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LOW TEMPERATURE MECHANICAL PROPERTIES OF HP 9-4-25 ALLOY

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ABSTRACT

The mechanical properties of HP 9-4-25 alloy sheet (0.062-inch thick) were determined at temperatures from 27°C (80°F) to -253°C (-423°F). The ultimate tensile and yield strengths were considerably greater at -253°C (-423°F) than at 27°C (80°F), and the notched/unnotched tensile ratios were greater than 0.81 at temperatures from 27°C (80°F) to -196°C (-320°F). This alloy is not recommended for critical applications below -196°C (-320°F) since the elongation and notched/unnotched tensile ratio decreased rapidly below this temperature.

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RESEARCH AND DEVELOPMENT OPERATIONS

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SUMMARY

The mechanical properties of annealed and heat-treated HP 9-4-25 alloy sheet (0.062-inch thick) were determined at temperatures from 27°C (80°F) to -253°C (-423°F). Although the test results indicated no outstanding differences in the mechanical properties with respect to the rolling direction, the transverse properties tended to exceed the longitudinal properties over the test temperature spectrum. The ultimate tensile and yield strengths were considerably greater at -253°C (-423°F) than at 27°C (80°F).

The elongation remained almost constant at temperatures down to -196°C (-320°F) and then decreased with further decrease in temperature. The notched/unnotched tensile ratios exceeded 0.81 in the temperature range of 27°C (80°F) to -196°C (-320°F) but dropped rapidly to values of less than 0.69 at -253°C (-423°F), which indicated a deterioration of toughness at temperatures below -196°C (-320°F). The annealed and the heat-treated material behaved in approximately the same manner, qualitatively, over the test temperature range. As expected, the heat-treated material had higher tensile strengths with lower elongation.

INTRODUCTION

To assist in the proper material selection for application at cryogenic temperatures, an extensive evaluation is in progress to determine the low temperature mechanical properties of selected engineering alloys. This report covers the investigation of one of these alloys, *HP 9-4-25. This alloy is a nickel-cobalt, quenched and tempered, martensitic steel containing approximately 9% nickel, 4% cobalt, and 0.25% carbon with varying amounts of manganese, phosphorous, sulphur, silicon, chromium, molybdenum, and vanadium. HP 9-4-25 alloy was developed recently by Republic Steel Corporation for use in large structural applications (e.g., large rocket motor cases) where the material must be able to tolerate the imperfections that may occur during normal manufacturing processes (ref. 1).

Republic Steel Corporation uses carbon rather than conventional aluminum or silicon additives to deoxidize the melt. The basic arc furnace

*Hi-Performance

is used to produce a melt which is low in sulphur and phosphorous content Deoxidation with carbon is accomplished by processing the air melt steel in a vacuum. The deoxidation reaction takes place mainly in a vacuum consumable-electrode arc furnace with oxygen being removed as carbon monoxide (ref. 2). In general, the corrosion resistance and fabrication practices for this alloy are similar to AISI 4340. Hot forming is more difficult because of the high cobalt content (ref. 3).

This report gives the results of tests which were made to determine the mechanical properties of HP 9-4-25 alloy sheet (0.062-inch thick) at temperatures from 27°C (80°F) to -253°C (-423°F). The strength values presented are not to be interpreted as minimum guaranteed values but simply indicate the typical strengths at the various temperatures. The test specimens were obtained from one heat of material (heat 3930786) and do not necessarily represent typical values from other heats.

EQUIPMENT AND SPECIMEN PREPARATION

The testing equipment and specimen preparation are discussed in a previous MSFC report (ref. 4).

RESULTS AND DISCUSSIONS

The low temperature mechanical properties of annealed and heat-treated HP 9-4-25 alloy were determined parallel and transverse to the principal direction of rolling. The test material (0.062-inch sheet) was furnished by Republic Steel Corporation in the annealed condition, and the heat treatment was accomplished at this Center. The heat-treating operation consisted of austenitizing at 843°C (1550°F) for one-half hour and oil quenching, followed by a double draw at 204°C (400°F) (one hour at temperature each draw) and air cooling. The chemical composition of the alloy is given in Table I, and the experimental test results are listed in Tables II and III.

The ultimate tensile strength of the annealed material (FIG 1) increased continuously from approximately 150,000 psi at 27°C (80°F) to about 250,000 psi at -253°C (-423°F), while the yield strength decreased approximately 20,000 psi between 27°C (80°F) and -73°C (-100°F) and then increased with corresponding decrease in test temperatures to a maximum of over 168,000 psi at -253°C (-423°F). The elongation remained nearly constant, approximately 13 percent over the temperature range of 27°C (80°F) to -196°C (-320°F) but decreased to seven percent at -253°C (-423°F). The notched/unnotched tensile ratios (FIG 2) were 0.82 or greater at test temperatures down to -196°C (-320°F). At -253°C (-423°F), a significant

deterioration in the toughness of the material is indicated by the low notched/unnotched tensile ratios of 0.67 and 0.58 for the longitudinal and transverse directions, respectively. The tensile strengths of the annealed material in the transverse direction either exceeded or were approximately equal to the tensile strengths in the longitudinal direction with one exception. At -253°C (-423°F), the notched tensile strength in the transverse direction was 18,000 psi less than the notched tensile strength in the longitudinal direction.

The ultimate tensile strength of the heat-treated material (FIG 3) increased from 220,000 psi to 290,000 psi over the temperature range of 27°C (80°F) to -253°C (-423°F), and the yield strength increased from 180,000 psi to approximately 260,000 psi over the same temperature range. The elongation increased gradually from 6.5 percent at 27°C (80°F) to 8.5 percent at -196°C (-320°F) and then decreased to 3.6 percent at -253°C (-423°F). The notched/unnotched tensile ratios (FIG 4) were near unity or above for temperatures down to -196°C (-320°F), indicating that the alloy in the heat-treated condition does not become notch sensitive (utilizing K_t = 10) over this temperature range. However, the notched/unnotched tensile ratio dropped to approximately 0.67 at -253°C (-423°F), which indicates a substantial depreciation of toughness of the heat-treated material, as in the annealed material, at temperatures below -196°C (-320°F). The differences in the directional properties for the heat-treated material were very slight.

CONCLUSIONS

Based upon the data obtained in this investigation, it is believed that HP 9-4-25 alloy sheet has good mechanical properties at temperatures down to -196°C (-320°F). The test results indicated no great differences in the mechanical properties with respect to the rolling direction; however, the transverse properties tended to exceed the longitudinal properties over the temperature range of 27°C (80°F) to -253°C (-423°F). The ultimate tensile and yield strengths were considerably greater at -253°C (-423°F) than at 27°C (80°F). The ductility, as defined by percent elongation, remained almost constant down to -196°C (-320°F) but decreased at -253°C (-423°F). This decrease in elongation also is accompanied by low notched/unnotched tensile ratios of less than 0.69 at -253°C (-423°F), indicating a depreciation in material toughness at temperatures below -196°C (-320°F). Therefore, caution should be exercised in the use of HP 9-4-25 sheet for critical applications at cryogenic temperatures approaching that of liquid hydrogen.

REFERENCES

1. Pascover, J. S.; and Mates, S. J.: Properties of HP 9-4-X Alloy Steels, Republic Steel Corporation, 1964.

2. Anon.: Preliminary Technical Data on the Republic Hi-Performance Steels, Republic Steel Corporation, 1962.

3. Anon.: Technical Data on Republic's Hi-Performance Steels, Aerospace Structural Metals Handbook, Syracuse University Press, 1964.

4. Miller, P. C.: Low Temperature Mechanical Properties of Several Aluminum Alloys and Their Weldments, MTP-S&M-M-61-16, 1961.

TABLE I

CHEMICAL COMPOSITION[1] OF HP 9-4-25 ALLOY SHEET

	ANALYZED COMPOSITION	RANGE
Nickel	8.42	7.5-9.0
Cobalt	3.90	3.5-4.5
Carbon	0.26	0.24-0.30
Manganese	0.27	0.15-0.35
Phosphorous	0.005	0.01 Max.
Sulphur	0.009	0.01 Max.
Silicon	0.04	0.10 Max.
Chromium	0.49	0.35-0.55
Molybdenum	0.43	0.35-0.55
Vanadium	0.11	0.06-0.12

[1] The chemical composition data were furnished by Republic Steel Corporation.

TABLE II

MECHANICAL PROPERTIES[1] OF ANNEALED[2] HP 9-4-25 ALLOY, 0.062-INCH SHEET

Test Temperature	Direction	Y.S. psi (.2% Offset)	Ultimate T.S. psi	% Elongation (2" Gauge)	Notched T.S. psi (Kt = 10)	Notched/ Unnotched Tensile Ratio
27°C (80°F)	Long.	117,600	151,200	14.0	151,400	1.00
	Trans.	131,100	154,200	14.0	156,500	1.01
-73°C (-100°F)	Long.	94,900	173,600	12.0	169,200	0.97
	Trans.	108,700	178,000	12.0	169,500	0.95
-129°C (-200°F)	Long.	105,000	186,200	12.5	178,800	0.96
	Trans.	116,700	188,700	12.5	180,900	0.96
-196°C (-320°F)	Long.	130,100	218,500	15.5	180,900	0.82
	Trans.	128,000	223,600	14.5	184,800	0.83
-253°C (-423°F)	Long.	168,900	240,100	8.2	161,400	0.67
	Trans.	183,600	249,200	7.0	143,700	0.58

[1]Each value listed is an average of three tests.
[2]Mill annealed, descaled, and oiled.

TABLE III

MECHANICAL PROPERTIES[1] OF HEAT TREATED[2] HP 9-4-25 ALLOY, 0.062-INCH SHEET

Test Temperature	Direction	Y.S. psi (.2% Offset)	Ultimate T.S. psi	% Elongation (2" Gauge)	Notched T.S. psi (K_t = 10)	Notched/ Unnotched Tensile Ratio
27°C (80°F)	Long.	175,000	215,100	6.5	231,700	1.08
	Trans.	182,400	221,900	6.5	234,100	1.05
-73°C (-100°F)	Long.	186,500	225,500	7.5	246,100	1.09
	Trans	192,800	234,500	7.0	242,300	1.03
-129°C (-200°F)	Long.	196,600	235,200	7.5	256,600	1.09
	Trans.	197,800	240,900	7.5	254,300	1.05
-196°C (-320°F)	Long.	220,700	264,800	8.5	269,700	1.02
	Trans.	234,000	273,000	8.5	266,100	0.97
-253°C (-423°F)	Long.	251,100	286,300	3.6	188,700	0.66
	Trans.	264,400	291,600	3.6	197,600	0.68

[1]Each value listed is an average of three tests.

[2]Heat treatment - Austenitize 843°C (1550°F) for one-half hour and oil quench; double draw at 204°C (400°F) (one hour at each draw) and air cool.

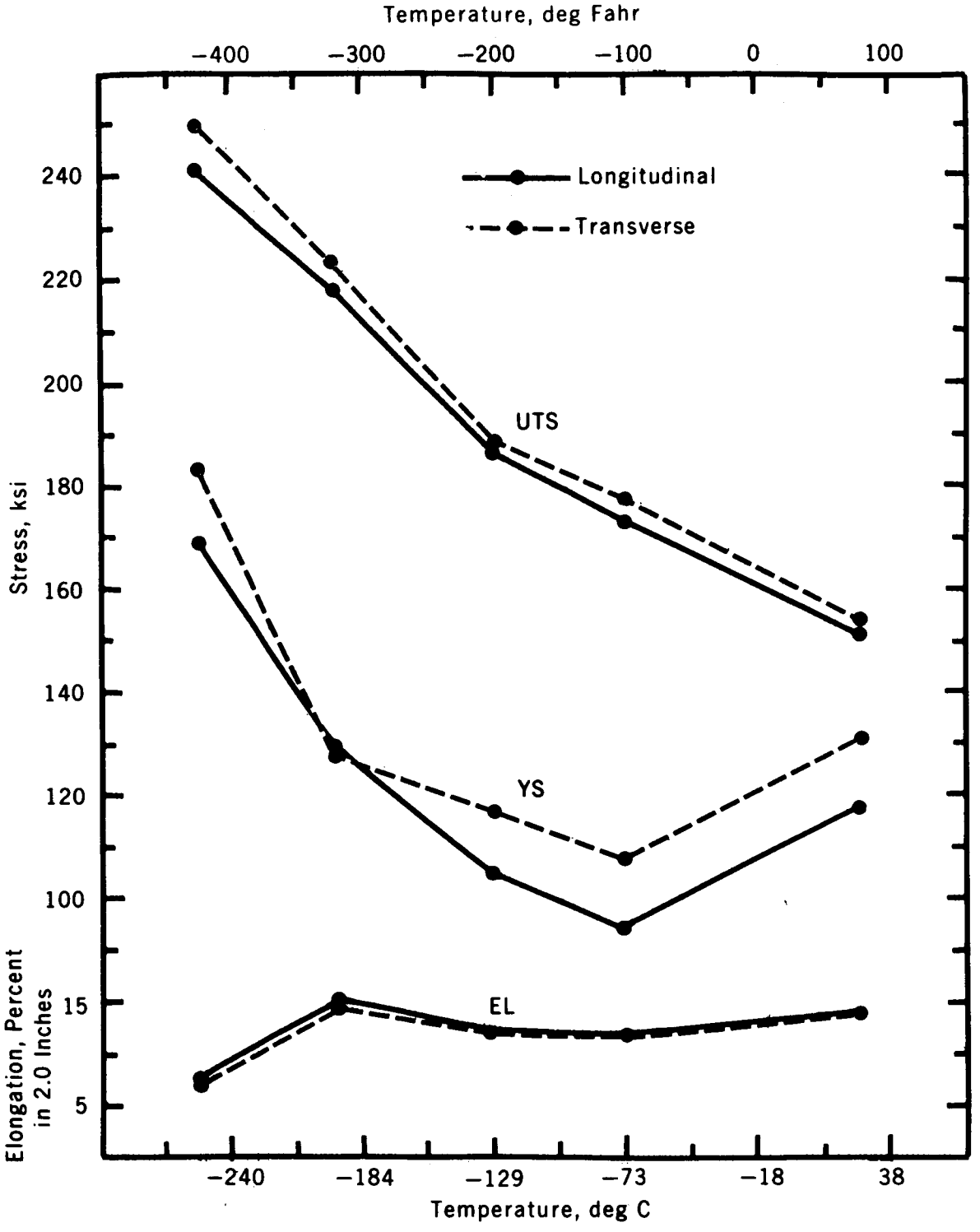

FIGURE 1.-LOW TEMPERATURE MECHANICAL PROPERTIES OF ANNEALED HP 9-4-25 ALLOY, 0.062-INCH SHEET

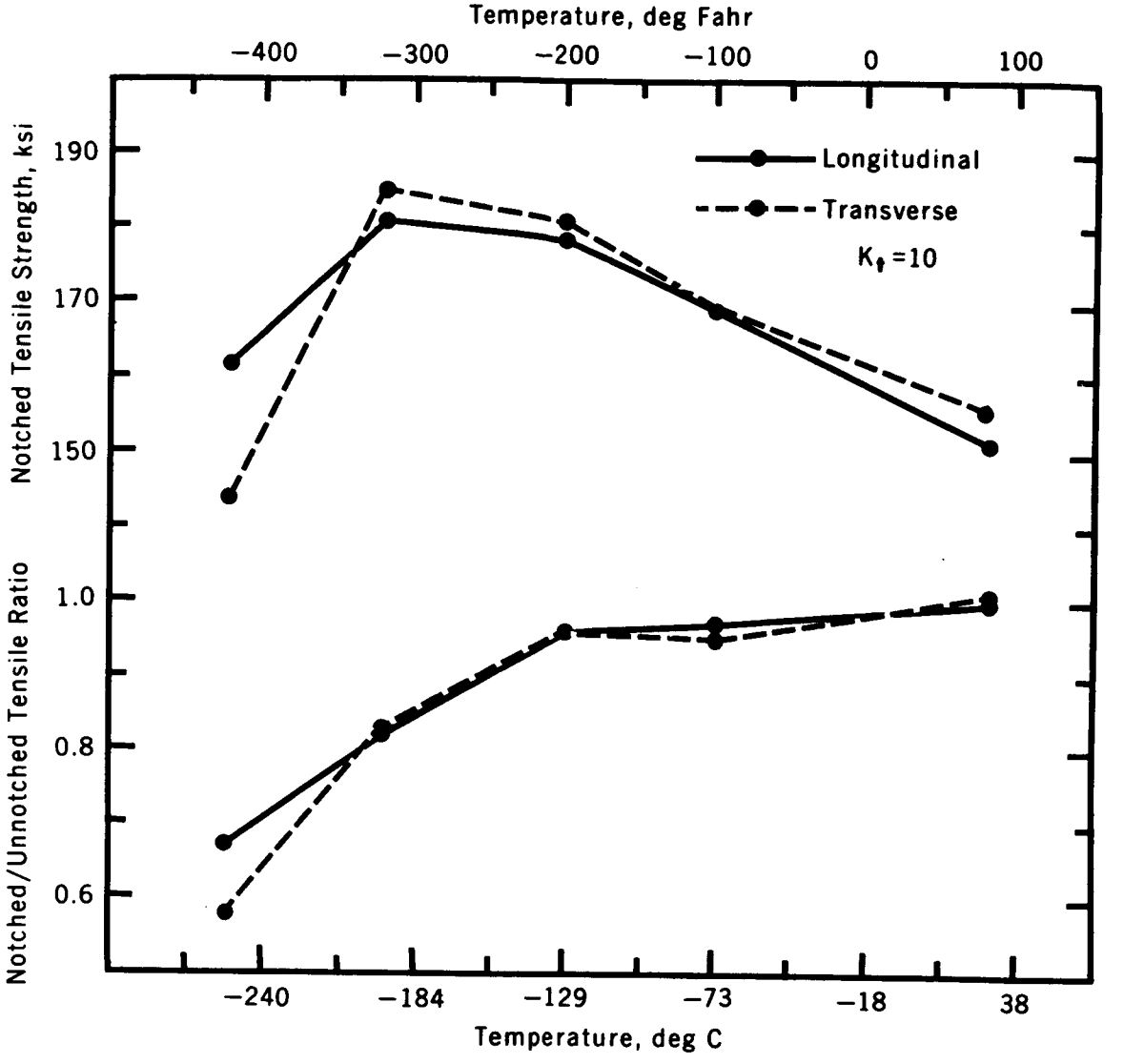

FIGURE 2.-LOW TEMPERATURE NOTCHED TENSILE STRENGTH AND NOTCHED/UNNOTCHED TENSILE RATIO OF ANNEALED HP 9-4-25 ALLOY, 0.062-INCH SHEET

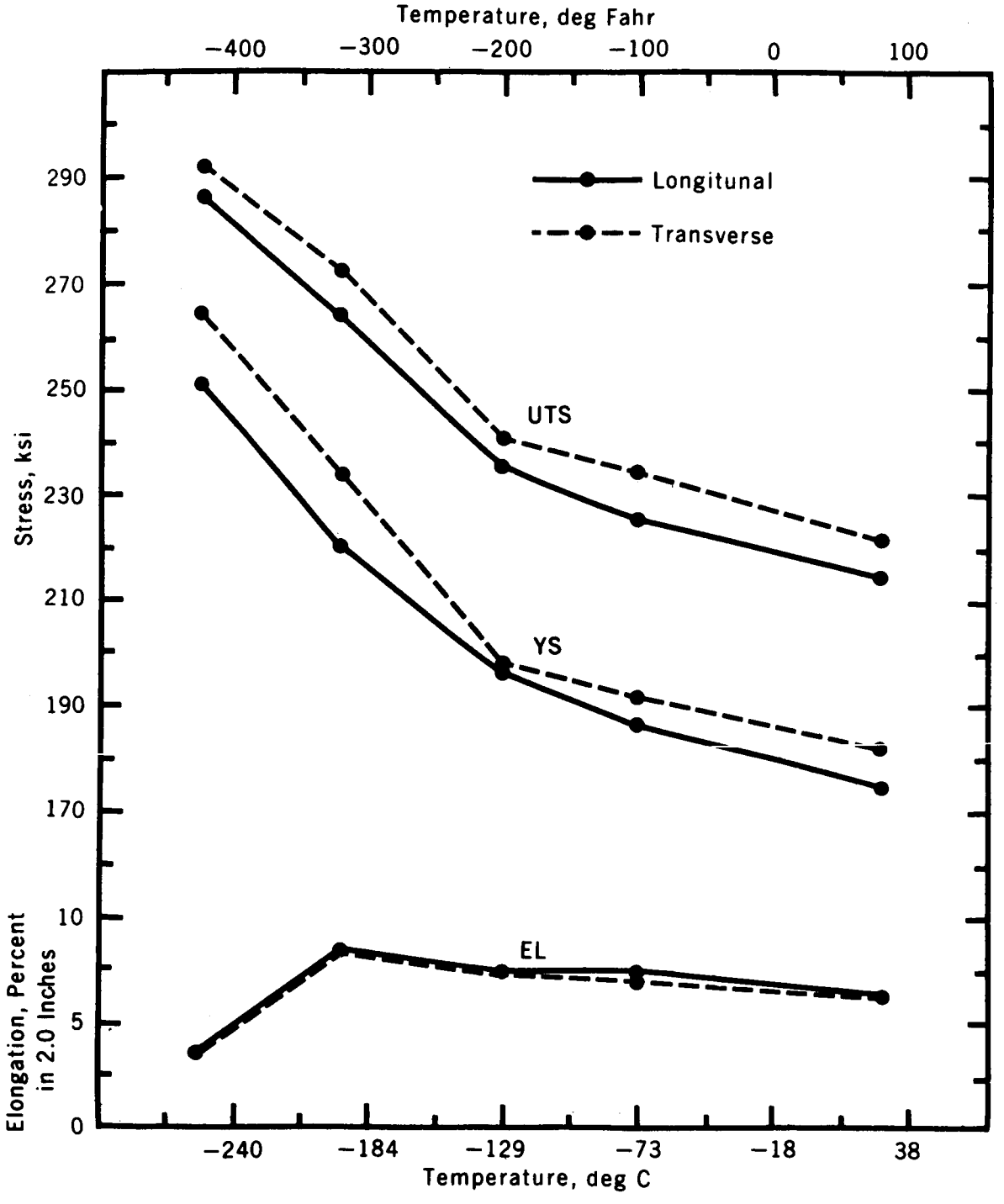

FIGURE 3.-LOW TEMPERATURE MECHANICAL PROPERTIES OF HEAT TREATED HP 9-4-25 ALLOY, 0.062-INCH SHEET

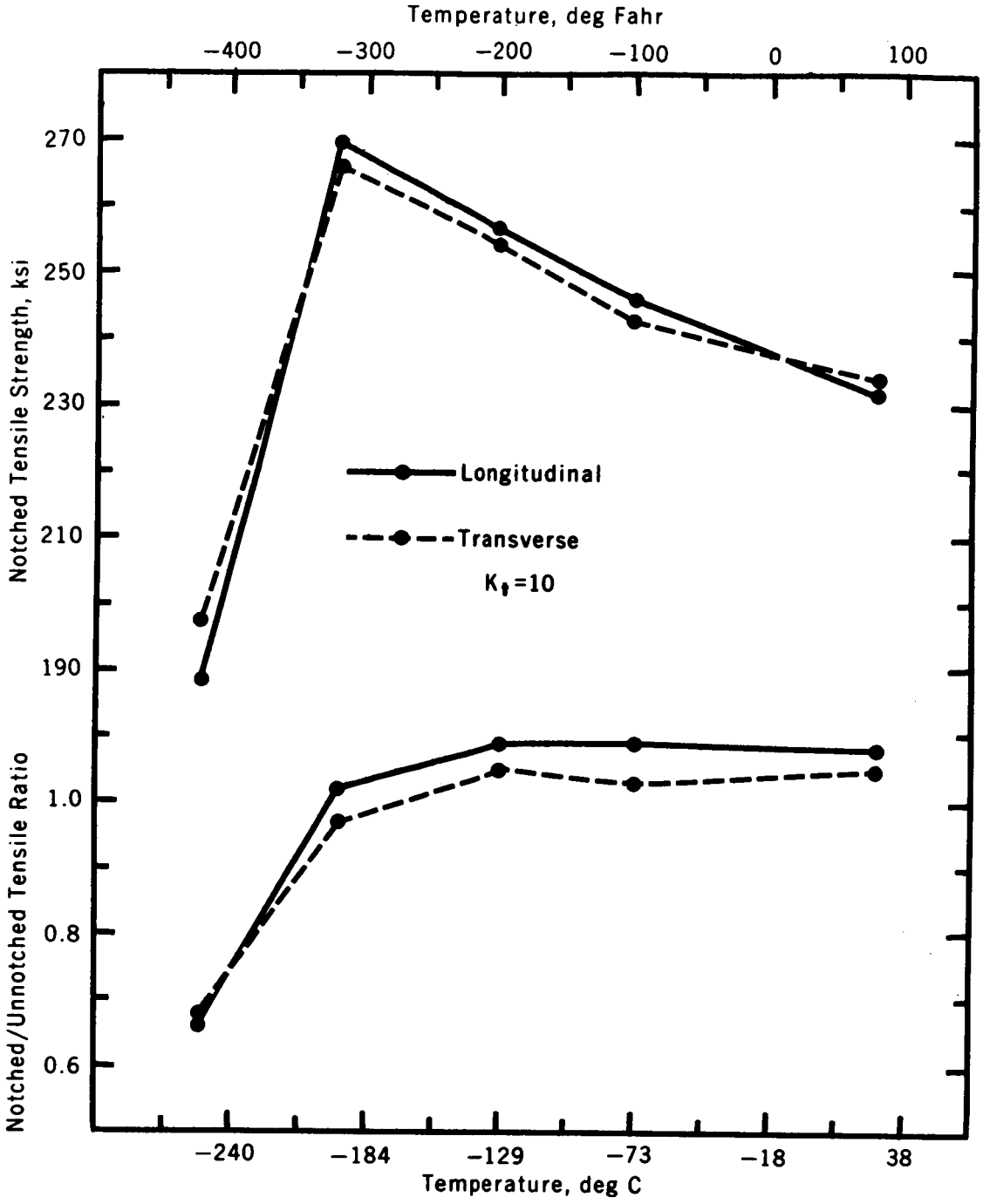

FIGURE 4.-LOW TEMPERATURE NOTCHED TENSILE STRENGTH AND NOTCHED/UNNOTCHED TENSILE RATIO OF HEAT TREATED HP 9-4-25 ALLOY, 0.062-INCH SHEET

LOW TEMPERATURE MECHANICAL PROPERTIES OF HP 9-4-25 ALLOY

By W. R. Morgan

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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

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