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LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87, 0.040-INCH THICK SHEET THROUGH 5.000-INCH THICK PLATE

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RESEARCH AND DEVELOPMENT OPERATIONS

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ABSTRACT

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The mechanical properties of aluminum alloy 2219-T87 sheet and plate of various thicknesses were determined over the temperature range from ambient through -253°C (-423°F). The ultimate tensile and yield strengths in the longitudinal and transverse direction increased as the temperature decreased. The ultimate tensile strength ranged from 66.4 to 69.4 ksi at ambient temperature and 95.8 to 107.3 ksi at -253°C (-423°F). The yield strength at ambient temperature was between 54.1 and 57.1 ksi; however, at -253°C (-423°F), it ranged between 68.8 and 79.5 ksi.

The elongation, in general, increased as the temperature decreased. Elongation in the longitudinal and transverse directions for all the thicknesses investigated averaged 9.0 percent at ambient temperature and 11 percent at -253°C (-423°F).

The tensile strength in the short transverse direction for the two-inch thick plate was 64.0 ksi at ambient temperature and 78.9 ksi at -253°C (-423°F). The elongation was 4.6 percent at ambient temperature and decreased to 1.3 percent at -253°C (-423°F).

The tensile strength in the short transverse direction of the five-inch thick plate was 54.6 ksi at ambient temperature and 65.1 ksi at -253°C (-423°F). Elongation was 0.6, 0.2, and 1.6 percent in two inches for ambient temperature, -196°C (-320°F), and -253°C (-423°F), respectively.

Previous evaluations of aluminum alloy 2219 by this division are referenced.

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LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87, 0.040-INCH THICK SHEET THROUGH 5.000-INCH THICK PLATE

SUMMARY

The mechanical properties of aluminum alloy 2219-T87 sheet and plate (0.040, 0.090, 0.250, 0.375, 0.500, 1.000, 1.500, 2.000, and 5.000 inches thick) were determined over the temperature range from ambient through -253°C (-423°F) for the longitudinal and transverse directions. The determinations of properties in the short transverse direction were limited to the two- and five-inch thick plates.

The tensile strengths for all thicknesses in the longitudinal and transverse directions ranged from 66.4 to 69.4 ksi at ambient temperature and from 95.8 to 107.3 ksi at -253°C (-423°F). The yield strength values determined were within the ranges of 54.1 to 57.1 ksi at ambient temperature and 68.8 to 79.5 ksi at -253°C (-423°F). The elongation varied between 5.8 and 11 percent at ambient temperature and 6.4 and 16 percent at -253°C (-423°F). The notched-to-unnotched tensile ratio varied from 0.83 to 1.04 at ambient temperatureand from 0.68 to 0.88 at -253°C (-423°F). The stress concentration factor (K_t=10) was maintained for all notched tensile tests.

The short transverse tensile strength of the two-inch thick plate was 64 ksi at ambient temperature and 78.9 ksi at -253°C (-423°F). The yield strength values were 54.3 and 77.1 ksi, respectively.

The short transverse tensile strength of the five-inch thick plate was 54.6, 66.6, and 65.1 ksi for ambient temperature, -196°C (-320°F), and -253°C (-423°F), respectively. The yield strengths determined at ambient temperature and -196°C (-320°F) were 54.4 and 65.0 ksi, respectively. However, the specimens tested at -253°C (-423°F) failed before reaching the yield strength at 0.2 percent offset.

INTRODUCTION

Aluminum alloy 2219 was developed originally by Aluminum Company of America for aircraft forgings used in highly stressed areas between 260°C (500°F) and 316°C (601°F) (ref. 1). Subsequently, the alloy, containing approximately six percent copper as the major alloying element, has been fabricated into sheet and plate thicknesses and used for space vehicle tank skins and structural components. The chemical composition of 2219 is shown in Table I.

The S-IC stage of the Saturn V vehicle uses aluminum alloy 2219 tank skins fabricated from approximately 2-1/4-inch thick plate in the -T37 condition. The plate is machined to approximately 1/4- to 1/3-inch thick skins with integral stiffeners, formed, and heat treated to the -T87 condition. The bulkhead gore segments are purchased in 1/2- and 3/4-inch thick plate, heat treated to the -T87 condition, bulge formed, and presculptured to final specifications.

This evaluation presents the low temperature mechanical properties of aluminum alloy 2219-T87 sheet and plate in thicknesses as great as five inches. Also presented is the variation in properties through the thickness of the five-inch thick plate.

The mechanical properties were determined in the longitudinal and transverse directions for all thicknesses, and, in addition, the short transverse direction properties were determined for the two- and five-inch thick materials.

References 2, 3, 4, 5, 6, 7, 8, 9, and 10 identify previous evaluations of aluminum alloy 2219 by this division.

EQUIPMENT AND SPECIMEN PREPARATION

A description of the equipment used in this investigation can be found in references 11 and 12. Smooth and notched tensile specimen configuration from 0.040- through 0.375-inch thick material is shown in reference 11. Smooth tensile specimens from the 1.000-, 1.500-, and 2.000-inch thick plate were designed to fail within the capacity of the testing machine in the Liquid Hydrogen Materials Testing Facility. Specimen geometry was not changed for the higher temperatures.

The gage width for the tensile specimens fabricated from 0.500- through 5.000-inch thick plate was 0.125-inch in a two-inch gage length with a thickness equal to that of the plate. The specimens for low temperature evaluation of the five-inch thick plate were machined from five equal segments through the plate thickness, as shown in FIG 1. The 1.500- and 2.000-inch thick plates were fabricated into two segments, each approximately one-half the original plate thickness. The notched tensile specimens were fabricated from these segments.

RESULTS AND DISCUSSION

The ambient and low temperature mechanical properties of all thicknesses of the material tested are given in Tables II through X. The ambient temperature properties obtained from specimens representing the full thickness of the five-inch thick plate and the ambient and low temperature properties obtained using specimens removed from various locations through the thickness of the five-inch thick plate are given in Tables XI and XII. The range of mechanical properties (longitudinal and transverse), which were obtained at various test temperatures for all thicknesses tested, is illustrated in FIG 2. As shown in FIG 2, the minimum ultimate tensile strength was 66.4 ksi at ambient temperature, 83.4 ksi at -196°C (-320°F), and 95.8 ksi at -253°C (-423°F). The minimum yield strengths at ambient temperature, -196°C (-320°F), and -253°C (-423°F) were 54.1, 64.9, and 69 ksi, respectively.

Figure 3 shows the mechanical properties (ultimate tensile and yield strengths) in the longitudinal direction of all thicknesses tested. The minimum ultimate tensile strength values obtained were 66.4 ksi at ambient temperature, 83.5 ksi at -196°C (-320°F), and 96.5 ksi at -253°C (-423°F). These minimum values were obtained from the 0.375-inch thick plate. The minimum yield strength values were 54.6 ksi (obtained from the 0.040-inch thick sheet) at ambient temperature, 65.9 ksi (obtained from the 0.375-inch thick plate) at -196°C (-320°F), and 68.2 ksi (obtained from the 0.500-inch thick plate) at -253°C (-423°F).

The mechanical properties (ultimate tensile and yield strengths) in the transverse direction for all thicknesses tested are shown in FIG 4. The minimum ultimate tensile strengths measured were 67.3 ksi (obtained from both the 0.375-inch thick sheet and the 1.500-inch thick plate) at ambient temperature, 83.4 ksi (obtained from the 0.040-inch thick sheet) at -196°C (-320°F), and 97.2 ksi (obtained from the 1.500-inch thick plate) at -253°C (-423°F). The minimum yield strengths at ambient temperature and -196°C (-320°F) were 54.1 ksi and 64.9 ksi, respectively (which were obtained from the 0.040-inch thick sheet), and 69.7 ksi (obtained from the 1.500-inch thick plate) at -253°C (-423°F).

The percent elongation for the various material thicknesses is shown in FIG 5. A wide variation in percent elongation is evident, particularly in thicknesses below 1.500 inches and at cryogenic temperatures. Figures 6 and 7 show the notched tensile strengths and notched-to-unnotched tensile ratios, respectively, for the range of material thickness tested. In the longitudinal direction, both the notched tensile strength and the notched-to-unnotched tensile ratio are fairly uniform, the thicker materials having slightly higher values than the thinnest material tested at each test temperature. There is more scattering of data for the transverse direction and more of the downward trend for thicknesses greater than 1.500 inches.

The short transverse mechanical properties were determined for the two- and five-inch thick plate material and are shown in FIG 8 and 9. As illustrated in FIG 8, the ultimate tensile and yield strengths of the two-inch thick plate increase with a decrease in temperature and are slightly lower than the properties of this thickness in the other two directions. The elongation decreased from 4.3 percent at ambient temperature to 1.3 percent at -253°C (-423°F). The notched tensile properties of the two-inch thick plate in the short transverse direction were not determined. The short transverse properties of the five-inch thick plate (FIG 9) were significantly lower than the properties in the longitudinal and transverse directions for this thickness. The ultimate tensile strength was 54.6 ksi at ambient temperature, 66.6 ksi at -196°C (-320°F), and 65.0 ksi at -253°C (-423°F). The ambient temperature yield strength was 99.6 percent of the ultimate tensile strength at -196°C (-320°F). The specimens tested at -253°C (-423°F) failed before reaching the 0.2 percent offset yield point. The elongation was less than 1.0 percent at ambient temperature and -196°C (-320°F) and increased to 1.6 percent at -253°C (-423°F).

The mechanical properties (longitudinal and transverse) of the five-inch thick plate, determined by testing specimens removed from various locations through the plate thickness, are shown in FIG 10. As expected, the strength is lowest in the center of the plate thickness (segment 3 in FIG 10) and highest at the surfaces (segments 1 and 5). The elongation values also were lowest in the center of the thickness and highest at the surfaces. These values are not illustrated in FIG 10 but are shown in Tables XI and XII. The average strength values of the five segments through the plate thickness are approximately equal to the values obtained from specimens representing the full plate thickness (FIG 1). This comparison is made for ambient temperature properties only since full thickness specimens were not tested at cryogenic temperatures.

The notched-to-unnotched tensile strength ratios at the various locations through the thickness of the five-inch thick plate are shown in FIG 11. As illustrated, these values decreased with a decrease in test temperatures. These values are also different with respect to direction of rolling. In the transverse direction, a higher notched-to-unnotched tensile ratio was obtained at the center of the plate (segment 3) than at the intermediate segments 2 and 4 and, in some cases, higher than the surface segments.

CONCLUSIONS

The low temperature mechanical properties of 2219-T87 sheet and plate were found to be good over the temperature range of 27°C (81°F) to -253°C (-423°F). The mechanical properties in the transverse direction were approximately the same as those in the longitudinal direction over the test temperature range. The tensile and yield strengths for the thicknesses investigated increased considerably as the temperature decreased. Slight variations in tensile and yield strengths, as the thickness increased, were noted. The ultimate tensile strengths of the sheets and plates evaluated varied within 10 percent at all test temperatures. The maximum variation in the yield strengths was approximately 12 percent. The elongation ranged between 4.8 and 16 percent. Toughness, indicated by notched-to-unnotched tensile strength ratio, was slightly higher in the longitudinal direction than in the transverse direction. However, the values obtained indicate that the material is suitable for applications at temperatures from 27°C (81°F) to -253°C (-423°F).

The short transverse direction tensile and yield strengths of the two-inch thick plate increased with a decrease in temperature. It was observed, however, that the tensile strength at -253°C (-423°F) increased only 23 percent over the ambient temperature value, 64.0 ksi, which was significantly less than the values obtained from the other directions. Elongation in the short transverse direction also was significantly less than in other directions.

The maximum tensile strength of 66.6 ksi was obtained at -196°C (-320°F) for the short transverse direction of the five-inch thick plate. Maximum elongation of 1.6 percent was obtained at -253°C (-423°F). However, failure to reach the yield strength at 0.2 percent offset at -253°C (-423°F) shows even less ductility than is indicated by the percent elongation.

It is concluded that the two- and five-inch thick plates are suitable for low temperature applications. However, caution should be used when dynamic tensile loads are introduced in the short transverse direction of the five-inch thick plate to prevent premature failures due to low ductility and low tensile strengths at temperatures ranging from 27°C (81°F) to -253°C (-423°F).

TABLE I. - COMPOSITION OF ALUMINUM ALLOY 2219-T87

	Maximum	Minimum
Copper	6.8	5.8
Iron	0.30	
Magnesium	0.02	
Manganese	0.40	0.20
Silicon	0.20	
Titanium	0.10	0.02
Vanadium	0.15	0.05
Zinc	0.10	
Zirconium	0.25	0.10
Other	0.15	
Aluminum	Bal.	

TABLE II. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 SHEET, 0.040 INCH THICK

Temperature (°C)	Rolling Direction	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y. S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (K_t=10) (ksi)	Notched-to-Unnotched Tensile Ratio
+27	L	67.3	54.6	9.4	64.5	0.96
+27	T	67.1	54.1	9.3	62.6	0.93
-196	L	84.3	66.8	11.5	75.3	0.89
-196	T	83.4	64.9	11.5	73.7	0.88
-253	L	103.8	74.7	13.8	73.7	0.71
-253	T	107.3	79.5	14.7	84.0	0.78

TABLE III. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 SHEET, 0.090 INCH THICK

Temperature (°C)	Rolling Direction	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y. S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (K_t=10) (ksi)	Notched-to-Unnotched Tensile Ratio
+27	L	68.8	57.1	9.3	63.4	0.92
+27	T	69.3	56.9	8.8	63.1	0.91
-196	L	85.3	67.0	10.2	76.4	0.90
-196	T	87.1	69.2	8.2	72.9	0.84
-253	L	102.5	75.3	10.2	80.6	0.79
-253	T	105.1	74.3	10.5	76.6	0.73

TABLE IV. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 PLATE, 0.250 INCH THICK

Temperature (°C)	Rolling Direction	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y. S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (K_t=10) (ksi)	Notched-to-Unnotched Tensile Ratio
+27	L	68.0	55.8	10.8	66.0	0.97
+27	T	68.3	55.3	9.8	64.8	0.98
-196	L	84.2	66.9	12.2	80.5	0.96
-196	T	86.2	66.7	12.0	78.3	0.91
-253	L	98.1	70.3	16.0	83.2	0.85
-253	T	100.1	70.4	14.3	81.8	0.82

TABLE V. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 PLATE, 0.375 INCH THICK

Temperature (^{o}C)	Rolling Direction	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y. S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (K_t=10) (ksi)	Notched-to-Unnotched Tensile Ratio
+27	L	66.4	54.5	10.7	65.6	0.99
+27	T	67.3	54.3	11.0	65.2	0.97
-196	L	83.5	65.9	12.8	78.3	0.94
-196	T	84.9	65.1	11.2	79.5	0.94
-253	L	96.5	70.9	12.5	84.5	0.88
-253	T	98.4	69.0	15.0	82.5	0.84

TABLE VI. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 PLATE, 0.500 INCH THICK

Temperature (°C)	Rolling Direction	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y. S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (K_t=10) (ksi)	Notched-to-Unnotched Tensile Ratio
+27	L	68.0	56.0	9.8	67.8	0.99
+27	T	67.8	54.7	8.5	67.3	0.99
-196	L	85.8	68.2	11.2	81.3	0.95
-196	T	84.8	67.6	10.3	76.5	0.90
-253	L	99.7	69.1	10.0	84.5	0.85
-253	T	101.0	72.0	9.8	81.3	0.81

TABLE VII. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 PLATE, 1.000 INCH THICK

Temperature (^{o}C)	Rolling Direction	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y. S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (K_t = 10) (ksi)	Notched-to-Unnotched Tensile Ratio
+27	L	68.6	57.0	9.7	66.6	0.97
+27	T	68.0	55.9	9.5	65.1	0.96
-196	L	87.1	69.4	12.5	80.7	0.93
-196	T	86.6	67.5	9.3	75.4	0.87
-253	L	97.6	77.2	12.0	84.5	0.87
-253	T	100.9	72.0	14.3	79.3	0.79

TABLE VIII. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 PLATE, 1.500 INCHES THICK

Temperature (^{o}C)	Rolling Direction	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y.S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (K_t=10) (ksi)	Notched-to-Unnotched Tensile Ratio
+27	L	68.0	56.3	10.3	69.9	1.03
+27	T	67.3	55.1	7.5	69.9	1.04
-196	L	86.1	68.5	12.3	79.5	0.92
-196	T	85.8	65.4	7.0	84.0	0.98
-253	L	100.2	74.6	11.7	86.7	0.87
-253	T	97.2	69.7	8.8	83.6	0.86

TABLE IX. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 PLATE, 2.000 INCHES THICK

Temperature (°C)	Rolling Direction	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y. S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (K_t=10) (ksi)	Notched-to-Unnotched Tensile Ratio
+27	L	69.4	55.4	10.0	69.4	1.00
+27	T	68.5	55.9	8.0	60.1	0.98
+27	ST	64.0	54.3	4.3	----	----
-196	L	89.4	70.9	10.5	83.3	0.93
-196	T	89.8	71.8	7.0	71.7	0.80
-196	ST	75.9	67.6	2.7	----	----
-253	L	101.5	75.6	7.5	87.6	0.86
-253	T	98.9	72.9	6.3	74.6	0.75
-253	ST	78.9	77.1	1.3	----	----

TABLE X. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 PLATE, 5.000 INCHES THICK

Temperature (°C)	Rolling Direction	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y.S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (K_t=10) (ksi)	Notched-to-Unnotched Tensile Ratio
FULL THICKNESS TEST SPECIMENS						
+27	L	67.5	56.7	5.8	66.3	0.98
+27	T	67.4	56.1	7.3	59.4	0.89
SHORT TRANSVERSE TEST SPECIMENS						
+27	ST	54.6	54.4	0.6	41.1	0.75
-196	ST	66.6	65.0	0.2	46.7	0.70
-253	ST	65.1	----	1.6	52.5	0.81
SEGMENT AVERAGE						
+27	L	67.8	56.3	7.4	66.8	0.99
+27	T	67.1	55.8	5.8	55.7	0.83
-196	L	86.6	69.1	7.9	79.3	0.92
-196	T	84.4	65.7	6.2	63.1	0.75
-253	L	99.6	74.9	7.7	85.0	0.85
-253	T	95.8	71.2	6.4	65.5	0.68

TABLE XI. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 SEGMENTS THROUGH 5.000-INCH THICK PLATE, LONGITUDINAL DIRECTION*

Average	Temperature (°C)	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y.S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (ksi)	Notched-to-Unnotched Tensile Ratio
1 through 5	+27	67.8	56.3	7.4	66.8	0.99
1	+27	69.9	57.7	8.7	70.1	1.00
2	+27	66.3	55.5	6.8	66.0	0.99
3	+27	66.0	54.9	6.3	63.9	0.97
4	+27	66.2	54.9	6.6	64.1	0.97
5	+27	70.6	58.4	8.7	69.7	0.99
1 and 5	+27	70.3	58.1	8.5	69.9	0.99
2 and 4	+27	66.3	55.3	6.8	65.1	0.98
3	+27	66.0	54.9	6.3	63.9	0.97
1 through 5	-196	86.6	69.1	7.9	79.3	0.92
1	-196	89.4	71.1	8.5	83.2	0.93
2	-196	85.7	67.2	7.3	77.0	0.90
3	-196	83.6	67.6	5.8	75.0	0.90
4	-196	85.8	68.3	7.3	78.3	0.91

* See Figure 1 for segment location.

TABLE XI. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 SEGMENTS THROUGH 5.000-INCH THICK PLATE, LONGITUDINAL DIRECTION - Concluded

Average	Temperature (°C)	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y.S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (ksi)	Notched-to-Unnotched Tensile Ratio
5	-196	89.7	71.4	10.2	83.0	0.93
1 and 5	-196	89.5	71.3	9.3	83.1	0.93
2 and 4	-196	85.8	67.7	7.5	77.1	0.90
3	-196	83.6	67.6	5.8	75.0	0.90
1 through 5	-253	99.6	74.9	7.7	85.0	0.85
1	-253	102.7	76.5	8.5	87.1	0.85
2	-253	100.9	74.0	8.7	80.6	0.80
3	-253	94.9	73.6	4.7	83.0	0.87
4	-253	94.5	73.5	6.7	80.7	0.85
5	-253	105.1	78.0	9.5	90.3	0.86
1 and 5	-253	103.9	77.7	9.0	88.7	0.85
2 and 4	-253	98.9	73.7	7.7	80.7	0.82
3	-253	94.9	73.6	4.7	83.0	0.87

TABLE XII. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 SEGMENTS THROUGH 5.000-INCH THICK PLATE, TRANSVERSE DIRECTION *

Average	Temperature (°C)	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y.S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (ksi)	Notched-to-Unnotched Tensile Ratio
1 through 5	+27	67.1	55.8	5.8	55.7	0.83
1	+27	68.6	57.0	6.5	61.7	0.90
2	+27	67.3	56.0	6.3	51.7	0.77
3	+27	64.3	53.7	5.0	56.0	0.87
4	+27	66.7	55.2	5.7	52.6	0.79
5	+27	68.3	57.0	5.8	56.4	0.83
1 and 5	+27	68.6	57.0	6.2	59.1	0.86
2 and 4	+27	67.0	55.6	6.0	53.3	0.80
3	+27	64.3	53.7	5.0	56.0	0.87
1 through 5	-196	84.4	65.7	6.2	63.1	0.75
1	-196	87.4	69.0	7.8	69.8	0.80
2	-196	84.1	65.2	6.2	60.5	0.72
3	-196	80.4	61.9	4.7	59.2	0.74
4	-196	84.3	65.2	6.0	58.6	0.70

*See Figure 1 for segment location.

TABLE XII. - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 SEGMENTS THROUGH 5.000-INCH THICK PLATE, TRANSVERSE DIRECTION - Concluded

Average	Temperature (°C)	Ultimate Tensile Strength (ksi)	0.2 Percent Offset Y.S. (ksi)	Elongation (Percent in 2.0 Inches)	Notched Tensile Strength (ksi)	Notched-to-Unnotched Tensile Ratio
5	-196	86.1	66.9	6.3	67.3	0.78
1 and 5	-196	86.7	68.0	7.1	68.6	0.79
2 and 4	-196	84.2	65.2	6.8	59.6	0.71
3	-196	80.4	61.9	4.7	59.2	0.74
1 through 5	-253	95.8	71.2	6.4	65.5	0.68
1	-253	100.3	72.8	8.2	68.5	0.68
2	-253	94.4	72.1	5.5	63.6	0.67
3	-253	89.3	68.8	4.8	65.3	0.73
4	-253	95.5	69.9	5.5	63.9	0.67
5	-253	99.2	72.5	8.0	66.3	0.67
1 and 5	-253	99.8	72.6	8.1	67.4	0.68
2 and 4	-253	95.0	71.0	5.3	63.7	0.67
3	-253	89.3	68.8	4.8	65.3	0.73

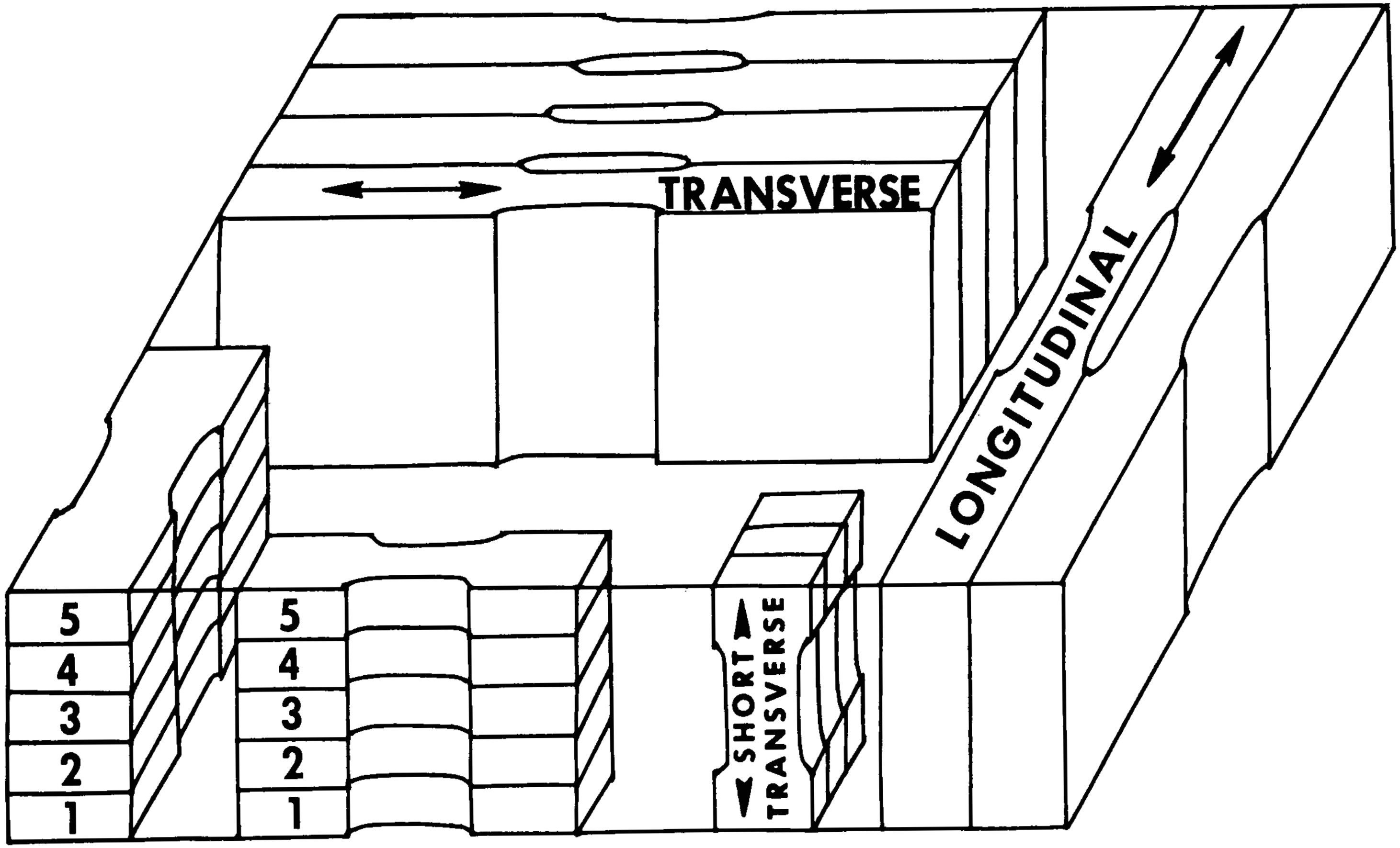


FIGURE 1. SPECIMEN ORIENTATION 5.000-INCH THICK PLATE

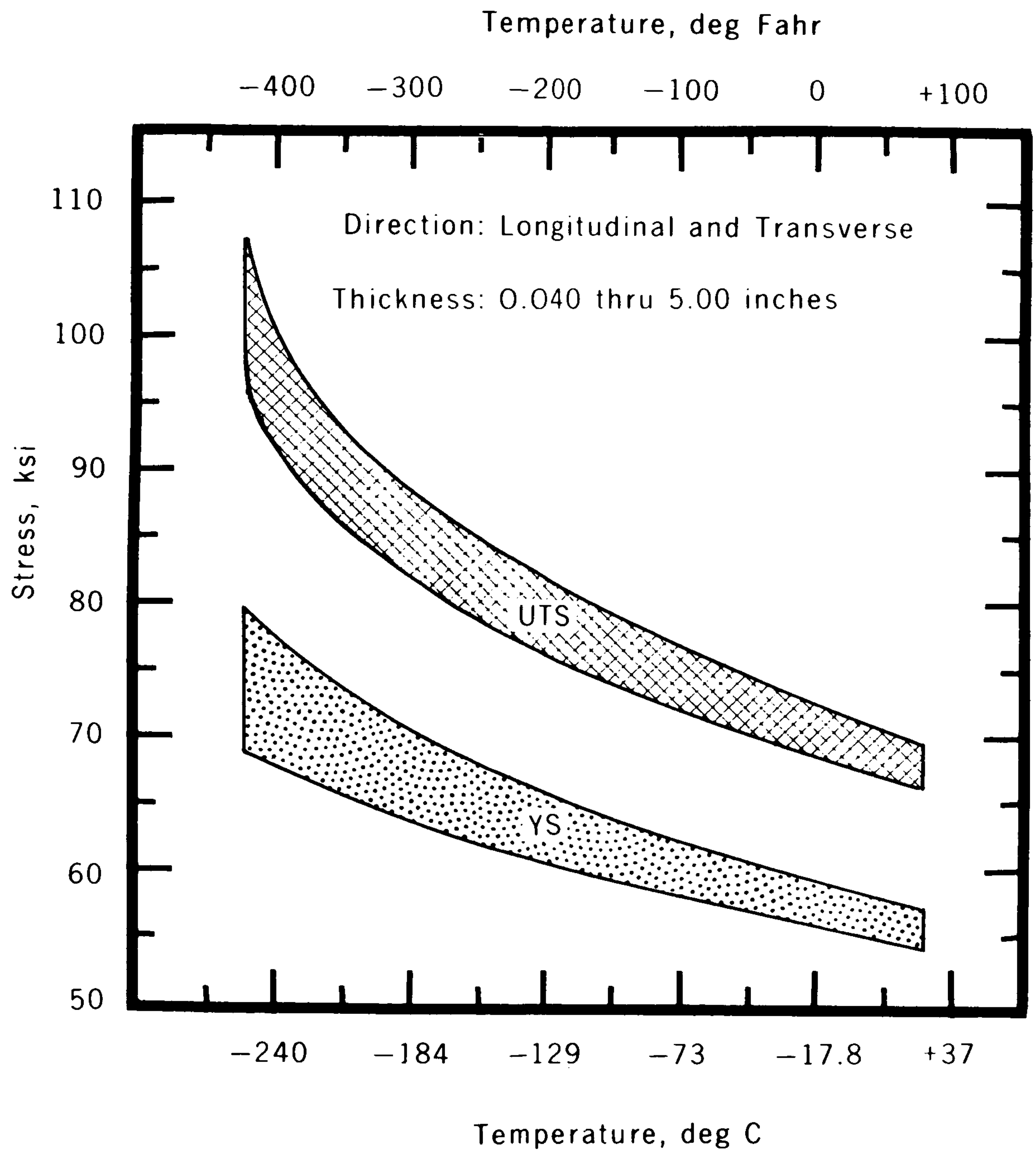


FIGURE 2. LOW TEMPERATURE TENSILE PROPERTIES OF ALUMINUM ALLOY 2219-T87

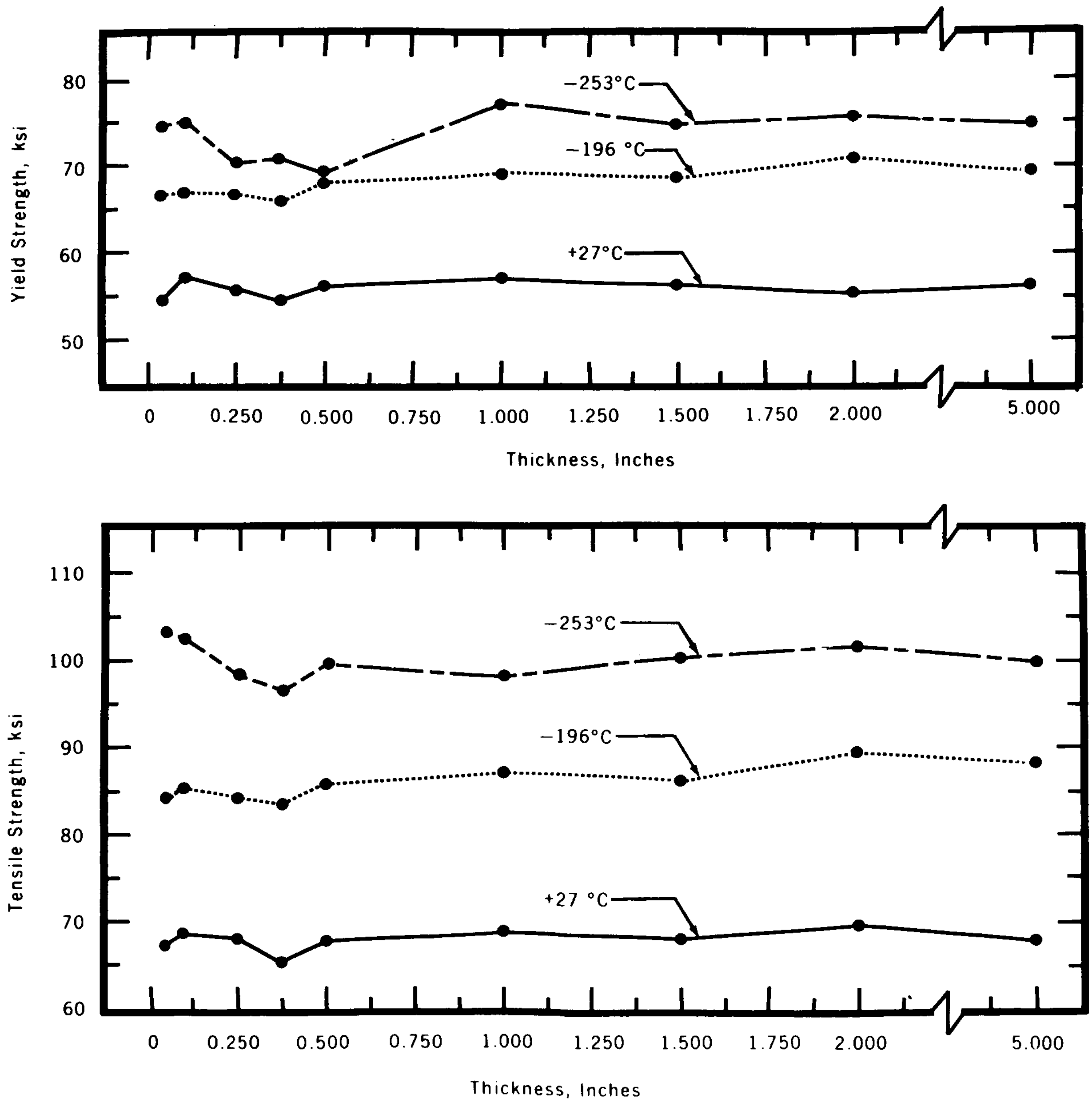


FIGURE 3. LOW TEMPERATURE TENSILE PROPERTIES OF ALUMINUM ALLOY 2219-T87, LONGITUDINAL DIRECTION

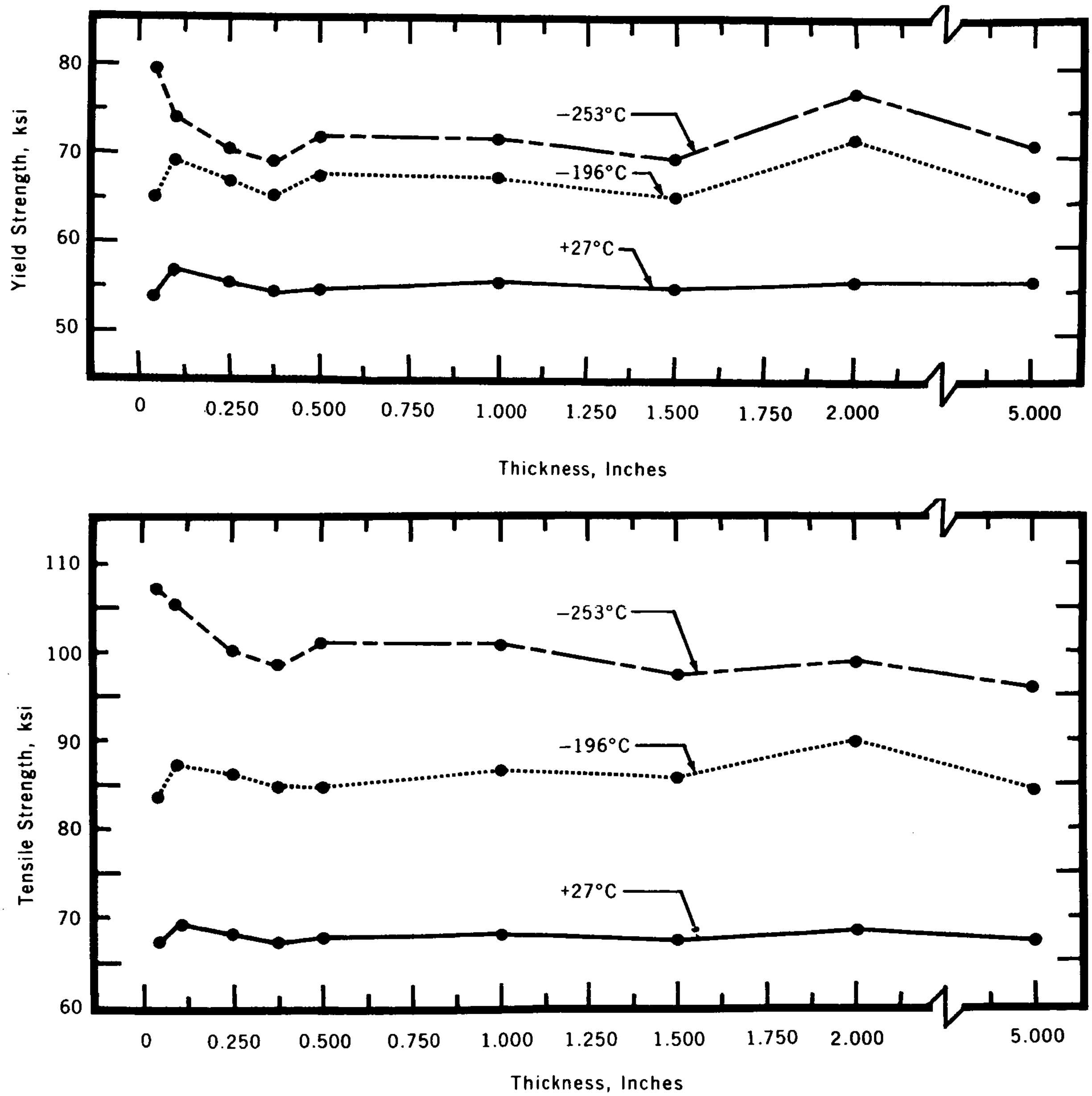


FIGURE 4. LOW TEMPERATURE TENSILE PROPERTIES OF ALUMINUM ALLOY 2219-T87, TRANSVERSE DIRECTION

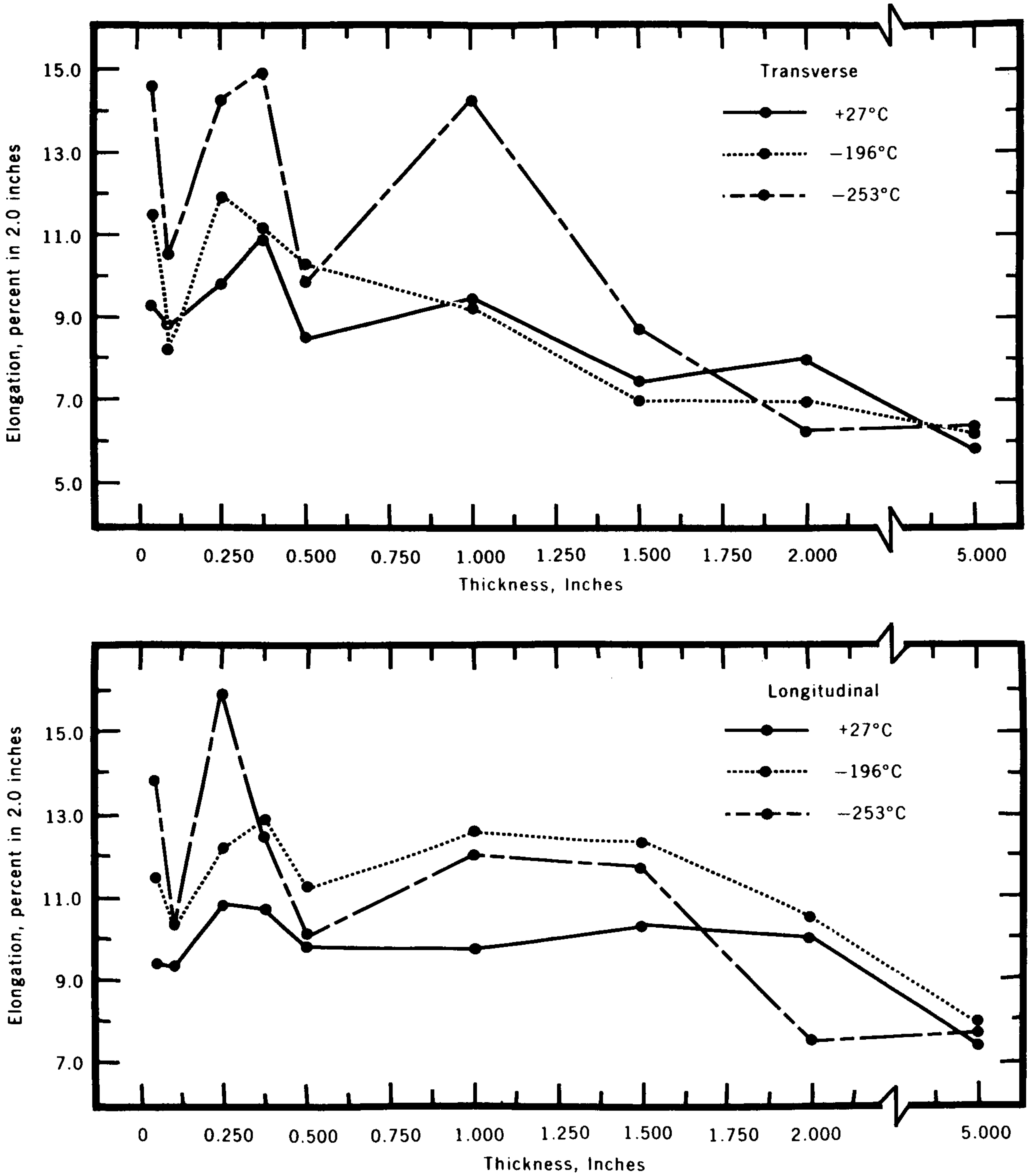


FIGURE 5. ELONGATION AT LOW TEMPERATURES OF ALUMINUM ALLOY 2219-T87

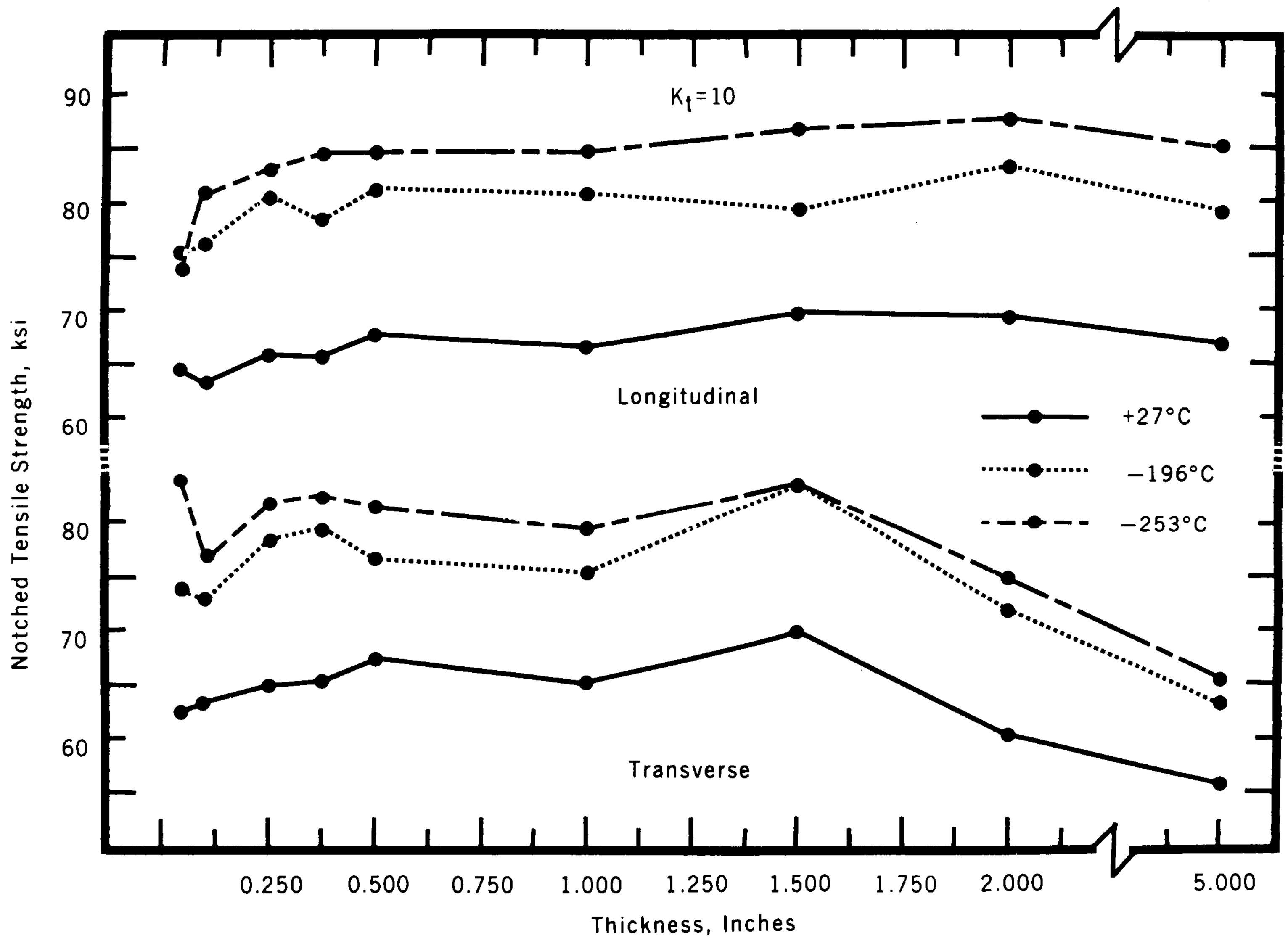


FIGURE 6. NOTCHED TENSILE STRENGTH AT LOW TEMPERATURES OF ALUMINUM ALLOY 2219-T87

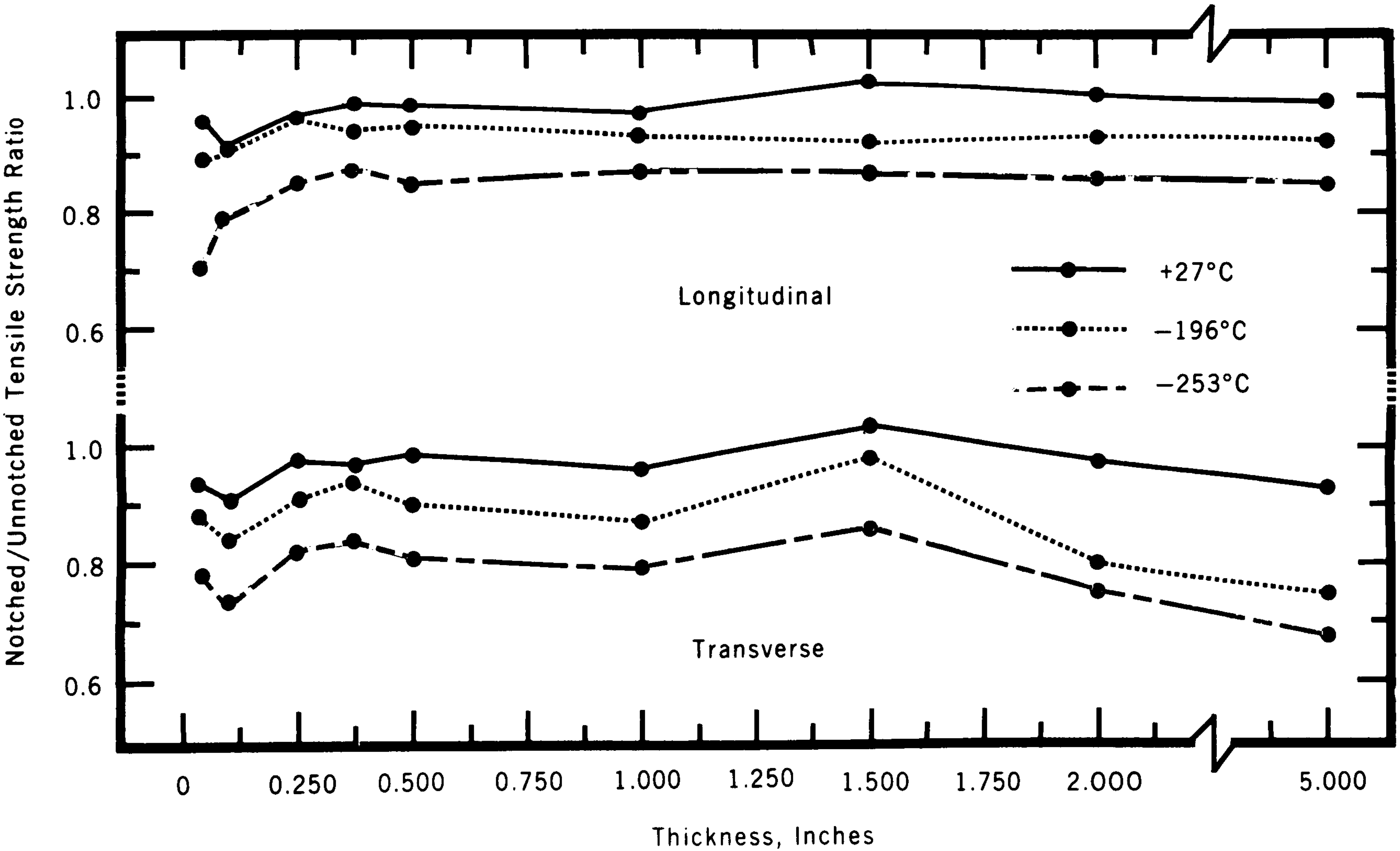


FIGURE 7. NOTCHED TO UNNOTCHED TENSILE STRENGTH RATIO OF ALUMINUM ALLOY 2219-T87 (K_t=10)

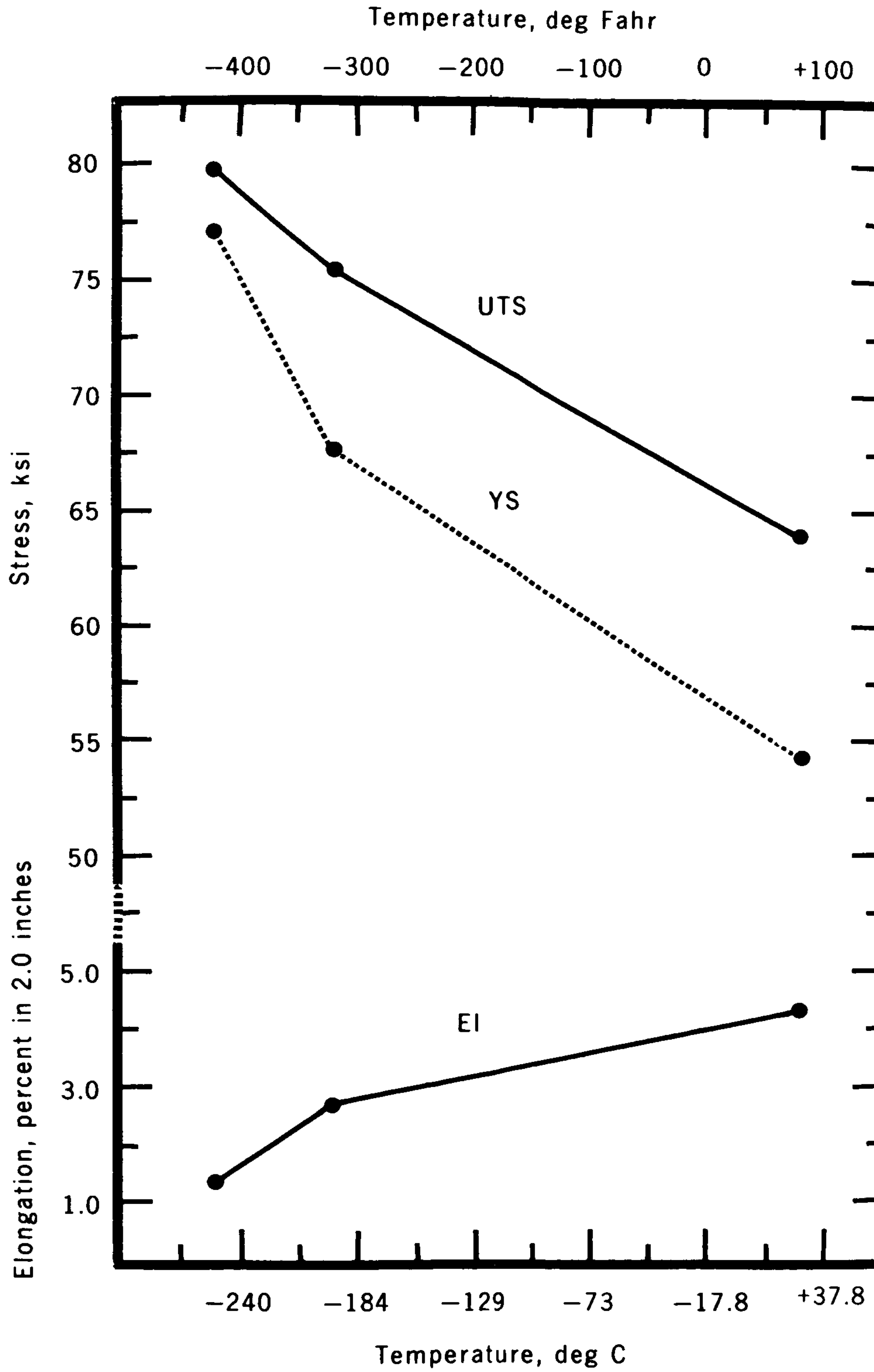
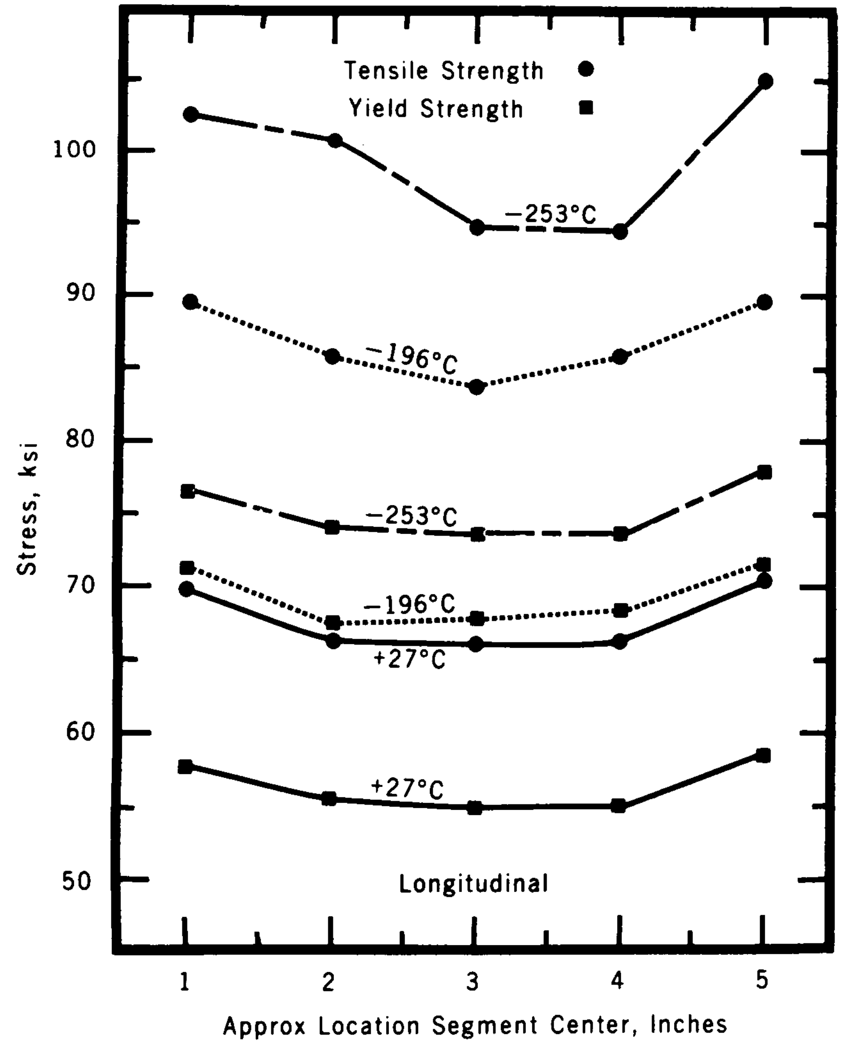


FIGURE 8. LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87, 2.000-INCH THICK PLATE (SHORT TRANSVERSE)



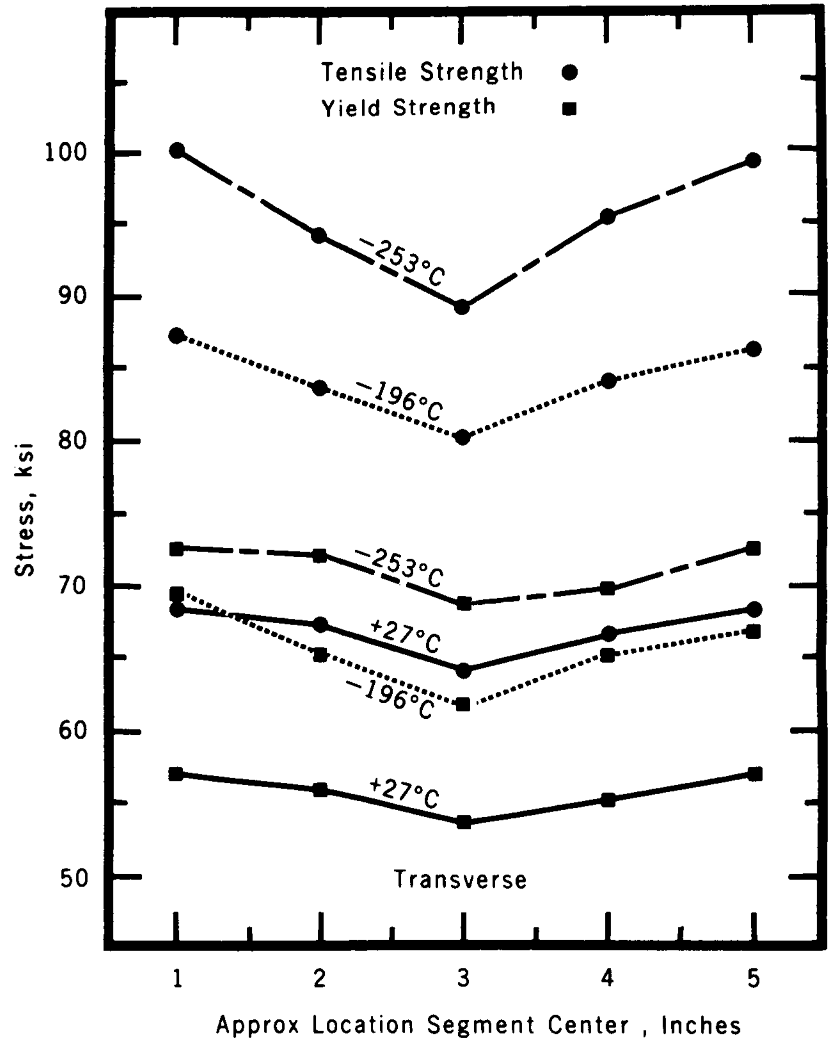


FIGURE 9. MECHANICAL PROPERTIES OF SEGMENTS THROUGH ALUMINUM ALLOY 2219-T87 PLATE, 5.000 INCHES THICK

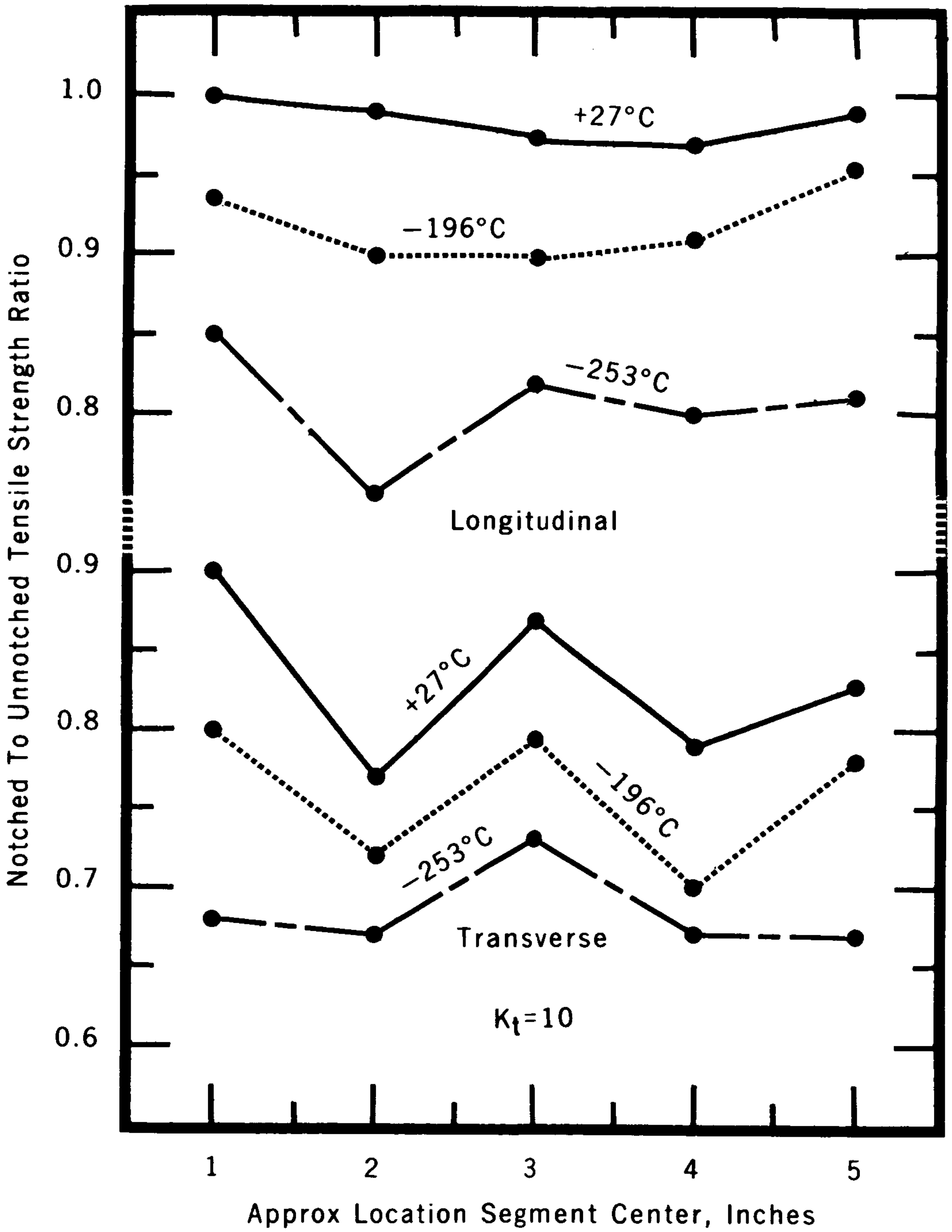


FIGURE 10. NOTCHED TO UNNOTCHED TENSILE STRENGTH RATIO OF SEGMENTS THROUGH ALUMINUM ALLOY 2219-T87 PLATE, 5.000 INCHES THICK

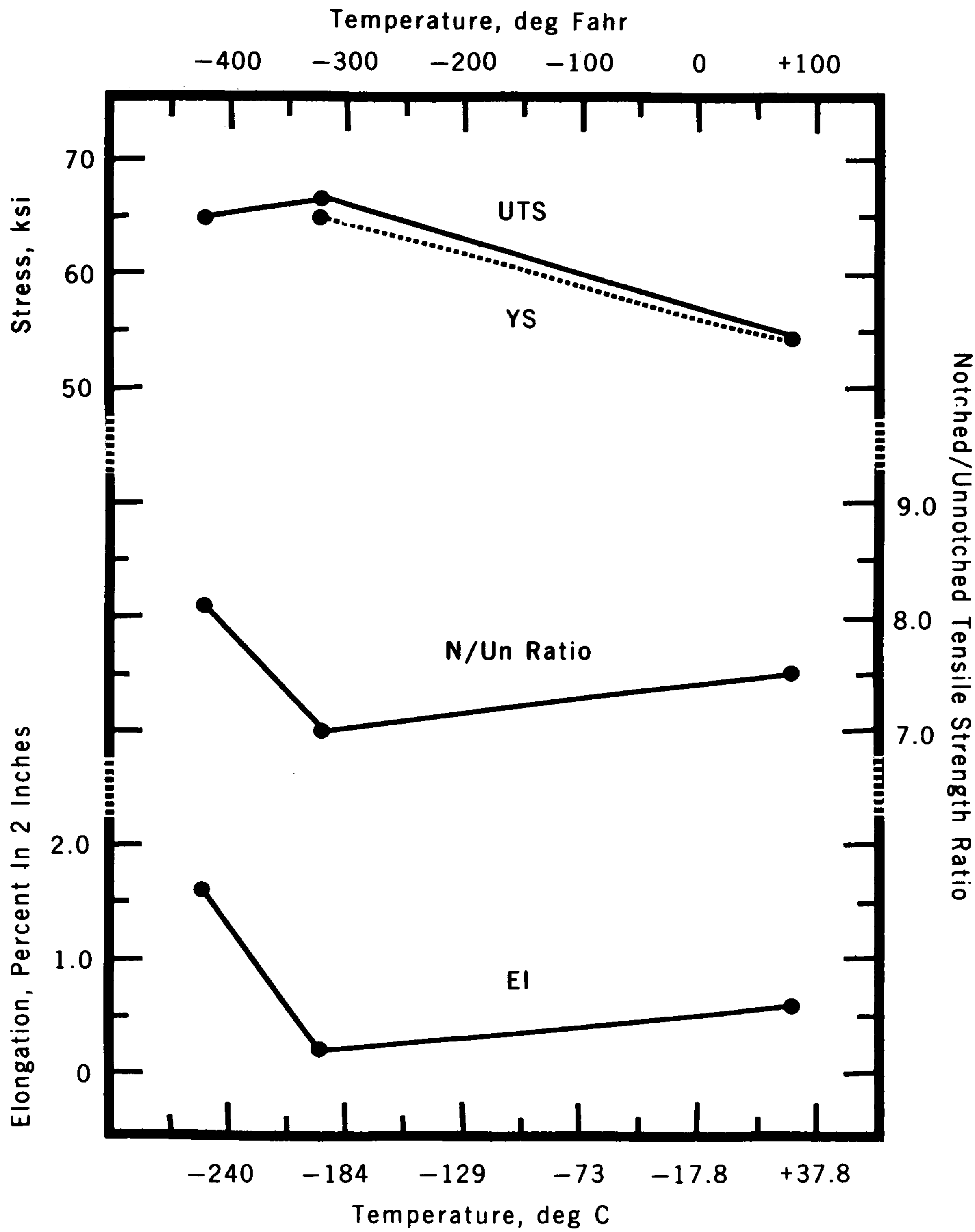


FIGURE 11. LOW TEMPERATURE MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2219-T87 PLATE, 5.000 INCHES THICK (SHORT TRANSVERSE)

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LOW TEMPERATURE MECHANICAL PROPERTIES OF
ALUMINUM ALLOY 2219-T87, 0.040-INCH THICK SHEET
THROUGH 5.000-INCH THICK PLATE

By C. R. Denaburg

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This document has also been reviewed and approved for technical accuracy.

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