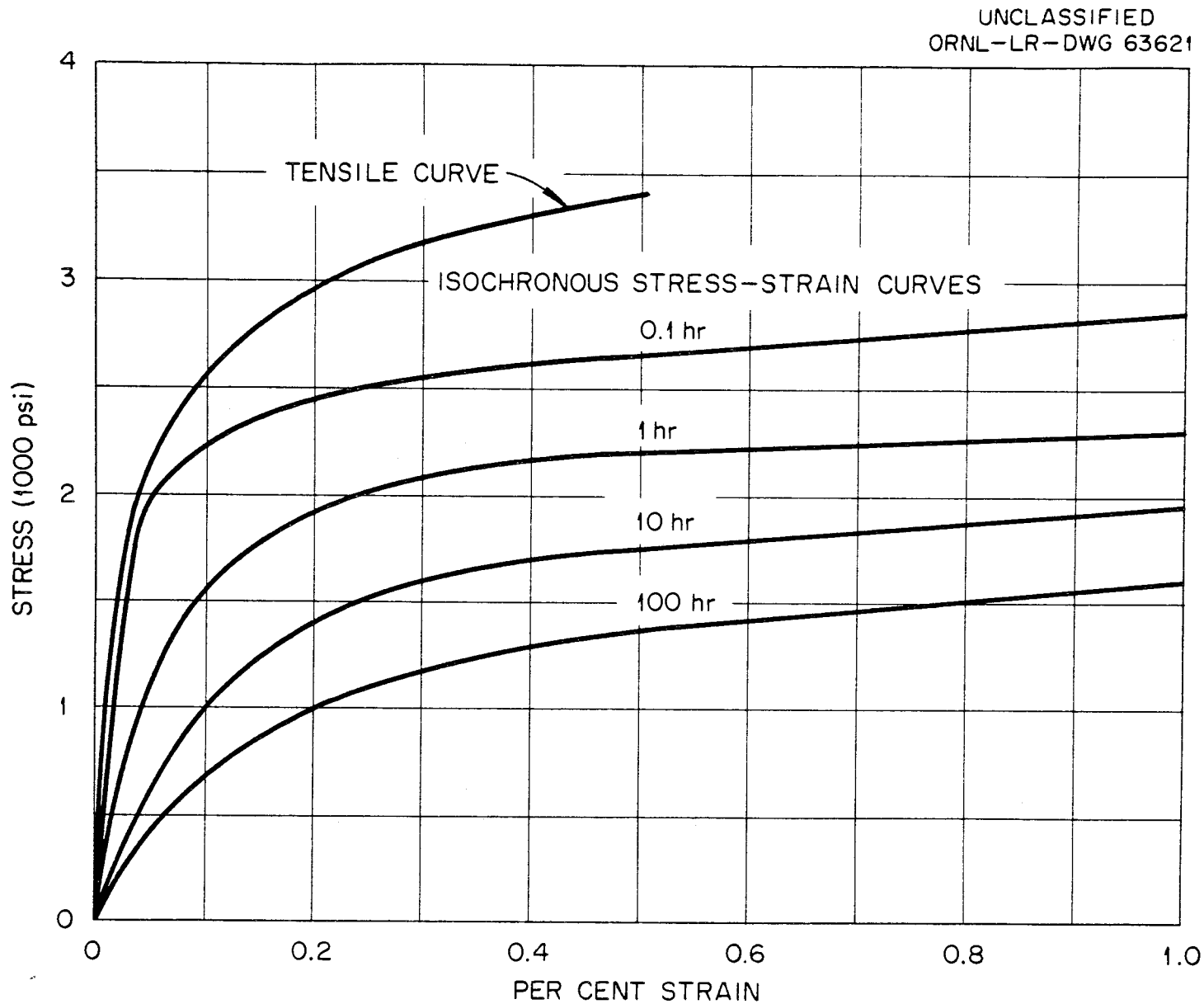

Fig. 3. Stress-Strain Curves for Aluminum Alloy X-8001-O Tested at 500°F in Air.

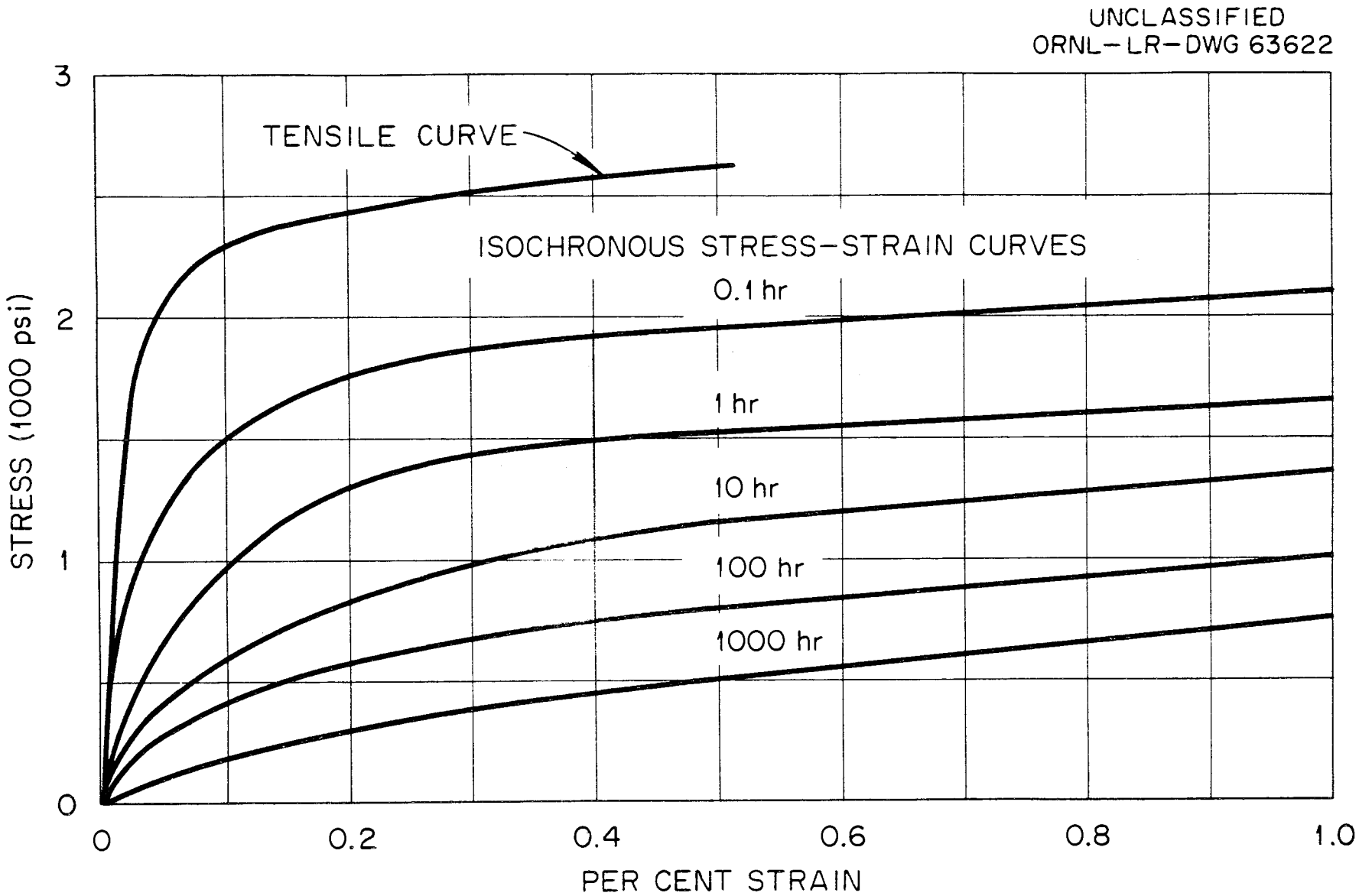

Fig. 4. Stress-Strain Curves for Aluminum Alloy X-8001-0 Tested at 600°F in Air.

Table 4. Room-Temperature Yield Strength* of Cold-Worked and Annealed X-8001 Aluminum

Annealing Temperature (°F)	0.2% Yield Strength x 10^{-3} psi			
	Annealing Time (hr)			
	1	7	100	1000
10% Cold Work				
RT	13.9	-	-	-
302	12.0	12.4	12.3	12.6
392	12.1	11.8	11.1	11.6
482	11.3	11.0	10.0	-
572	10.3	10.4	9.8	-
662	9.9	9.5	6.4	-
752	7.1	4.0	4.9	-
25% Cold Work				
RT	17.0	-	-	-
302	15.5	15.6	15.6	15.7
392	15.2	14.6	14.9	14.0
482	13.7	13.3	12.6	-
572	12.3	5.0	5.4	-
662	4.7	4.2	4.4	-
752	4.2	3.8	4.5	-

*R. S. Kemper and K. F. Powell, Mechanical Properties of Aluminum Alloy M-388: Effect of Fabrication Variables, HW-54364 (Jan. 6, 1958).

Table 5. Short-Time Tensile Properties of X-8001 Cold Worked 10%

Test Temperature (°F)	Yield Strength (psi)	Ultimate Tensile Strength (psi)	% Elongation at Rupture
RT	15,550	17,085	26.0
400	8,405	8,665	9.0
500	6,530	6,685	16.5
600	4,410	4,740	15.0

indeed improve the short-time tensile properties of X-8001 at elevated temperatures. Although the 10% cold work seems an obvious method of improving certain mechanical properties of the X-8001, the creep properties have not been investigated. Many alloy systems are strengthened at lower temperatures by cold working, but have poorer creep properties at the elevated temperatures than the annealed material. A cursory examination of the creep properties of a cold-worked X-8001 alloy is in progress at ORNL.

The modulus values in Table 2 are static modulus values obtained at a strain rate of 1.5 hr^{-1} (cross-head speed 0.05 in./min) that represent neither the maximum nor minimum modulus values available for design calculation. Maximum dynamic modulus values have not yet been determined. It is noted that at the elevated temperatures the material plastically deforms quite rapidly at low loads, therefore making the application of such static modulus values quite limited. Application of these modulus values to the calculation of stress from a given strain is only proper if the loads in service will be applied at a rate that results in a strain rate comparable to that of these tests. Calculations on material strained at a high strain rate require the use of a dynamic modulus, and consideration of lower loading rates requires the use of the isochronous stress-strain curve.

SUMMARY

The short-time tensile properties of several aluminum alloys have been presented. A possible means of increasing the strength of X-8001 aluminum by cold working has been shown while a possible deleterious effect of cold work on the creep properties has been indicated. The creep properties of X-8001 aluminum at 500 and 600°F in the form of isochronous stress-strain curves have been presented for design application.

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