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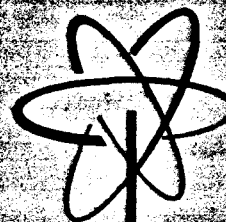
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GENERAL ELECTRIC CO.
Nuclear Energy Division

MASTER



THE EFFECTS OF REMELTING AND HEAT TREATMENT ON 2-1/4 Cr-1Mo STEEL ELEVATED TEMPERATURE TENSILE PROPERTIES

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J. F. Copeland
J. L. Yuen

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STEAM GENERATOR MATERIAL QUALIFICATION

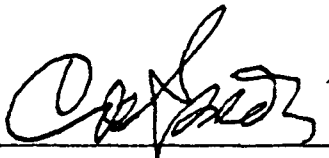
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Task 10G-2

189 No. SG029

THE EFFECTS OF REMELTING AND HEAT TREATMENT
ON 2½Cr-1Mo STEEL ELEVATED TEMPERATURE TENSILE PROPERTIES

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by

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Sunnyvale, California

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The Effects of Remelting and Heat Treatment
on 2½Cr-1Mo Steel Elevated Temperature Tensile Properties

H. P. Offer
J. F. Copeland
J. L. Yuen

INTRODUCTION

Vacuum arc remelting (VAR) and electroslag remelting (ESR) processes have been chosen for the Clinch River Breeder Reactor Plant (CRBRP) steam generator tubesheet forgings and tubing, respectively. This selection was made in order to ensure the highest integrity tube/tubesheet welds by minimizing non-metallic inclusions and porosity. These welds are a critical part of the sodium/steam boundary. An extensive study was conducted to determine the effect, if any, on the mechanical properties resulting from these remelting techniques, relative to air melting. A variety of heat treatments were studied, including the actual heat treatments of the tubing, the tubesheet forging, and the ASME Code data base for annealed 2½Cr-1Mo steel. This report discusses the findings of the elevated temperature tensile tests, and the recommended reduction of the allowable stress intensity S_m for CRBRP steam generator components.

It has been confirmed in this study that 1) there is essentially no significant effect of vacuum arc remelting or electroslag remelting on the uniaxial tensile properties of 2½Cr-1Mo steel relative to air melting, and that 2) the heat treatments chosen for CRBRP steam generator tubing and tubesheets, combined with post weld heat treatment (PWHT), can produce elevated temperature yield strengths for this alloy below the ASME Code Case 1592 expected minimum yield strength curve. The purpose of this report is to present a summary of the results of these tests so that they may be taken into account in the steam generator design as necessary.

RESULTS

Room and elevated temperature tensile tests have been completed on two VAR, two ESR, and two air melted heats of 2½Cr-1Mo steel plate. These heats were given a variety of heat treatments, with and without PWHT, as detailed in the appendix to this memorandum. Four air melted heats, tested by ORNL, without PWHT, are also reported here for comparison. The yield strengths were compared to the Code Case 1592 expected minimum curve. The yield strength ratio and tensile strength ratio (the ratio of the elevated temperature to the room temperature strength) were compared with those of the data base for Code Case 1592. Additionally, the yield strength (0.2% offset), ultimate strength, total elongation, and reduction in area were evaluated relative to the Nuclear Systems Materials Handbook (NSMH) expected value curves and upper and lower tolerance curves for annealed material.

Dynamic strain aging (related to carbide precipitation during deformation) occurs in this alloy and substantially affects the shape of the strength-temperature curves above 204C (400F). The effect is to produce an increase in strength at elevated temperature over the value it would have without this effect. The net result is a constant or an increasing strength with increasing temperature. This phenomenon is dependent on time and strain; thus it is more pronounced for ultimate tensile strength than for yield strength, and is greater at low strain rates. It has been determined from the results of these tests that heat treatments of relatively long times at relatively high temperatures allow these precipitation reactions to occur during heat treatment to preclude or limit the effects of dynamic strain aging, reducing the elevated temperature short term strength. Post weld heat treatment has been shown to substantially reduce the effects of strain aging above and beyond that due to long time/high temperature primary heat treatments. It should be clearly noted that Code Case 1592 was based on short time/low temperature anneals without PWHT. The NSMH design correlations for the strength of annealed 2½Cr-1Mo steel were based on long time/high temperature anneals, also without PWHT. It should also be noted

that material exposure under service conditions (approximately 510C; 950F) for long periods of time (on the order of years) will also substantially reduce the effects of strain aging¹ and that high strain rate loading during service may also preclude strain aging strengthening effects.

The difference between the composite data set representing isothermally annealed and fully annealed material with PWHT and the Code data set can be seen by the allowable stress intensity, S_m , of each set. This value is the lower of 1/3 the expected minimum ultimate tensile strength and 2/3 the expected minimum yield strength. The S_m value for the data set with PWHT falls approximately 6.8 to 27.5 MPa (1 to 4 ksi) below the ASME Code curve. The maximum difference occurs between 427 and 510C (800 and 950F) and is controlled by the yield strength in this temperature range (see Figure 1 and Table I of Appendix B). Calculations of the allowable stress intensity for the annealed data set with PWHT are given along with the corresponding values from the ASME Code.

The impact of the above facts is that regardless of the primary heat treatment, PWHT plus in-service conditions will, with a high probability, reduce the yield strength at elevated temperature below the Code Case 1592 expected minimum curve, which does not take into account these conditions.

The method of deriving the ASME Code expected minimum yield strength curve must be understood in order to realize the significance of comparing data to it. A ratio trend curve for yield strength is developed from data by plotting the ratio of elevated temperature to room temperature yield strength versus temperature. An average, or expected (not minimum), ratio trend curve is then drawn through this data, based on a least squares regression analysis. At room temperature the yield strength ratio is, of course, unity, and it usually proceeds to decrease as the temperature increases. Any effect of the dynamic strain aging at elevated

temperature is not recognized by the Code expected minimum. The point here is that approximately half the actual Code data fall below the expected ratio trend curve. The ratios from this expected curve (of elevated temperature to room temperature yield strength) are then applied to the minimum specified room temperature yield strength [207 MPa (30 ksi), in this case] to derive the expected minimum Code Case 1592 yield strength curve and S_y values. Thus, within the method of deriving this curve, it is entirely possible that a material which just meets the room temperature yield strength specification of 207 MPa has a 50% probability of falling below the expected minimum Code Case 1592 yield strength curve at elevated temperatures. This is inherent in the method of deriving the S_y values, and has proven to be acceptable because of experience with the safety factors (2/3 on yield strength) applied in computing S_m . The summary point here is that, although it is desirable for all test data to fall above the expected minimum yield strength curve, the Code method of deriving this curve accepts the fact that some acceptable material (meets room temperature strength requirements) will have high temperature yield strengths below this curve. However, although the significance of data falling below the Code curve is uncertain, it is apparent that thorough annealing and PWHT have created a data set which is somewhat different from the Code data set.

CONCLUSIONS

1. The heat treatments chosen for CRBRP steam generator tubing and tube-sheets, combined with PWHT, produces a reduction of the allowable stress intensity S_m below the ASME Code values.
2. The full anneal, and the isothermal anneal yield relatively complete phase transformation [120 minutes at 704C (1300F)]. Above 454C these heat treatments can result in a high temperature yield strength below the ASME Code Case 1592 expected minimum curve. For a given heat treatment, heat to heat variation will determine whether the yield strength will be above or below this curve. Heat treatments producing incomplete phase transformations (such as 90 minutes at 704C generally produce high temperature yield strength above this expected

minimum curve. Commercial type anneals (such as 60 minutes at 691C) always produced yield strength above the expected minimum curve.

3. Post weld heat treatment for 4 hours at 727C can lower the elevated temperature yield strength of material with incomplete phase transformation below the Code Case 1592 expected minimum curve. The same post weld heat treatment can reduce the yield strength of material with a complete phase transformation to values below the NSMH lower tolerance curve, which is 17.2 to 24.1 MPa (2.5 to 3.5 ksi) below the Code expected minimum curve.
4. Specimens of an ESR heat (No. R0110) were tested with both a fine grain size (ASTM No. 9-10) and a coarse grain size (ASTM No. 4-5). The fine grain size material generally had high temperature yield strength below the Code expected minimum curve; however, the coarse grain size specimens had a yield strength well above this curve, and near or above the NSMH expected value.
5. Remelted material given the same commercial-type isothermal anneal (without post weld heat treatment) as air melted material of similar carbon content yielded similar yield strength. Post weld heat treatment reduced the strength of material with this anneal more than for the anneals producing a complete phase transformation.
6. Yield strength ratio results were similar to the yield strength results at high temperature. Anneals producing incomplete phase transformation without a post weld heat treatment gave yield strength ratios near the curve for the Code data. Full anneals or isothermal anneals producing complete transformation without a post weld heat treatment gave yield strength ratios below the Code data. Post weld heat treatment reduced these ratios even further.
7. No expected minimum ultimate tensile strengths are given in Code Case 1592. The tensile strength data fall, in general, above the

NSMH lower tolerance limit for both the air melted and remelted material. The tensile strength ratios usually fall below those for the Code data at high temperature, except for the commercial-type anneal without post weld heat treatment. The effects of a complete transformation and of post weld heat treatment on tensile strength are similar in trend to the effects on yield strength, however, the data do not fall below the NSMH lower tolerance curve.

8. For both the air melted and remelted conditions, all heat and heat treatment combinations tested were found to have total elongation values consistently above the NSMH lower tolerance curve. Most of the data are above the NSMH expected value curve for annealed material.
9. The air melted and remelted materials generally yielded reduction in area values above the NSMH expected value curve. However, two heat treatments given to air melted material, a full anneal without PWHT [approximately 4% below at 454C (850F)] and a commercial anneal without PWHT [approximately 20% below at 371C (700F)] produce reduction in area values below the NSMH lower tolerance limit.

For the CRBRP specific heat treatments with PWHT [a full anneal and an 80 to 100 minute - 718±27.8C (1325±50F) isothermal anneal] the elevated temperature yield strength values fall as much as 41 MPa (6 ksi) below the Code Case 1592 expected minimum value curve and 17 MPa (2.5 ksi) below the NSMH lower tolerance at 510C (950F). Ultimate tensile strength is generally between the NSMH expected value and lower tolerance curves. Total elongation and reduction in area are generally between the NSMH upper tolerance and expected value curves.

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2. G. V. Smith, "Supplemental Report on the Elevated-Temperature Properties of Chromium-Molybdenum Steels (An Evaluation of 2½Cr-1Mo Steel)", ASTM Data Series, DS-6S2, (1971).
3. ASME Boiler and Pressure Vessel Code Case 1592-7, Class 1, "Components in Elevated Temperature Service", Section III, Table 1-14.5.
4. D. A. Canonico, "Influence of Processing History on Microstructure and Tensile Properties of 1½ in. Diameter 2½Cr-1Mo Steel Tubing", CRBRP Steam Generator Materials Program Review Meeting, June 5-6, 1974.
5. C. R. Brinkman and Others, "Steam Generator Material Technology Program Quarterly Progress Report for Period Ending March 31, 1975", ORNL-TM-4969.

APPENDIX A

EXPANDED SUMMARY OF TENSILE TEST RESULTS

Heat ESR R0110

A 90 minute-704C (1300F) isothermal anneal with a 4 hour-727C (1340F) post weld heat treatment (PWHT) produces an elevated-temperature yield strength ratio (YSR) curve slightly below the average ratio curve for the data base² of the ASME Code Case 1592 (CC 1592). This result was for material with a large grain size (ASTM No. 4-5), typical of the CRBR steam generator components. With a non-prototypic fine grain size, a full anneal, both with and without PWHT, produced a YSR much below the CC 1592 ratio curve.

Above 454C (850F) only the coarse grain material exhibited a 0.2% offset yield strength above the CC 1592 expected minimum yield strength curve³. Increasing the PWHT time from 4 to 40 hours reduced the yield strength of the coarse grained, isothermally annealed material from the Nuclear Systems Materials Handbook (NSMH) upper tolerance curve to the expected value curve.

Heat VAR 55262

The full anneal treatment without PWHT yielded YSR values approximately on the CC 1592 ratio curve. Only the 90 minute-704C (1300F) isothermal anneal without PWHT produced a YSR consistently above the CC 1592 ratio curve. At 371C (700F), and above, the lowest YSR values were generated with a 120 minute-704C (1300F) isothermal anneal plus a 40 hour-727C (1340F) PWHT.

Testing at 454C (850F), and above, showed the 90 minute-704C (1300F) isothermal anneal produced yield strengths above the NSMH expected

value without PWHT. The full anneal without PWHT data fell on this curve. In this elevated-temperature range, three heat treatments gave yield strengths below the CC 1592 expected minimum curve: 120 minute-704C (1300F) isothermal anneals with 4 and 40 hour PWHT, and a 90 minute-718C (1325F) isothermal anneal with a 4 hour PWHT. These three heat treatments produced yield strengths about 14 to 21 MPa (2 to 3 ksi) below this minimum curve. The full anneal with PWHT data fell above the CC 1592 curve from room temperature to 566C (1050F), but was below the full anneal without PWHT data at 454C (850F) and above.

Heat ESR 91505

At elevated temperatures two isothermal anneals without PWHT produced YSR values equal to the CC 1592 curve: 90 minutes at 704C (1300F) and 66 minutes at 677F (1250F) (the second was slightly higher). Five heat treatments resulted in YSR values below the CC 1592 curve at 454C (850F) and higher: 90 minute and 120 minute-704C (1300F) isothermal anneals with PWHT, a full anneal with and without PWHT, and a 66 minute-691C (1275F) isothermal anneal with PWHT. Of these five heat treatments, the lowest YSR values were from the full anneal with PWHT specimens.

For all seven treatments considered, the full anneal with PWHT produced the lowest yield strength from room temperature to 566C (1050F). In this temperature range, the yield strength of these specimens was consistently below the CC 1592 expected minimum curve by 27.5 to 41 MPa (4 to 6 ksi) and below the NSMH lower tolerance curve by 14 to 21 MPa (2 to 3 ksi). The only heat treatments giving values at or above the Code curve for temperatures of 454C (850F) and higher were the 66 minute-691C (1275F) and the 90 minute-704C (1300F) isothermal anneals, both without PWHT. Post weld heat treatment reduced the elevated-temperature yield strength of these two relatively short term isothermal anneals below the CC 1592 expected minimum curve by 14 to 34 MPa (2 to 5 ksi).

Heat VAR 91506

Five heat treatments were given to this material, all of which resulted in YSR values below the CC 1592 curve at 371C (700F) and higher. These heat treatments were a 90 minute-704C (1300F) isothermal anneal and a full anneal both with and without PWHT, and an isothermal anneal for 120 minutes at 704C (1300F) with PWHT. The highest elevated temperature values resulted from the 90 minute isothermal anneal without PWHT; the lowest values resulted from the 120 minute anneal with PWHT. This result is in contrast to that from heat ESR 91505 for which the lowest values resulted from the full anneal plus PWHT.

As with the YSR values, the yield strength values for this heat were highest at elevated temperatures for the 90 minute-704C (1300F) isothermal anneal without PWHT. However, the lowest values of yield strength occurred with the full anneal plus PWHT. At 454C (850F), and higher, only the 90 minute anneal yield strengths were at or above the CC 1592 expected minimum curve. The full anneal plus PWHT yield strengths were near or below the NSMH lower tolerance curve at 204C (400F) and higher.

Heats X6216 and 72768 (Air Melted ORNL Data)

The YSR for a 66 minute-691C (1275F) isothermal anneal without PWHT⁴ was approximately the same as the CC 1592 data base ratio curve from 454 to 510C (850 to 950F) (the only elevated temperatures tested).

The short term [66 minute-691C (1275F)] isothermal anneal produced yield strengths at room temperature, 454 and 510C (850 and 950F) well above the NSMH expected value curve. This was the only heat treatment reported which was similar to treatments given remelted heats. Heat ESR 91505 with the same treatment fell above the CC 1592 curve, however, a 4 hour PWHT reduced its yield strength below this curve at 454 and 510C (850 and 950F).

Heats 3P5601 and 86693 (Air Melted GE and ORNL Data)

Post weld heat treatment reduces the YSR of both fully annealed and commercially annealed air melted material. This ratio was reduced from

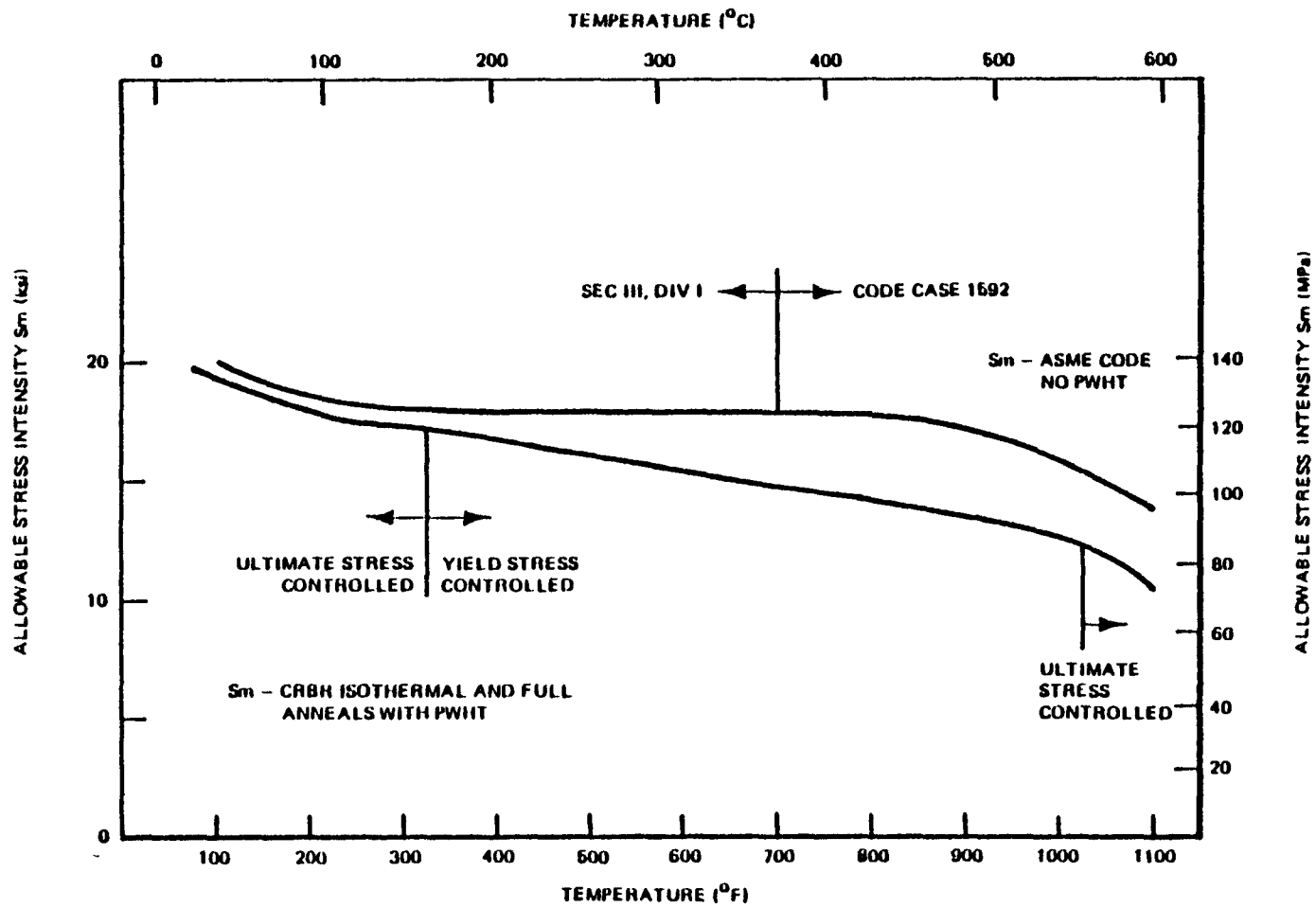
above to below the CC 1592 data base YSR curve from 371 to 566C (700 to 1050F).

The yield strength of air melted, fully annealed material is reduced by PWHT 21 to 34 MPa (3 to 5 ksi) (10 to 15%) which leaves the material strength 14 to 26 MPa (2 to 4 ksi) below the CC 1592 expected minimum curve from 371 to 566C (700 to 1050F). Air melted, commercially annealed material yield strength is reduced 14 to 26 MPa (2 to 4 ksi) by PWHT, leaving the strength slightly above the CC 1592 curve. Without PWHT the fully annealed material has 21 to 34 MPa (3 to 5 ksi) (approximately 10%) lower yield strength than material with a 120 minute-704C (1300F) isothermal anneal (also without PWHT) ⁵.

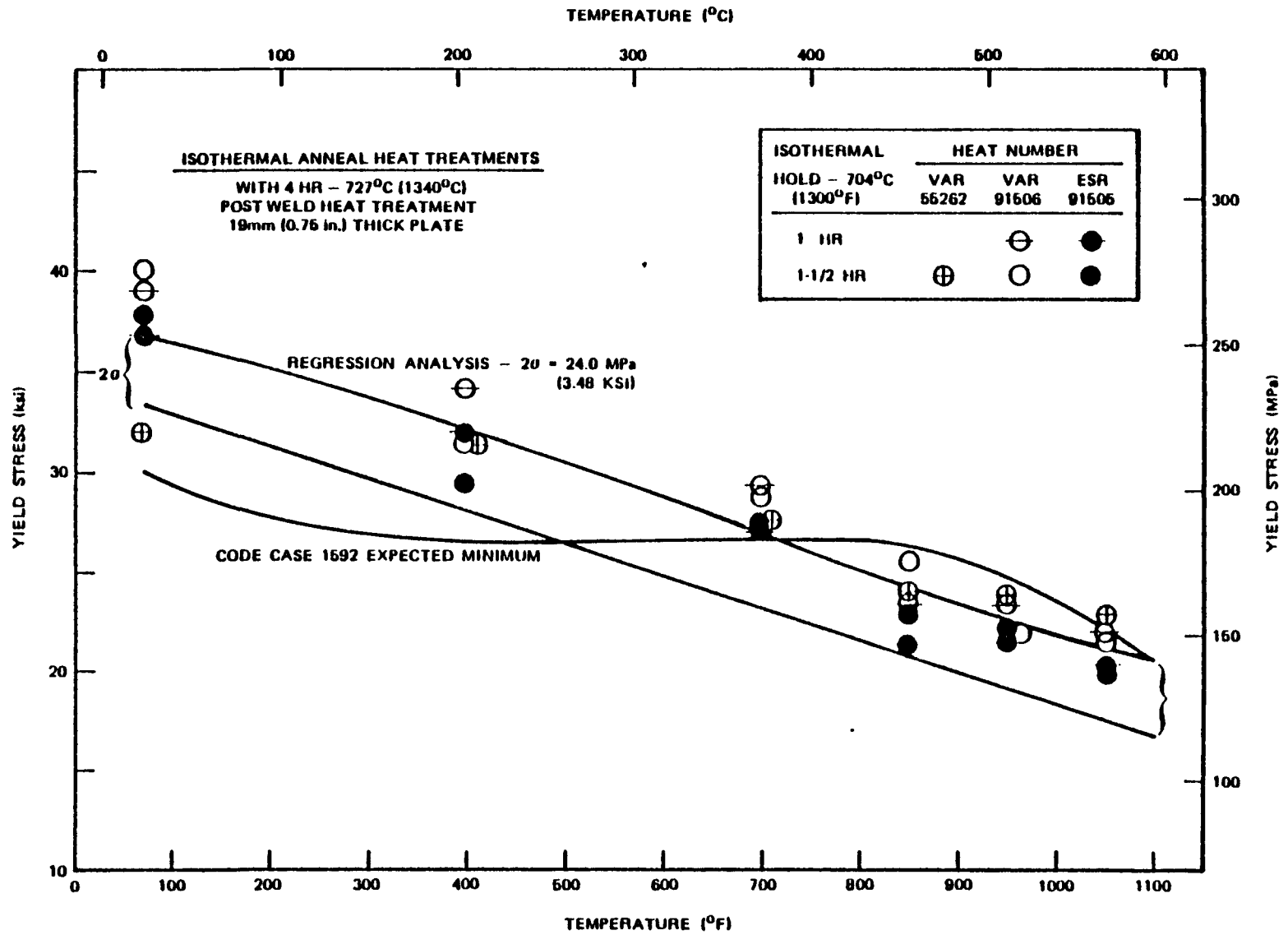
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APPENDIX B

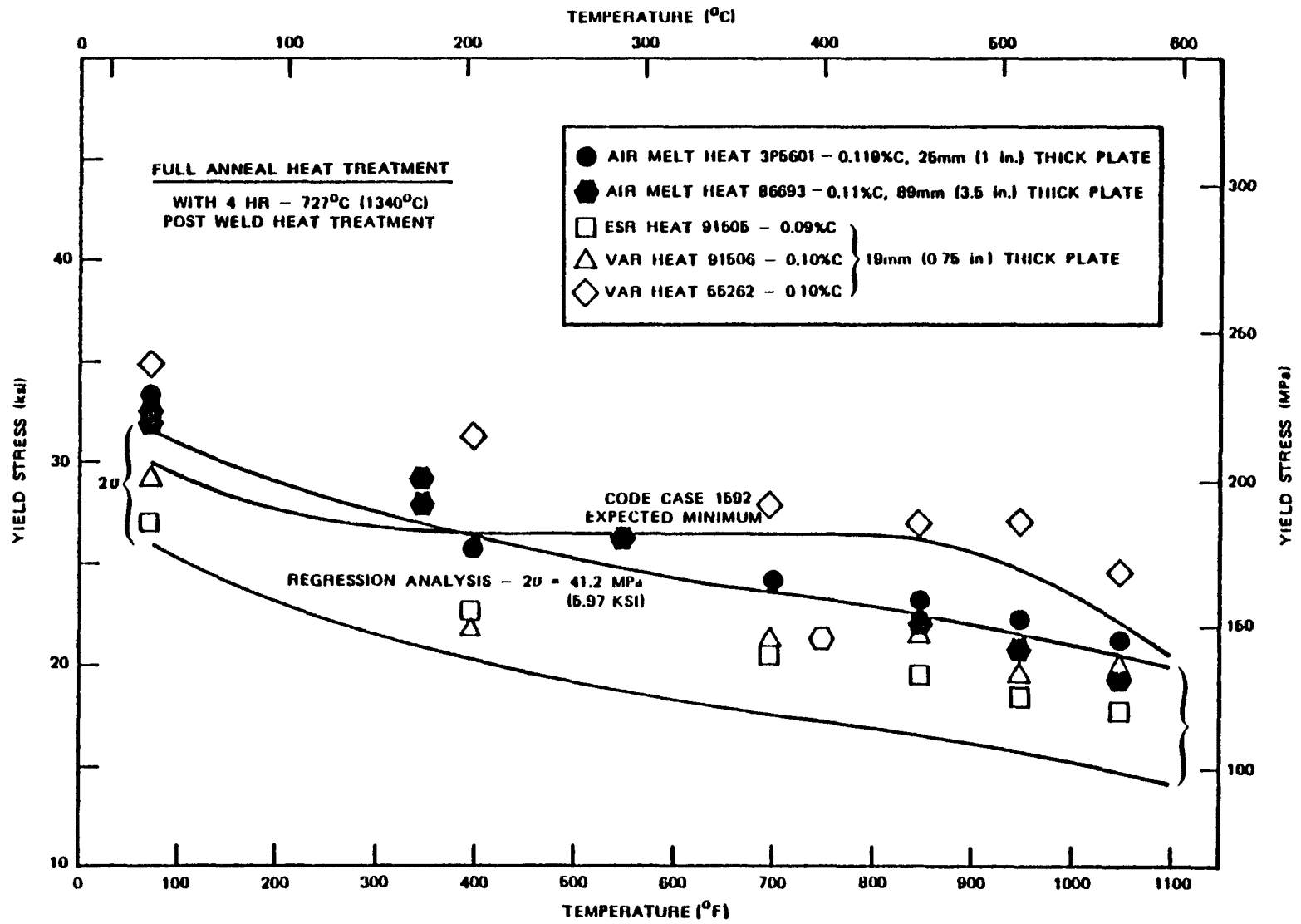
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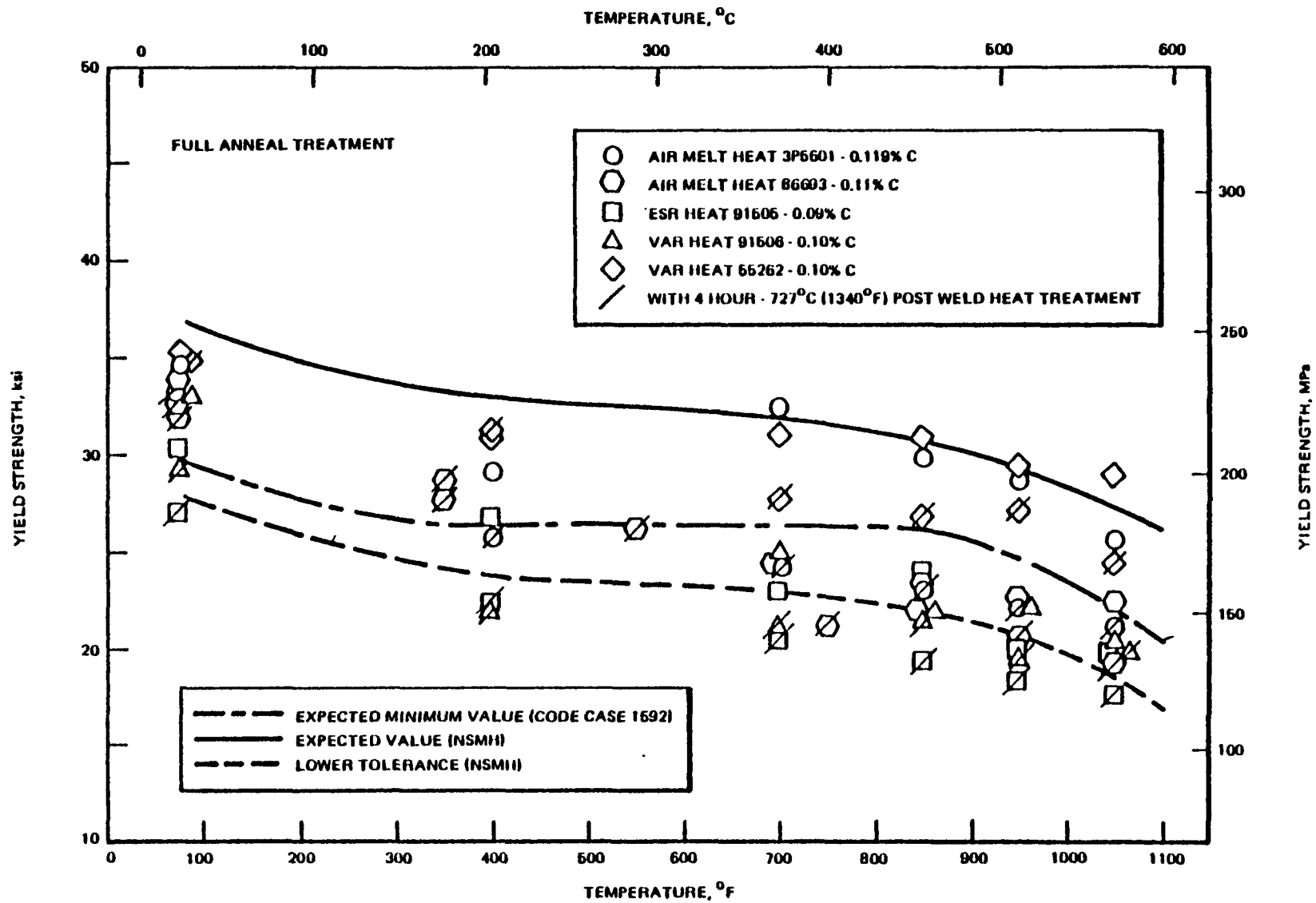
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VARIATION OF 0.2% OFFSET YIELD STRESS WITH TEMPERATURE



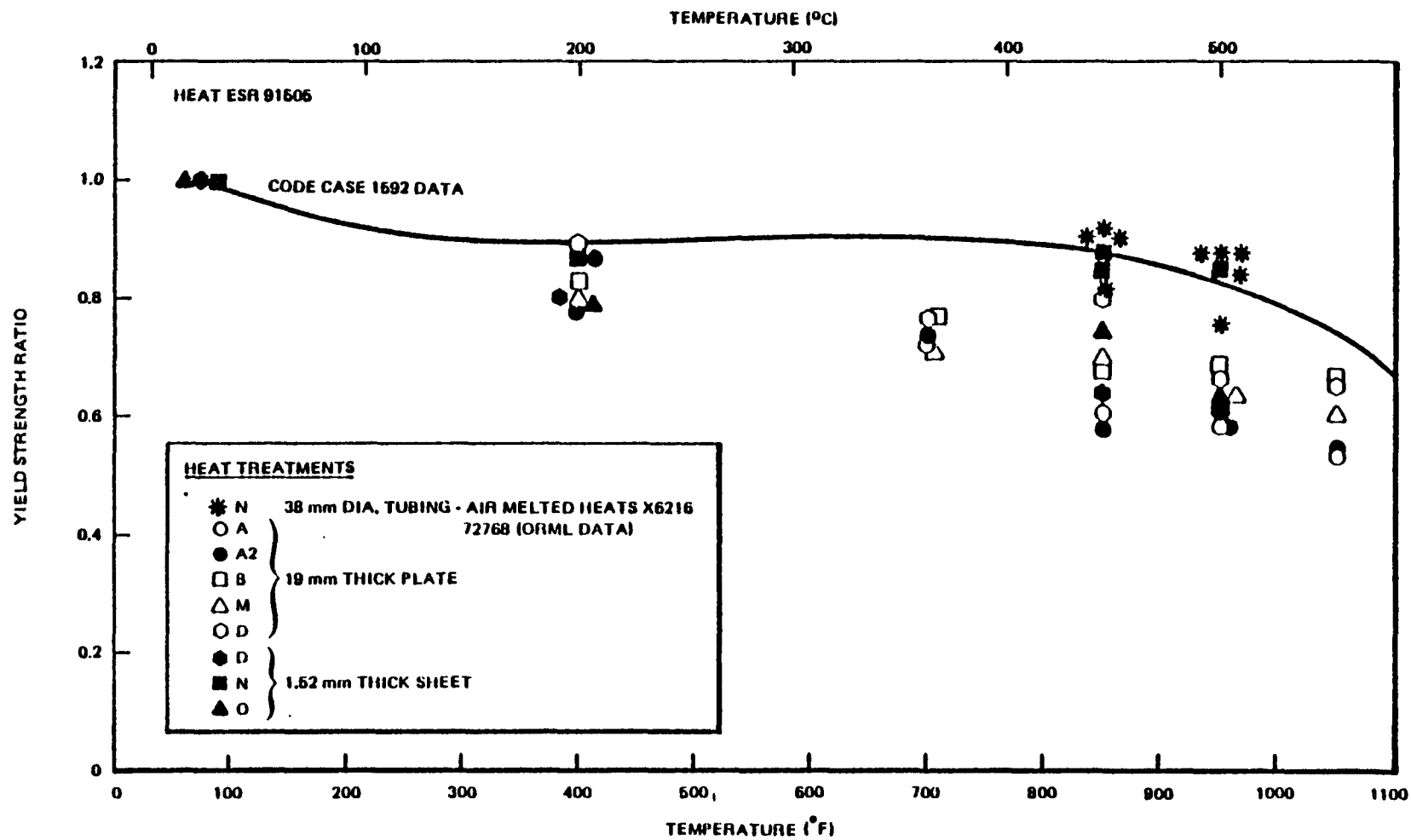
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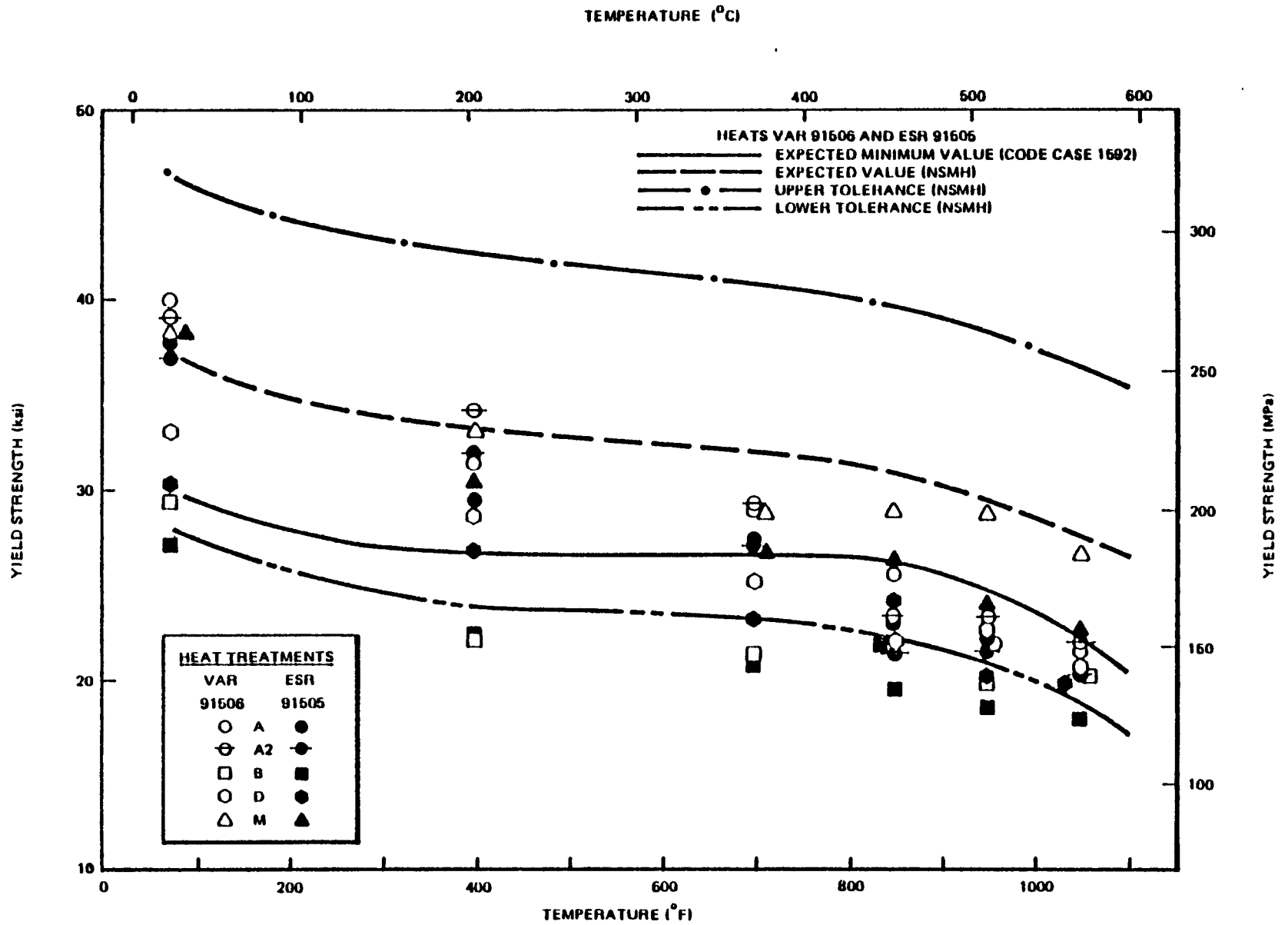
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VARIATION OF TENSILE PROPERTIES WITH TEMPERATURE

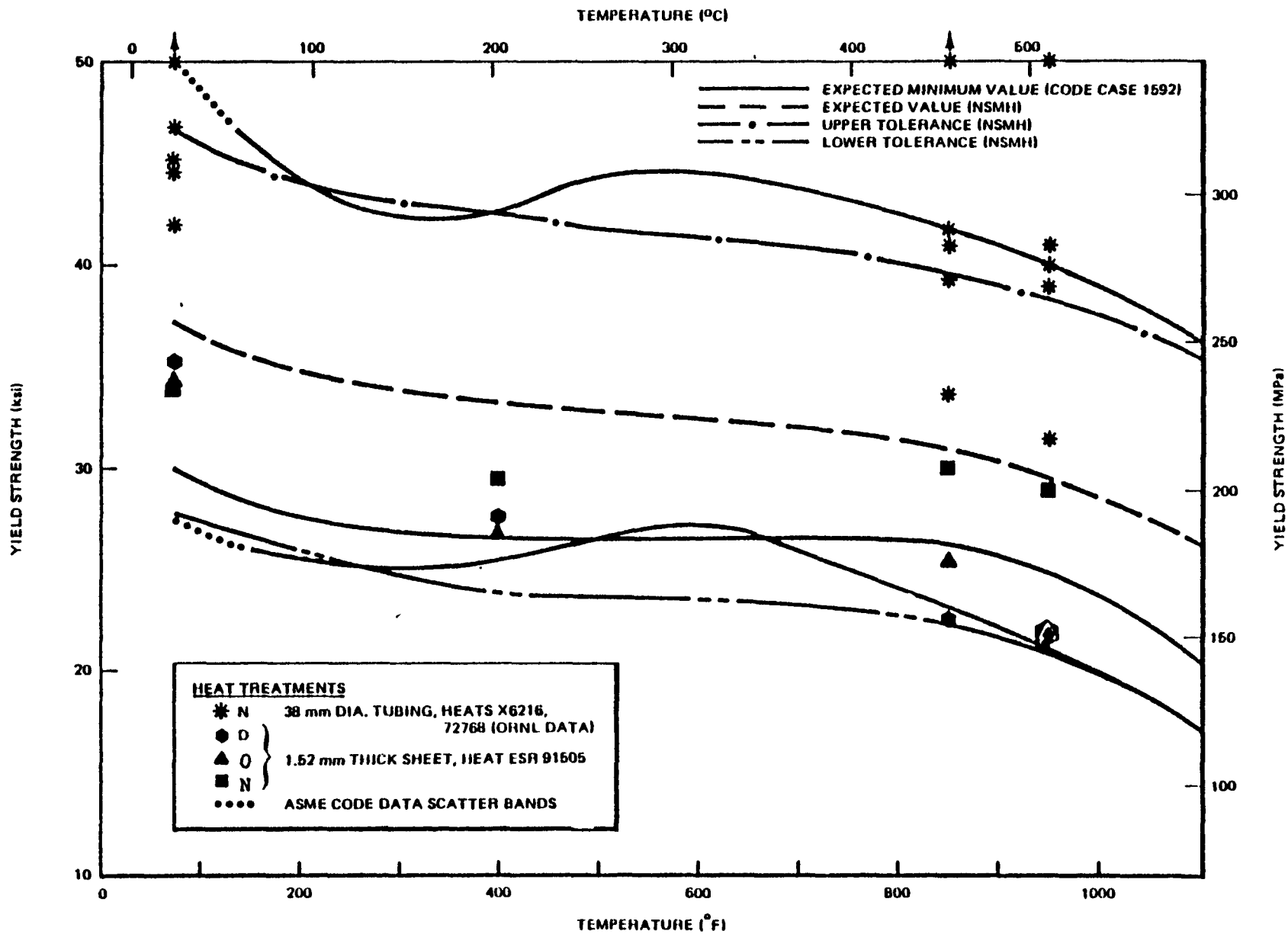
FOR ESR HEAT 91505, VAR HEAT 91506, AIR HEAT X6216 AND AIR HEAT 72768



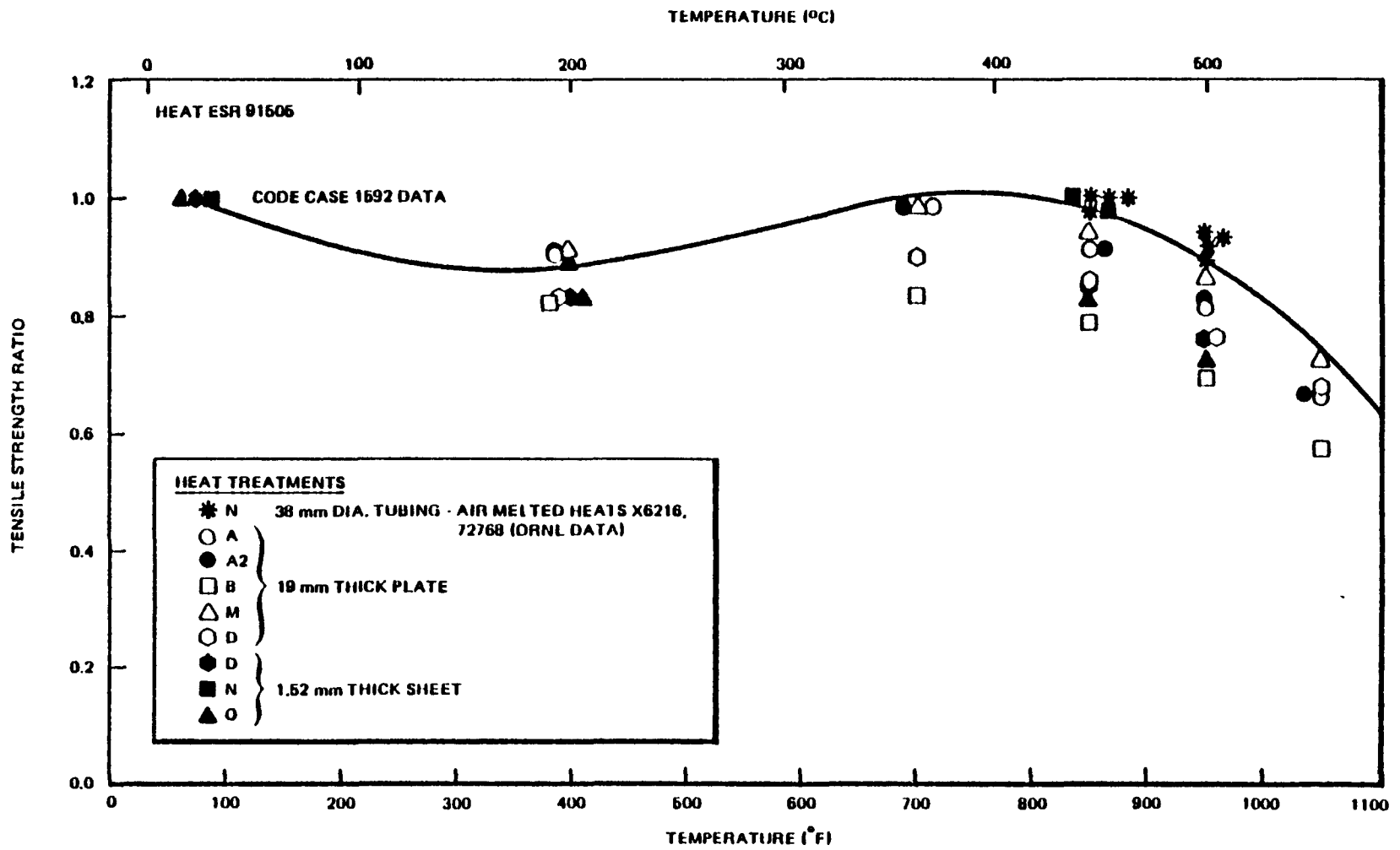
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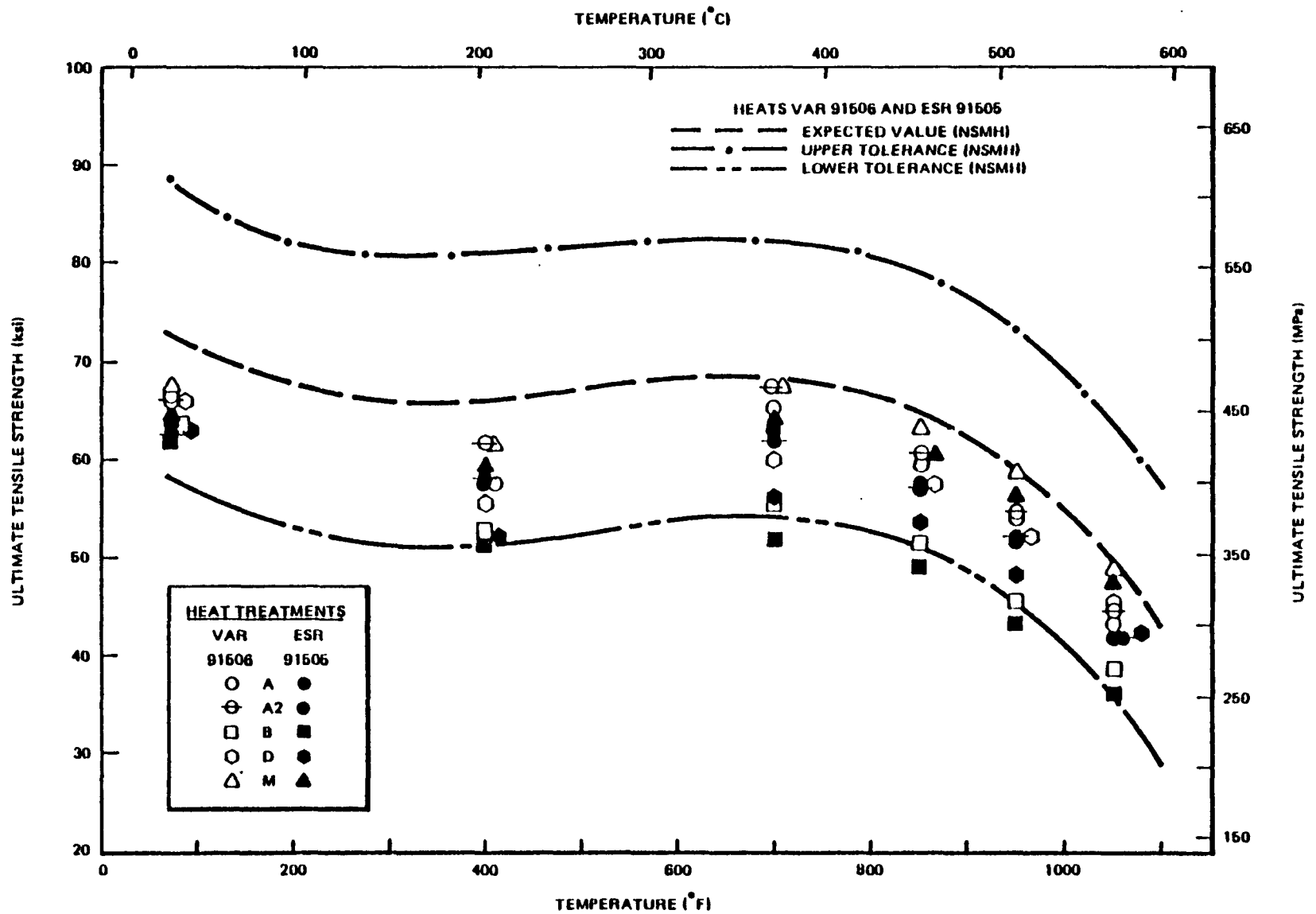
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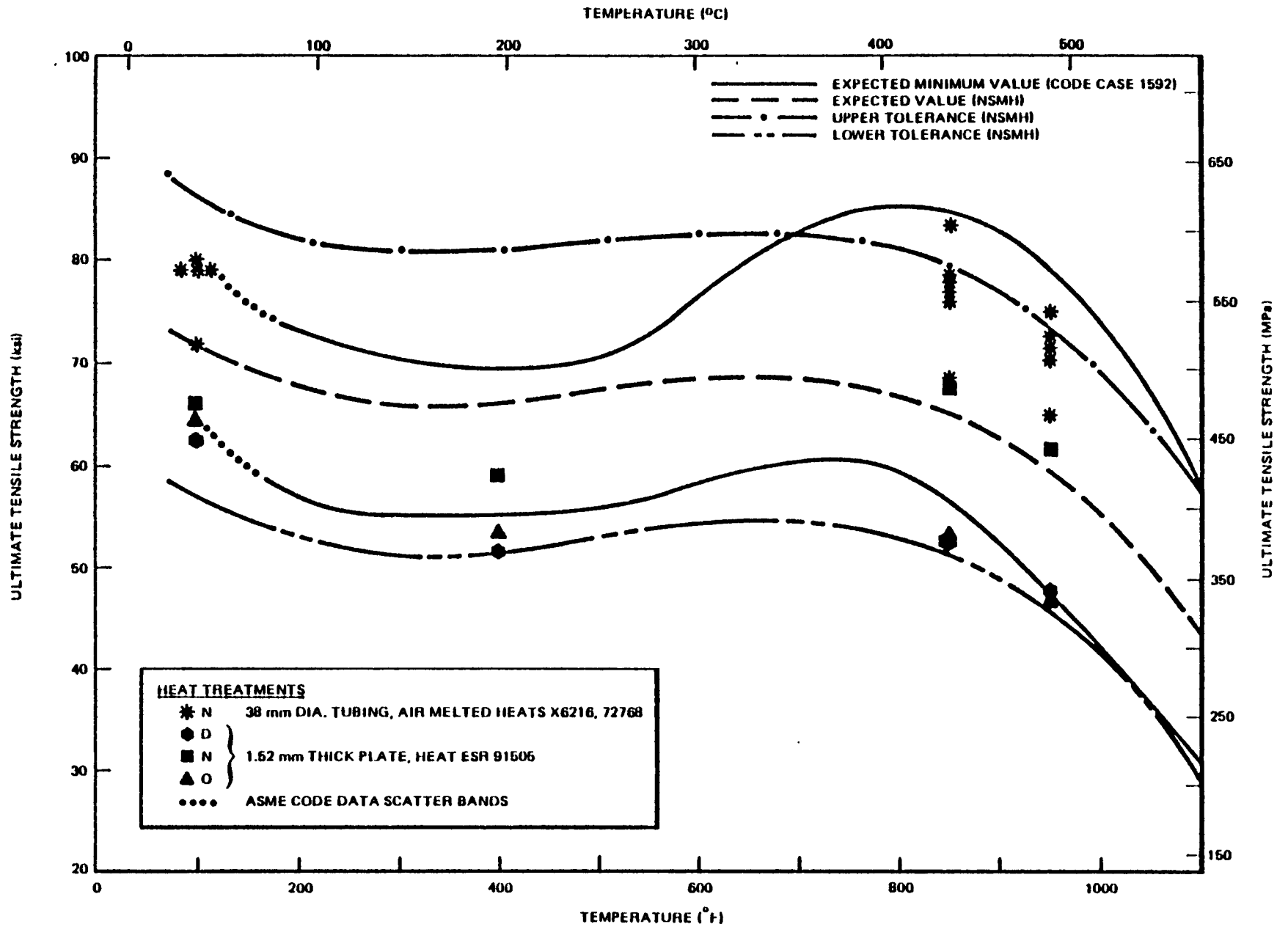
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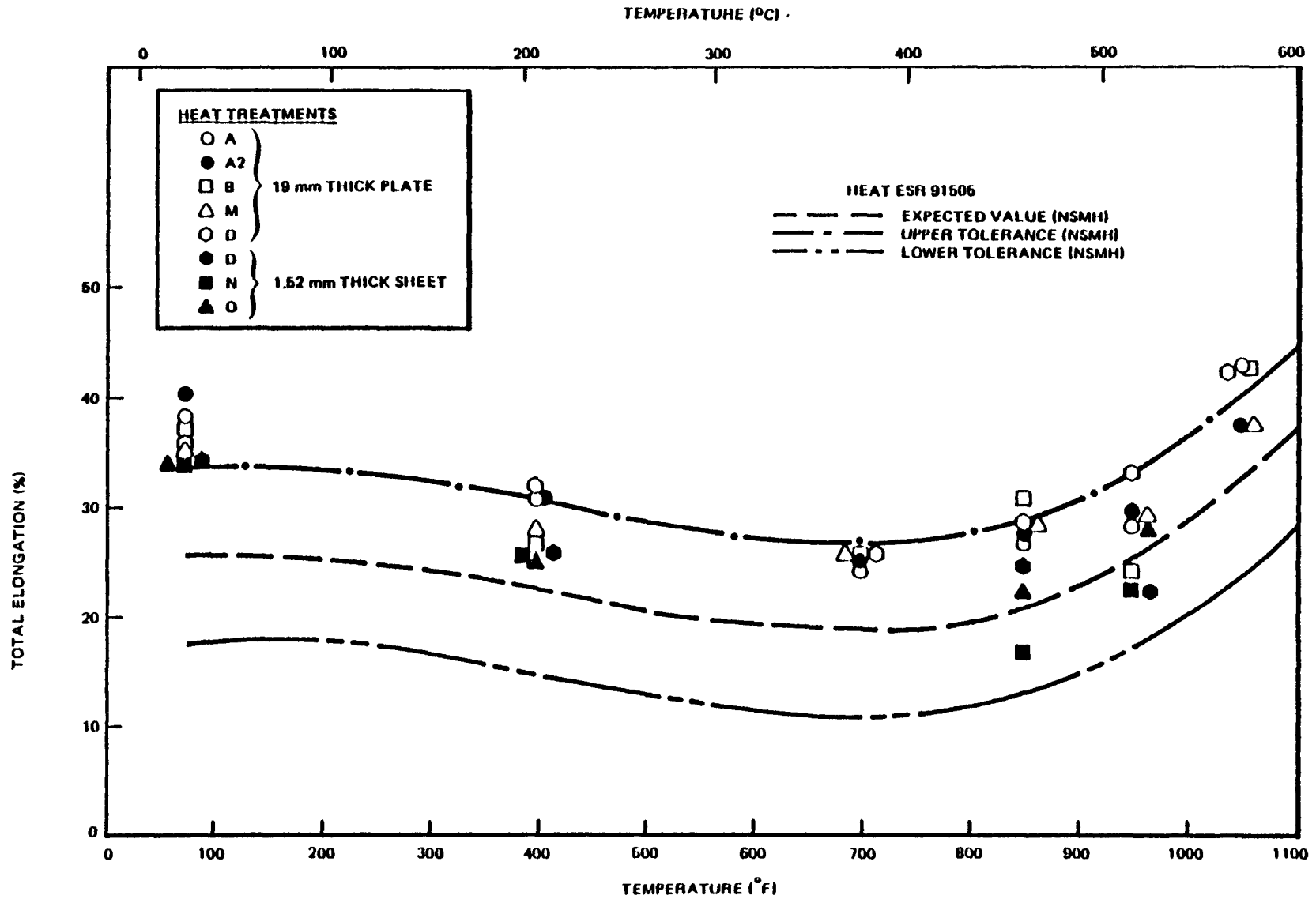
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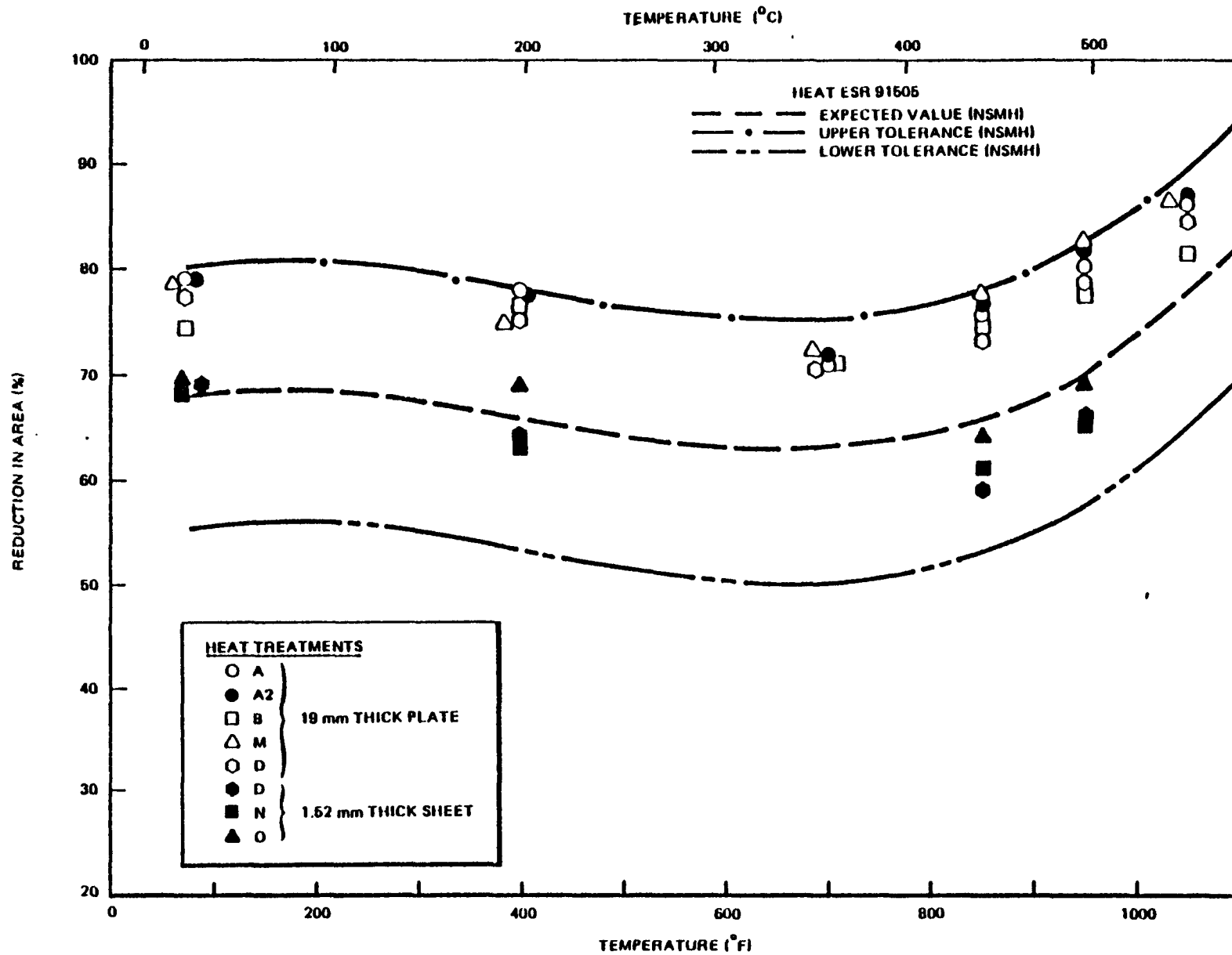
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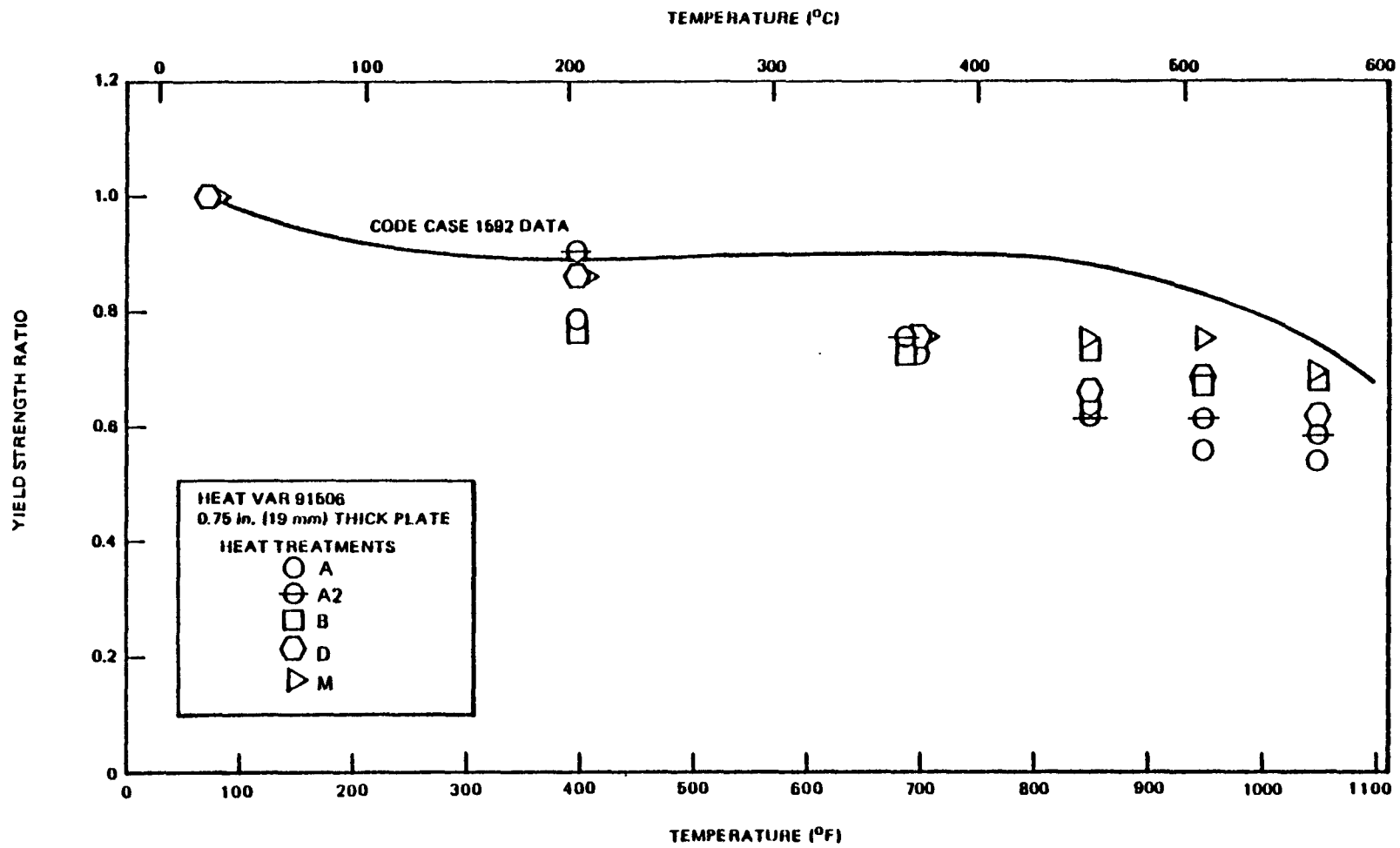
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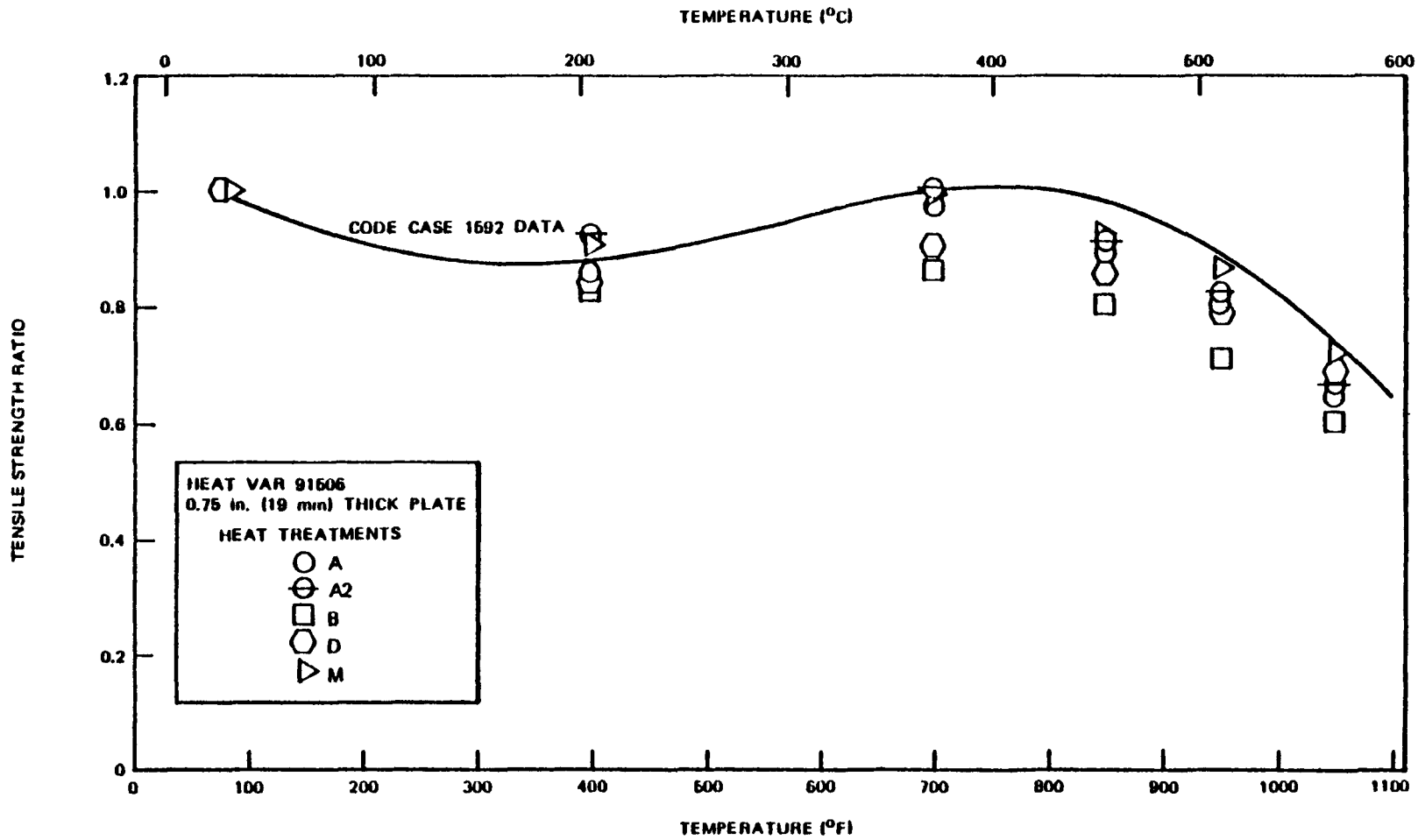
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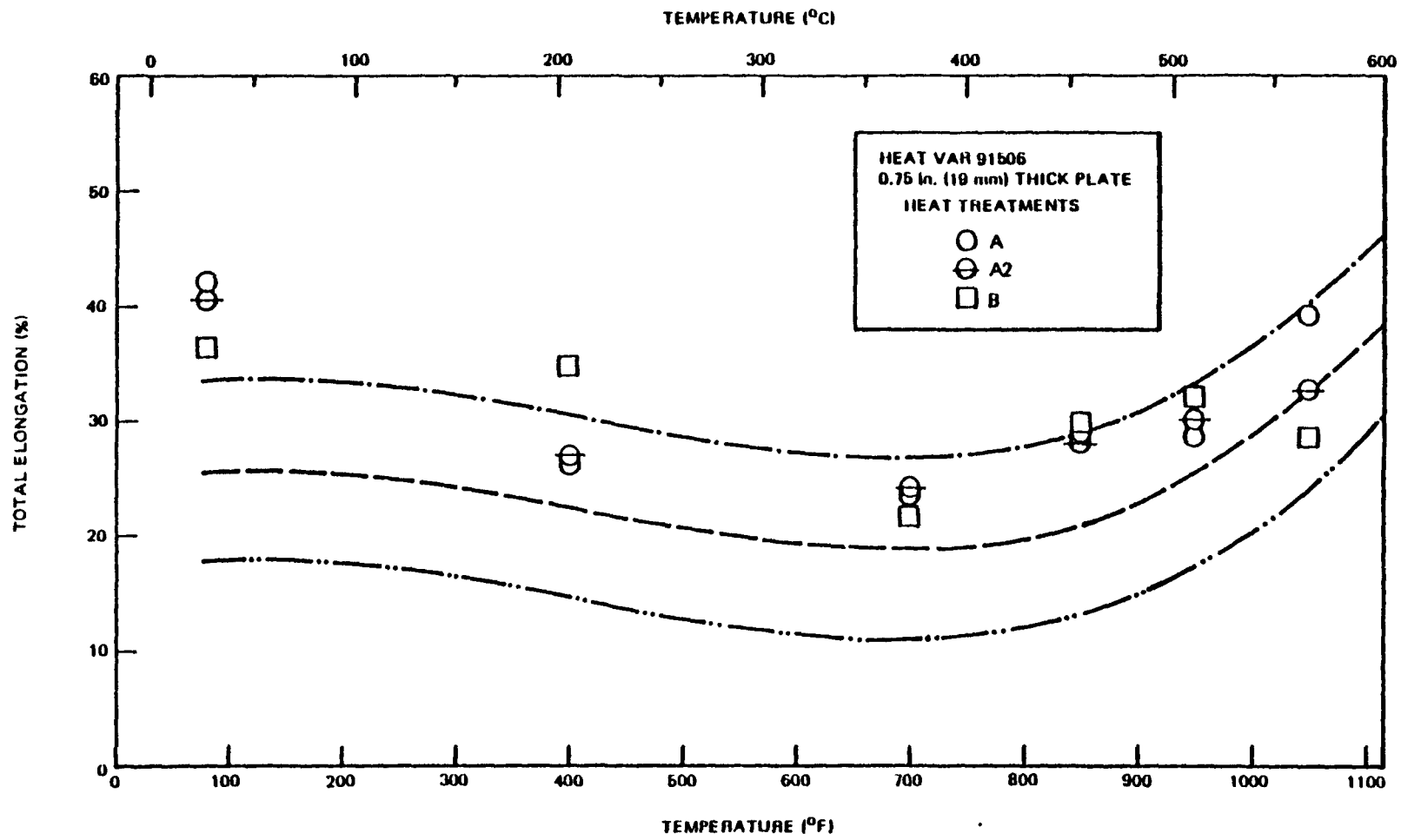
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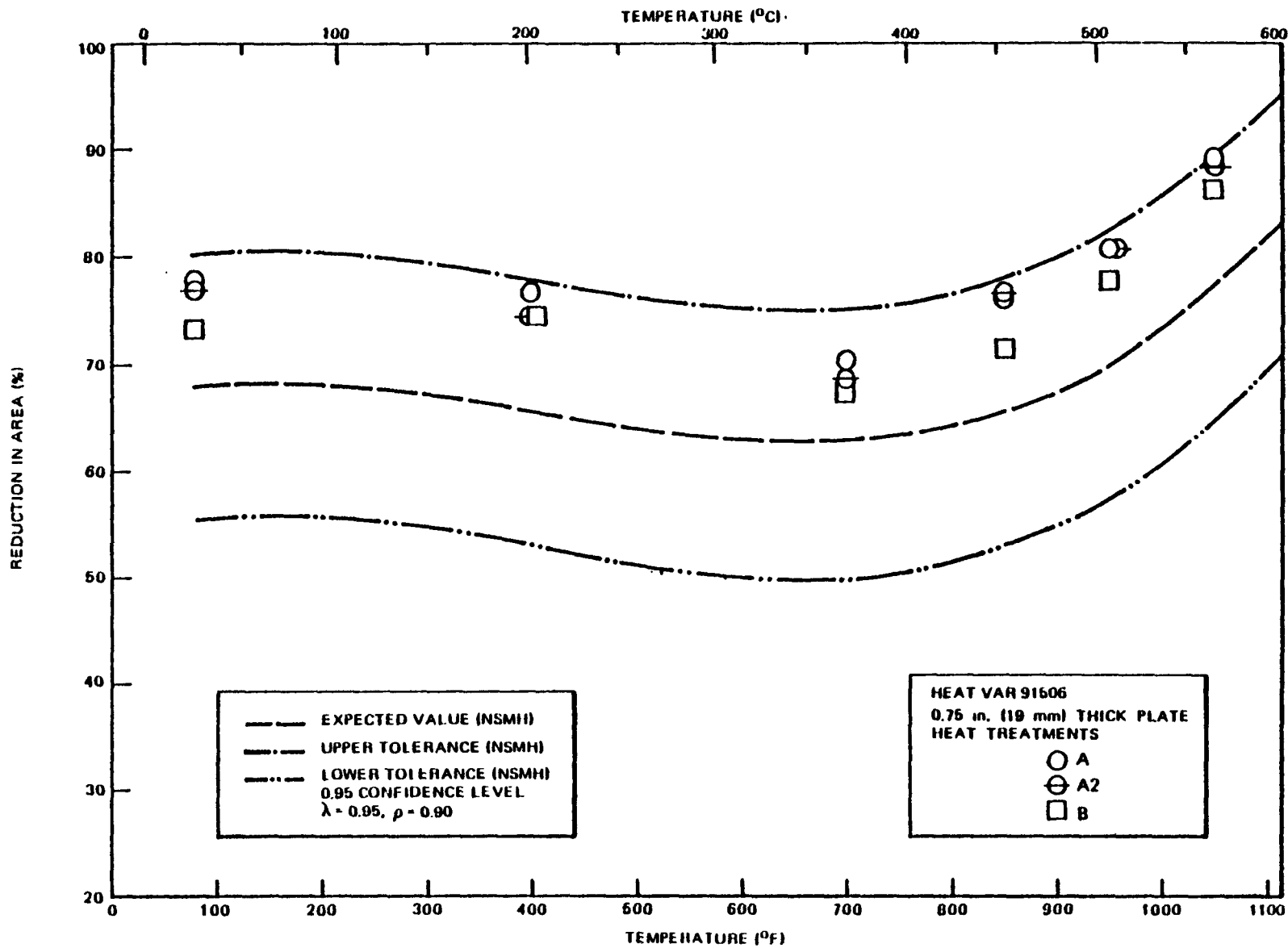
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VARIATION OF TENSILE STRENGTH RATIO WITH TEMPERATURE



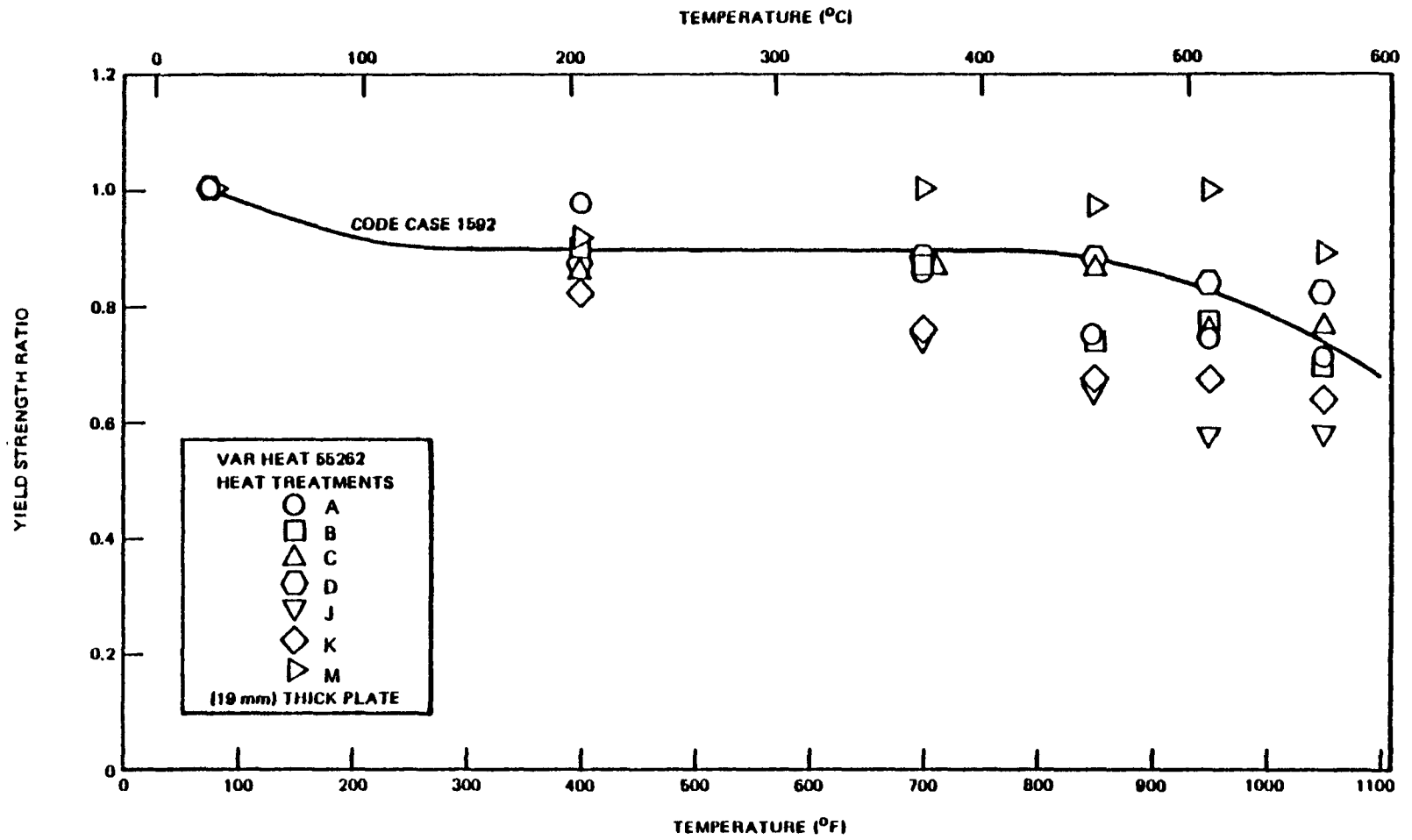
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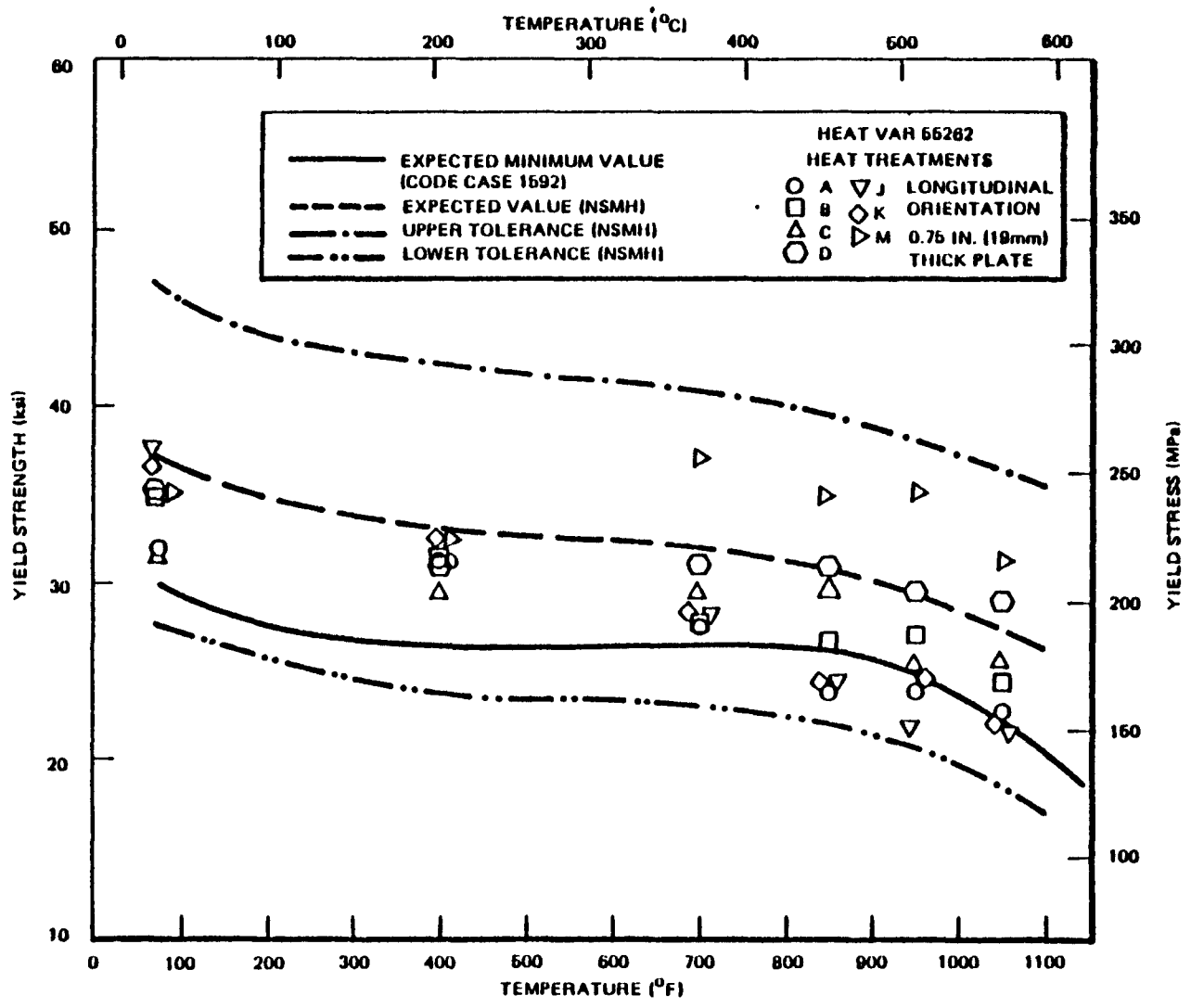
VARIATION OF REDUCTION IN AREA WITH TEMPERATURE

VARIATION OF TENSILE PROPERTIES WITH TEMPERATURE

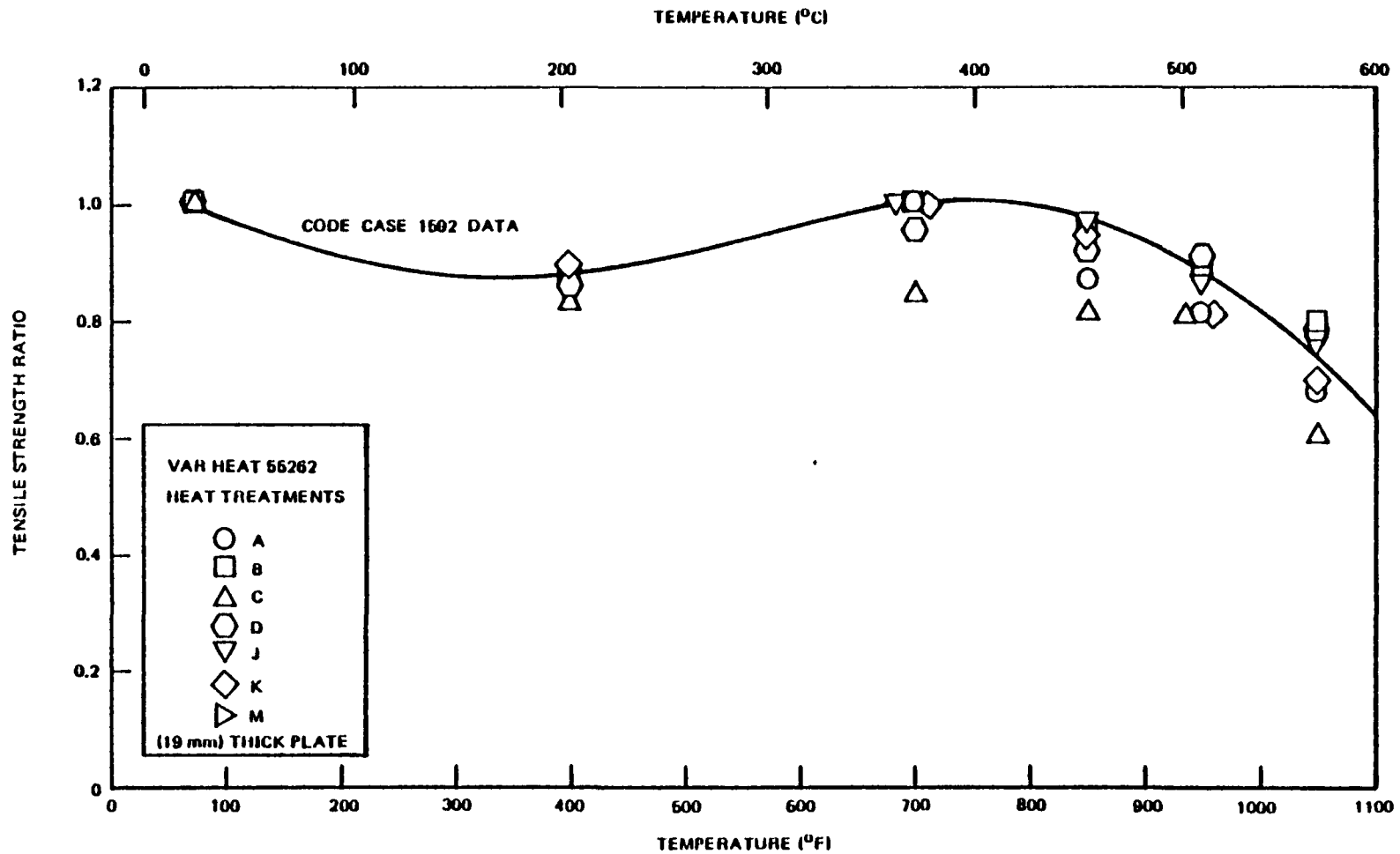
FOR VAR HEAT 55262



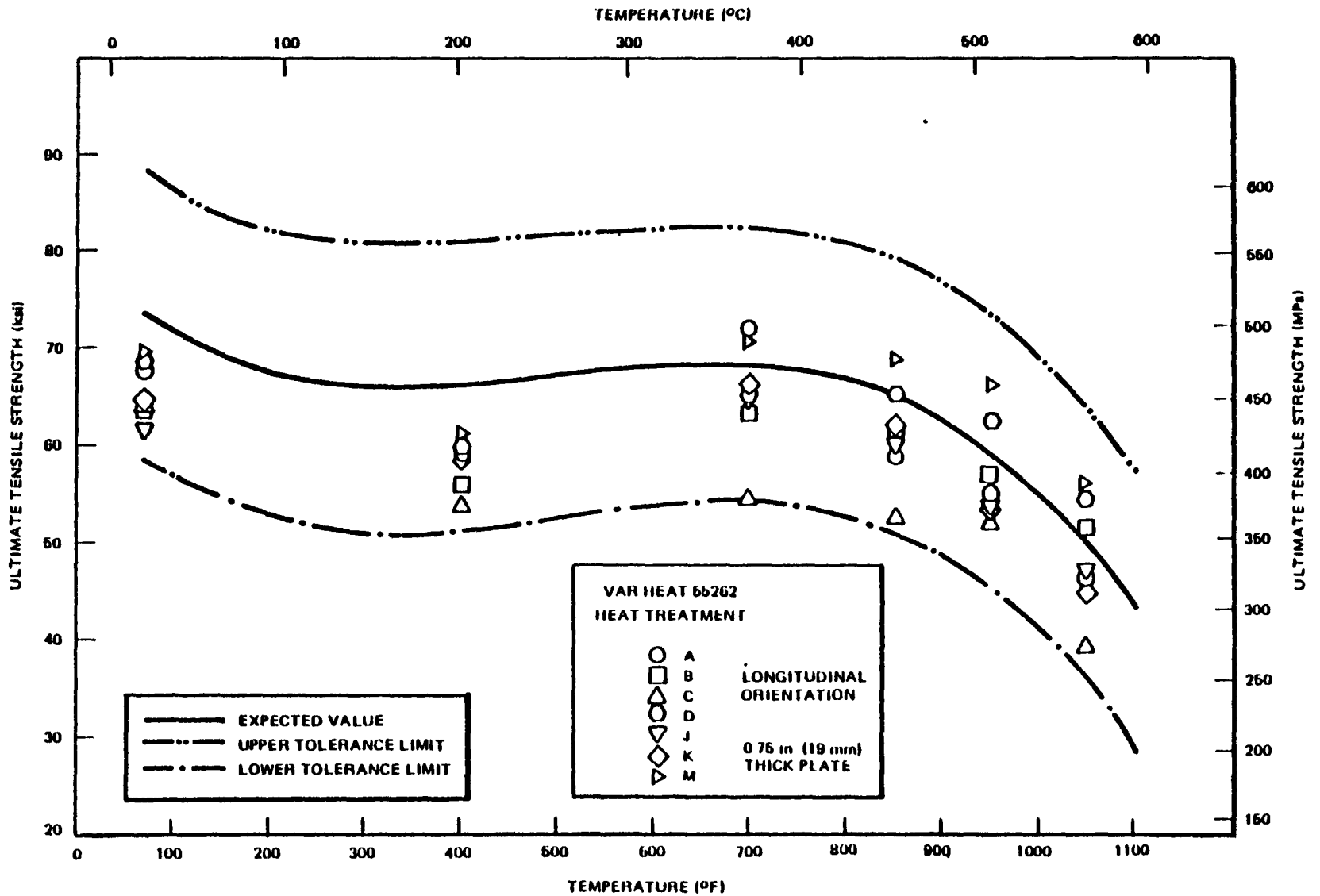
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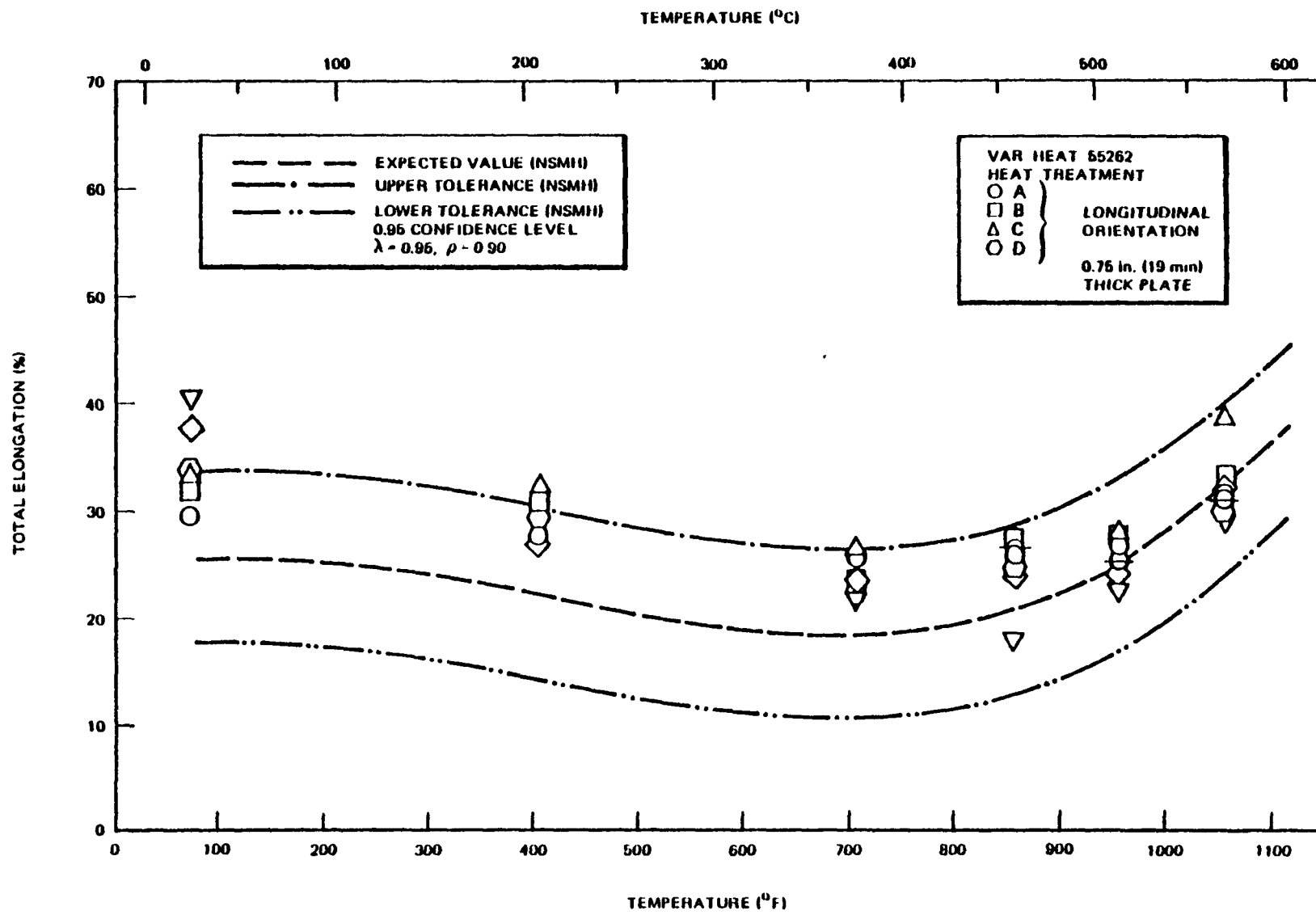
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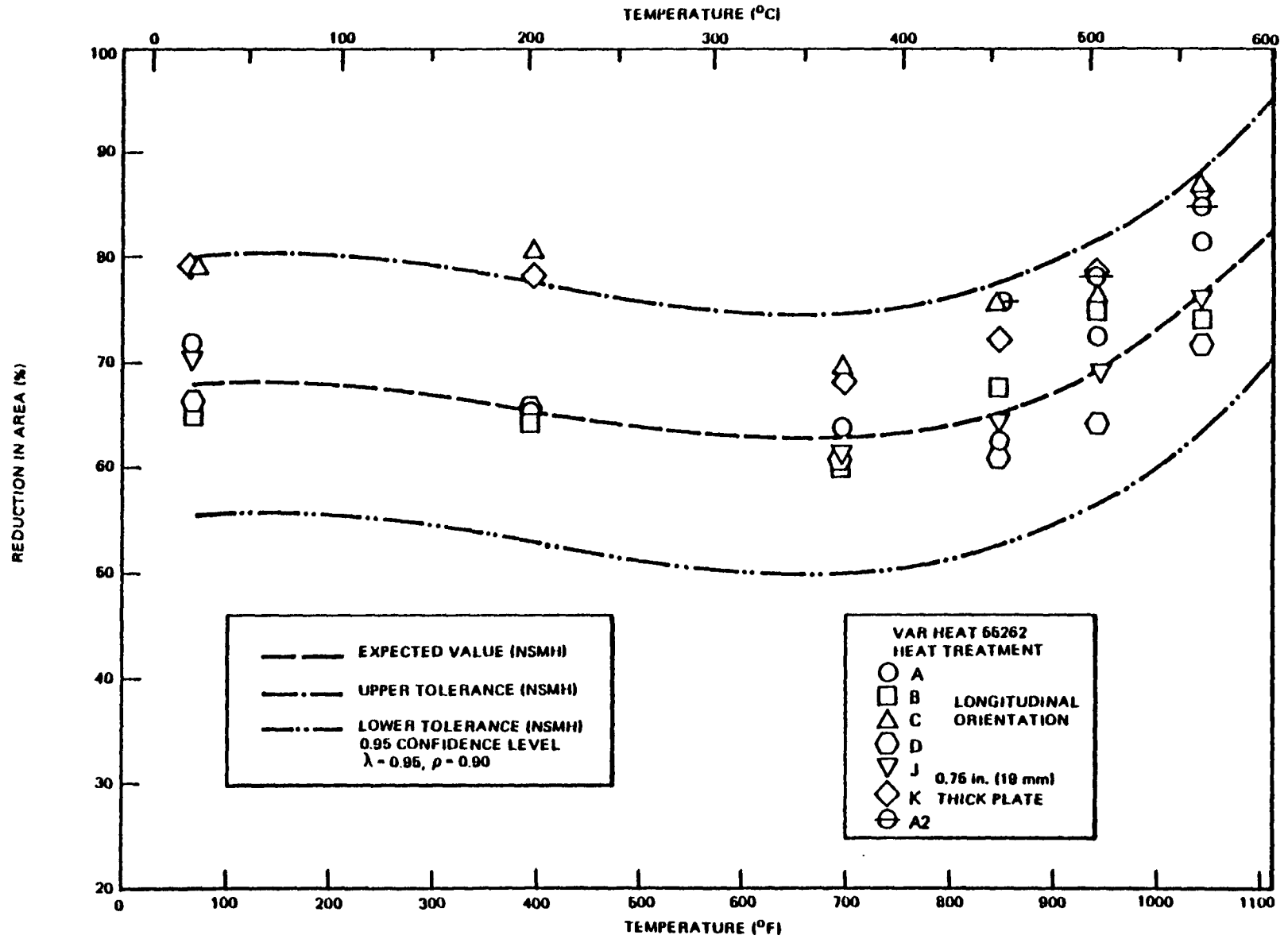
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VARIATION OF ULTIMATE TENSILE STRENGTH WITH TEMPERATURE



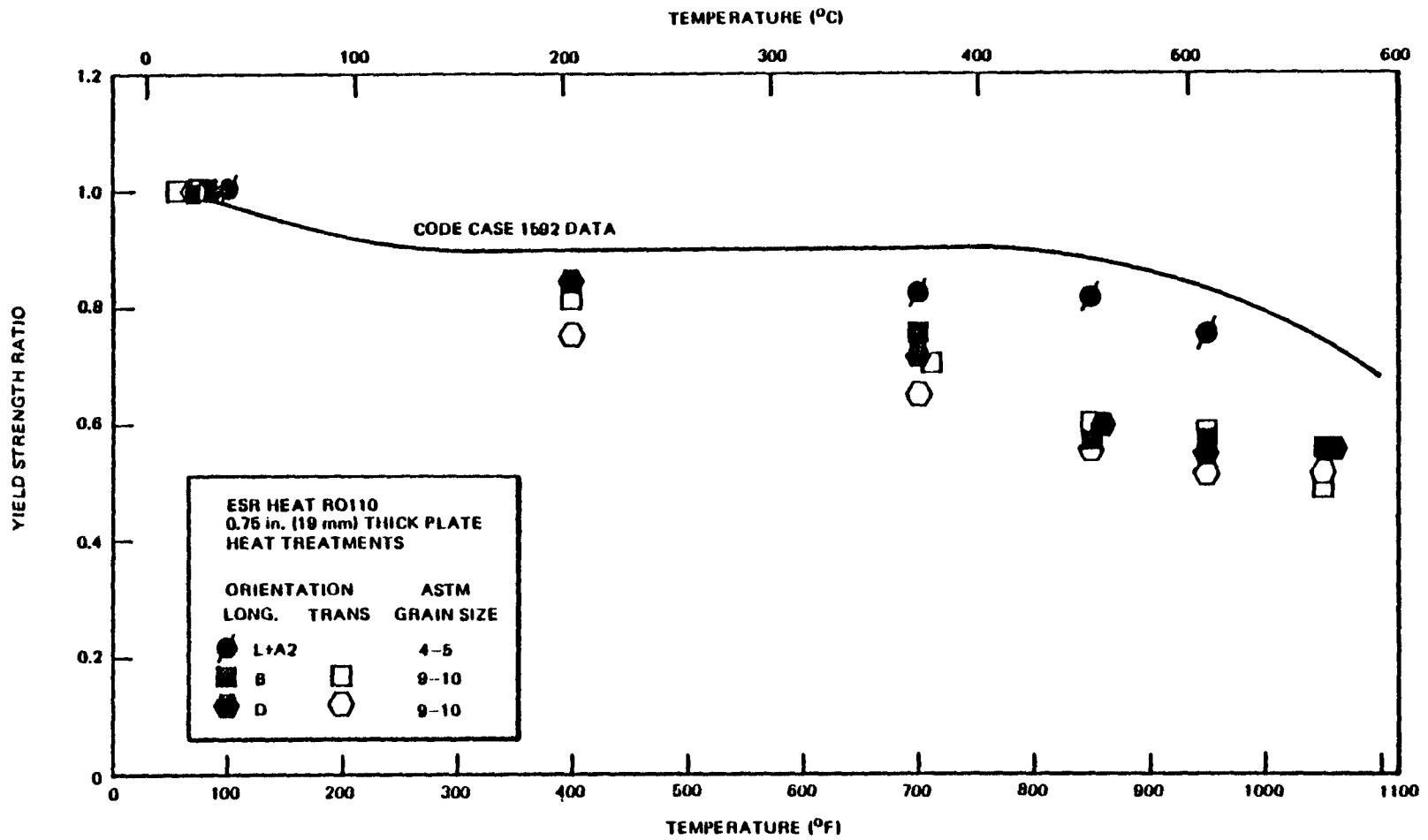
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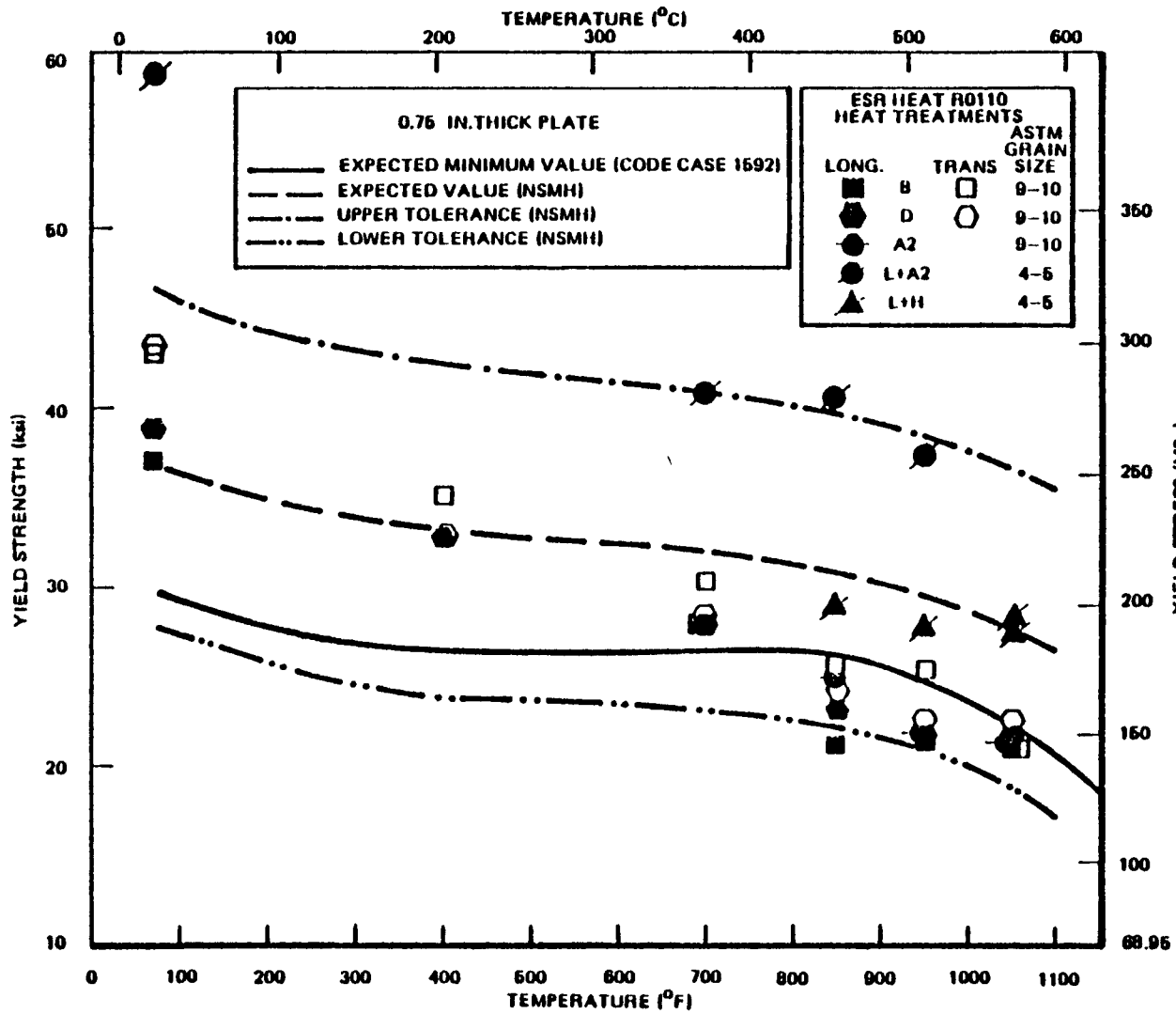
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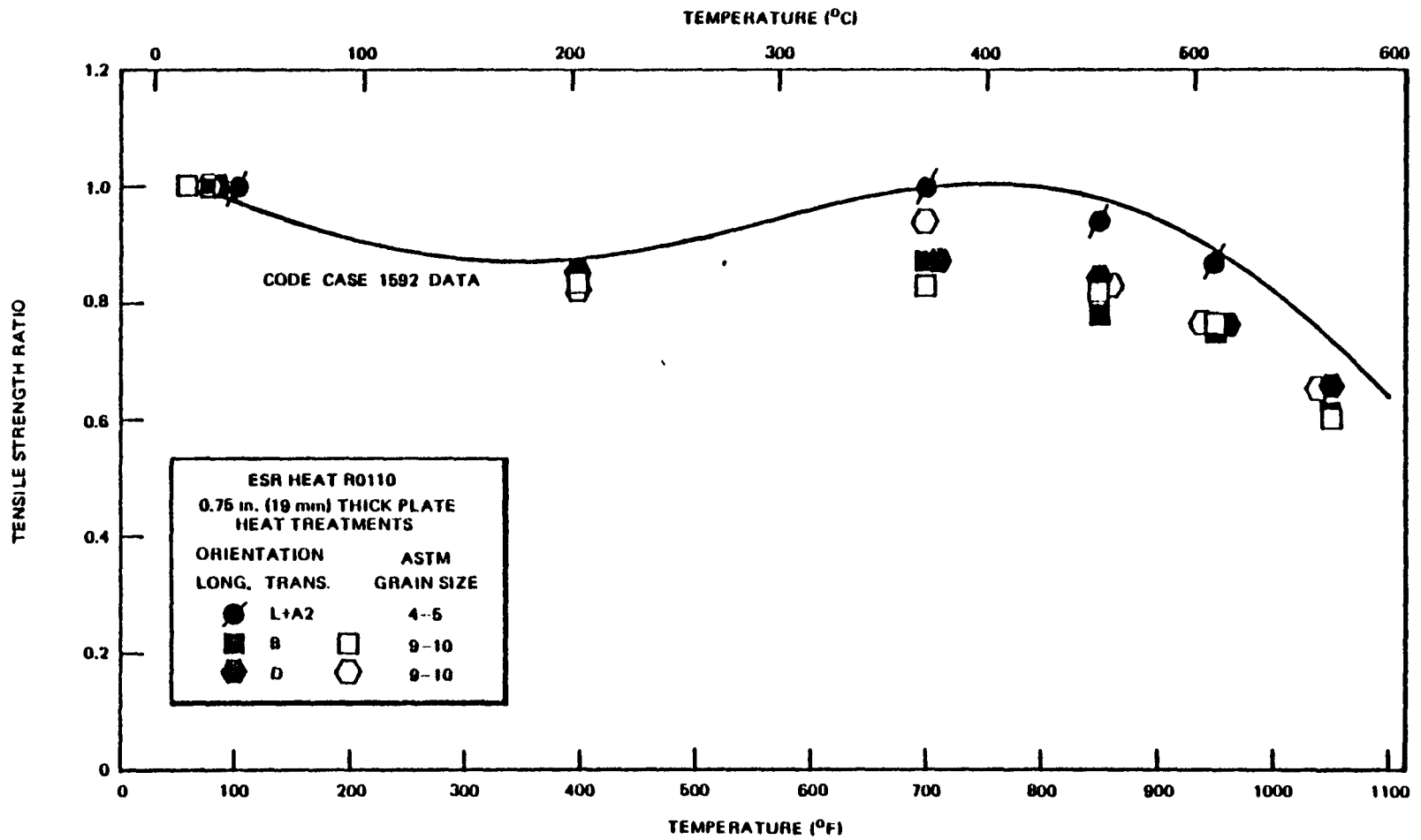
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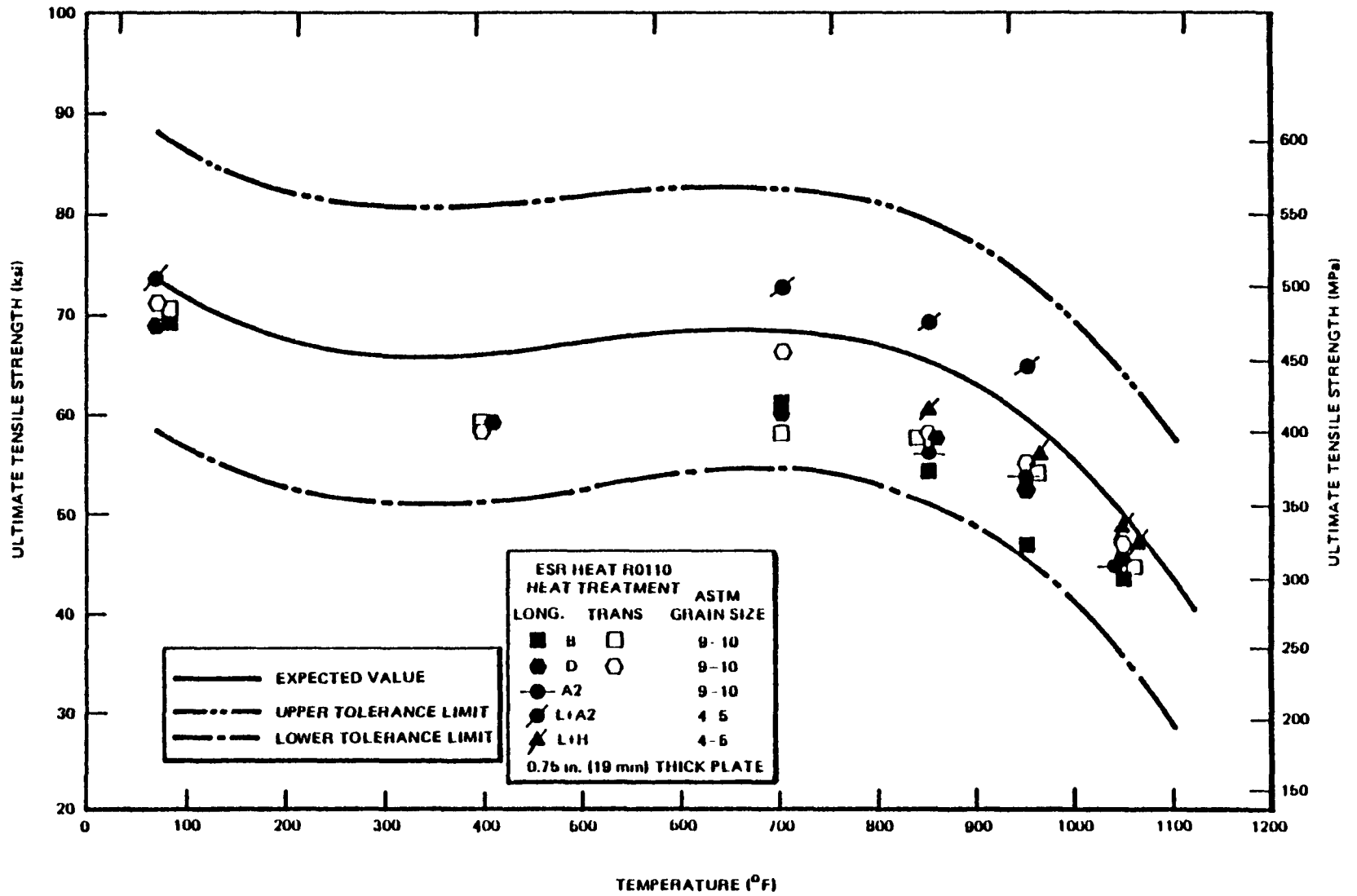
VARIATION OF YIELD STRENGTH RATIO WITH TEMPERATURE



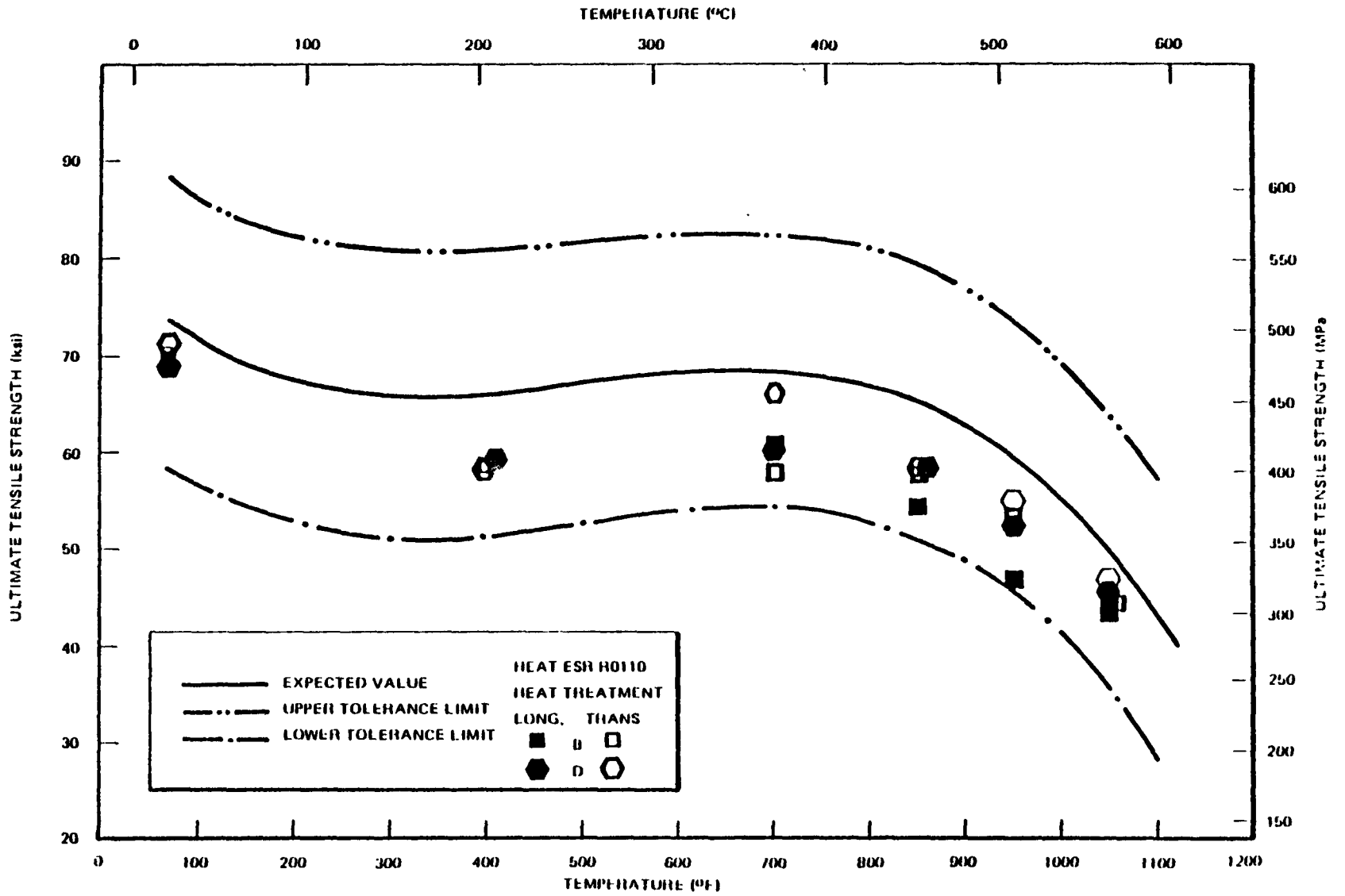
VARIATION OF 0.2% OFFSET YIELD STRENGTH WITH TEMPERATURE



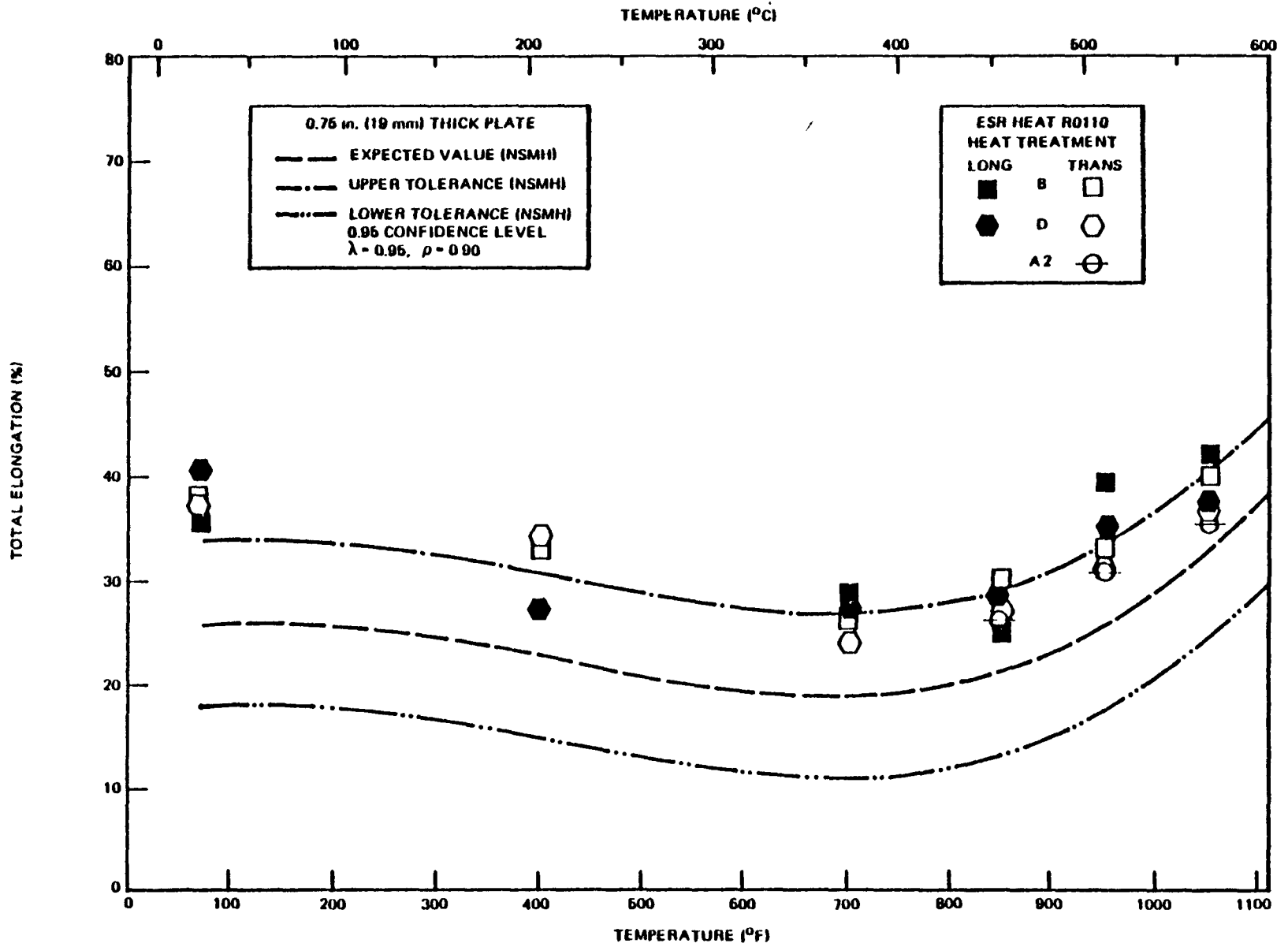
VARIATION OF TENSILE STRENGTH RATIO WITH TEMPERATURE



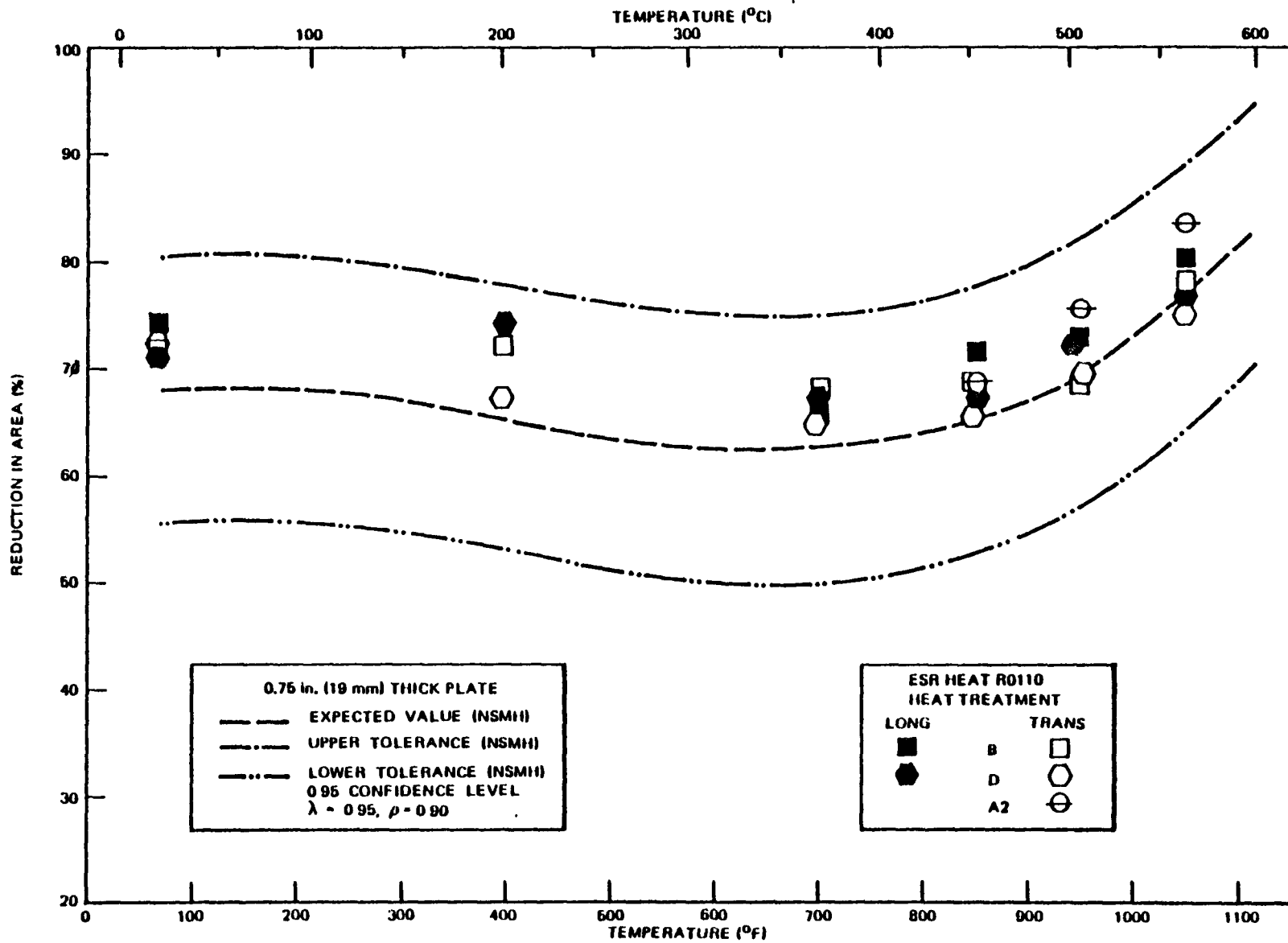
VARIATION OF ULTIMATE TENSILE STRENGTH WITH TEMPERATURE



VARIATION OF ULTIMATE TENSILE STRENGTH WITH TEMPERATURE



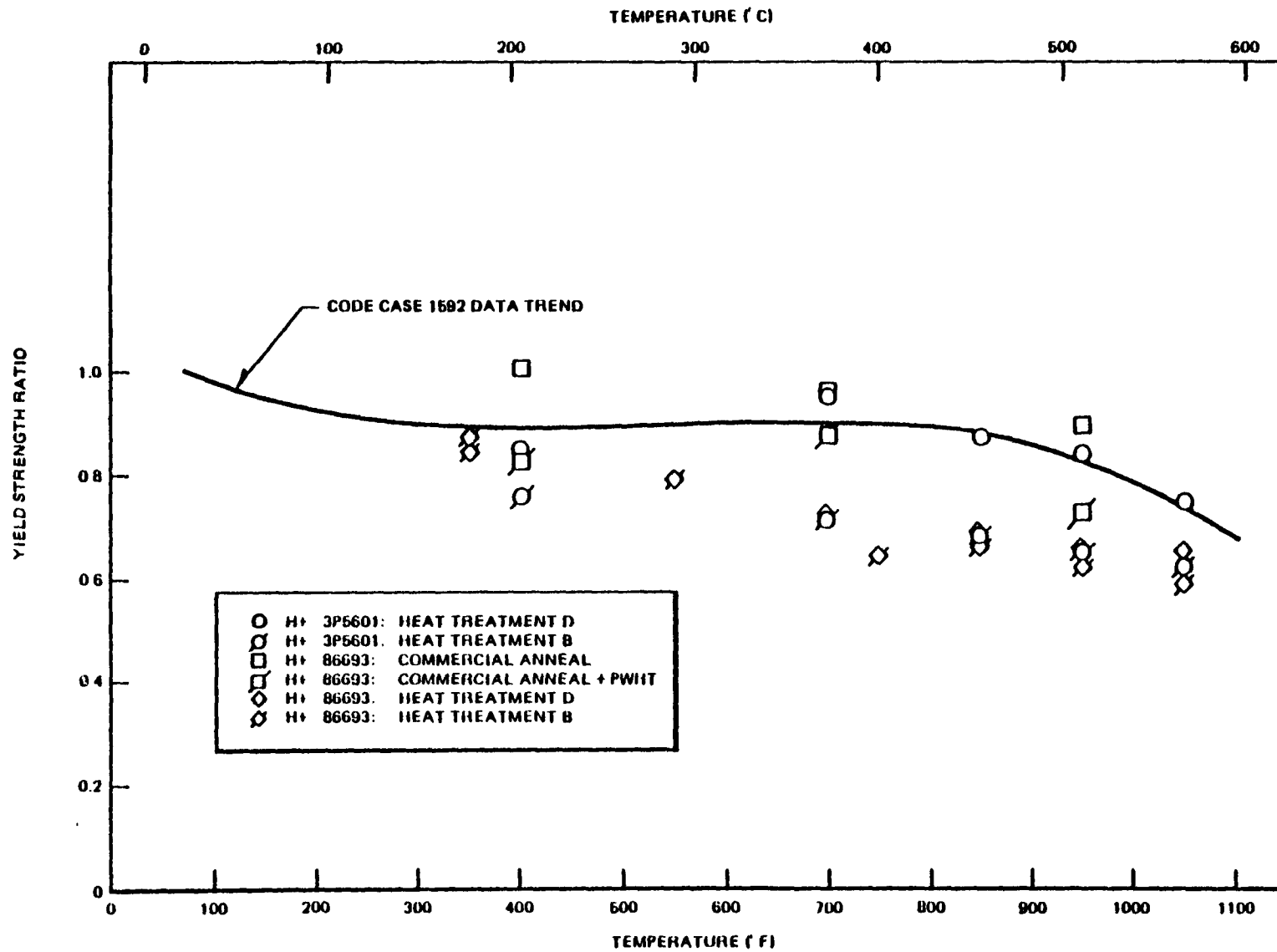
VARIATION OF TOTAL ELONGATION IN 25.4 MM WITH TEMPERATURE



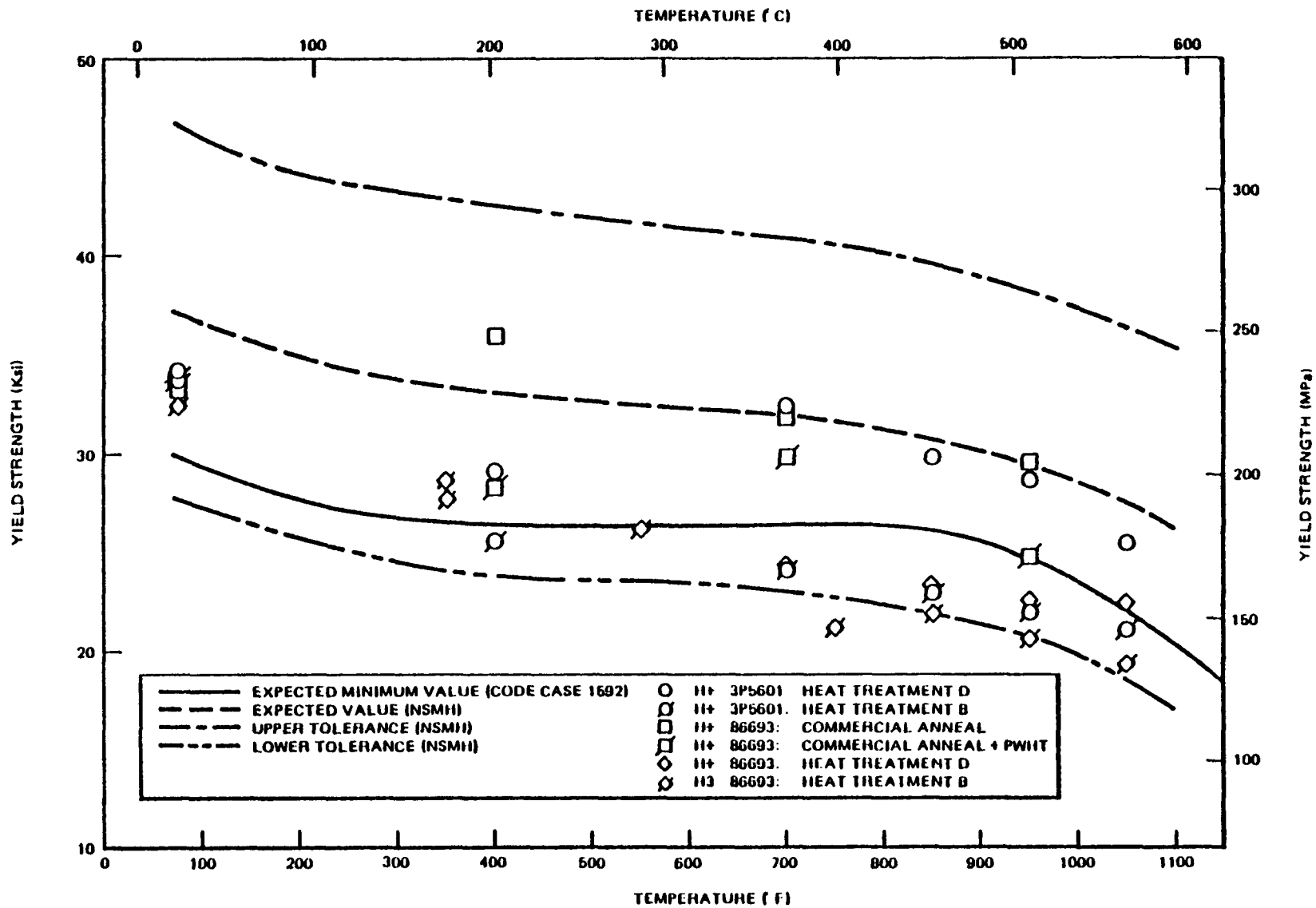
VARIATION OF REDUCTION IN AREA WITH TEMPERATURE

VARIATION OF TENSILE PROPERTIES WITH TEMPERATURE

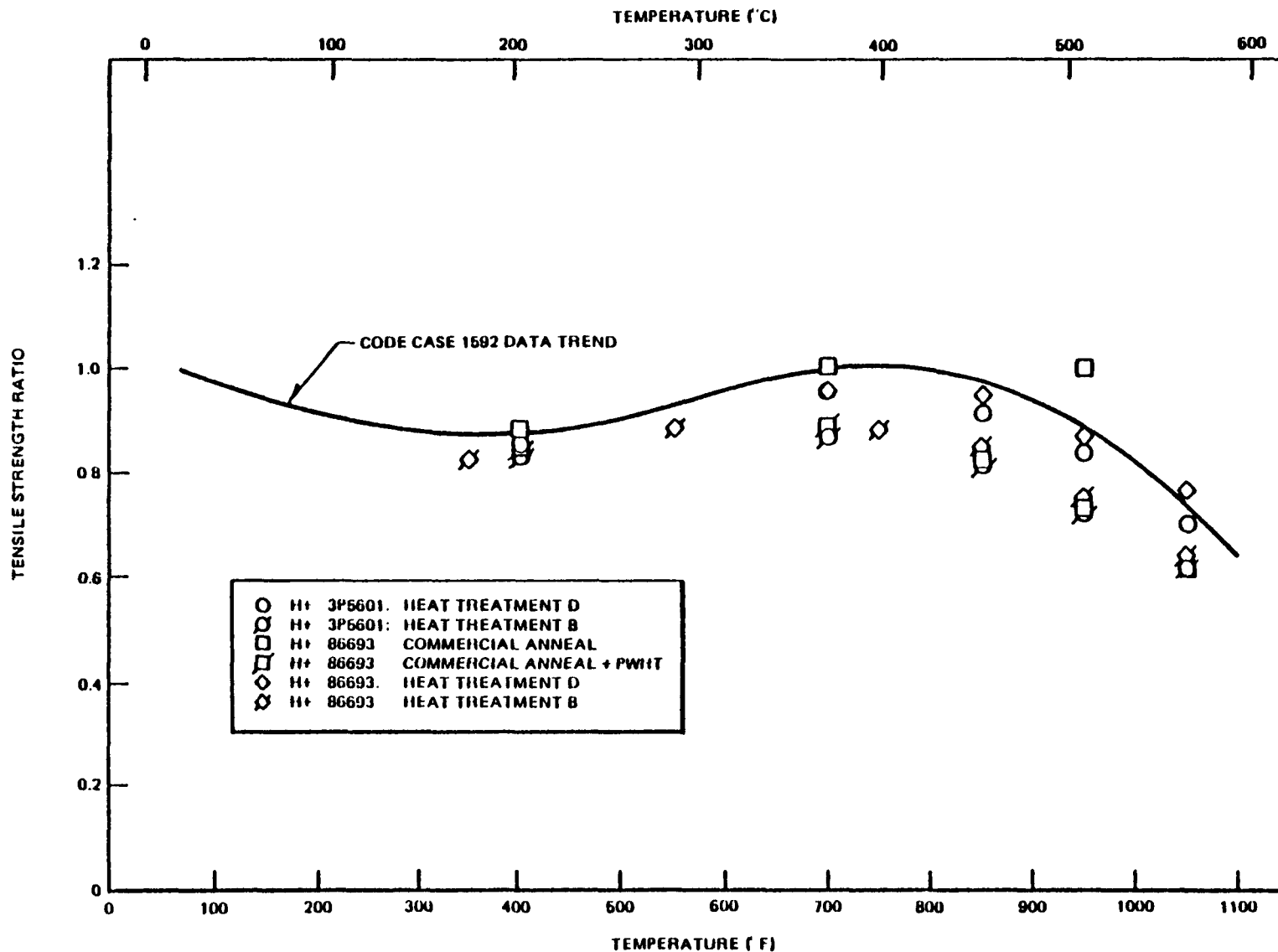
FOR AIR HEAT 3P5601 AND AIR HEAT 86693



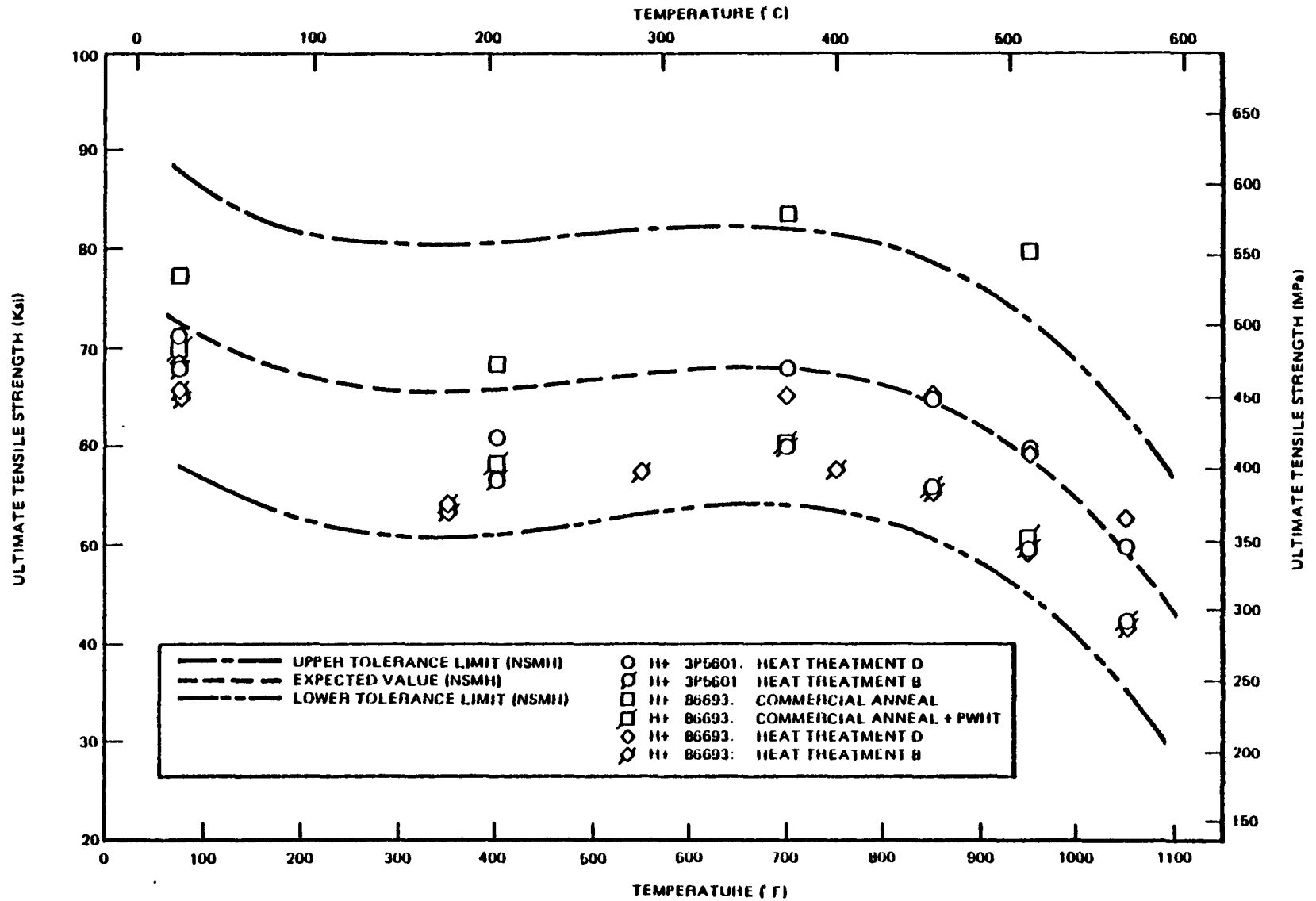
VARIATION OF YIELD STRENGTH RATIO WITH TEMPERATURE



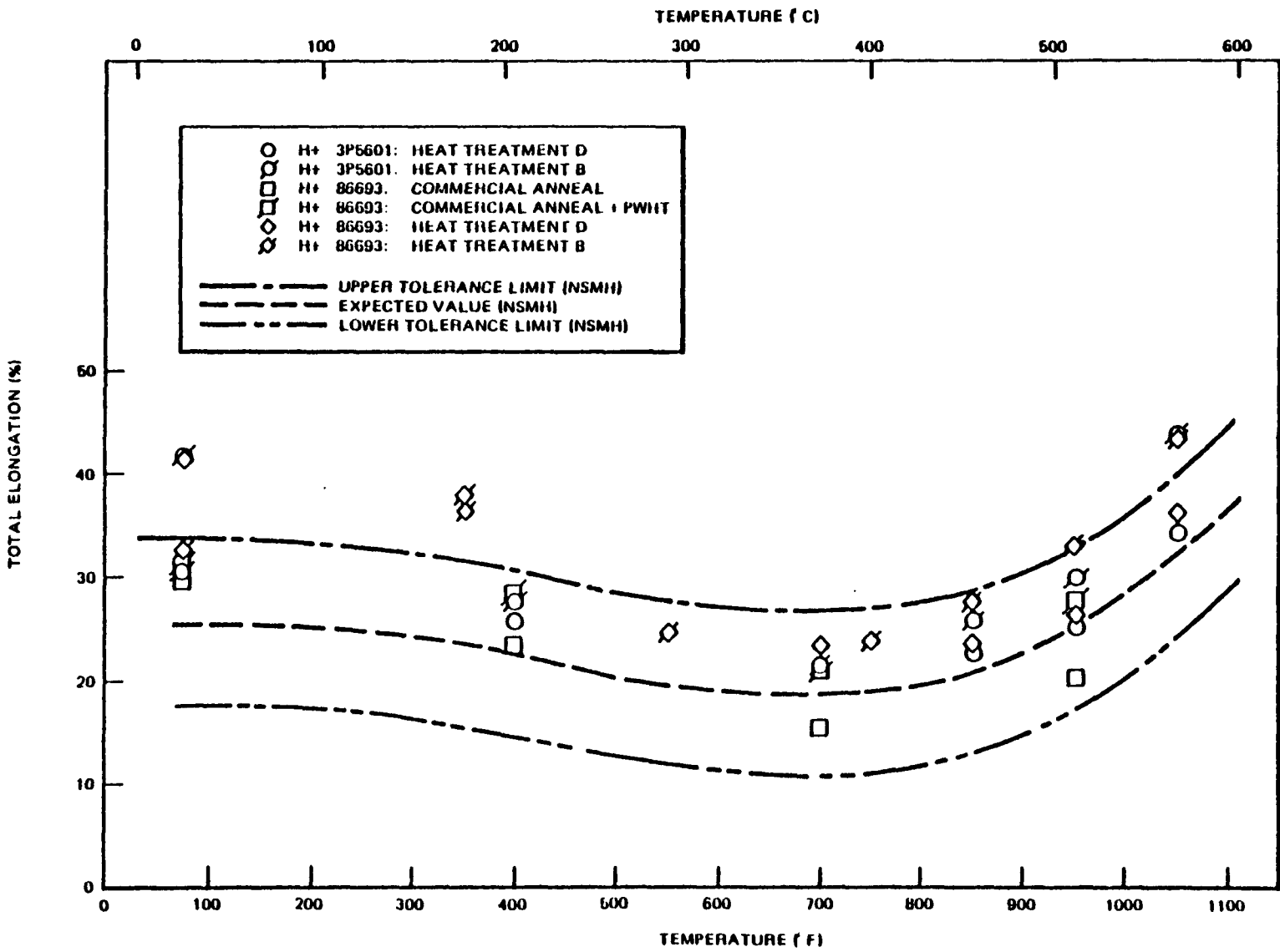
VARIATION OF 0.2% OFFSET YIELD STRENGTH WITH TEMPERATURE



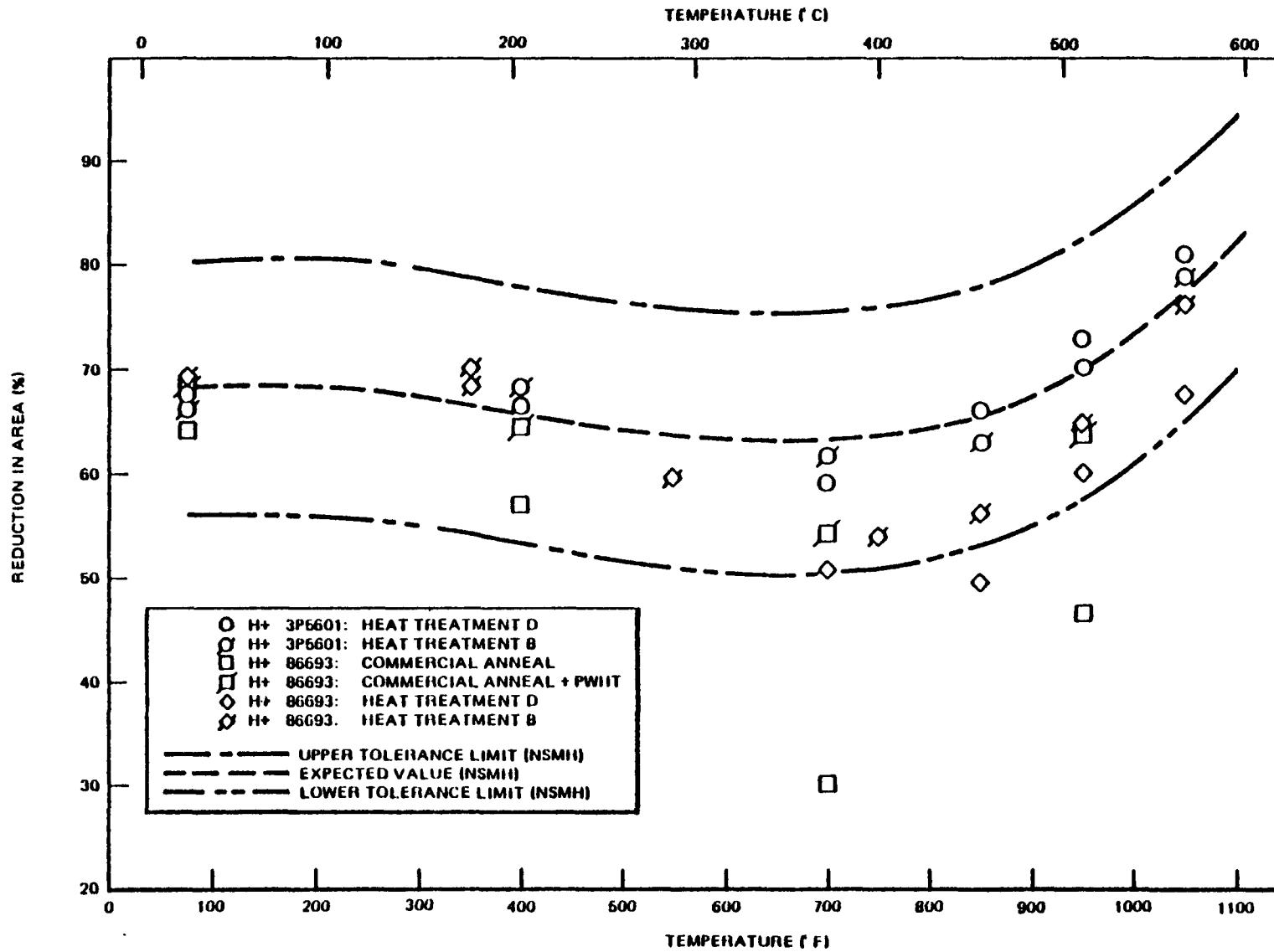
VARIATION OF TENSILE STRENGTH RATIO WITH TEMPERATURE



VARIATION OF ULTIMATE TENSILE STRENGTH WITH TEMPERATURE



VARIATION OF TOTAL ELONGATION IN 25.4 MM WITH TEMPERATURE



VARIATION OF REDUCTION IN AREA WITH TEMPERATURE

TABLE I
CALCULATIONS FOR ALLOWABLE STRESS INTENSITY S_m

Temp. °F	YS R	YS, Min KSI	.66 YS* KSI	US R	US, Min KSI	.33 US* KSI	SM, KSI CRBR	SM, KSI ASME
50	1.013	30.39	20.26	1.029	61.76	20.59	20.26	
100	0.984	29.52	19.68	0.970	58.22	19.41	19.41	20.0
150	0.957	28.71	19.14	0.927	55.60	18.53	18.53	
200	0.932	27.95	18.64	0.896	53.79	17.93	17.93	18.5
250	0.908	27.24	18.16	0.878	52.68	17.56	17.56	
300	0.886	26.57	17.72	0.869	52.17	17.39	17.39	18.0
350	0.865	25.94	17.30	0.869	52.12	17.37	17.30	
400	0.845	25.34	16.90	0.874	52.44	17.48	16.90	17.9
450	0.826	24.77	16.52	0.883	53.01	17.67	16.52	
500	0.808	24.23	16.15	0.895	53.71	17.90	16.15	17.9
550	0.790	23.70	15.80	0.907	54.44	18.15	15.80	
600	0.773	23.19	15.46	0.918	55.08	18.36	15.46	17.9
650	0.756	22.69	15.12	0.925	55.51	18.50	15.12	17.9
700	0.740	22.19	14.79	0.927	55.63	18.54	14.79	17.9
750	0.723	21.69	14.46	0.922	55.33	18.44	14.46	17.9
800	0.706	21.19	14.12	0.908	54.48	18.16	14.12	17.9
850	0.689	20.67	13.78	0.883	52.98	17.66	13.78	17.6
900	0.672	20.15	13.43	0.845	50.72	16.91	13.43	17.2
950	0.653	19.60	13.07	0.793	47.57	15.86	13.07	16.7
1000	0.635	19.04	12.69	0.724	43.43	14.48	12.69	15.9
1050	0.615	18.44	12.29	0.637	38.19	12.73	12.29	15.0
1100	0.594	17.81	11.87	0.529	31.74	10.58	10.58	13.8

Sec. III
Div. I



CC 1592



- B37 -

* Calculates Yield and Ultimate Strengths Based on Regression Fit Strength Ratios for Heat Treatments B, A, A2, K

TABLE II

HEAT TREATMENTS FOR 2%Cr-1%Ni STEEL

Heat Treatment	Type	Austenitizing		Cooling	Isothermal Hold [†]		Additional Heat Treatment [†]		
		Temp.	Time		Temp.	Time	Type	Temp.	Time
B	Full Anneal	927·14°C	60 min.	Furnace Cool to 316°C, 56°C/hr. max. [*]	NA ^{**}	NA	PWHT	727·19°C	4 hrs.
D	Full Anneal	927·14°C	60 min.	Furnace Cool to 316°C, 56°C/hr. max. [*]	NA	NA	None		
G	Full Anneal	927·14°C	60 min.	Furnace Cool to 316°C, 56°C/hr. max. [*]	NA	NA	PWHT Embrittlement	727·19°C 510·10°C	4 hrs. 1000 hrs.
A	Simulated CRBR Isothermal Anneal	927·14°C	30 min.	Furnace Cool to 704°C, 125°C/hr. max.	704·8°C	120 min.	PWHT	727·19°C	4 hrs.
A2	Simulated CRBR Isothermal Anneal	927·14°C	30 min.	Furnace Cool to 704°C, 125°C/hr. max.	704·8°C	90 min.	PWHT	727·19°C	4 hrs.
H	Simulated CRBR Isothermal Anneal	927·14°C	30 min.	Furnace Cool to 704°C, 125°C/hr. max.	704·8°C	90 min.	PWHT	727·19°C	40 hrs.
M	Simulated CRBR Isothermal Anneal	927·14°C	30 min.	Furnace Cool to 704°C, 125°C/hr. max.	704·8°C	90 min.	None		
F	Simulated CRBR Isothermal Anneal	927·14°C	30 min.	Furnace Cool to 704°C, 125°C/hr. max.	704·8°C	120 min.	PWHT Embrittlement	727·19°C 510·10°C	4 hrs. 1000 hrs.
J	Simulated CRBR Isothermal Anneal	927·14°C	30 min.	Furnace Cool to 704°C, 125°C/hr. max.	704·8°C	120 min.	PWHT	727·19°C	40 hrs.
K	Simulated CRBR Isothermal Anneal	927·14°C	30 min.	Furnace Cool to 718°C, 125°C/hr. max.	718·8°C	90 min.	PWHT	727·19°C	4 hrs.
N	Simulated Industrial Isothermal Anneal	857°C	45 min.	Furnace Cool to 677°C	677°C	66 min.	None		
O	Simulated Industrial Isothermal Anneal	857°C	45 min.	Furnace Cool to 677°C	677°C	66 min.	PWHT	727·19°C	4 hrs.
L	Grain Growth	1093·14°C	60 min.	Furnace Cool to 927°C and begin additional heat treatment					

[†] PWHT - Post Weld Heat Treatment; ^{*} Followed by an air cool to room temperature; ^{**} NA - Not Applicable

TABLE III
CHEMICAL ANALYSIS OF 2½Cr-1Mo STEEL

	VAR 91506 Check	ESR 91505 Check	Estimated Detection	RDT M2-19	
	Chemical Analysis	Chemical Analysis		RDT M3-33	
	(Anamet)	(Anamet)	Limits	Minimum	Maximum
Aluminum	<0.005%	0.017%	0.005%		
Antimony	<0.002%	<0.002%	0.002%		
Arsenic	0.006%	0.006%	0.002%		
Carbon	0.102%	0.087%	0.005%	0.070%	0.110%
Chromium	2.32%	2.31%	0.01%	1.90%	2.60%
Cobalt	0.008%	0.007%	0.005%		
Copper	0.04%	0.04%	0.01%		0.35%
Hydrogen	0.0009%	0.0007%	0.0001%		
Manganese	0.42%	0.47%	0.01%	0.30%	0.60%
Molybdenum	1.00%	0.99%	0.01%	0.87%	1.13%
Nickel	0.06%	0.05%	0.005%	0.25%	
Nitrogen	0.009%	0.008%	0.001%		
Oxygen	0.005%	0.013%	0.001%		
Phosphorus	0.007%	0.007%	0.003%		0.015%
Silicon	0.32%	0.26%	0.01%	0.20%	0.40%
Sulfur	0.008%	0.003%	0.002%		0.015%
Tin	<0.002%	<0.002%	0.002%		
Titanium	0.003%	<0.002%	0.002%		0.03%
Vanadium	0.006%	0.006%	0.002%		0.03%

TABLE IV

CHEMICAL ANALYSIS OF 2½Cr-1Mo STEEL

	VAR 55262 Check Chemical Analysis (Anamet)	3P5601 Melt Chemical Analysis	ESR R0110 Check Chemical Analysis (Anamet)	86693 Chemical Analysis	
				Melt	Check
Aluminum	<0.005%		0.027%		
Antimony	<0.002%		<0.002%		
Arsenic	0.008%		0.010%		
Carbon	0.099%*	0.119%	0.100%**	0.11%	0.12%
Chromium	2.26%	2.30%	2.26%	2.01%	2.00%
Cobalt	<0.002%		<0.002%		
Copper	0.09%		0.10%		
Hydrogen	0.0006%		0.0005%		
Manganese	0.50%	0.35%	0.50%	0.45%	0.41%
Molybdenum	1.00%	0.96%	0.99%	1.04%	0.99%
Nickel	0.15%	0.20%	0.15%	--	0.12%
Nitrogen	0.008%		0.008%		
Oxygen	<0.001%		<0.001%		
Phosphorus	0.013%	0.009%	0.013%	0.009%	0.014%
Silicon	0.07%	0.27%	0.018%	0.20%	0.19%
Sulfur	0.016%	0.022%	0.006%	0.028%	0.026%
Tin	0.004%		<0.002%		
Titanium	<0.002%		<0.002%		
Vanadium	0.013%		0.013%		

* Average of 0.093%, 0.090%, 0.115%

** Average of 0.113%, 0.103%, 0.086%

TABLE V
TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)		Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
				Yield 0.2% Offset	Ultimate	Yield	Ultimate		
<u>Heat VAR 91506 - 0.10% C</u>									
VT1	A	24	(76)	275 (39.9)	461 (66.9)	1.000	1.000	42.2	77.8
VT2	A	204	(400)	216 (31.4)	396 (57.5)	.787	.859	26.4	76.7
VT3	A	371	(700)	199 (28.9)	450 (65.2)	.724	.975	23.6	70.3
VT4	A	454	(850)	174 (25.3)	413 (59.9)	.634	.895	29.0	76.1
VT5	A	510	(950)	153 (22.2)	372 (54.0)	.556	.807	28.6	80.7
VT6	A	566	(1050)	148 (21.5)	299 (43.3)	.539	.649	39.3	89.2
VT10	A2	24	(76)	260 (37.8)	459 (66.6)	1.000	1.000	40.5	77.1
VT11	A2	204	(400)	236 (34.2)	425 (61.7)	.905	.926	26.6	74.5
VT12	A2	371	(700)	201 (29.2)	466 (67.6)	.772	1.015	24.3	68.9
VT13	A2	454	(850)	161 (23.4)	419 (60.8)	.619	.913	28.2	76.5
VT14	A2	510	(950)	161 (23.3)	377 (54.7)	.616	.821	30.3	80.9
VT15	A2	566	(1050)	152 (22.0)	308 (44.7)	.582	.671	32.8	88.4
VT19	B	24	(76)	202 (29.3)	440 (63.8)	1.000	1.000	36.6	73.3
VT20	B	204	(400)	154 (22.3)	365 (53.0)	.761	.831	34.8	74.4
VT21	B	371	(700)	147 (21.3)	381 (55.3)	.727	.867	21.8	67.4
VT22	B	454	(850)	149 (21.6)	356 (51.7)	.737	.810	29.6	72.4
VT23	B	510	(950)	137 (19.8)	312 (45.3)	.676	.710	32.3	77.9
VT24	B	566	(1050)	139 (20.1)	268 (38.8)	.686	.608	28.8	86.2

TABLE V, CONTINUED

TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)		Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
				Yield 0.2% Offset	Ultimate	Yield	Ultimate		
<u>Heat VAR 91506 - 0.10% C</u>									
VT20	D	24	(76)	228 (33.1)	456 (66.1)	1.000	1.000	34.5	73.8
VT21	D	204	(400)	197 (28.6)	383 (55.6)	.864	.841	31.1	72.2
VT22	D	371	(700)	173 (25.1)	414 (60.0)	.758	.908	24.7	66.5
VT23	D	454	(850)	151 (21.9)	397 (57.6)	.622	.871	28.4	71.6
VT24	D	510	(950)	156 (22.6)	363 (52.6)	.683	.796	31.2	79.0
VT25	D	566	(1050)	142 (20.6)	314 (45.6)	.622	.690	38.1	85.9
VT27	M	24	(76)	263 (38.1)	467 (67.8)	1.000	1.000	34.5	77.7
VT28	M	204	(400)	228 (33.0)	425 (61.7)	.866	.910	27.3	74.3
VT29	M	371	(700)	199 (28.8)	465 (67.5)	.756	.996	24.5	72.8
VT30	M	454	(850)	198 (28.7)	439 (63.5)	.753	.937	28.2	78.5
VT31	M	510	(950)	198 (28.7)	406 (58.9)	.753	.869	28.4	81.0
VT32	M	566	(1050)	183 (26.6)	339 (49.1)	.698	.724	37.6	85.9
<u>Heat ESR 91505 - 0.09% C</u>									
ET1	A	24	(76)	261 (37.9)	440 (63.8)	1.000	1.000	38.3	79.1
ET2	A	204	(400)	203 (29.5)	397 (57.6)	.778	.903	30.7	78.0
ET3	A	371	(700)	188 (27.3)	434 (63.0)	.720	.987	24.5	71.1
ET4	A	454	(850)	159 (23.0)	398 (57.7)	.607	.904	26.6	75.9
ET5	A	510	(950)	153 (22.2)	357 (51.8)	.586	.812	28.3	80.2
ET6	A	566	(1050)	139 (20.1)	290 (42.1)	.530	.660	43.1	86.2

TABLE V, CONTINUED

TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)		Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
				Yield 0.2% Offset	Ultimate	Yield	Ultimate		
Heat ESR 91505 - 0.09% C									
ET10	A2	24	(76)	254 (36.9)	434 (63.0)	1.000	1.000	40.3	79.3
ET11	A2	204	(400)	220 (31.9)	398 (57.7)	.864	.916	30.9	77.6
ET12	A2	371	(700)	186 (27.0)	429 (62.2)	.732	.987	25.0	71.8
ET13	A2	454	(850)	148 (21.4)	394 (57.1)	.580	.906	27.6	76.6
ET14	A2	510	(950)	149 (21.6)	359 (52.1)	.585	.827	29.9	81.7
ET15	A2	566	(1050)	139 (20.2)	290 (42.1)	.547	.668	37.6	86.8
ET19	B	24	(76)	187 (27.1)	433 (62.8)	1.000	1.000	37.3	74.5
ET20	B	204	(400)	154 (22.4)	356 (51.6)	.827	.822	26.6*	76.6
ET21	B	371	(700)	143 (20.7)	360 (52.2)	.764	.831	25.8	71.0
ET22	B	454	(850)	134 (19.5)	340 (49.3)	.720	.785	30.9	74.5
ET23	B	510	(950)	128 (18.5)	301 (43.6)	.683	.694	24.2	77.8
ET24	B	566	(1050)	123 (17.9)	248 (35.9)	.661	.572	42.8	81.3
ET20	D	24	(76)	209 (30.3)	436 (63.2)	1.000	1.000	36.1	77.3
ET21	D	204	(400)	184 (26.7)	361 (52.3)	.881	.828	32.6	75.3
ET22	D	371	(700)	159 (23.1)	388 (56.3)	.762	.891	26.0	70.4
ET23	D	454	(850)	166 (24.1)	372 (53.9)	.795	.853	28.7	73.4
ET24	D	510	(950)	139 (20.1)	334 (48.5)	.663	.767	33.1	78.5
ET25	D	566	(1050)	137 (19.8)	294 (42.7)	.653	.676	42.3	84.3

TABLE V, CONTINUED

TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)		Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
				Yield 0.2% Offset	Ultimate	Yield	Ultimate		
<u>Heat ESR 91505 - 0.09% C</u>									
ET27	M	24	(76)	262 (38.0)	452 (65.5)	1.000	1.000	35.4	78.5
ET28	M	204	(400)	209 (30.3)	410 (59.5)	.797	.908	28.0	74.8
ET29	M	371	(700)	185 (26.9)	444 (64.4)	.708	.983	25.5	72.3
ET30	M	454	(850)	183 (26.5)	419 (60.8)	.697	.928	28.4	77.5
ET31	M	510	(950)	166 (24.1)	390 (56.5)	.634	.863	29.1	82.3
ET32	M	566	(1050)	156 (22.6)	329 (47.7)	.595	.728	37.5	86.3
ETS1	N	24	(76)	235 (34.1)	457 (66.3)	1.000	1.000	34.3	69
ETS2	N	204	(400)	203 (29.5)	407 (59.1)	.865	.891	25.0	63
ETS3	N	454	(850)	207 (30.0)	465 (67.5)	.880	1.018	16.8	61
ETS4	N	510	(950)	199 (28.9)	425 (61.6)	.848	.929	22.5	65
ETS5	O	24	(76)	236 (34.3)	445 (64.6)	1.000	1.000	34.1	70
ETS6	O	204	(400)	185 (26.8)	369 (53.5)	.781	.828	25.8	69
ETS7	O	454	(850)	175 (25.4)	367 (53.2)	.741	.824	22.3	64
ETS8	O	510	(950)	151 (21.9)	323 (46.9)	.638	.726	28.2	69
ETS9	D	24	(76)	243 (35.3)	431 (62.5)	1.000	1.000	34.3	69
ETS10	D	204	(400)	191 (27.7)	358 (51.9)	.785	.830	26.0	64
ETS11	D	454	(850)	156 (22.6)	364 (52.8)	.640	.845	24.7	59
ETS12	D	510	(950)	150 (21.8)	329 (47.7)	.618	.763	22.5	66

TABLE V, CONTINUED

TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)		Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
				Yield 0.2% Offset	Ultimate	Yield	Ultimate		
<u>Heat ESR R0110 - 0.10% C</u>									
D12-1	L + A2	21	(70)	340 (49.3)	504 (73.1)	1.000	1.000	31.2	71.8
D12-2	L + A2	371	(700)	281 (40.8)	504 (73.1)	.828	1.000	19.8	61.3
D12-3	L + A2	454	(850)	279 (40.4)	476 (69.1)	.820	.945	21.1	68.6
D12-4	L + A2	510	(950)	257 (37.3)	440 (63.8)	.757	.873	24.1	73.5
D16-2	L + H	454	(850)	199 (28.9)	422 (61.2)	---	---	27.4	66.8
D16-3	L + H	510	(950)	194 (28.1)	384 (55.7)	---	---	21.9	70.0
D16-1	L + H	566	(1050)	195 (28.3)	320 (46.4)	---	---	30.7	77.4
D16-4	L + H	566	(1050)	190 (27.5)	336 (48.8)	---	---	29.0	77.1
<u>Heat VAR 55262 - 0.10% C</u>									
T20	M	24	(76)	241 (35.0)	479 (69.5)	1.000	1.000	31.6	72.4
T21	M	204	(400)	222 (32.2)	421 (61.0)	.920	.878	26.9	70.7
T22	M	371	(700)	256 (37.1)	483 (70.0)	1.060	1.007	21.8	62.7
T23	M	454	(850)	236 (34.2)	475 (68.9)	.977	.991	22.9	68.6
T24	M	510	(950)	243 (35.2)	456 (66.2)	1.006	.953	25.9	72.9
T25	M	566	(1050)	215 (31.2)	383 (55.5)	.891	.799	31.0	80.1

TABLE VI

TENSILE PROPERTIES OF 2½Cr-1Mo STEEL - 1½ INCH DIAMETER TUBING*

Wall Thickness mm (in.)	Heat Treatment	Test Temp. °C (°F)		Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
				Yield 0.2% Offset	Ultimate	Yield	Ultimate		
<u>Heat Air X6216 - 0.11% C</u>									
7.32 (.288)	N	21	(70)	306 (44.4)	543 (78.7)	1.00	1.00	21.2	75.0
8.92 (.351)	N	21	(70)	312 (45.2)	541 (78.5)	1.00	1.00	20.3	73.0
8.33 (.328)	N	21	(70)	410 (59.5)	552 (80.0)	1.00	1.00	19.0	72.7
8.97 (.353)	N	21	(70)	322 (46.7)	546 (79.2)	1.00	1.00	21.7	75.3
7.32 (.288)	N	454	(850)	271 (39.3)	524 (76.0)	0.89	0.97	15.5	75.1
8.92 (.351)	N	454	(850)	282 (40.9)	538 (78.1)	0.90	0.99	15.3	72.2
8.33 (.328)	N	454	(850)	350 (50.8)	575 (83.4)	0.85	1.04	14.1	70.8
8.97 (.353)	N	454	(850)	290 (42.0)	541 (78.4)	0.90	0.99	15.4	75.0
7.32 (.288)	N	510	(950)	270 (39.1)	485 (70.3)	0.88	0.89	17.2	79.6
8.92 (.315)	N	510	(950)	275 (39.9)	496 (72.0)	0.88	0.92	17.1	78.1
8.33 (.328)	N	510	(950)	345 (50.1)	517 (75.0)	0.84	0.94	16.0	75.4
8.97 (.353)	N	510	(950)	282 (40.9)	503 (73.0)	0.88	0.92	17.5	77.7
<u>Heat Air 72768 - 0.09% C</u>									
8.97 (.353)	N	21	(70)	290 (42.0)	488 (70.8)	1.00	1.00	23.2	66.1
8.97 (.353)	N	454	(850)	232 (33.7)	476 (69.1)	0.80	0.98	17.1	76.4
8.97 (.353)	N	510	(950)	218 (31.6)	448 (65.0)	0.75	0.92	15.7	64.1

* ORNL Data (2)

TABLE VII

TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)		Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
				Yield 0.2% Offset	Ultimate	Yield	Ultimate		
<u>Heat A.M. 86693 - 0.11% C</u>									
G19	B	24	(76)	223 (32.4)	453 (65.7)	1.00	1.00	32.7	69.5
G20	B	24	(76)	231 (33.5)	448 (65.0)	1.00	1.00	41.3	68.7
G22	B	177	(350)	192 (27.8)	373 (54.2)	0.84	0.83	36.5	68.3
G23	B	177	(350)	198 (28.7)	371 (53.9)	0.87	0.83	38.0	70.4
G25	B	288	(550)	181 (26.2)	398 (57.7)	0.80	0.88	24.9	59.7
G28	B	399	(750)	146 (21.2)	399 (57.9)	0.64	0.87	24.0	54.3
G26	B	454	(850)	152 (22.0)	386 (56.0)	0.67	0.86	27.8	56.3
G31	B	510	(950)	143 (20.7)	340 (49.3)	0.63	0.75	33.2	65.1
G29	B	566	(1050)	133 (19.3)	291 (42.3)	0.59	0.65	43.6	76.6
<u>Heat A.M. 86693 - 0.11% C</u>									
G21	D	21	(69)	235 (34.1)	470 (68.2)	1.00	1.00	41.5	66.9
G24	D	371	(700)	167 (24.3)	450 (65.3)	0.71	0.96	23.5	50.7
G27	D	454	(850)	160 (23.2)	449 (65.1)	0.68	0.96	23.8	49.5
G30	D	510	(950)	156 (22.6)	410 (59.5)	0.66	0.87	26.5	60.3
G33	D	566	(1050)	154 (22.4)	363 (52.7)	0.65	0.77	36.4	72.5

TABLE VII, CONTINUED
TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)	Strength, MPa (KSI)		Strength Ratio		Elongation, % in 25.4 mm	Reduction in Area, %
			Yield 0.2% Offset	Ultimate	Yield	Ultimate		
<u>Heat AM 86693 - 0.11% C</u>								
C1	VA*	24 (75)	229 (33.2)	533 (77.3)	1.00	1.00	30.1	63.9
C2	VA*	204 (400)	247 (35.8)	470 (68.2)	1.08	0.88	23.2	56.8
C3	VA*	371 (700)	220 (31.9)	579 (84.0)	0.96	1.09	15.5	30.0
C4	VA*	510 (950)	204 (29.6)	551 (80.0)	0.89	1.03	20.2	46.3
D1	VA + P**	24 (75)	235 (34.1)	482 (69.9)	1.00	1.00	31.4	68.0
D2	VA + P**	204 (400)	194 (28.2)	402 (58.3)	0.83	0.83	28.0	64.4
D3	VA + P**	371 (700)	205 (29.8)	418 (60.7)	0.87	0.87	21.0	54.2
D4	VA + P**	510 (950)	172 (24.9)	351 (51.0)	0.73	0.73	27.8	63.9

* VA - Vendor Annealed, heat treatment conditions unknown.

** VA + P - Vendor Annealed Plus 727C (1340F) - 4 hour Post Weld Heat Treatment.

TABLE VII, Continued
TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)	Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
			Yield 0.2% Offset	Ultimate	Yield	Ultimate		
<u>Heat A.M. 3P5601</u>								
A1	D	24 (75)	235 (34.1)	490 (71.1)	1.00	1.00	30.0	67.5
A2	D	204 (400)	201 (29.2)	420 (61.0)	0.86	0.86	25.6	66.6
A3	D	371 (700)	224 (32.5)	469 (68.1)	0.95	0.96	21.0	59.3
A4	D	454 (850)	206 (29.9)	449 (65.1)	0.88	0.92	22.9	66.2
A5	D	510 (950)	198 (28.7)	414 (60.1)	0.84	0.85	25.4	73.2
A6	D	566 (1050)	176 (25.6)	345 (50.0)	0.75	0.70	34.6	81.4
<u>Heat A.M. 3P5601 - 0.119% C</u>								
B1	B	24 (75)	233 (33.8)	469 (68.0)	1.00	1.00	30.3	66.1
B2	B	204 (400)	177 (25.7)	392 (56.9)	0.76	0.84	27.6	68.4
B3	B	371 (700)	167 (24.2)	414 (60.1)	0.72	0.88	21.4	61.9
B4	B	454 (850)	159 (23.1)	387 (56.1)	0.68	0.83	26.1	63.0
B5	B	510 (950)	152 (22.1)	342 (49.7)	0.65	0.73	30.1	70.3
B6	B	566 (1050)	145 (21.1)	292 (42.4)	0.62	0.62	43.9	79.0

TABLE VII, Continued

TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)		Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
				Yield 0.2% Offset	Ultimate	Yield	Ultimate		
Heat VAR 55262 - 0.099% C									
	D	21	(70)	243 (35.2)	472 (68.5)	1.000	1.000	33.1	66.4
	D	204	(400)	213 (30.9)	410 (59.5)	0.878	0.869	29.7	66.4
	D	371	(700)	215 (31.2)	452 (65.6)	0.886	0.958	22.9	60.7
	D	454	(850)	214 (31.0)	449 (65.2)	0.881	0.952	26.1	61.9
	D	510	(950)	204 (29.6)	429 (62.2)	0.841	0.908	24.6	64.8
	D	566	(1050)	200 (29.0)	372 (54.0)	0.824	0.788	30.0	72.4
D4-2	J	21	(70)	259 (37.5)	425 (61.6)	1.000	1.000	40.6	70.6
D4-3	J	371	(700)	193 (28.0)	450 (65.3)	0.746	1.060	22.2	61.1
D4-4	J	454	(850)	168 (24.4)	414 (60.1)	0.652	0.976	18.7	64.6
D10-3	J	510	(950)	150 (21.8)	367 (53.3)	0.580	0.865	23.2	69.0
D10-4	J	566	(1050)	151 (21.9)	325 (47.2)	0.584	0.766	30.0	76.2
T60	K	21	(70)	251 (36.4)	447 (64.9)	1.000	1.000	37.8	79.8
T61	K	204	(400)	208 (30.2)	401 (58.1)	0.831	0.896	27.2	78.6
T62	K	371	(700)	192 (27.9)	459 (66.6)	0.767	1.027	24.0	68.2
T63	K	454	(850)	170 (24.7)	425 (61.6)	0.679	0.950	25.0	72.3
T64	K	510	(950)	169 (24.6)	367 (53.2)	0.676	0.820	21.8	78.8
T65	K	566	(1050)	161 (23.3)	310 (45.0)	0.641	0.693	32.7	86.4

Table VII, Continued

TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)	Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
			Yield 0.2% Offset	Ultimate	Yield	Ultimate		
Heat VAR 55262 - 0.099% C								
	A	21 (70)	221 (32.0)	465 (67.5)	1.000	1.000	29.5	72.9
	A	204 (400)	216 (31.3)	406 (58.9)	0.978	0.873	27.6	65.2
	A	371 (700)	190 (27.6)	491 (71.2)	0.863	1.055	26.0	64.2
	A	454 (850)	165 (24.0)	405 (58.8)	0.750	0.871	26.2	62.4
	A	510 (950)	165 (23.9)	379 (54.9)	0.747	0.813	26.6	73.0
	A	566 (1050)	157 (22.8)	317 (46.0)	0.713	0.681	32.2	81.6
C42	A2	454 (850)	181 (26.3)	416 (60.4)	--	--	26.4	75.8
C43	A2	510 (950)	179 (25.9)	330 (47.8)	--	--	26.2	78.6
C44	A2	566 (1050)	170 (24.7)	330 (47.8)	--	--	31.8	84.9
	B	21 (70)	241 (34.9)	441 (63.9)	1.000	1.000	32.1	65.4
	B	204 (400)	216 (31.3)	384 (55.7)	0.897	0.872	30.1	65.2
	B	371 (700)	208 (30.2)	444 (64.4)	0.865	1.008	23.7	60.7
	B	454 (850)	179 (25.9)	423 (61.4)	0.742	0.961	27.1	68.3
	B	510 (950)	187 (27.1)	396 (57.4)	0.777	0.898	27.2	75.2
	B	566 (1050)	168 (24.4)	352 (51.1)	0.699	0.800	33.2	74.7
T70	C	21 (70)	230 (33.3)	443 (64.2)	1.000	1.000	33.5	79.2
T71	C	204 (400)	198 (28.7)	370 (53.6)	0.861	0.835	32.5	80.8
T72	C	371 (700)	197 (28.6)	376 (54.5)	0.859	0.848	26.4	75.2
T73	C	454 (850)	199 (28.9)	359 (52.0)	0.867	0.817	26.0	76.2
T15	C	510 (950)	172 (25.0)	361 (52.4)	0.752	0.815	31.0	77.0
T74	C	566 (1050)	177 (25.7)	407 (59.1)	0.772	0.608	39.2	87.5

Table VII, Continued
TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)	Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
			Yield 0.2% Offset	Ultimate	Yield	Ultimate		
<u>Heat ESR R0110 - 0.100% C</u>								
	D	21 (70)	268 (38.9)	472 (68.5)	1.000	1.000	40.6	72.8
	D	204 (400)	226 (32.8)	403 (58.4)	0.843	0.853	27.6	74.2
	D	371 (700)	192 (27.9)	413 (59.9)	0.717	0.869	28.3	67.7
	D	454 (850)	160 (23.2)	399 (57.9)	0.596	0.845	28.9	68.0
	D	510 (950)	148 (21.4)	360 (52.2)	0.550	0.762	34.5	73.9
	D	566 (1050)	150 (21.7)	314 (45.5)	0.558	0.664	38.3	77.5
	D*	21 (70)	299 (43.4)	487 (70.6)	1.000	1.000	37.5	72.1
	D*	204 (400)	226 (32.8)	401 (58.2)	0.756	0.824	34.0	67.7
	D*	371 (700)	195 (28.3)	459 (66.5)	0.652	0.942	25.1	65.3
	D*	454 (850)	168 (24.3)	403 (58.5)	0.560	0.829	27.6	65.6
	D*	510 (950)	154 (22.4)	378 (54.8)	0.516	0.776	31.8	70.1
	D*	566 (1050)	155 (22.5)	321 (46.5)	0.518	0.659	37.8	75.8

* Transverse Orientation

TABLE VII, Continued
TENSILE PROPERTIES OF 2½Cr-1Mo STEEL

Specimen Number	Heat Treatment	Test Temp. °C (°F)	Strength, MPa (KSI)		Strength Ratio		Total Elongation, % in 25.4 mm	Reduction in Area, %
			Yield 0.2% Offset	Ultimate	Yield	Ultimate		
Heat ESR R0110 - 0.100% C								
T39	A2	454 (850)	170 (24.7)	390 (56.6)	--	--	26.0	69.0
T58	A2	510 (950)	154 (22.4)	363 (52.7)	--	--	30.8	76.0
T59	A2	566 (1050)	149 (21.6)	304 (44.1)	--	--	35.3	83.9
	B	21 (70)	225 (37.0)	480 (69.6)	1.000	1.000	36.1	74.4
	B	204 (400)	-- --	-- --	--	--	--	--
	B	371 (700)	192 (27.9)	421 (61.0)	0.754	0.876	29.4	66.4
	B	454 (850)	146 (21.2)	378 (54.8)	0.573	0.787	24.8	70.3
	B	510 (950)	149 (21.6)	360 (52.2)	0.584	0.750	39.3	75.3
	B	566 (1050)	144 (20.9)	301 (43.7)	0.565	0.628	42.1	80.8
	B*	21 (70)	296 (43.0)	483 (70.0)	1.000	1.000	37.5	73.4
	B*	204 (400)	242 (35.1)	405 (58.7)	0.816	0.839	33.7	72.5
	B*	371 (700)	209 (30.3)	402 (58.3)	0.705	0.833	27.1	68.1
	B*	454 (850)	177 (25.7)	399 (57.8)	0.598	0.826	30.2	68.9
	B*	510 (950)	174 (25.3)	370 (53.7)	0.588	0.767	33.4	69.2
	B*	566 (1050)	145 (21.1)	305 (44.2)	0.491	0.631	40.3	79.9

* Transverse Orientation