DEVELOPMENT OF A HIGH STRENGTH ALUMINUM ALLOY, READILY WELDABLE IN PLATE THICKNESSES, AND SUITABLE FOR APPLICATIONS AT -423°F (-253°C)

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Progress Report 11 - Phase III, Experimental Program

by

R. W. Westerlund

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Alcoa Research Laboratories
Aluminum Company of America
New Kensington

STATUS

The advanced evaluation of promising compositions and tempers (Phase III) is nearing completion, as shown in Table I. Items of the two alloys being fabricated at Alcoa's Davenport Plant (M825 and M826) have been arriving since about June 6. The proposed work schedule for evaluation of the material is given in Table II.

RESULTS AND DISCUSSION

2000 SERIES

Examination of the Microstructure

This research program has substantiated the findings of previous investigators on the effect of Cd and/or Sn on the properties of 2000 series alloys. Three of the main points are as follows. First, these additions increase the strength. Second, stretching before aging reduces the strengths achieved. Third, a short aging treatment before stretching and aging (pre-aging) results in a partial restoration of the strengths to the level achieved with no stretching.

A tentative explanation of these effects has been attempted, based on information obtained from studies with the electron microscope. Such studies* have shown that when 2219 is aged without intermediate deformation, the structure consists entirely of zones (Figure 1). With a small amount of deformation

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*Unpublished information: Alcoa Research Laboratories Report No. 13-64-6; May 6, 1964; G. R. Frank, Jr.

(1 1/2%) prior to aging, the strengths are increased slightly and a small number of precipitate platelets are formed (Figure 2). With higher amounts of deformation, the strength increases still further and the density of platelets also increases (Figure 3). It is assumed, therefore, that deformation before aging promotes the formation of precipitate platelets and these platelets increase the strength. Also, the strengthening effect from the platelets is proportional to the platelet size and density.

Using the ideas shown above for 2219, an explanation of the effects observed in the 2000 series alloys containing Cd and/or Sn will be attempted by using electron micrographs. Alloy 2219 + Cd + Sn (M825) was studied since it has been selected for further evaluation under this contract. For any intensive investigation of these effects, it would be best to use 2219 + Cd because the effects of stretching are more drastic in this alloy.

The effects observed for 2219 + Cd + Sn can be explained using the ideas brought out above for 2219. Figure 4 shows the addition of Cd + Sn produces a dense distribution of fine precipitate platelets. When deformed a small amount before aging, the platelets become larger and less numerous (Figure 5). Pre-aging before stretching and aging results in a smaller precipitate in a more dense distribution (Figure 6). These observations tie in well with the postulate that the strength is dependant on the size and density of the precipitate platelets.

Optical micrographs of two tempers of 2219 + Cd + Sn are shown in Figures 7 and 8. No noticeable difference in microstructure can be seen between the two tempers.

The above suggestions are only temporary. Work will continue in an attempt to understand the phenomena observed in these 2000 series alloys containing Cd and/or Sn.

7000 SERIES

Tensile properties have been determined at testing temperatures to -423°F for several composition-temper combinations of the 7000 series alloys (Table IV). These properties are plotted against testing temperature in Figure 9. The elongation gradually decreases with decreasing testing temperatures while the strength increases. The strength and elongation curves are quite similar for all composition-temper combinations.

The notch toughness of the best combinations of composition and temper for these 7000 series alloys meets or closely approaches the contract goals. At room temperature the notch strength ratio is much higher than the established minimum goal of 1.0. The notch strength ratio decreases rapidly with decreasing testing temperature, but at -423°F the ratio is still approximately equal to the contract minimum goal of 0.9.

Table IV shows it is possible to approach the minimum goals of strength and notch toughness with a 7000 series alloy. Aging practice -K for M793 develops strengths equal to the minimum strength goals (TS = 75 ksi, YS = 65 ksi) and notch toughness essentially equal to the minimum notch strength ratio of 0.9. By aging to a slightly lower strength it is possible to achieve notch tensile ratios of 0.98 (aging practice -J).

Figure 10 compares the tensile properties of the 2000 and 7000 series alloys as a function of testing temperature. Compositions and tempers with equal strengths were compared. The major difference between the two types of alloys is the lower temperature sensitivity of the notch toughness for the 2000 series alloys. Even though there is this great difference, both types of alloys have sufficient notch toughness to meet the minimum notch toughness goals.

Figure 10 also shows the following minor differences between the 2000 and 7000 series alloys. The elongation of the 7000 series alloys gradually decreases with decreasing testing temperature, while the elongation of the 2000 series alloys remains above the room temperature level for the lower temperatures. The increase in tensile strength with decreasing testing temperature is greater for the 7000 series alloys.

Effect of Aging Treatment

In Progress Report No. 8 the effect of aging treatment on notch toughness was reported, but additional work was needed to clarify certain points. New data have been obtained (Table V) and will be considered along with the old data in an attempt to clarify several points.

The first point studied was a comparison of the notch toughness of equal strength tempers of high and low solute alloys. The alloys used were M790 (6.5 Zn, 2.5 Mg) and M792 (9.0 Zn, 2.5 Mg). A summary of the pertinent data is given in Table VI. The aging curves and the notch strength ratio-yield strength curves for M790 and M792 are shown in Figure 11.

The notch strength ratio-yield strength curve for M790 appears to lie slightly above that for M792, suggesting than an underaged temper of a high solute alloy may have lower notch toughness than the fully aged temper of a lower solute alloy having the same yield strength.

The second investigation included a comparison of the notch toughness of underaged tempers and overaged tempers. Table VII gives a summary of the data for aging treatments providing underaging and overaging in alloys M790 and M792. Figure 12 shows aging curves and notch strength ratios-yield strength curves for the above alloys.

Figure 12 shows that at peak strength or slightly beyond, there is a drop in notch toughness. It is possible that this may be due to the formation of a transition precipitate phase which has been associated with the same general position on the aging curve. The data also suggest that with considerable overaging, the notch toughness rises above the notch toughness of underaged material of equal yield strength. The above observations are based on a limited amount of data; therefore, additional work would be desirable.

Figure 13 consolidates all the data of aging treatment versus notch toughness for the 7000 series alloys. For all four alloys, notch toughness decreased as the yield strength increased. The two alloys containing Zr (M791 and M793) have higher notch toughness than the alloys without Zr (M790 and M792). The curve for M792 which was quenched in 180°F water and aged after six months (291705) is lower than the curve for M792 which was cold water quenched and aged after three days (291707). This is attributed to the large loss in strength due to the slower cooling rate used for 291705.

Effect of Zr on Structure

The microstructures of M790 (6.5 Zn, 2.5 Mg) and M791 (6.5 Zn, 2.5 Mg, 0.10 Zr) have been studied, using the electron microscope, to determine in what way Zr changes the microstructure to improve the notch toughness. Figures 14 and 15 show the microstructure of M790 and M791, respectively. The most significant effect of Zr, at least as shown by the micrographs, is that it retards recrystallization.

Since Zr affects recrystallization, the program shown in Table VIII was conducted to determine if notch toughness varied with the degree of recrystallization. Various degrees of recrystallization were achieved by varying the solution heat treating (SHT) temperature. M790 was included to determine if notch toughness is dependant on the SHT temperature. Table VIII shows that the notch toughness becomes poorer as the SHT temperature increases.

The alloys containing Zr (M791 and M793) were shown by X-ray pinhole examination to have varying degrees of recrystallization. The change in notch toughness for M793 is very similar to the change in M790, while the change for M791 is of the same sign but smaller in magnitude. Since the alloys with a change in degree of recrystallization act much like the alloy with no change in degree of recrystallization, it is assumed that there is little or no effect of degree of recrystallization on notch toughness.

ABSTRACT OF TECHNICAL CONTENT

The microstructure of 2219 + Cd + Sn has been studied using optical and electron microscopy. Tentative explanations of the phenomena observed in these 2000 series alloys containing Cd and/or Sn were made using electron micrographs.

Properties were determined at temperatures to -423°F for selected composition-temper combinations of 7000 series alloys. For combinations having strengths approximately equal to the contract minimum strength goals, the notch strength ratio at -423°F was equal to the contract minimum ratio of 0.9. These most promising properties were for M793.

When the most promising composition-temper combinations of the 2000 and 7000 series alloys are compared, it was shown that both groups approach the minimum strength goals and the minimum notch toughness goals. The major difference between the two alloy groups is the temperature sensitivity of the notch toughness.

Additional work on the effect of aging treatments on the notch toughness of the Al-Zn-Mg alloys has shown the following. First, a high solute alloy in an underaged temper appears to have slightly lower notch toughness than an alloy with less solute at full strength, provided they have equal yield strengths. Second, the notch toughness appears to decrease abruptly during isothermal aging at strengths near or just beyond the maximum. With extended overaging, some increase in notch toughness is obtained.

The effect of Zr on the microstructure of a 7000 series alloy was studied using the electron microscope to determine in what way Zr improves the notch toughness. Zr was shown to

retard recrystallization. A program to determine if notch toughness is dependant on the degree of recrystallization did not reveal any direct connection between notch toughness and the degree of recrystallization.

ANTICIPATED WORK

During June all work on Phase III, advanced evaluation of selected alloys, should be finished, with the exception of long term stress corrosion testing. Evaluation of the plant produced material should be well underway by the end of June. An annual summary report will be prepared to be submitted in July.

During May, 571.5 man-hours were expended on this contract.

TABLE I

PROGRESS CHART FOR PHASES III AND IV

	Initiation		Ingot		Material Prepared		Specimens Prepared		Results	
	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual
Phase III	11-15-63									
2000 series		11-7-63								
Parent Metal			12-1-63	12-4-63	12-15-63	1-15-64	1-15-64			
N & U Tensile*								1-28-64	2-15-64	2-11-64
Stress Corrosion								3-16-64		
Welds - MIG						1-8-64	1-15-64			
N & U Tensile								4-1-64	2-15-64	3-30-64
Stress Corrosion								4-8-64		
Welds - TIG						1-8-64	1-15-64			
N & U Tensile								4-1-64	2-15-64	3-30-64
Stress Corrosion								4-8-64	No Work Planned	
Weld Cracking						12-26-63	12-25-63	1-3-64	1-15-64	2-4-64
7000 series		2-25-64				2-25-64				
Welds - MIG						4-9-64				
N & U Tensile								6-1-64		
Stress Corrosion								5-10-64		
Welds - TIG						4-9-64				
N & U Tensile								6-1-64		
Stress Corrosion								5-10-64		
Phase IV	2-11-64	2-21-64								
Parent Metal						6-15-64				
N & U Tensile										
Stress Corrosion										
Welds (MIG & TIG)										
Tensile										
Stress Corrosion										

*Notched and unnotched tensile specimens.

TABLE II

PROPOSED WORK SCHEDULE FOR EVALUATION OF PLANT PRODUCED MATERIAL

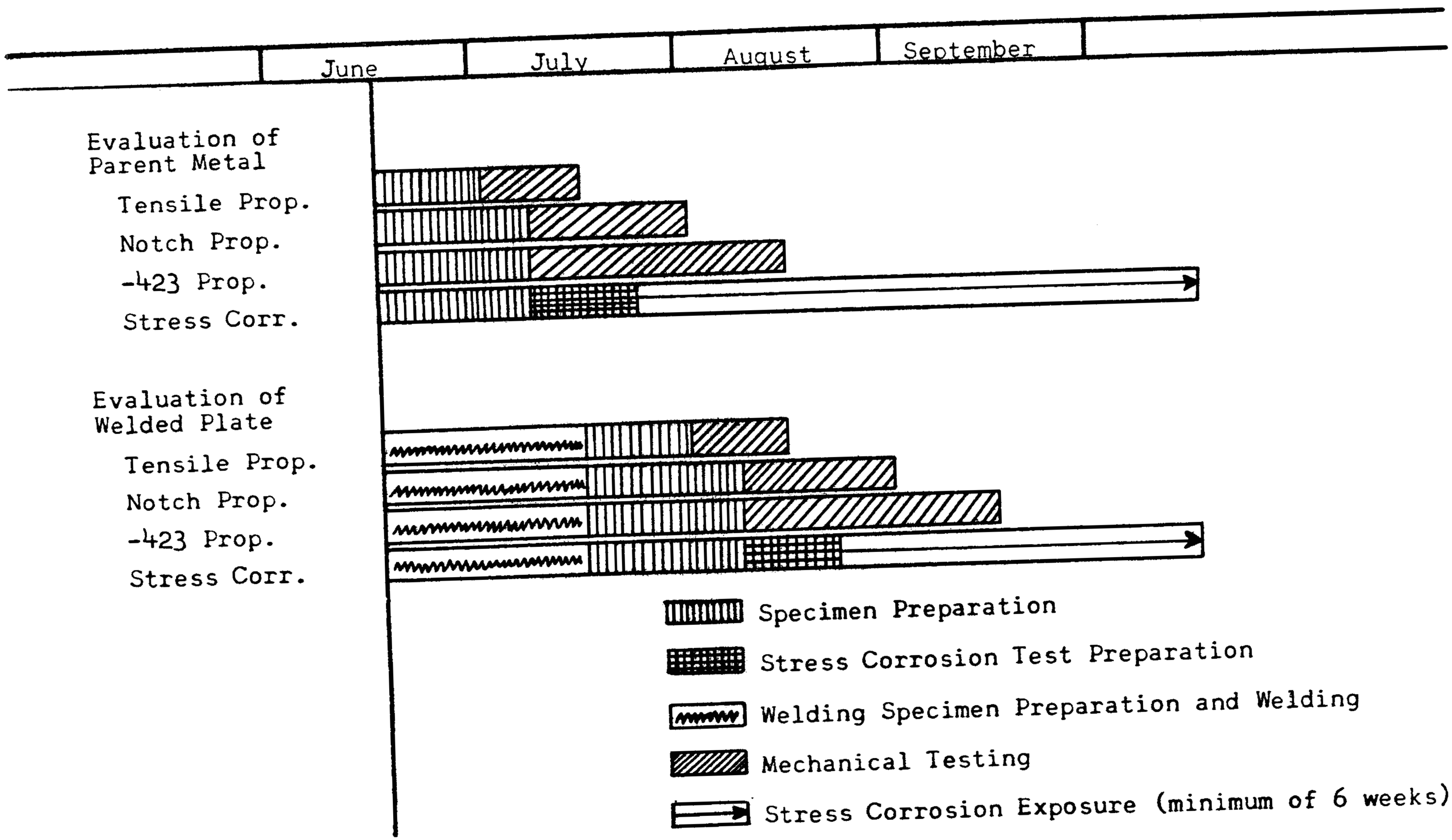


TABLE III

RESULTS OF CHEMICAL ANALYSIS

Alloys From Phase IIa - Section 1 and 2

Series	S. No.	Cu	Fe	Si	Mn	Mg	Zn	Cr	Zr	V	Ti	Cd	Sn	Ni	Analytical Report No.
2000	291076	6.53	.20	.12	.31	.00	.00	.00	.17	.10	.08	.00	.00	.00	63-071802
	291077	6.32	.19	.11	.31	.31	.01	.00	.18	.10	.08	.00	.00	.01	63-071802
	291079	6.25	.19	.30	.31	.31	.01	.00	.17	.10	.08	.00	.00	.01	63-071802
	291080	6.43	.20	.12	.32	.00	.00	.00	.16	.10	.07	.20	.00	.01	63-071802
	291081	6.26	.19	.11	.32	.00	.00	.00	.17	.10	.07	.18	.05	.01	63-071802
	291082	6.33	.19	.29	.32	.00	.00	.00	.17	.11	.09	.20	.00	.01	63-071802
7000	291104	.02	.19	.06	.21	1.29	7.40	.16			.03			.00	63-032313
	291105	.02	.19	.06	.22	1.24	8.95	.16			.03			.00	63-032313
	291106	.02	.19	.06	.21	1.76	5.60	.15			.03			.00	63-032313
	291107	.02	.19	.06	.21	1.80	7.30	.16			.03			.00	63-032313
	291108	.02	.20	.07	.22	1.78	9.05	.16			.02			.00	63-032313
	291109	.02	.19	.06	.20	2.29	4.34	.15			.03			.00	63-032313
	291110	.02	.19	.07	.21	2.29	5.54	.15			.03			.00	63-032313
	291111	.02	.19	.07	.21	2.20	7.35	.16			.03			.00	63-032313
	291112	.02	.19	.07	.22	2.26	8.90	.16			.03			.00	63-032313
	291113	.02	.19	.07	.20	2.76	4.12	.15			.03			.00	63-032313
	291114	.02	.17	.07	.21	2.78	5.48	.15	.00		.03			.00	63-072410
	291115	.02	.18	.07	.22	2.75	6.96	.16	.00		.03			.00	63-072410
	291116	.02	.17	.07	.21	3.16	5.60	.15	.00		.03			.00	63-072410
	291117	.01	.18	.07	.22	1.24	7.00	.16	.14		.03			.00	63-072410
	291118	.02	.18	.07	.21	2.32	4.34	.15	.14		.03			.01	63-072410
	291119	.02	.18	.07	.21	2.28	5.60	.15	.12		.03			.00	63-072410
	291120	.02	.18	.07	.22	2.31	7.16	.16	.12		.03			.00	63-072410
5000	291138	.10	.12	.06	.30	7.22	.00	.10	.00		.03			.00	63-080909
	291139	.11	.12	.06	.32	8.55	.00	.10	.00		.03			.00	63-080909
	291140	.11	.12	.07	.31	8.64	2.05	.10	.00		.03			.00	63-080909
	291141	.11	.14	.07	.30	8.45	2.02	.08	.11		.03			.01	63-080909
7000	291342	.26	.13	.06	.20	2.28	4.20	.11	.15		.03			.01	63-091706
	291343	.28	.13	.07	.21	2.33	5.49	.13	.15		.03			.01	63-091706
	291344	.28	.13	.07	.25	2.23	7.13	.14	.15		.03			.01	63-091706
7000 Series (Davenport)															
	M790	.11	.16	.15	.20	2.65	6.18	.12	.00		.01			.00	63-081904
	M791	.12	.16	.09	.21	2.22	6.20	.13	.10		.01			.00	63-081904
	M792	.09	.21	.09	.21	2.65	9.14	.12	.00		.02			.00	63-081904
	M793	.12	.18	.09	.20	1.64	6.51	.13	.10		.01			.00	63-081904
2000 Series (Phase III)															
	291597	6.16	.17	.07	.29	.31	.00	.00	.17	.11	.06	.00	.00	.01	63-120502
	291598	6.37	.18	.07	.31	.00	.00	.00	.01	.01	.06	.17	.00	.00	63-120502
	291599	6.27	.18	.07	.28	.00	.00	.00	.00	.01	.06	.15	.05	.00	63-120502
	291715	6.21	.18	.07	.29	.00	.00	.00	.17	.11	.06	.17	.00	.00	63-120502
	291716	6.24	.18	.07	.28	.00	.00	.00	.17	.11	.06	.14	.05	.00	63-120502
	291816	6.02	.16	.07	.28	.00	.01	.00	.17	.10	.07	--	.04	.00	64-010908

TABLE IV

TENSILE PROPERTIES OF 7000 SERIES ALLOYS

Smooth and Notched Specimens from 1.0" Plate

S. No.	Alloy	Description of Material: Aging Treatment Time - Hr	Aging Treatment Temp - °F	Properties at Room Temperature: TS ksi	YS ksi	% El. in 2"	% R of A	NTS* ksi	NTS** / TS
291704-I	M791	16	225	73.6	60.9	12.2	16	92.5	1.26
291706-A	M793	4	300	70.4	64.0	12.5	26	96.4	1.37
291706-J	M793	24	225	73.6	63.4	11.5	15	96.6	1.31
291706-K	M793	48	225	74.8	66.9	11.0	16.5	98.9	1.32

S. No.	Properties at -320°F: TS ksi	YS ksi	% El. in 2"	% R of A	NTS* ksi	NTS** / TS	Properties at -423°F: TS ksi	YS ksi	% El. in 2"	% R of A	NTS* ksi	NTS** / TS
291704-I	91.4	73.7	10.5	12	87.2 87.6 91.6	1.00	104	79.2	10.0	7.7	80.8 83.7 86.2	.83
291706-A	89.7	76.4	10.0	16	92.5 93.4 98.4	1.10	102	80.2	10.2	13.2	92.5 99.8 101	.97
291706-J	91.8	77.0	11.0	14	93.4 93.8 100.6	1.10	104	82.3	10.2	13.4	94.2 99.2 103	.98
291706-K	92.3	81.2	7.3	10	91.6	.99	106.5	87.7	8.5	14.0	93.3 94.3 94.6	.89

*All test values are included if there were large deviations among them, otherwise, the value listed is the average.

**Highest notch tensile strength used if all test values are listed.

1. A more complete description of the material was given in the Third Quarter Progress Report.

2. Transverse properties - YS = 0.2% Offset - Notched round specimens, K_t = 10, ARL Dwg. 9178.

TABLE V

EFFECT OF AGING TREATMENT ON THE NOTCH TOUGHNESS OF 7000 SERIES ALLOYS[1]

S. No.	Alloy	Quench	Aging Treatment Time-Hr	Aging Treatment Temp-°F	Room Temperature TS ksi	YS ksi	% El. in 2"	% R of A	NTS* ksi	NTS** / TS	-320°F TS ksi	YS ksi	% El. in 2"	% R of A	NTS* ksi	NTS** / TS
291703-M	M790	180° Water	1	225	72.3	53.7	14.8	16	82.5	1.14	89.0	65.3	11.7	12	81.2	.91
-G	M790	180° Water	4	225	72.3	56.0	14.0	18	85.1	1.18	90.0	69.0	11.0	12	83.2 86.2	.96
292071-M	M790	Cold Water	1	225	70.7	50.6	16.5	20	83.1		88.0	63.0	13.5	15	78.3	.89
-G	M790	Cold Water	4	225	73.2	57.8	15.5	20	88.9		90.4	71.2	11.5	12	77.0	.85
291703-O	M790	180° Water	2	250	73.6	59.2	13.5	18	88.3	1.20	92.4	72.7	11.5	13	79.2	.86
-P	M790	180° Water	168	250	76.6	71.0	11.8	27	95.2	1.24	98.4	87.0	7.0	9	60.8 62.3 65.1	.66
-Q	M790	180° Water	336	250	71.7	64.6	11.8	27	90.5	1.26	93.5	78.8	8.0	11	71.7 76.1	.81
291707-M	M792	Cold Water	1	225	85.4	67.6	12.8	13	89.6	1.05	94.9	83.1	3.0	4	62.2 65.8	.69
-N	M792	Cold Water	2	225	86.4	70.6	12.8	14	88.3	1.02	97.1	85.6	3.0	4	58.6 62.5	.64
291707-O	M792	Cold Water	2	250	86.8	75.6	12.5	14	82.5	.95	100.0	89.9	1.5	3	51.8	.52
-P	M792	Cold Water	168	250	86.0	82.5	9.8	22	84.5 89.1 93.4	1.09	107.4	103.7	2.0	4	49.8	.46
-Q	M792	Cold Water	336	250	80.6	76.1	11.2	25	92.4 92.4 98.5	1.22	101.7	93.9	3.3	4	56.2 59.4	.58

*All test values are included if there were large deviations among them, otherwise, the value listed is the average.

**Highest notch tensile strength used if all test values are listed.

1. Transverse properties - YS = 0.2% Offset - Notch round specimens, $K_t = 10$, ARL Dwg. 9178.

TABLE VI

SUMMARY OF PROPERTIES FOR ISOTHERMAL AGING AT 225°F

Aging Time at 225°F	TS ksi	YS ksi	% El. in 2"	$\left(\frac{NTS}{TS}\right)_{RT}$	$\left(\frac{NTS}{TS}\right)_{-320°F}$
		M790			
1 hr	72.3	53.7	14.8	1.14	.91
4	72.3	56.0	14.0	1.18	.96
16	77.2	65.0	12.0	1.18	.79
48	80.0	71.0	11.0	1.17	.69
168	80.7	74.2	10.2	1.18	.60
		M792			
1 hr	85.4	67.6	12.8	1.05	.69
2	86.4	70.6	12.8	1.02	.64
4	88.0	73.0	11.5	1.04	.55
8	89.8	77.8	10.8	.96	.50
16	91.3	82.2	9.8	.83	.45
48	93.8	87.1	7.8	.81	.41
168	94.2	90.1	6.8	.82	.41

TABLE VII

SUMMARY OF PROPERTIES FOR ISOTHERMAL AGING AT 250°F

Aging Time at 250°F	TS ksi	YS ksi	% El. in 2"	$\left(\frac{NTS}{TS}\right)_{RT}$	$\left(\frac{NTS}{TS}\right)_{-320°F}$
		M790			
2 hr	73.6	59.2	13.5	1.20	.86
4	77.2	65.8	12.8	1.21	.80
8	77.5	68.0	10.8	1.19	.79
48	77.0	71.2	10.5	1.21	.73
96	77.6	71.4	10.5	1.20	.64
168	76.6	71.0	11.8	1.24	.66
336	71.7	64.6	11.8	1.26	.81
		M792			
2 hr	86.8	75.6	12.5	.95	.52
8	91.8	86.3	8.2	.84	.44
48	92.8	89.6	7.5	.90	.41
96	92.4	88.4	7.5	.92	.38
168	86.0	82.5	9.8	1.09	.46
336	80.6	76.1	11.2	1.22	.58

TABLE VIII

EFFECT OF DEGREE OF RECRYSTALLIZATION ON NOTCH TOUGHNESS

(0.064" Sheet)

			Room Temperature					-320°F				
S. No.	Solution Heat Treatment	Degree of Recrystallization*	TS ksi	YS ksi	% El. in 2"	NTS/ ksi	NTS// / TS	TS ksi	YS ksi	% El. in 2"	NTS/ ksi	NTS// / TS
M790 292134-1	30 min/775°F	Complete	77.0	70.4	11.0	73.7 75.4 76.3	.99	95.4		6.2	39.0 47.9 52.3	.55
-2	30 min/860°F	Complete	77.3	70.7	11.0	73.0 75.0 75.5	.98	95.6	85.4	6.0	50.0	.52
-3	30 min/1000°F	Complete	78.8	72.7	10.5	75.3	.96	96.6	90.3	3.0	39.2	.40
-4	30 min/1000°F** + 15 min/860°F	Complete	78.2	72.4	10.0	75.8 77.2 78.4	1.00	96.0	85.6	3.0	37.3 38.3 40.8	.42
M791 291970-1	30 min/775°F	Just Started	77.8	72.7	9.8	73.3 75.8 75.9	.98	99.8	89.0	9.7	54.8 61.1 64.8	.65
-2	30 min/860°F	Started	77.5	72.2	9.8	75.9	.98	99.7	88.5	9.5	55.9 56.2 64.6	.65
-3	30 min/1000°F	Complete	79.2	74.4	9.5	78.4	.99	99.3	91.7	3.0	53.0 54.2 59.7	.60
-4	30 min/1000°F** + 15 min/860°F	Complete	79.3	74.5	9.5	79.3	1.00	98.6	***	3.0	47.7 54.4 60.9	.62
M793 291971-1	30 min/775°F	Just Barely Started	73.8	69.2	11.0	76.1	1.03	95.7	86.5	11.0	64.7 71.1 79.4	.83
-2	30 min/860°F	Started Plus	74.8	70.6	9.5	76.4	1.02	96.4	87.5	8.0	73.4	.76
-3	30 min/1000°F	Complete	74.6	70.0	10.5	76.2	1.02	92.0	***	3.0	60.8 61.0 62.9	.68
-4	30 min/1000°F** + 15 min/860°F	Complete	74.2	69.8	10.0	76.0	1.02	91.8	82.8	3.5	58.6 62.6 66.1	.72

*Determined by X-ray pinhole examination.

/All test values are included if there were large deviations among them, otherwise, the value listed is the average.

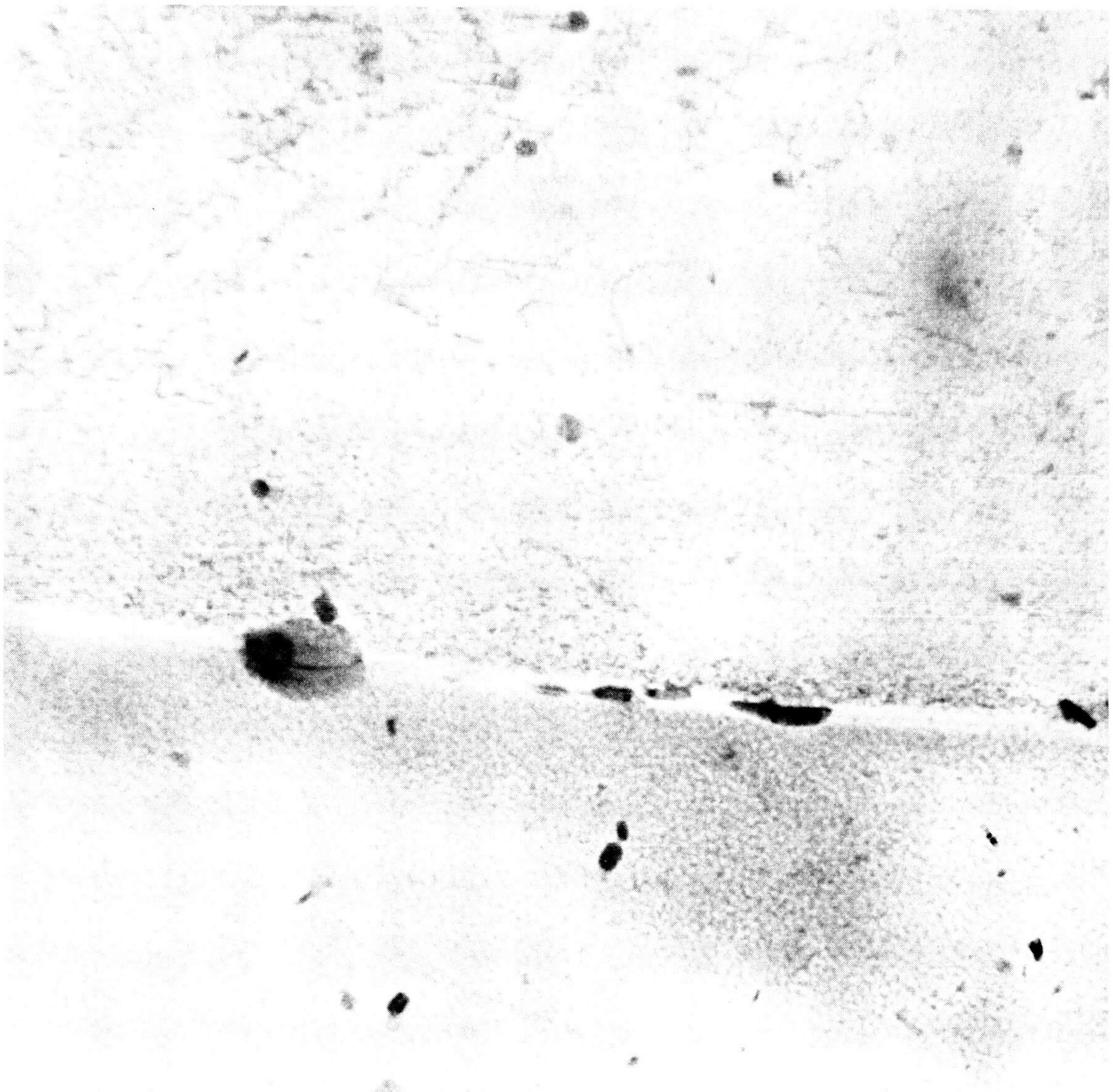
//The highest notch tensile strength was used if all test values are listed.

**Furnace cooled from 1000°F to 860°F.

***Malfunction of strain gage.

1. The starting material was about -H18 temper. All material boiling water quenched, stretched 1 1/2% one day after quenching, and aged 48 hr at 250°F three days after quenching.

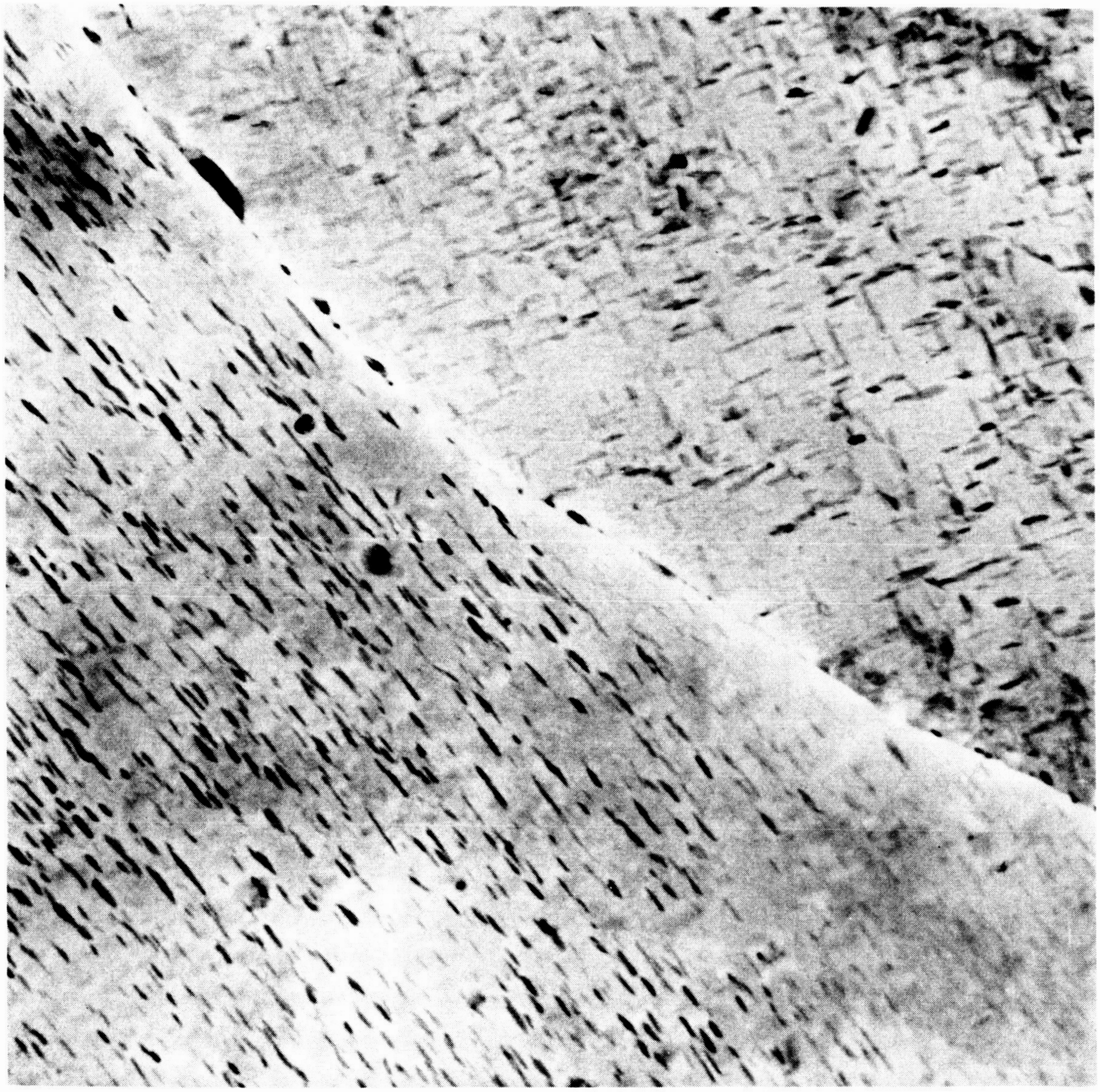
2. Transverse properties - YS = 0.2% Offset - Notch sheet specimen, K_t = 10, ARL Dwg. 9177.



122/6/6 50,000X

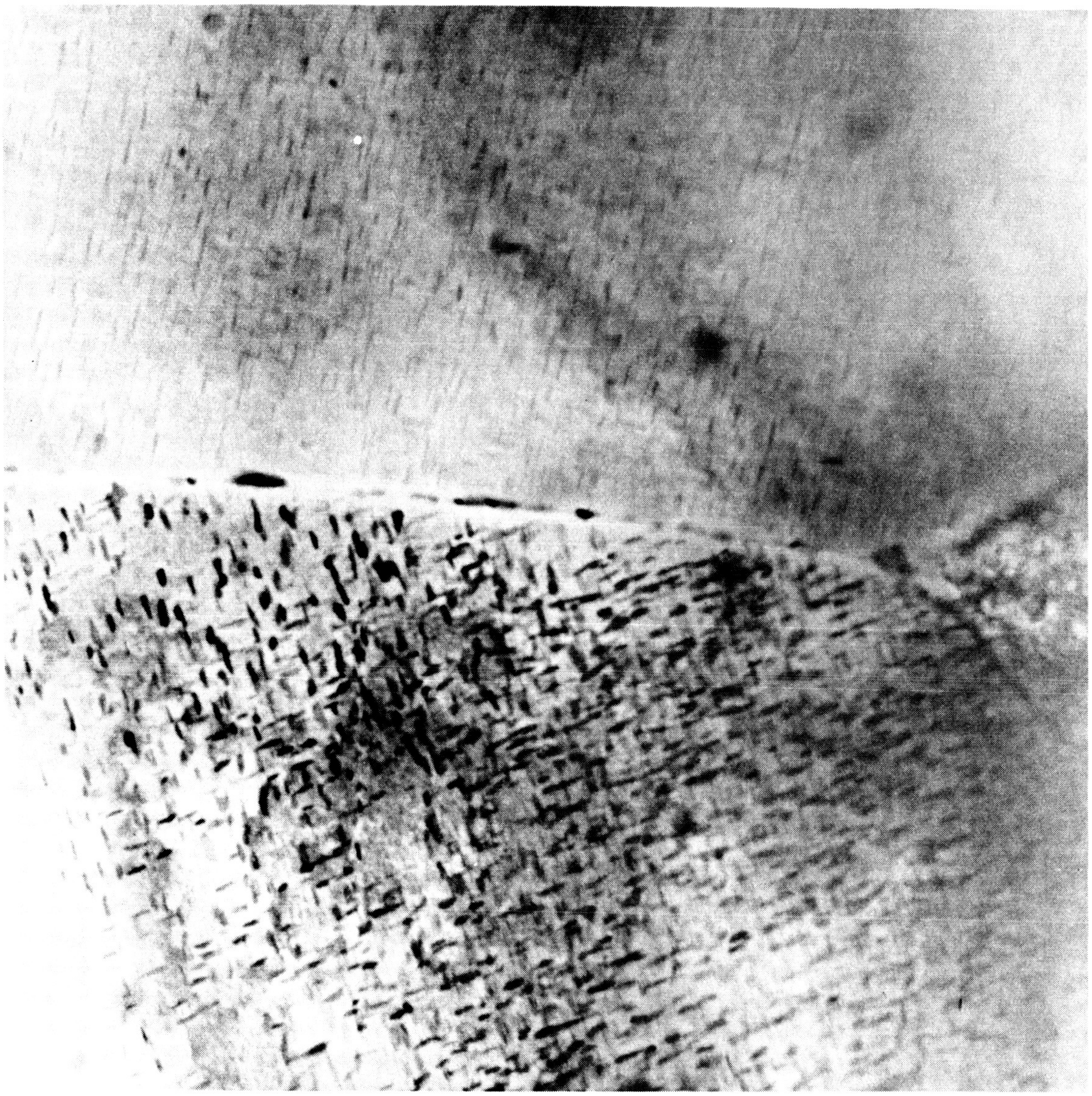
Figure 1 - Structure of 2219 with no deformation before aging.

122/6/6J



122/12/6 50,000X

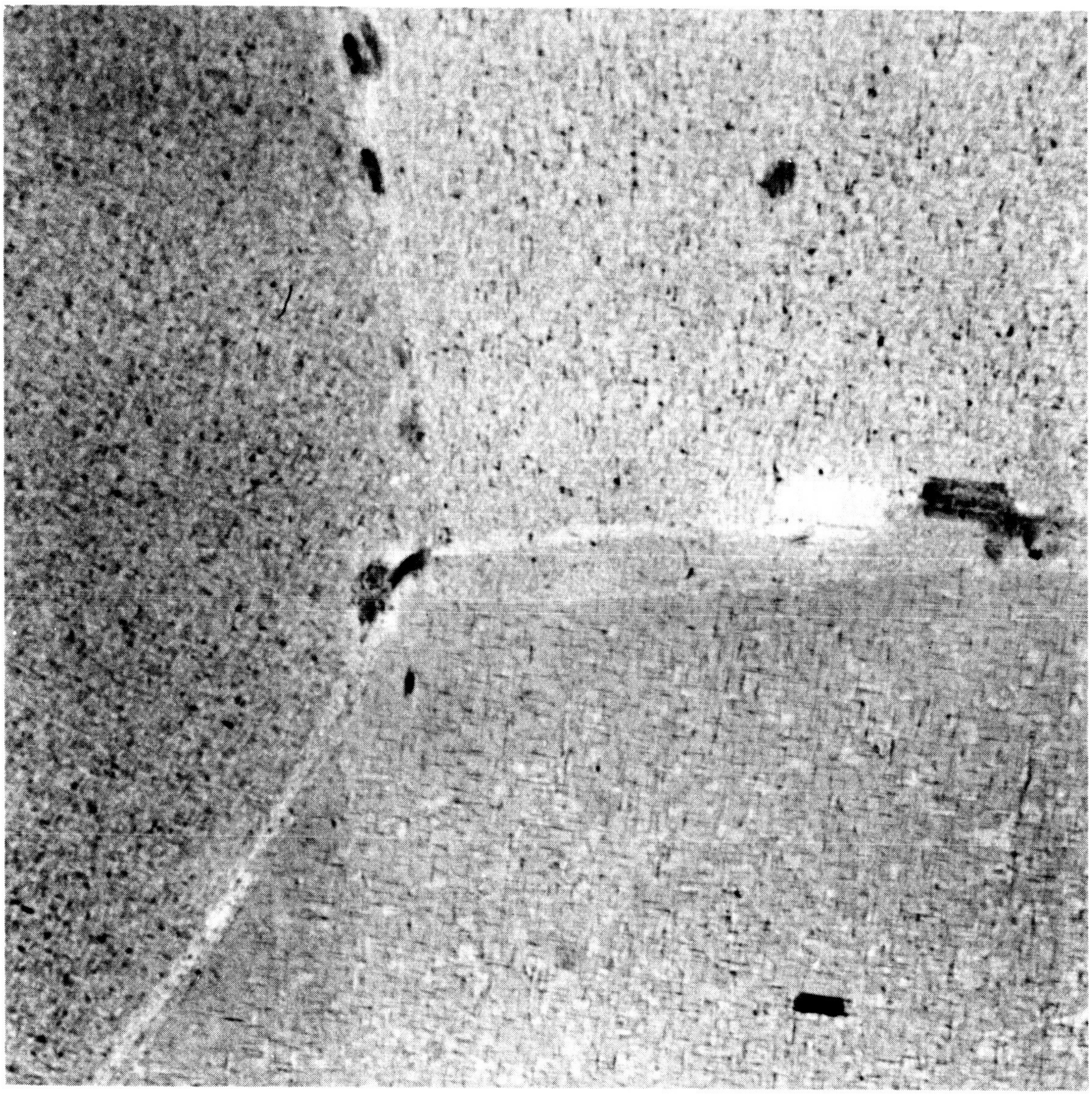
Figure 2 - Structure of 2219 with 1-1/2% deformation before aging.



122/12/4 50,000X

Figure 3 - Structure of 2219 with 10% deformation before aging.

122/12/4J

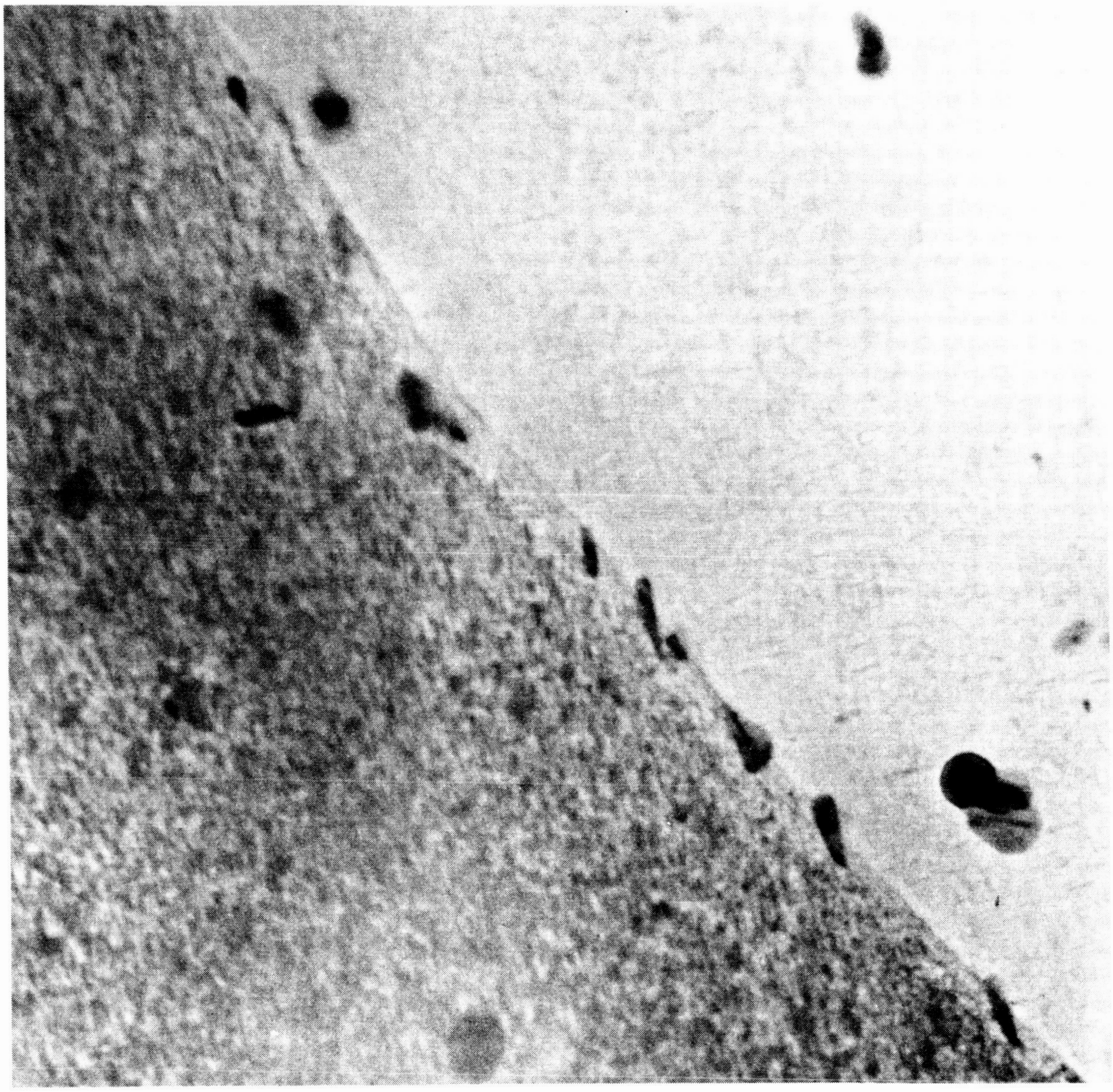


S-291090-A3 50,000X

Figure 4 - Structure of 0.064 in. sheet of 2219 + Cd + Sn which was aged 12 hrs. at 325°F.

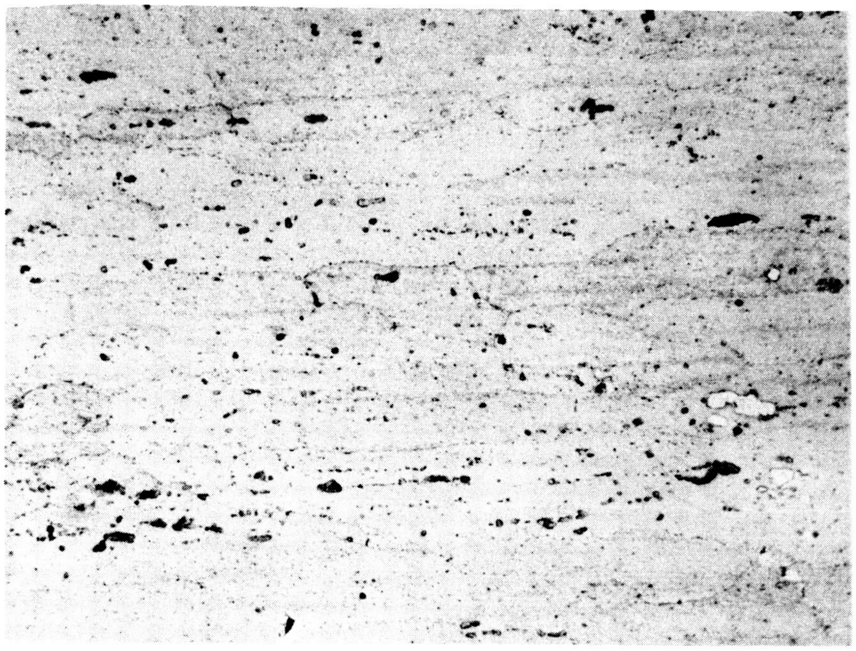
S-291183-C2 50,000X

Figure 5 - Structure of 0.064 in. sheet of 2219 + Cd + Sn which was stretched 1-1/2% and aged 8 hrs. at 325°F.



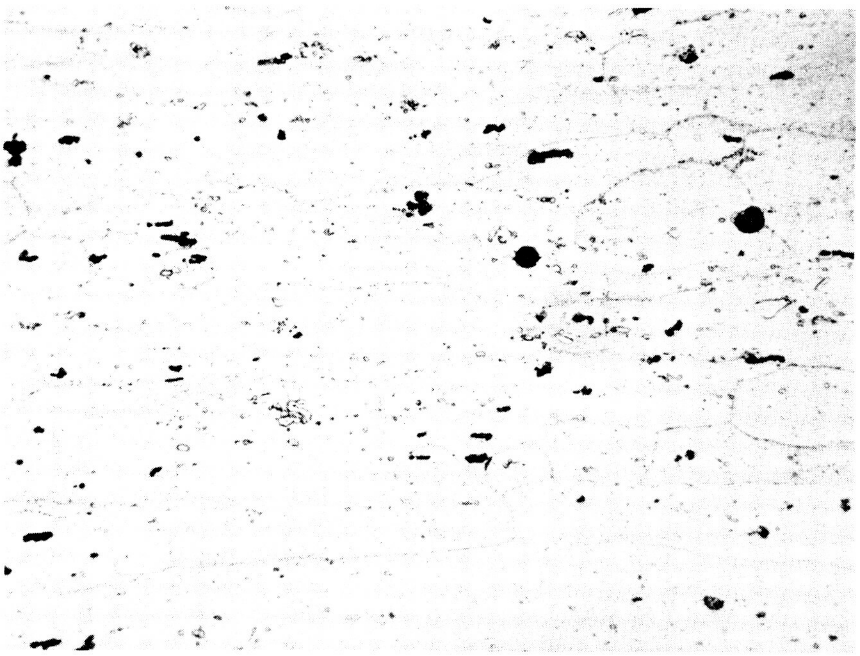
S-291081-02 50,000X

Figure 6 - Structure of 0.064 in. sheet of 2219 + Cd + Sn which was pre-aged 2 hrs. at 300°F, stretched 1-1/2% and aged 8 hrs. at 325°F.



S-291819 500X Keller's Etch

Figure 7 - Structure of 0.525 in. plate of 2219 + Cd + Sn which was stretched 1-1/2% and aged 8 hrs. at 325°F.



S-291905 500X Keller's Etch

Figure 8 - Structure of 0.525 in. plate of 2219 + Cd + Sn which was pre-aged 1-1/2 hrs. at 300°F, stretched 1-1/2% and aged 8 hrs. at 325°F.

141438J
141439J

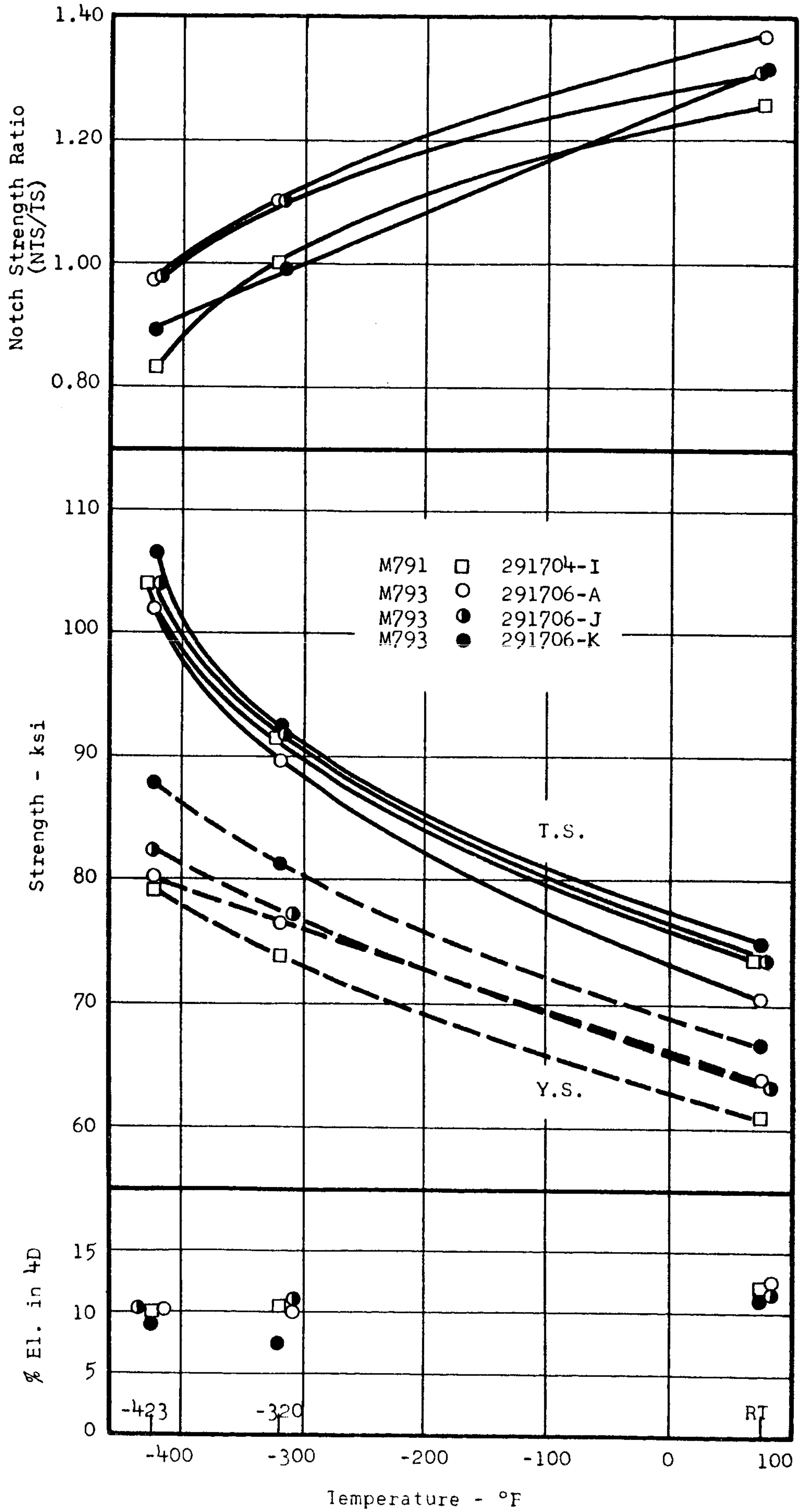


Figure 9 - The effect of testing temperature on the mechanical properties of several 7000 series alloys.

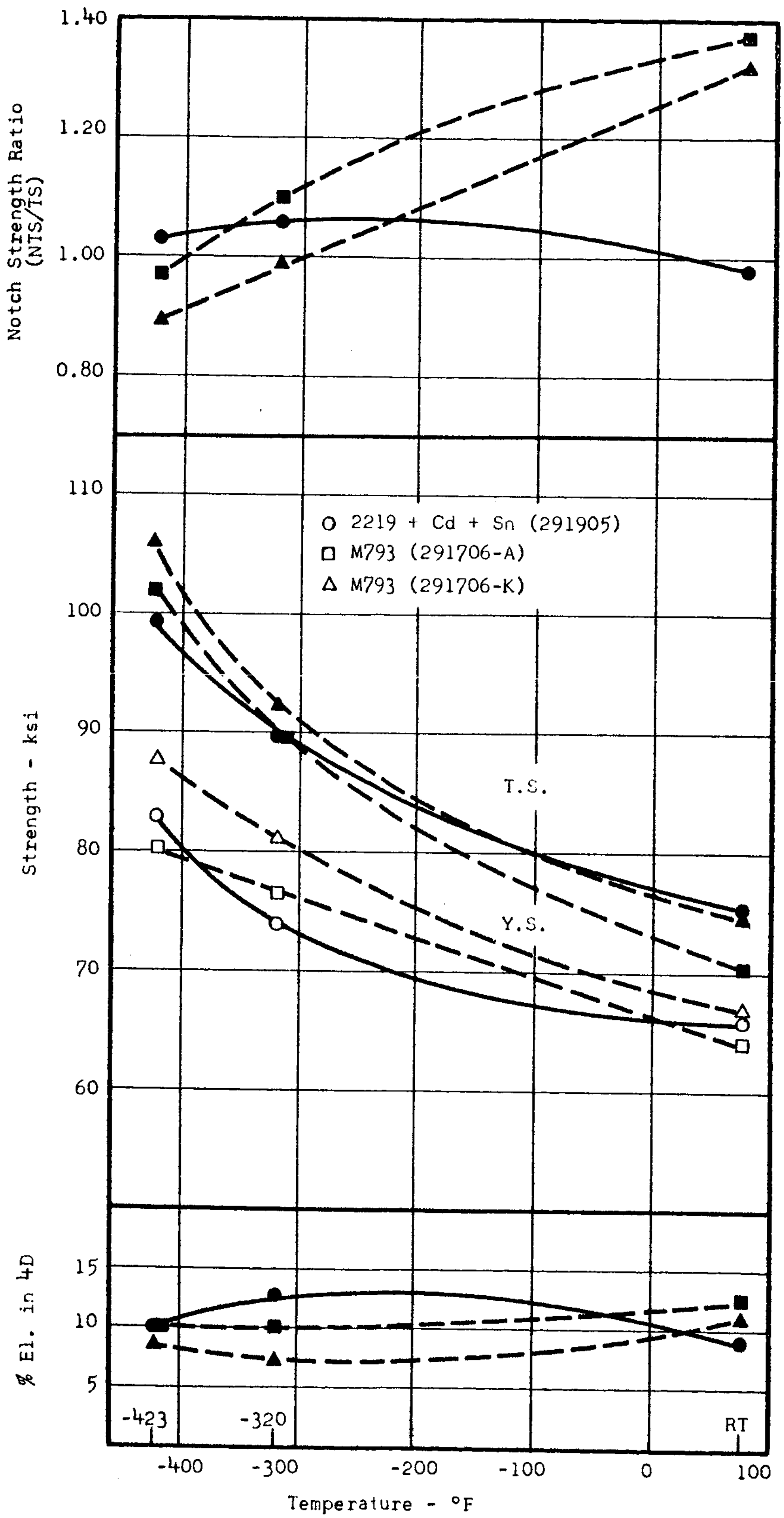
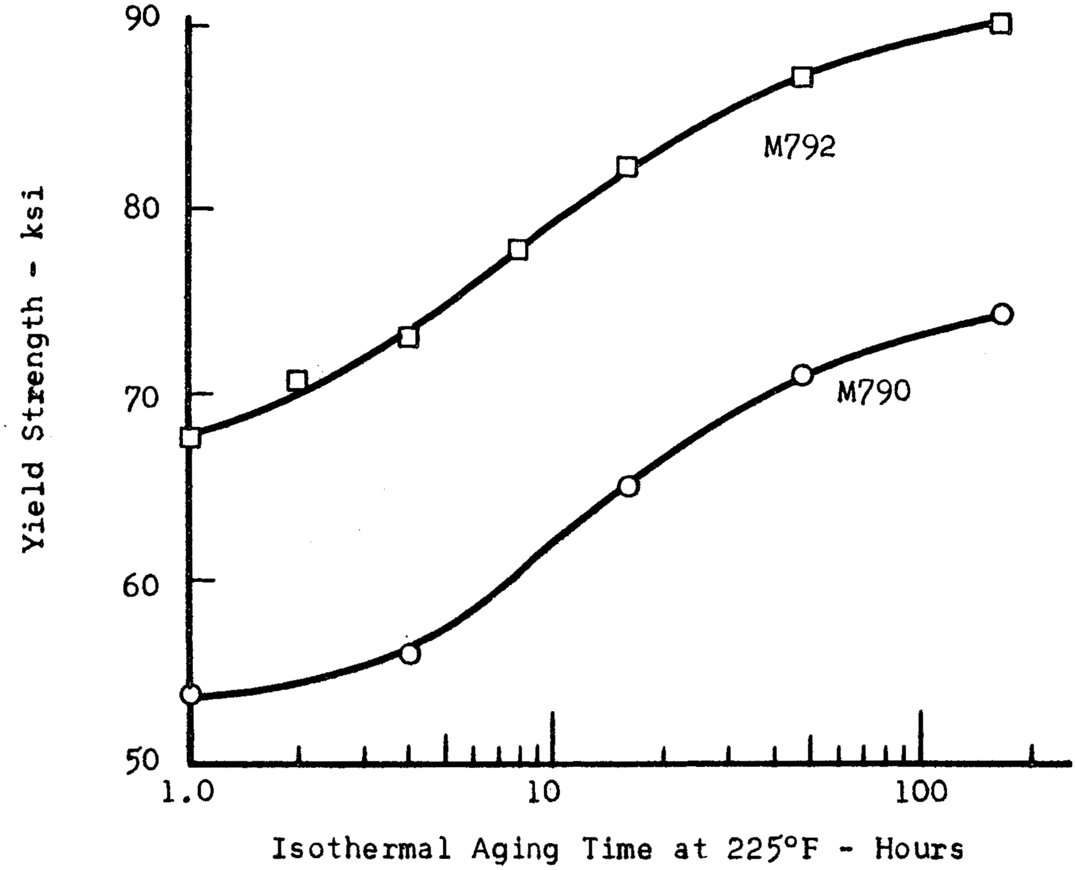


Figure 10 - Comparison of the 2000 and 7000 series alloys as a function of testing temperature.



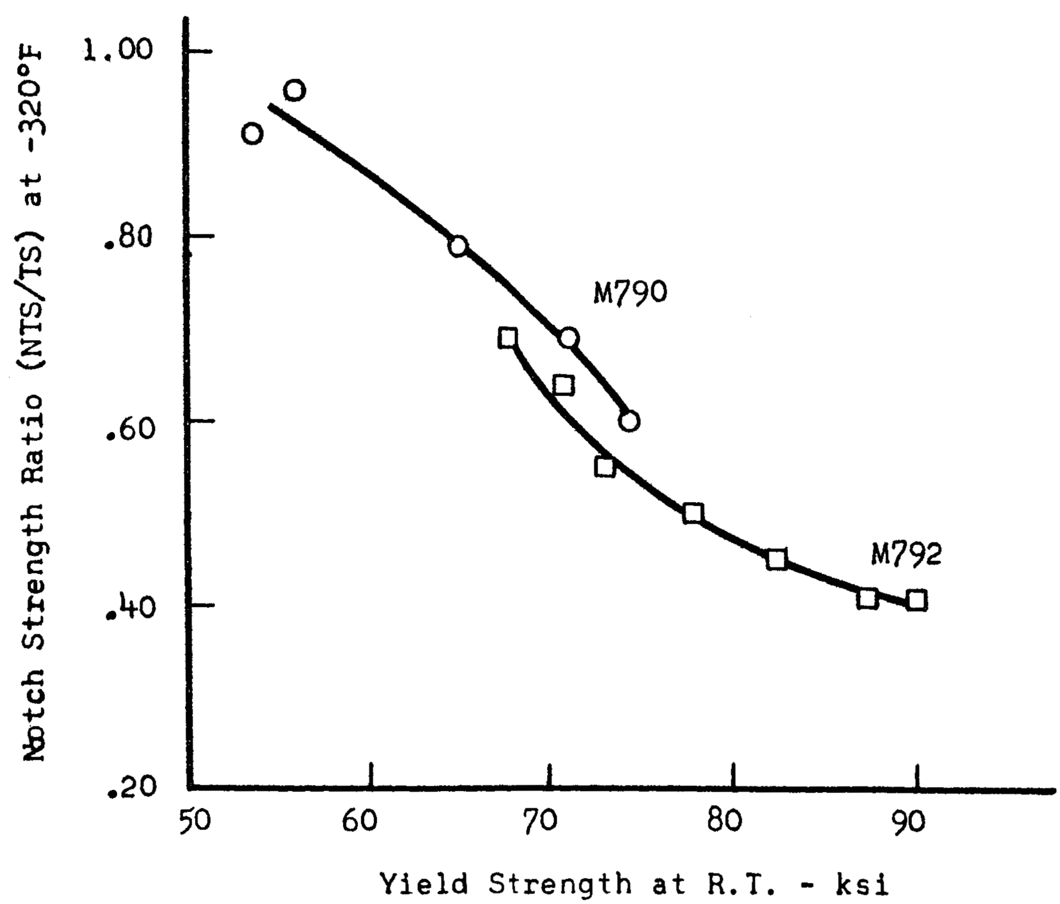


Figure 11 - Effect of aging at 225°F on the yield strength and notch toughness of M790 and M792. Notched round specimens (K_t = 10).

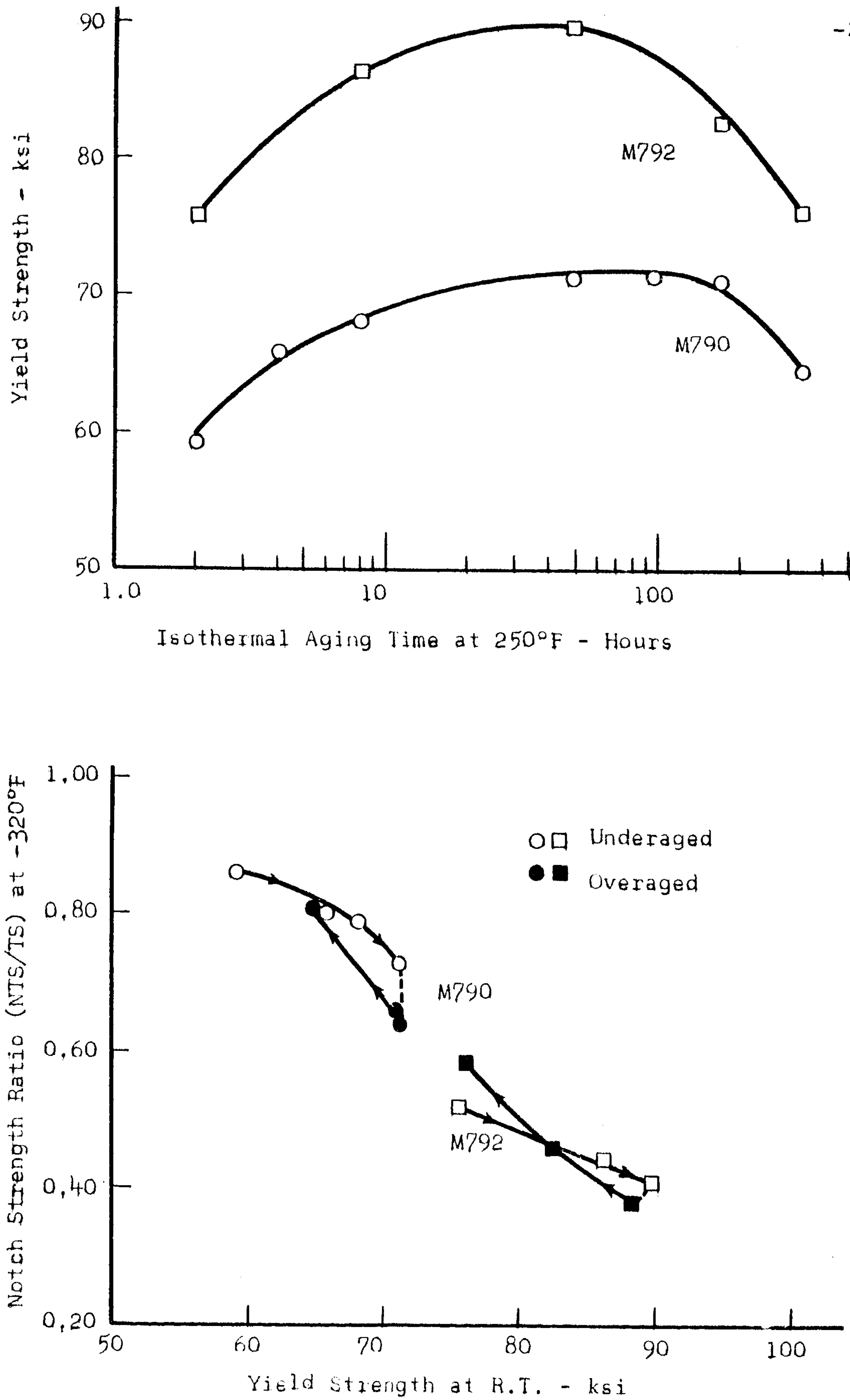


Figure 12 - Effect of aging at 250°F on the yield strength and notch toughness of M790 and M792. Notched round specimens (K_t = 10).

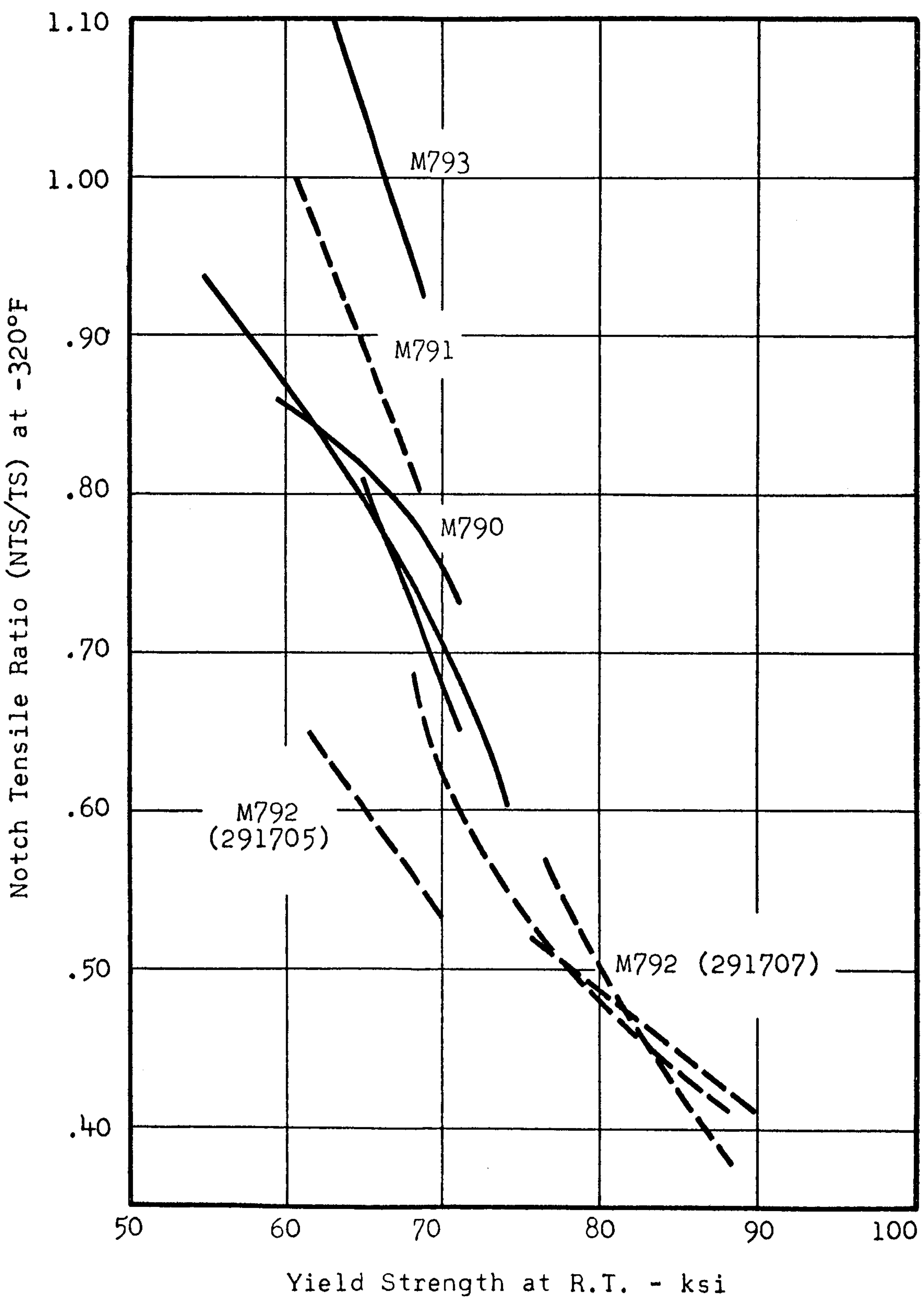


Figure 13 - Effect of aging treatment on the notch toughness of the 7000 series alloys. Notched round specimens (K_t = 10).

S-291321 50,000X

Figure 14 - Typical microstructure of M790
(6.5 Zn, 2.5 Mg)

S-291246 50,000X

Figure 15 - Typical microstructure of M791
(6.5 Zn, 2.5 Mg, .10 Zr)

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