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EVALUATION OF EFFECTS OF AGING ON ROOM TEMPERATURE TENSILE PROPERTIES OF COLD WORKED RENE' 41, A286, D979, AND WASPALOY

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SUMMARY

A limited study was made of the effects of aging conditions on the unnotched and sharp-edge notched tensile properties of annealed and cold worked Rene' 41, A286, D979 and Waspaloy in sheet or strip form. The object was to determine from the minimum amount of study those combinations of cold work and aging which would sufficiently enhance the properties of the alloys over those of the annealed and aged condition to be of interest for screening purposes in the program of evaluation of materials for possible use for the construction of the airframe of supersonic transports. It was considered that if the screening results should prove to be promising, more detailed studies of aging would be warranted at a later date.

Aging under the proper conditions raised strengths considerably above the level developed by cold working the annealed condition. Thus, increasing amounts of cold work plus aging increasingly raised strengths. Rene' 41 and Waspaloy had properties fairly insensitive to the temperature of aging, while A286 and D979 developed maximum strength at decreasing aging temperatures with increasing amounts of cold work. The N/S ratios of Rene' 41 and Waspaloy were also not very sensitive to aging temperature or degree of cold reduction. Increasing amounts of cold work resulted in progressive reduction of N/S ratios for A286 and D979. Also, these two alloys had to be aged below the aging temperature yielding maximum strength to obtain the useful combinations of unnotched and notched strength. Elongation of

all materials was reduced by cold work.

Combinations of degree of cold work and aging providing increased strength over the annealed and aged conditions were selected for inclusion in the screening program.

INTRODUCTION

The potential usefulness of superalloys for construction of the airframe of supersonic transports is being determined by a screening test program at the University of Michigan. These alloys are usually solution treated and aged to develop their best properties for use at high temperatures. At the intermediate service temperatures of supersonic transports, however, the possibility exists that their strength could be considerably enhanced by cold work. Alloys which are dependent on the precipitation of γ' for increased strength would be aged following cold work to develop their best properties. Because very little information was available regarding the influence of aging conditions after cold work, this investigation was undertaken using Rene' 41, A286, D979 and Waspaloy alloys in the form of sheet or strip. The objective was to carry out minimum studies of aging conditions after cold work which would enable selection of treatments suitable for inclusion of these alloys in the screening program with their strength enhanced by cold work.

The tensile properties at room temperature using both unnotched and ASTM sharp-edge notched specimens were used to evaluate the effects of aging. All alloys were considered with varying degrees of cold work. This report has been prepared to show the data obtained for the effects of aging conditions and to indicate the type of response to be expected for cold worked γ' strengthened alloys to aging. It is emphasized, however, that the investigation was extremely limited and was stopped as soon as conditions of aging were found which seemed to provide properties of interest for inclusion in the screening program for supersonic transport materials. The reservation has been made that if the screening of these materials indicates useful properties, a thorough study of aging conditions for cold worked alloys of this type would be warranted in the future.

Results of the screening tests are not included in this report. Summaries of the data from all materials being screened (refs. 1 and 2) have been reported previously. In addition, reports on the completed basic screening program have been issued for annealed Rene' 41 (ref. 3) and cold worked N155 (ref. 4).

This investigation was carried out under the sponsorship and with the financial assistance of the National Aeronautics and Space Administration under Grant NsG-124-61.

EXPERIMENTAL MATERIALS

The following materials in the form of approximately 0.025-inch thick strip or sheet have been included in the study of heat treatments:

1) Rene' 41 (Heat R217) annealed
2) Rene' 41 (Heat R216) cold worked 20 percent and 35 percent
3) A286 (Heat 21467) cold worked 30 percent, 50 percent, 65 percent, and 80 percent
4) D979 (Heat W23211) cold worked 30 percent, 50 percent, and 65 percent after annealing at 1850°F, and cold worked 80 percent after annealing at 1950°F
5) Waspaloy (Heat B114) annealed, cold worked 20 percent, and cold worked 40 percent.

The reported chemical compositions for each of these materials are included in Table I.

Items (1), (2) and (5) were obtained from the General Electric Company, Metallurgical Products Department. They were produced on a hand mill as 36-inch wide sheet.

Items (3) and (4) above were obtained through the NASA Lewis Research Center from the Wallingford Steel Company. They were produced on a strip mill as 12-inch wide strip.

EXPERIMENTAL PROCEDURES

Using the limited available information as a background, various aging treatments were applied to each of the alloys to determine which treatment would result in the optimum combination of properties. Sufficient treatments were included to indicate the way properties were changing as a function of increasingly severe aging conditions.

The properties of the four alloys with various degrees of cold work were evaluated from the results of room temperature tensile tests using the following criteria:

1) The level of room temperature tensile strength, yield strength, and elongation as determined by testing unnotched specimens;

2) The level of room temperature tensile strength using samples with sharp edge notches;

3) The ratio between the tensile strength of a notch sample and that of an unnotched sample (hereafter referred to as "N/S Ratio").

In order to evaluate the influence of aging on any anisotropy which might be present in the cold worked materials, samples were taken from both the longitudinal and the transverse directions of the sheets in most cases.

Aging

For aging, the specimen blanks were cut to size, cleaned with acetone and clamped between two stainless steel blocks to both minimize contact with air and reduce warping of the blanks during heat treatment. A thermocouple attached to the exposed edge of the blanks was used to measure temperature. Samples were placed in a furnace which was at the desired temperature. At the end of the aging period, the entire assembly was removed from the furnace and air cooled.

Test Specimens

The test specimen blanks were machined after aging.

Unnotched Specimens

The specimens used for determination of normal tensile properties had a reduced section 0.5-inch wide by 2.0-inches long (Fig. 1a). Specimens were prepared from rectangular blanks by milling. Eight to ten specimens were milled at a time, using a fixture to clamp the blanks together and assure accurate alignment throughout the machining operations.

Notched Specimens

The specimen with sharp edge notches recommended by the ASTM (ref. 5) was used (Fig. 1b). Eight to ten blanks were machined at a time, using a fixture to maintain alignment. The 1-inch wide reduced section was first milled to size. The notches were then ground almost to size with an alundum wheel dressed to a sharp point on a 60-degree included angle. The notch root was then finished by manually drawing a sharp carbide tool through the notches, using a shaper, until the required notch depth was achieved. The root radii and net-section width were then measured using a 50x optical comparator. Root radii varied from 0.0005 to 0.0007 inch.

Tensile-Test Procedures

All tests were conducted with a 60,000-pound capacity hydraulic tensile machine. Unnotched samples were tested at a strain rate of 0.01 inch per inch per minute up to about 2 percent strain. The strain rate was then increased up to 0.05 inch per inch per minute until failure. Notched samples were loaded at a rate of 1000 psi net section stress per second.

Strain measurements were made on the unnotched specimens using a modified Martens-type optical-lever extensometer. The extensometer was attached by collars clamped onto the gage section. For the specimens being tested, this system has a sensitivity of about 0.000005 inch per inch.

RESULTS AND DISCUSSION

Data from tensile tests at room temperature showing the effect of aging conditions on Rene' 41, A286, D979, and Waspaloy alloys comprise the results. The aging treatments for each of the alloy conditions to be studied in the screening program were derived from consideration of these data.

The order of presentation of the alloys represents the sequence in which they were received for the investigation and has no further significance. In the graphical presentations of the data (Figs. 2 through 5), lines have been drawn from point-to-point to make it easy to follow the data. These lines are not considered to be correlation curves because both temperature and time of aging were variables.

Rene' 41 Alloy

The aging response of Rene' 41 alloy was studied for two conditions of the material: (1) annealed plus 20-percent cold work; and (2) annealed plus 35-percent cold work.

Consideration of the data for the material with 20-percent cold work (table II and Fig. 2a) indicates the following:

1) For the aging conditions studied, maximum strength in unnotched specimens resulted with the standard age of 16 hours at 1400°F.

2) Aging for two hours at 1400° or 1500°F resulted in slightly lower strength and slightly higher ductility with unnotched specimens than the standard age. Aging at 1600° or 1650°F resulted in definitely lower strengths.

3) The strength and ductility with transverse specimens were slightly below the corresponding strength with longitudinal specimens.

4) The strength of notched specimens was essentially the same after aging either at 1400°, 1500°, or 1600°F. As a result, the N/S ratio increased somewhat as the strength with unnotched samples fell off. Only the transverse direction was evaluated since the properties were lower from this direction.

Since little difference in strength existed after aging at 1400° or 1500°F, the decision was made to age the material with 20-percent cold work for the screening program for 16 hours at 1400°F, the condition normally used for solution treated material. This seemed best due to the background of experience for the non-cold worked condition since no particular advantage was evident for other aging conditions. If it should show promise for the application in the screening tests, further studies of other aging conditions on properties in screening tests would then be justified.

The data obtained for the material with 35-percent cold work indicate the following (table II and Fig. 2b):

1) The strength levels with unnotched specimens were higher and the elongations somewhat lower than for 20-percent cold work.

2) The strength and N/S ratio obtained from notched specimens were considerably lower after aging at 1400°F than they were in material with 20-percent cold work. Increasing the aging temperature to 1500° or 1600°F resulted in notch strengths which were about the same for both amounts of cold work.

Due to the low notch strength associated with the maximum strength developed in unnotched specimens (for aging 16 hours at 1400°F), the decision was made to age the material with 35-percent cold work for 2 hours at 1500°F. This condition of the material was stronger than the material cold worked 20 percent and aged at 1400°F and gave a more favorable N/S ratio. Here again, if this material should show promise in the screening program, further study of aging conditions would be justified.

For both reductions, there was a substantial increase in unnotched strengths from aging over those of the materials as-cold worked. The increase was less for 35-percent than for 20-percent reduction.

Finally, notice should be taken of the differences between properties of the material from the longitudinal and transverse directions. These differences were relatively independent of heat treatment and were about the same for both amounts of cold work. Annealed Rene' 41 has been shown (ref. 3) to be quite free of this anisotropy.

The materials being evaluated in the screening program have the following approximate comparative properties at room temperature (all values for longitudinal specimens):

Cold Reduction (percent)	Aging Treatment	Ultimate Strength (psi)	0.2% Offset Yield Strength (psi)	N/S Ratio
None	16 hrs-1400°F	204,000	154,000	0.84
20	16 hrs-1400°F	229,000	208,000	0.89
35	2 hrs-1500°F	249,000	230,000	0.79

These data show that a considerable increase in ultimate strength and yield strength without any large change in the N/S ratio resulted from cold working Rene' 41 alloy.

A286 Alloy

Data available from the Allegheny-Ludlum Steel Corporation for aging of cold worked A286 alloy (ref. 6) indicated that aging temperature for maximum strength at room temperature would decrease with increasing amounts of cold work. For the cold work being considered in this investigation, these temperatures would be expected to decrease from about 1300°F at 30-percent cold work to about 1100°F for 80 percent. The testing was strictly limited to the minimum to verify this indication. In addition, only the 16 hours of aging recommended by Allegheny Ludlum was investigated.

The results of the study (table III and Fig. 3) indicate the following:

1) The expected decrease in aging temperature required to produce maximum strength as the amount of cold work was increased was confirmed. At the same time, the tensile strength of longitudinal samples increased from 185,000 psi for material cold-reduced 30 percent to 239,000 psi in the material with 80-percent cold work.

2) The yield strengths associated with the maximum ultimate strengths obtained for the three materials with the higher cold work were about 10,000 psi below the ultimate strength. The yield strength of the material with 30-percent cold work was about 20,000 psi lower than the ultimate strength.

3) The elongations at maximum strength decreased from about 9 percent with 30-percent cold work to about 3 percent in the materials with 65 or 80-percent cold work.

4) The N/S ratio was high (about 0.98) in the material cold worked 30 percent and decreased to about 0.6 as the amount of cold work increased to 80 percent.

5) The strength of unnotched samples from the transverse direction in the strip was slightly lower in the material with 30-percent cold work. With 65 or 80-percent cold work, transverse samples had strength levels above comparable longitudinal samples. Strength of notched samples seemed to be independent of sampling direction.

The decision was made to limit preliminary screening of A286 alloy to the two extreme amounts of cold work, 30 percent and 80 percent. Each of these is being aged at the temperature which produced maximum strength for that amount of cold work. These treatments produce the following properties at room temperature (longitudinal samples):

Cold Reduction (percent)	Aging Treatment	Ultimate Strength (psi)	0.2% Offset Yield Strength (psi)	N/S Ratio
30	16 hrs-1300°F	185,000	163,000	0.97
80	16 hrs-1100°F	239,000	230,000	0.60

As preliminary testing is completed, the decision will be made whether to include one of the other initial conditions of the material or to study alternative heat treatments.

D979 Alloy

Considerable information was available on D979 sheet (ref. 7) to serve as a guide for selection of heat treatments. These data showed that very high tensile and yield strengths can be developed in cold worked D979 by aging after the cold working. Accordingly, each of the four conditions of the alloy were aged at selected aging temperatures using the 16 hour time period recommended by Allegheny Ludlum. These treatments were then evaluated using both unnotched and notched specimens. Due to the large amount of testing required to evaluate this alloy, sampling was all done from the longitudinal direction with a few checks using transverse samples.

The following general trends are shown by the data (table IV and Fig. 4):

1) Maximum tensile and yield strength in unnotched

samples was obtained at successively lower temperatures of heat treatment as the amount of cold work was increased.

2) Heat treatment at temperatures below that for which maximum strength was obtained promoted high strength in notched samples and correspondingly high N/S ratios. This effect was very pronounced in the data from the three larger amounts of cold work. The N/S ratio remained fairly low as aging temperature was decreased until the maximum strength was obtained. Then a large increase in N/S ratio resulted as the aging temperature was decreased further.

3) Elongation increased as aging temperature was increased for all four initial conditions of the material. Elongations for the material with the three higher amounts of cold work were, however, all low.

4) A comparison among the sets of curves in Figure 4 shows that for all the aging temperatures studied, the ultimate strength increased as the amount of cold work increased.

5) The properties of the material cold reduced 65 percent were very similar to those of the material cold reduced 80 percent. Although this indicates that the properties as a function of amount of cold work tended to level off at the higher reductions, this may also be associated with the higher annealing temperature (1950°F) used prior to rolling the material cold reduced 80 percent. (The other three conditions were produced from material with an 1850°F anneal.) Data in reference 7 indicate that higher strength can result for a given cold reduction if a lower initial annealing temperature before cold work is employed.

For the material with 30-percent cold work, an age of 16 hours at 1200°F has been selected for the screening program. This condition provides maximum notch tensile strength and N/S ratio for the treatments studied. The properties with unnotched specimens were only slightly below maximum for 30-percent reduction.

For the material cold reduced 50 percent, the ultimate and yield strength with unnotched samples was relatively constant for aging temperatures from 1000° to 1300°F. Aging at 1400° or 1500°F caused the strength to decrease sharply. The tensile strength of notched samples was quite low after aging in the range from 1200° to 1500°F and was considerably higher after aging at 1100°F. Since maximum strength with both unnotched and notched samples resulted from aging at 1100°F, this condition was selected for screening the material cold reduced 50 percent.

When D979 alloy was cold reduced 65 and 80 percent, N/S ratios were all below 0.4 unless the aging temperature was dropped to 1000°F. Even aging at 1000°F only brought it up to 0.51 after a reduction of 65 percent. The trend of the data for 80-percent reduction indicated that the N/S ratio would be even lower. On the basis that materials with N/S ratios as low as 0.4 or 0.5 would not be useful for the application, both of the larger reductions were eliminated from consideration for the screening program. The larger reductions did result in high ultimate and yield strengths. Notched strengths, however, were no higher than for 50-percent reduction. Ductilities were also very low unless the material was aged at a high temperature where there was no advantage strengthwise.

The following comparative properties from longitudinal samples were obtained using the heat treatments which will be applied to the material in the screening program:

Cold Reduction (percent)	Aging Treatment	Ultimate Strength (psi)	0.2% Offset Yield Strength (psi)	N/S Ratio
30	16 hrs-1200°F	222,000	198,000	0.95
50	16 hrs-1100°F	273,000	257,000	0.64

The results from the screening program will be carefully analyzed to determine if the higher reductions and other heat treatments should be investigated.

Waspaloy

Aging of the solution annealed as well as the annealed and cold worked conditions was investigated for Waspaloy. Because it is metallurgically similar to Rene' 41 alloy, the aging treatments were selected using the previously obtained data from Rene' 41 as a guide. A rather complete study was conducted using notched and unnotched samples from both the longitudinal and transverse directions in the sheet.

The data obtained in the study (table V and Fig. 5) indicate the following general trends:

1) Over the range of conditions studied, the strength of Waspaloy could be substantially increased over the as-rolled values by aging as it was for the other alloys.

2) The strength levels obtained by aging were nearly independent of aging conditions for the conditions studied.

3) The notch strengths of the annealed material and the material with 20-percent cold work were above the yield strengths for all aging conditions. For the material with 35-percent cold work, they were slightly below the yield strengths.

4) The N/S ratios after aging were relatively insensitive to amount of cold work in the material.

5) Elongation was quite high for all conditions, although it was reduced by cold working.

For the annealed material (Fig 5a), all of the aging conditions increased the strength, increased the N/S ratio, and decreased elongation compared to the material without any aging. The highest strength (185,000 to 190,000 psi) was obtained by aging either 16 hours at 1400°F, 2 hours at 1500°F, or with the conventional double-aging treatment. Elongation was high for all aging conditions. The N/S ratios after aging were all about 0.8. The yield and notch strength were maximum after aging either 16 hours at 1400°F or 2 hours at 1500°F. The double-aging treatment gave lower yield and notch strengths.

Since aging 16 hours at 1400°F gave maximum values for ultimate, yield, and notch strengths with good elongation and a N/S ratio of 0.8, this treatment was chosen for the material to be subjected to the screening program.

Three heat treatments were studied with the two cold worked materials. Ultimate tensile strength was slightly higher than the other two aging conditions for 16 hours at 1300°F, while the yield strength was essentially the same for all heat treatments. The N/S ratios and elongations were highest after 2 hours at 1500°F. While there really was not much variation in properties for the three conditions of heat treatment, 2 hours at 1500°F seemed to be the best and was selected for material to be included in the screening program.

The selected heat treatments for the three conditions of the Waspaloy resulted in the following comparative properties (longitudinal samples):

Cold Reduction (percent)	Aging Treatment	Ultimate Strength (psi)	0.2% Offset Yield Strength (psi)	N/S Ratio
None	16 hrs-1400°F	191,000	139,000	0.81
20	2 hrs-1500°F	205,000	176,000	0.93
40	2 hrs-1500°F	237,000	216,000	0.89

When preliminary screening using material with these aging treatments has been completed, the possibility of including other treatments will be considered.

Materials Included in Screening Program

The preceding sections of the report have dealt with the effects of aging on properties of the four alloys under consideration. In each of these sections, a choice was indicated of those materials which will be included in the screening program at Michigan and the aging treatments which were deemed best for them were discussed.

A summary of these materials is given in Table VI, showing their relative properties. These data show that aging of each of the alloys studied produced tensile and yield strengths well over 200,000 psi for the higher cold reductions. N/S ratios and elongations varied widely among the materials.

CONCLUSIONS

The tensile strengths of annealed Rene' 41, A286, D979 and Waspaloy sheet or strip were progressively increased by increasing amounts of cold work. Aging under the proper conditions added the strengthening from γ' precipitation to the cold work effect so that substantially increased properties over the annealed and aged condition were obtained. Ductility was reduced by cold work.

In general, strengths increased to a maximum with increasing aging temperature and then fell off. Rene' 41 and Waspaloy were relatively insensitive to aging temperature and their N/S ratios were not drastically reduced by cold work. A286 and D979, however, developed maximum strengths at decreasing temperatures of aging as the amount of cold reduction was increased. Their N/S ratios also fell off with cold work. Generally, the best combinations of strength and N/S ratios were obtained by aging below the temperature yielding maximum unnotched strength. No aging treatment giving enhanced unnotched strength with a N/S ratio above 0.4 or 0.5 was found for A286 alloy cold reduced 65 or 80 percent prior to aging.

The way the combinations of cold work and aging of the four alloys were selected for inclusion in the screening program for materials for supersonic transports are shown in the report. These represent considerable increases in the strength levels of these alloys over that obtainable by aging without cold work. If these prove to have useful properties in the screening program, a considerably more extensive investigation of cold work and aging conditions will be warranted than the extremely limited work of this investigation.

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6. "Effects of Cold Work on the Hardness and Mechanical Properties of A286 Alloy", Allegheny Ludlum Data Sheet No. 1055-37, October 7, 1955.

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TABLE I

CHEMICAL COMPOSITIONS OF EXPERIMENTAL MATERIALS

Alloy	Heat Number	Chemical Composition (weight percent)														
		C	Si	Mn	Cr	Ni	Co	Mo	Ti	Al	W	Fe	P	S	B	Other
Rene' 41	R-217	.09	.07	.06	18.97	Bal	11.20	9.75	3.20	1.50	----	<.30	----	.006	.0045	-----
Rene' 41	R-216	.10	.06	.06	18.48	Bal	10.43	9.37	3.19	1.42	----	2.20	----	.007	.0047	-----
A286	---	.057	.60	1.10	15.22	24.86	-----	1.24	2.12	.23	----	Bal	.028	.007	.0015	.33V
D979	W23211	.078	.15	.18	15.02	43.97	-----	4.06	3.04	1.02	3.57	Bal	.007	.006	.12	-----
Waspaloy	B119	.08	.07	.04	19.63	Bal	13.49	4.26	2.99	1.40	----	2.30	----	.007	.0048	.03Zr

TABLE II

EVALUATION OF HEAT TREATMENT RENE' 41 ALLOY

(all tests at room temperature)

		CONDITION OF MATERIAL PRIOR TO AGING														
		ANNEALED					COLD WORKED 20%					COLD WORKED 35%				
Heat Treatment	Direction[a]	UTS[b] (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S
None	L	---	---	---	---	---	175	149	21	---	---	208	192	8	---	---
	T	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---
2 hrs at 1400°F	L	---	---	---	---	---	227	205	12	---	---	251	237	7	---	---
	L	---	---	---	---	---	---	---	--	---	---	250	236	6	---	---
	T	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---
16 hrs at 1400°F	L	204	151	20	172	.84	229	208	10	205	.89	253	240	6	---	---
	L	204	156	24	---	---	---	---	--	---	---	255	239	7.5	---	---
	T	206	153	21	171	.83	225	200	10	181	.80	246	224	6	155	.63
	T	203	154	25	---	---	---	---	--	---	---	---	---	---	---	---
2 hrs at 1500°F	L	---	---	---	---	---	228	202	14	---	---	249	230	8	196	.79
	T	---	---	---	---	---	220	195	12	187	.85	237	216	7	182	.77
2 hrs at 1600°F	L	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---
	T	---	---	---	---	---	206	182	8	182	.88	223	198	11	190	.85
4 hrs at 1650°F	L	---	---	---	---	---	211	168	20	---	---	224	190	13	---	---
	T	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---

(a) L = Longitudinal
T = Transverse

(b) UTS - ultimate tensile strength; YS - 0.2-percent offset yield strength; Elong. - elongation in 2 inches; NS - tensile strength of sharp edge notch sample; N/S - ratio of notch strength to unnotched tensile strength.

TABLE III

EVALUATION OF HEAT TREATMENT
A-286 ALLOY

(all tests at room temperature)

Heat Treatment	Direction (a)	CONDITION OF MATERIAL PRIOR TO AGING																			
		COLD WORKED 30%					COLD WORKED 50%					COLD WORKED 65%					COLD WORKED 80%				
		UTS(b) (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S
None	L	132	120	5	---	---	152	143	3.5	---	---	167	149	2.5	---	---	178	153	2.7	---	---
	T	133	121	7	---	---	162	147	3.3	---	---	180	157	2.5	---	---	204	177	3.5	---	---
16 hrs at 1100°F	L	---	---	-	---	---	---	---	---	---	---	221	212	3	---	---	239	230	2.8	143	.60
	T	---	---	-	---	---	---	---	---	---	---	---	---	---	---	---	263	250	3.8	140	.53
16 hrs at 1200°F	L	183	169	9	---	---	205	192	6	---	---	217	204	3.8	143	.66	224	202	3	116	.52
	T	---	---	-	---	---	---	---	--	---	---	232	220	6	146	.63	243	226	4.5	109	.45
16 hrs at 1300°F	L	185	163	11	180	.97	182	153	11	---	---	173	139	10	---	---	170	136	8	---	---
	L	---	---	-	---	---	187	153	10	---	---	177	140	10	---	---	174	135	10	---	---
	T	181	154	10	180	.99	---	---	---	---	---	184	157	10	---	---	---	---	---	---	---

(a) L = Longitudinal
T = Transverse
(b) UTS - ultimate tensile strength; YS - 0.2-percent offset yield strength; Elong. - elongation in 2 inches; NS - tensile strength of sharp edge notch sample; N/S - ratio of notch strength to unnotched tensile strength.

TABLE IV

EVALUATION OF HEAT TREATMENT
D-979 ALLOY

(all tests at room temperature)

		CONDITION OF MATERIAL PRIOR TO AGING																			
		COLD WORKED 30%					COLD WORKED 50%					COLD WORKED 65%					COLD WORKED 80%				
Heat Treatment	Direction (a)	UTS(b) (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S
None	L	186	167	7	---	---	---	---	---	187	---	---	---	--	---	---	249	214	1.5	---	---
	T	---	---	--	---	---	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---
16 hrs at 1000°F	L	---	---	--	---	---	261	259	1.3	---	---	289	287	<1	148	.51	---	---	---	153	---
	T	---	---	--	---	---	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---
16 hrs at 1100°F	L	---	---	--	---	---	273	257	1.8	176	.64	300	290	1	116	.39	294	294	1	107	.36
	T	---	---	--	---	---	262	238	3.8	190	.72	---	---	--	---	---	---	---	---	---	---
16 hrs at 1200°F	L	222	198	7	211	.95	271	260	2	126	.47	---	---	--	110	---	---	---	---	99	---
	T	216	182	8	197	.91	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---
16 hrs at 1300°F	L	232	208	7	189	.82	273	254	2.8	125	.46	---	---	--	---	---	---	---	---	100	---
	L	233	209	7	198	.85	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---
	T	---	---	--	---	---	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---
16 hrs at 1400°F	L	226	193	9	170	.75	256	229	3	102	.40	---	---	--	---	---	275	240	1.5	90	.33
	T	---	---	--	---	---	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---
16 hrs at 1500°F	L	210	162	11	147	.70	228	187	2.5	112	.49	246	196	4.5	97	.39	246	201	3.5	99	.40
	T	---	---	--	---	---	---	---	---	---	---	---	---	--	---	---	---	---	---	---	---

(a) L = Longitudinal
T = Transverse
(b) UTS - ultimate tensile strength; YS - 0.2-percent offset yield strength; Elong. - elongation in 2 inches; NS - tensile strength of sharp edge notch sample; N/S - ratio of notch strength to unnotched tensile strength.

TABLE V

EVALUATION OF HEAT TREATMENT
WASPALOY

(all tests at room temperature)

		CONDITION OF MATERIAL PRIOR TO AGING														
		ANNEALED					COLD WORKED 20%					COLD WORKED 40%				
Heat Treatment	Direction (a)	UTS(b) (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S	UTS (1000 psi)	YS (1000 psi)	Elong. (%)	NS (1000 psi)	N/S
None	L	129	62	64	87	.67	181	124	25	149	.82	189	171	5	187	.99
	T	129	61	63	91	.70	152	121	25	152	1.00	186	162	8	190	1.02
16 hrs at 1300°F	L	179	127	34	148	.83	218	190	15	197	.90	243	219	6	212	.87
	T	183	125	36	151	.82	213	183	13	201	.94	240	215	7	198	.82
2 hrs at 1400°F	L	181	127	34	140	.77	207	179	14	197	.95	241	219	6	195	.81
	T	179	123	36	141	.79	211	176	15	194	.92	232	205	8	187	.81
16 hrs at 1400°F	L	191	139	31	154	.81	---	---	---	---	---	---	---	---	---	----
	T	190	135	31	151	.80	---	---	---	---	---	---	---	---	---	----
2 hrs at 1500°F	L	190	136	32	154	.81	205	176	16	191	.93	237	216	9	212	.89
	T	187	132	33	154	.82	204	174	18	202	.99	232	206	11	201	.87
24 hrs at 1550°F + 16 hrs at 1400°F	L	186	120	28	143	.77	---	---	---	---	---	---	---	---	---	----
	T	190	128	27	147	.77	---	---	---	---	---	---	---	---	---	----

(a) L = Longitudinal
T = Transverse

(b) UTS - ultimate tensile strength; YS - 0.2-percent offset yield strength; Elong. - elongation in 2 inches; NS - tensile strength of sharp edge notch sample; N/S - ratio of notch strength to unnotched tensile strength.

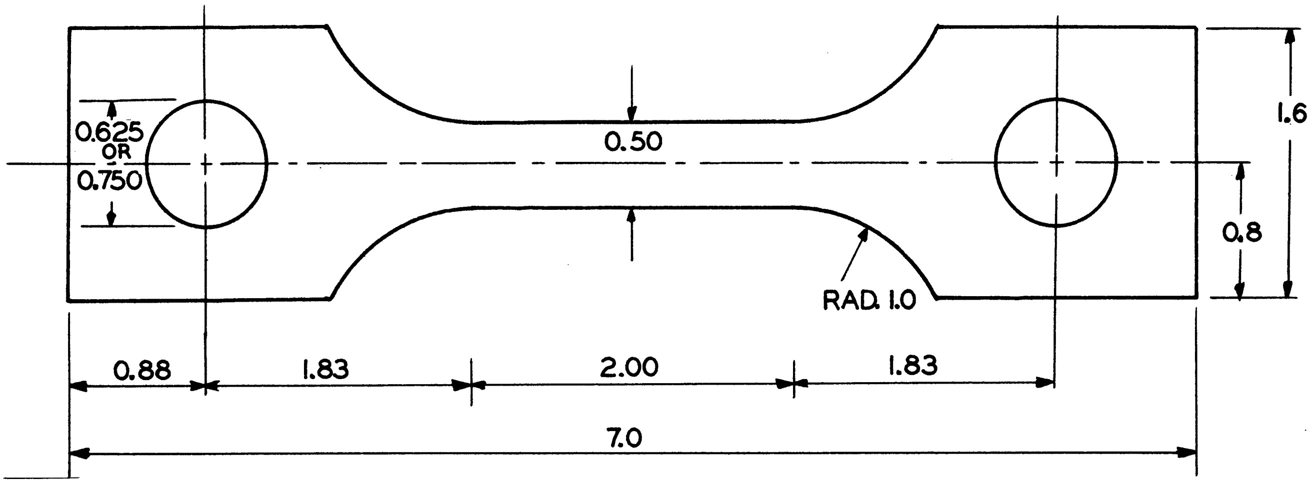
TABLE VI

COMPARATIVE ROOM TEMPERATURE PROPERTIES OF MATERIALS SELECTED FOR STUDY IN THE SCREENING PROGRAM

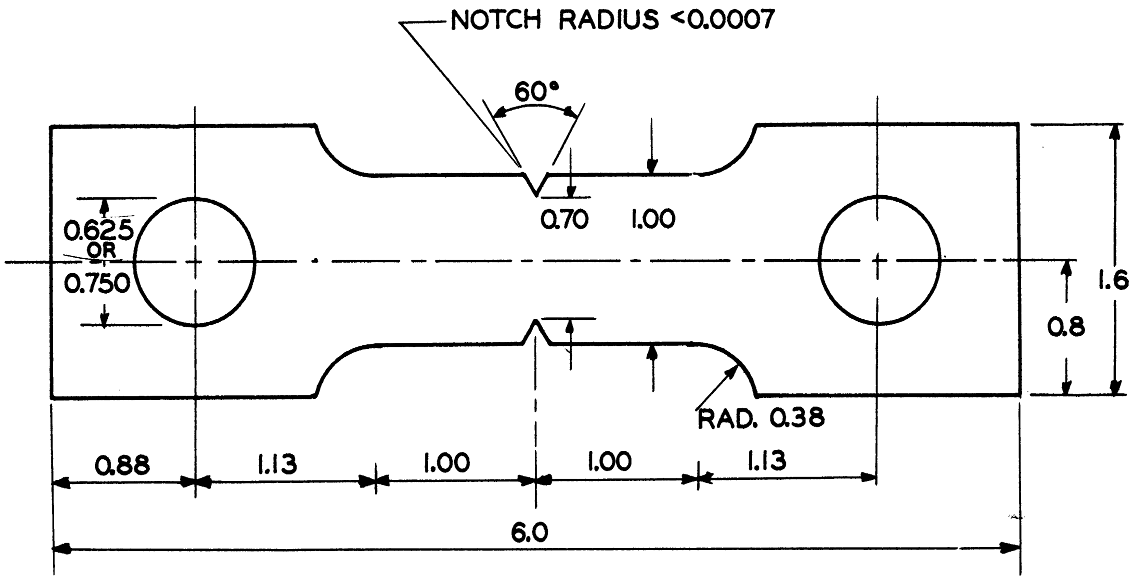
(All samples from longitudinal direction)

Alloy	Cold Work (percent)	Aging Treatment	Tensile Properties* UTS	YS	El	N/S
Rene' 41	None	16 hrs-1400°F	204	154	22	0.84
	20	16 hrs-1400°F	229	208	10	0.89
	35	2 hrs-1500°F	249	230	8	0.79
A286	30	16 hrs-1300°F	185	163	11	0.97
	80	16 hrs-1100°F	239	230	3	0.60
D979	30	16 hrs-1200°F	222	198	7	0.95
	50	16 hrs-1100°F	273	257	2	0.64
Waspaloy	None	16 hrs-1400°F	191	139	31	0.81
	20	2 hrs-1500°F	205	176	16	0.93
	40	2 hrs-1500°F	237	216	9	0.89

* UTS - Ultimate tensile strength, 1000 psi; YS - 0.2% offset yield strength, 1000 psi; El - elongation in 2 inches; N/S - ratio of notched tensile strength to unnotched tensile strength.

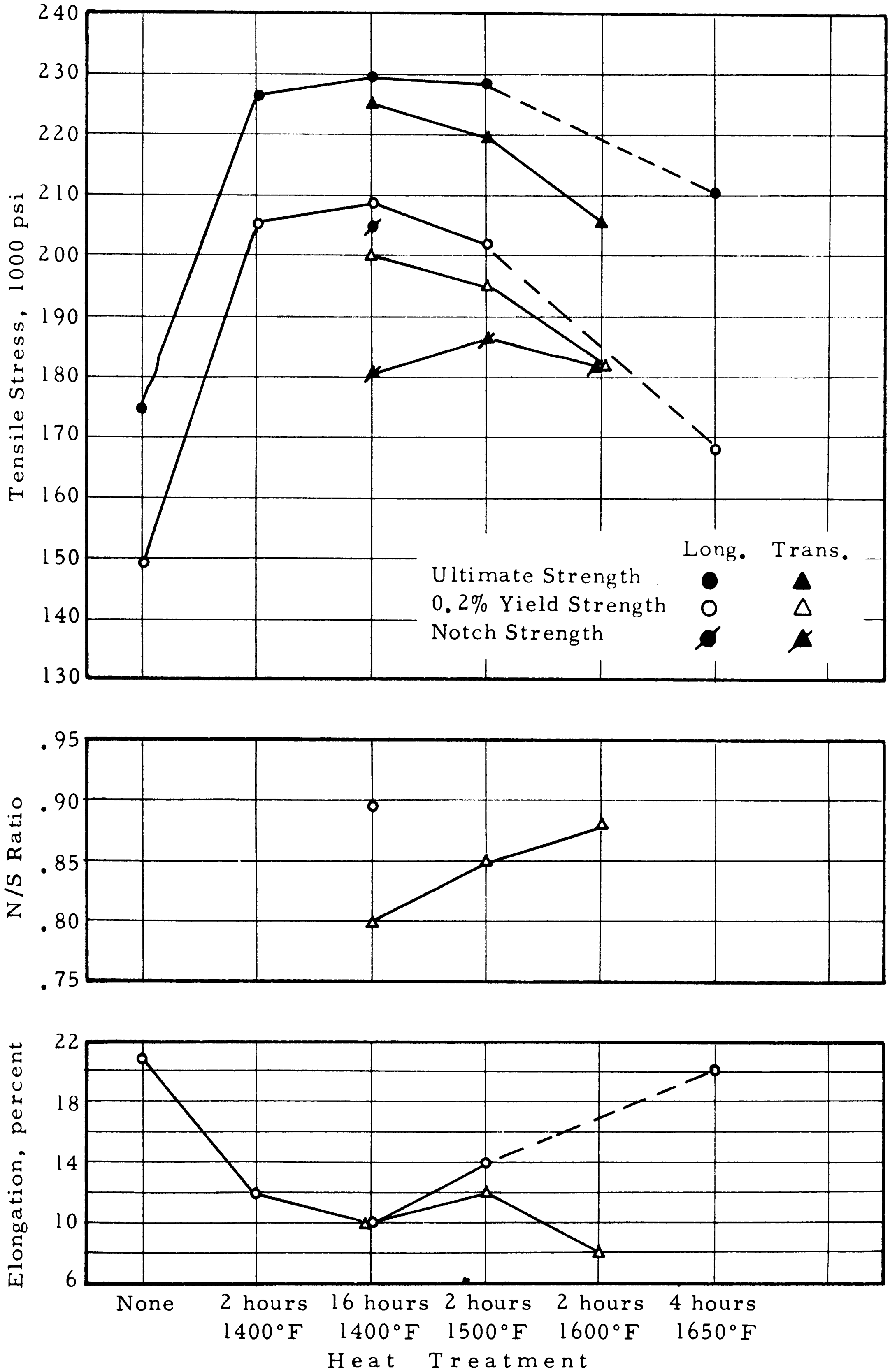


a) Unnotched specimen



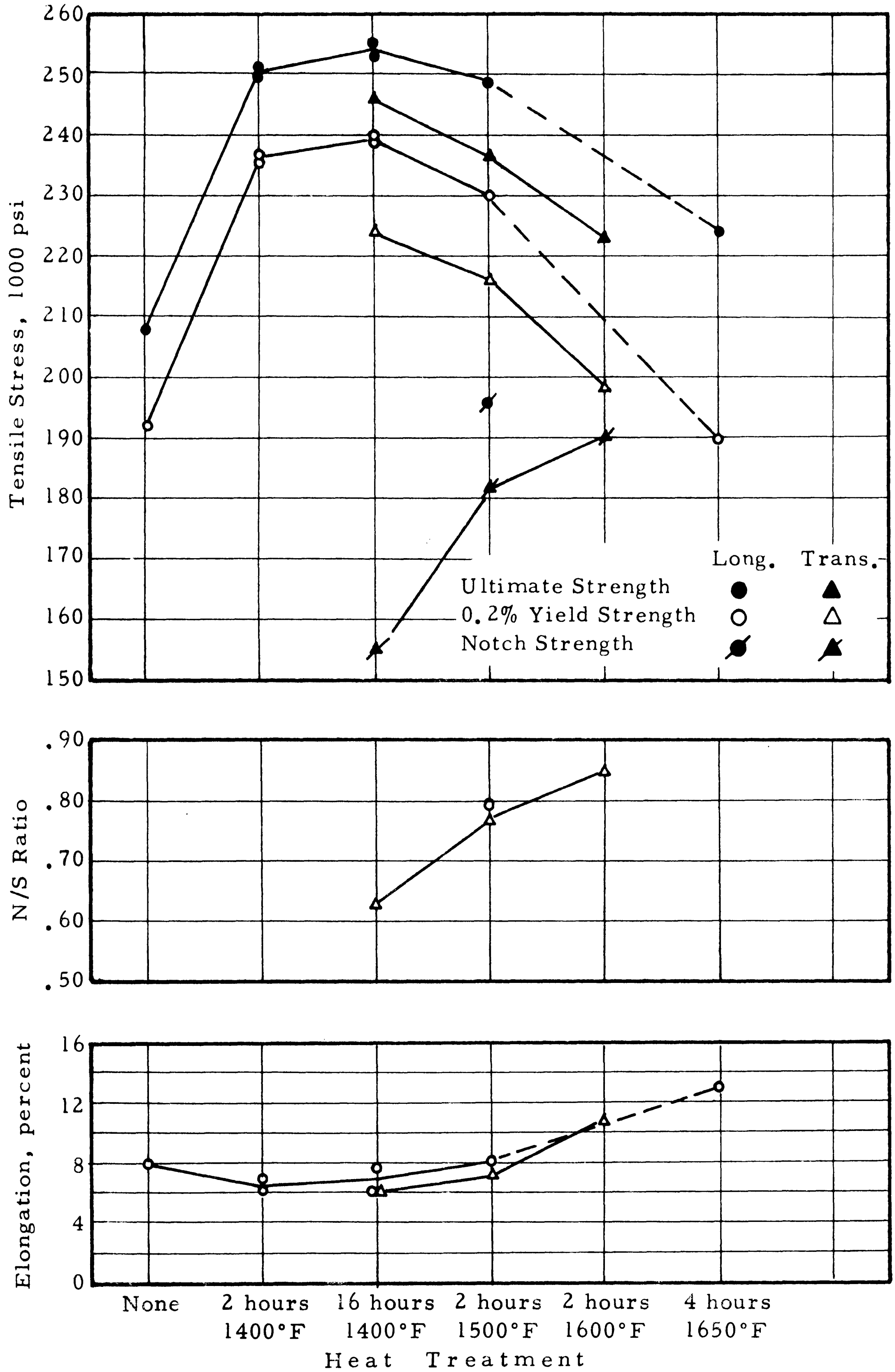
b) Specimen with sharp edge notches

Figure 1 - Test specimens used for screening tests. (All dimensions in inches)



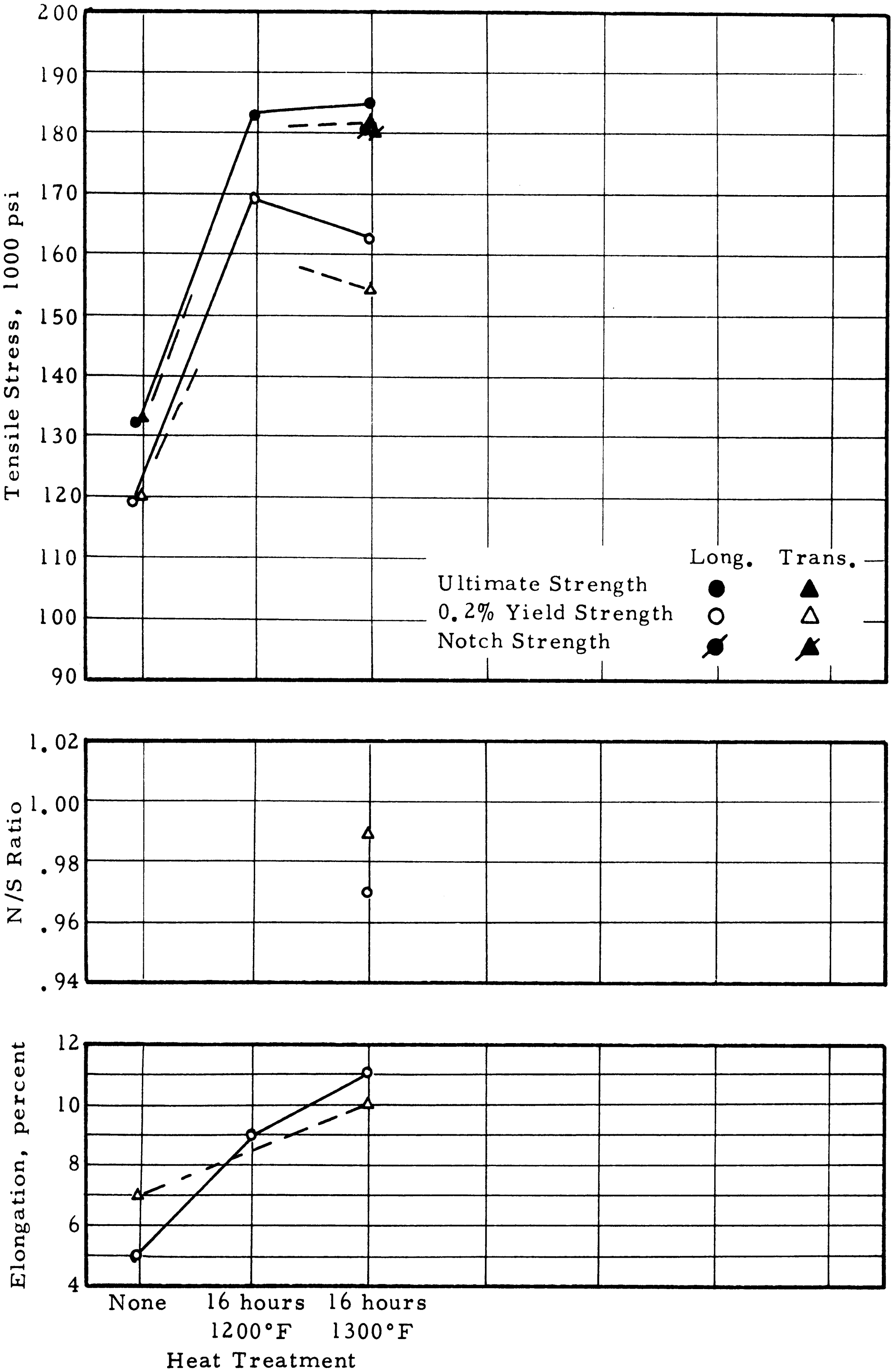
(a) Results for 20-percent cold worked sheet

Figure 2. Effect of heat treatment on the room temperature tensile properties of Rene' 41 alloy.



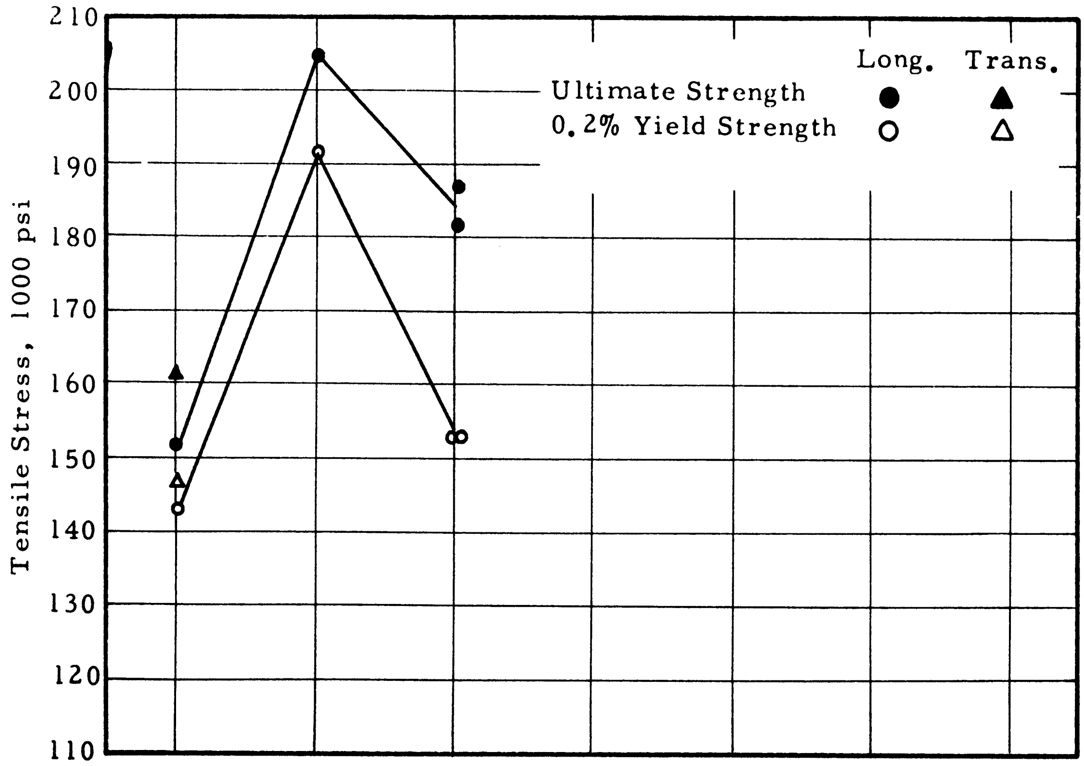
(b) Results for 35-percent cold worked sheet

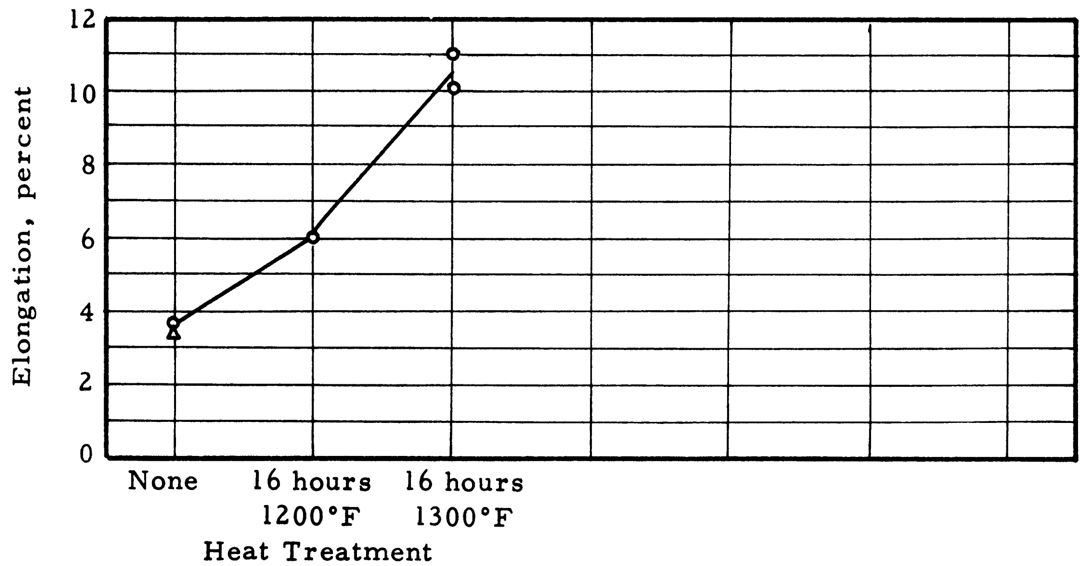
Figure 2 (concluded) Effect of heat treatment on the room temperature tensile properties of Rene' 41 alloy.



(a) Results for 30-percent cold worked strip

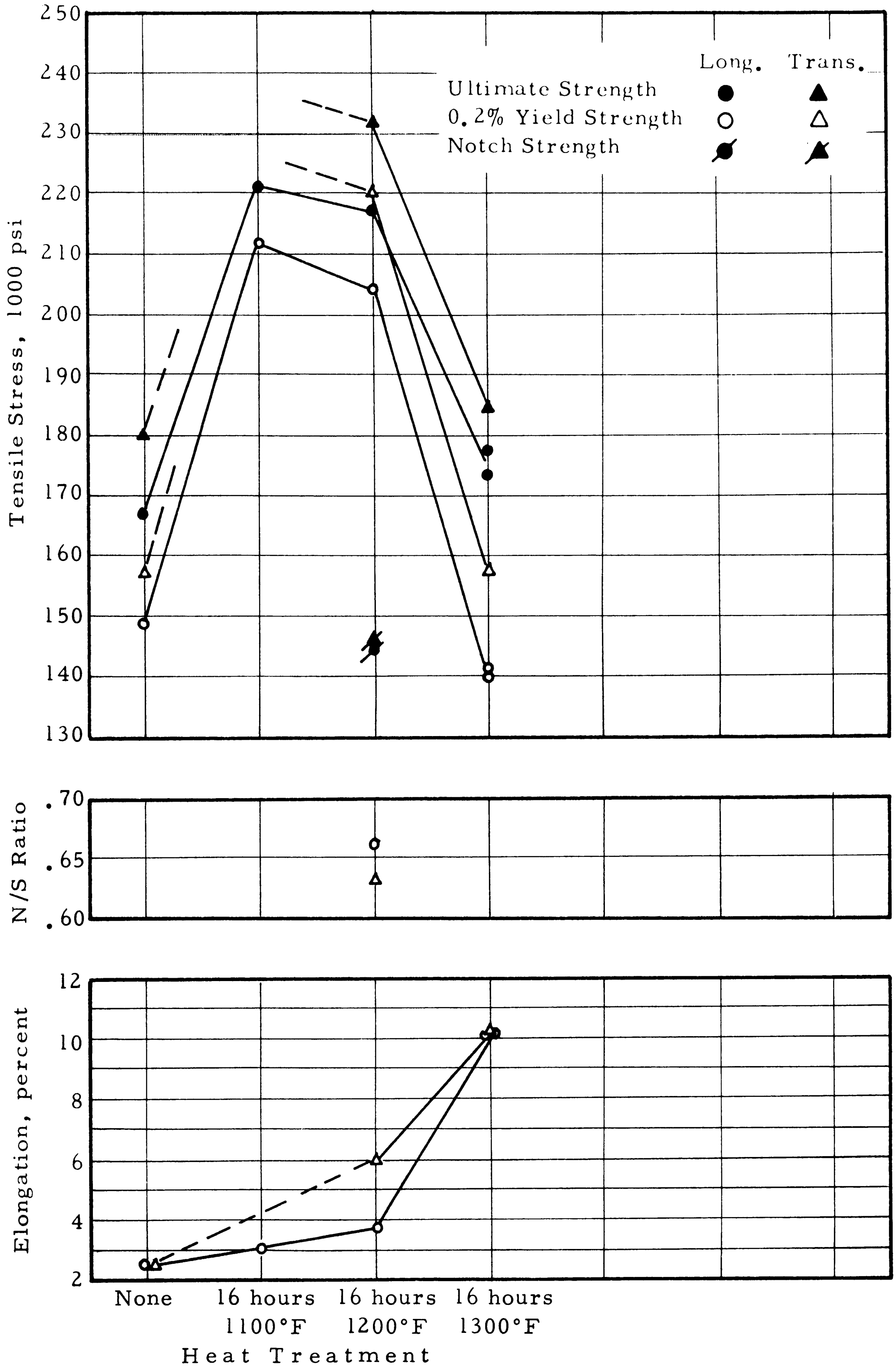
Figure 3. Effect of heat treatment on the room temperature tensile properties of A-286 alloy.





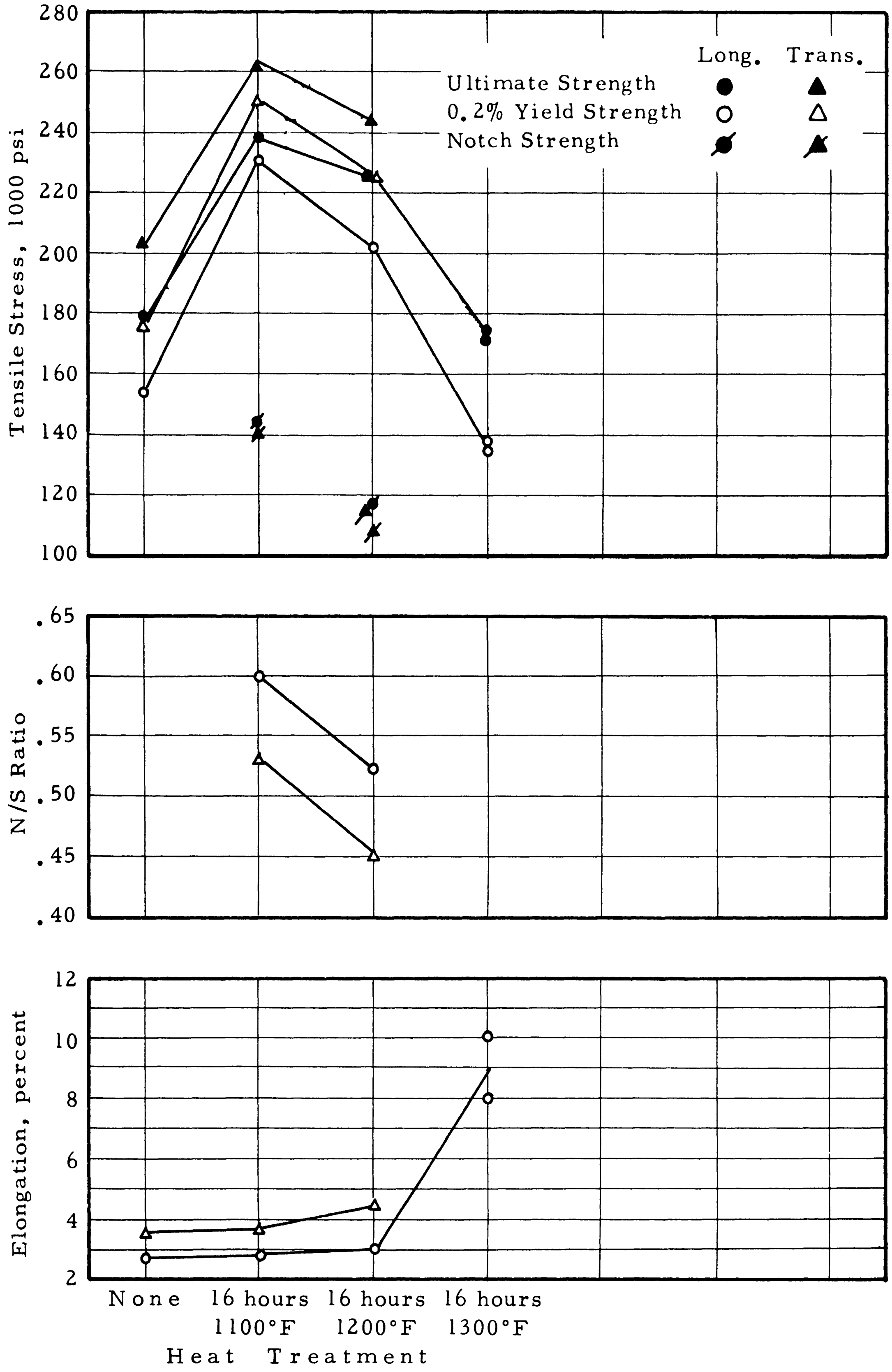
(b) Results for 50-percent cold worked strip

Figure 3 (continued) Effect of heat treatment on the room temperature tensile properties of A-286 alloy.



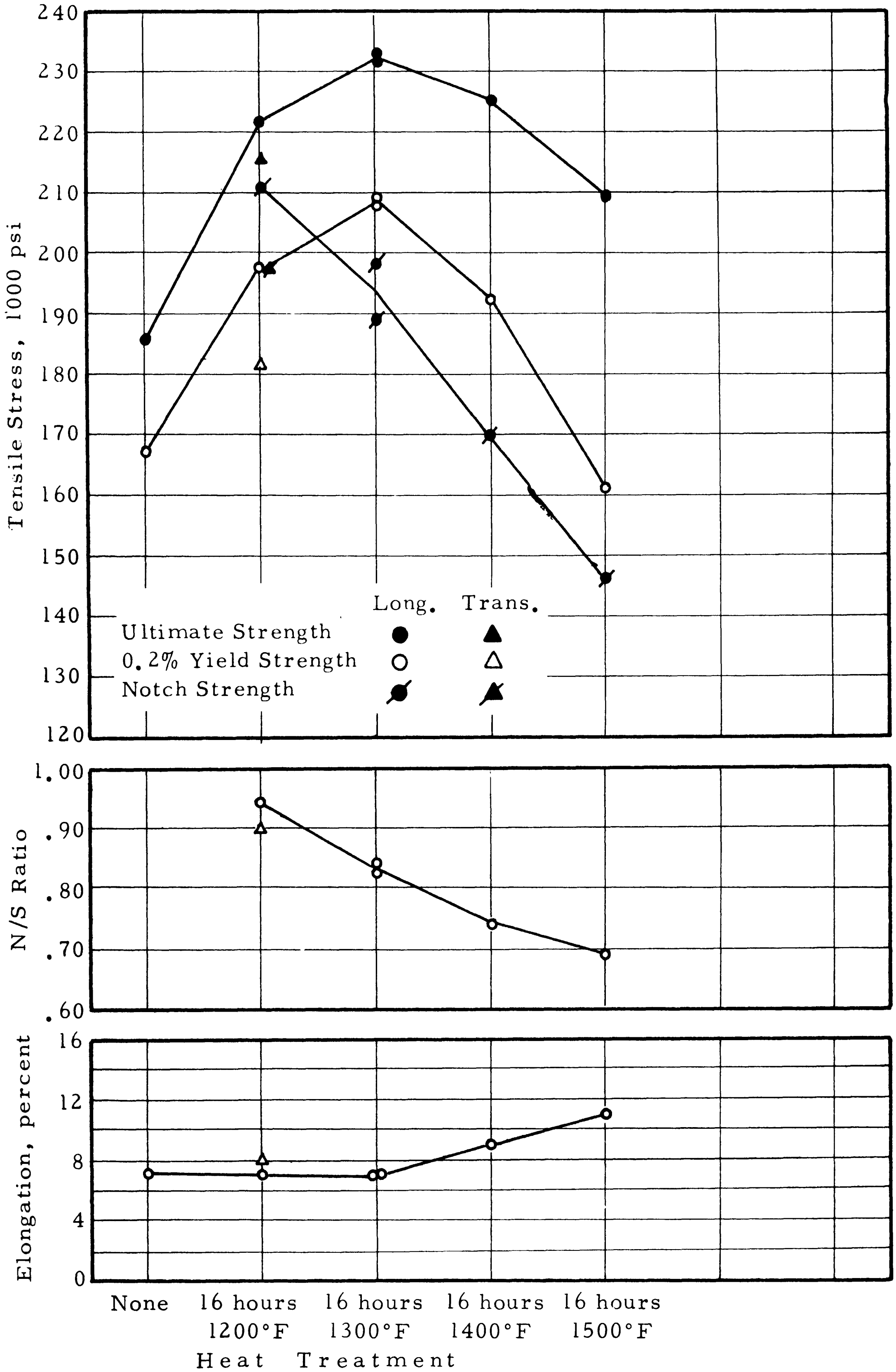
(c) Results for 65-percent cold worked strip

Figure 3 (continued) Effect of heat treatment on the room temperature tensile properties of A-286 alloy.



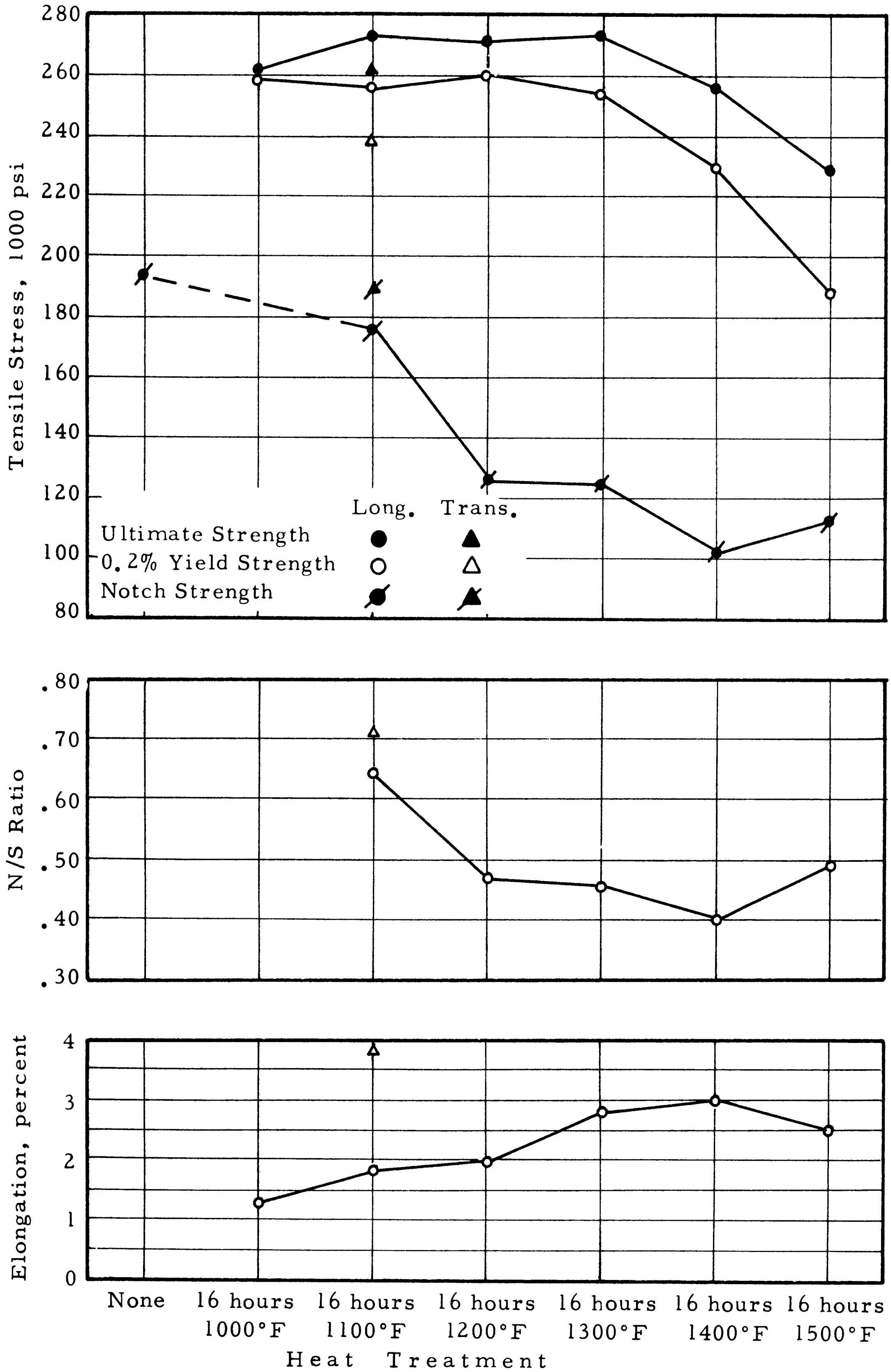
(d) Results for 80-percent cold worked strip

Figure 3 (concluded) Effect of heat treatment on the room temperature tensile properties of A-286 alloy.



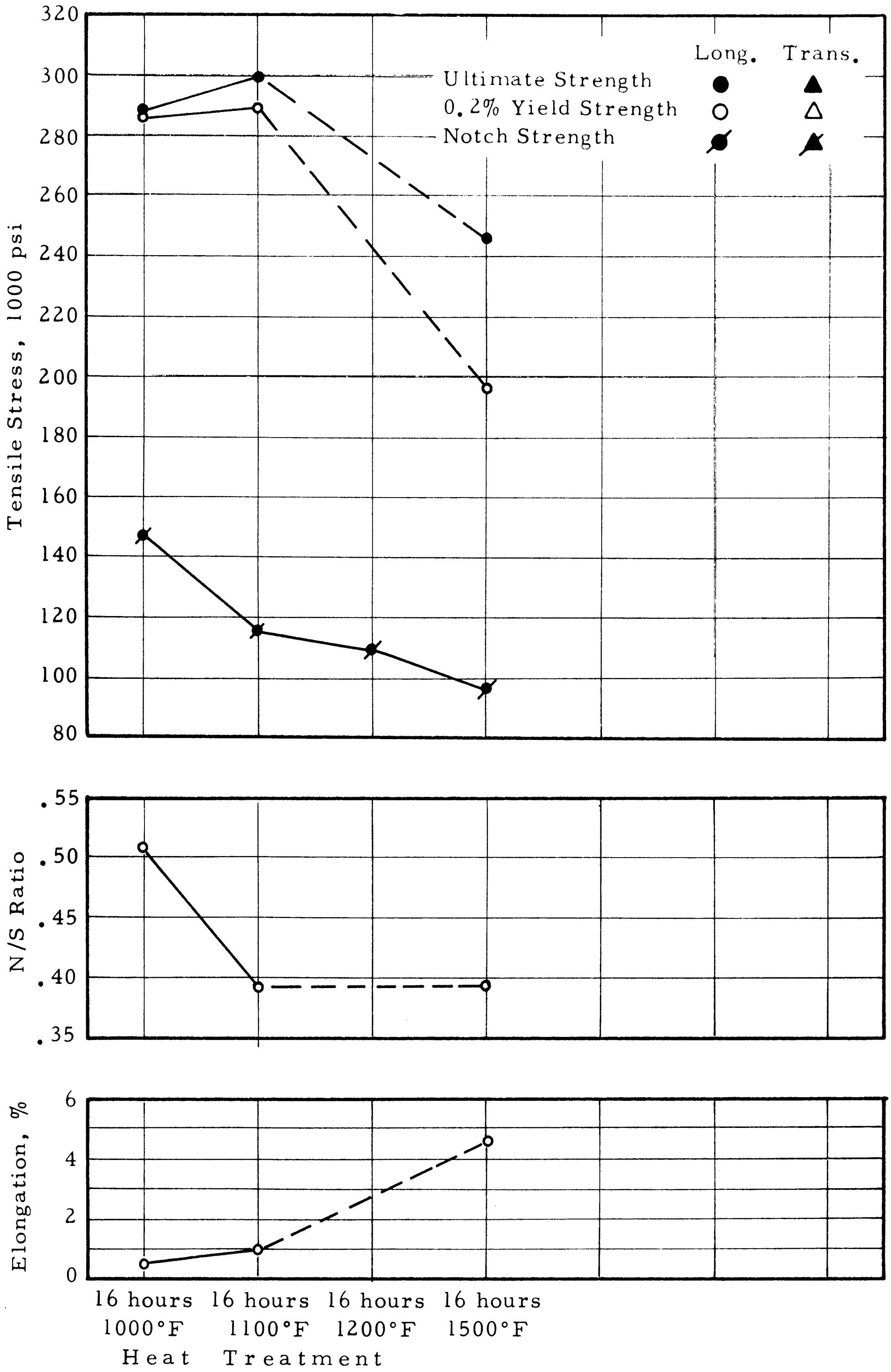
(a) Results for 30-percent cold worked strip

Figure 4. Effect of heat treatment on the room temperature tensile properties of D-979 alloy.



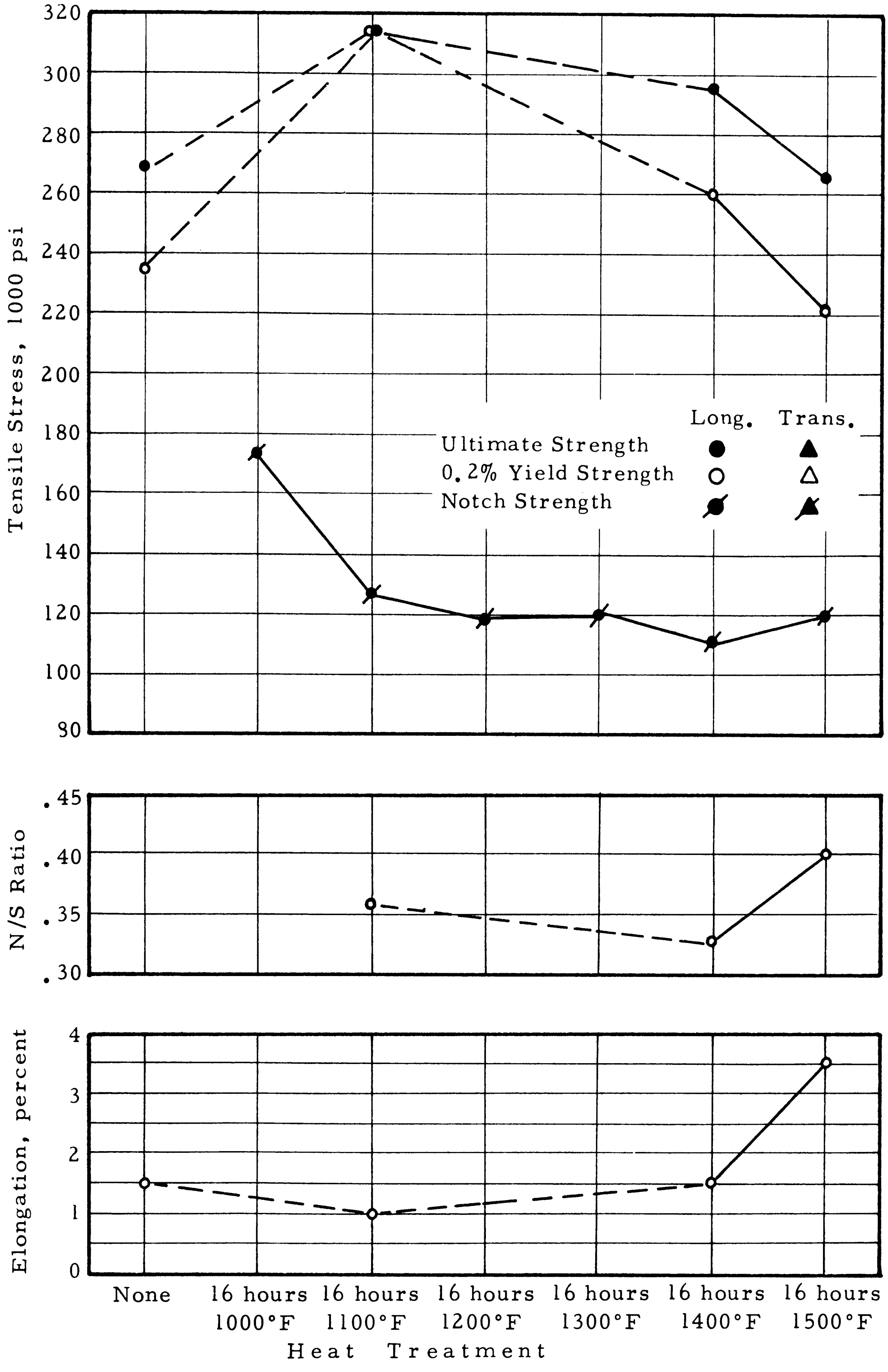
(b) Results for 50-percent cold worked strip

Figure 4 (continued) Effect of heat treatment on the room temperature tensile properties of D-979 alloy.



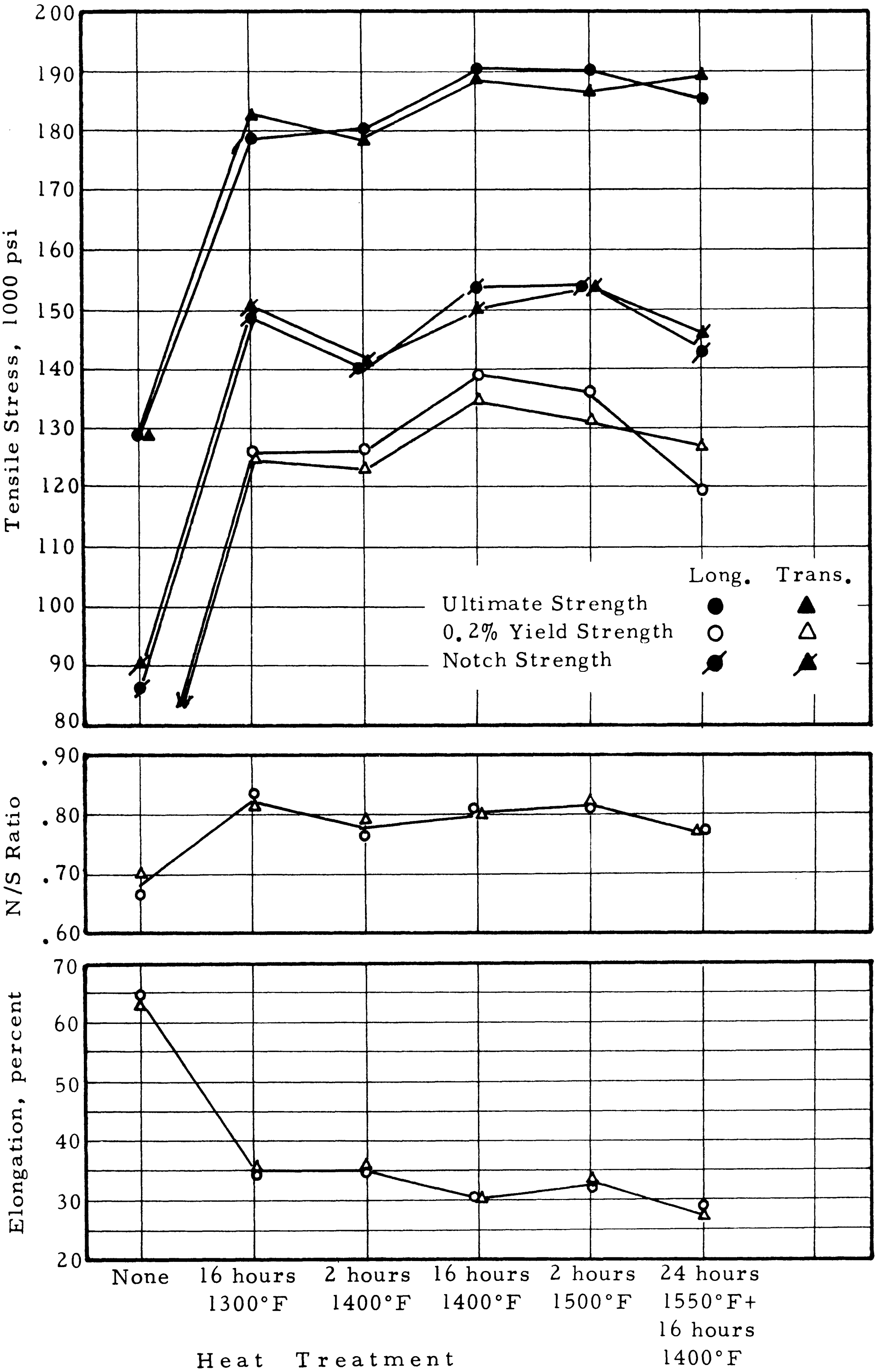
(c) Results for 65-percent cold worked strip

Figure 4 (continued) Effect of heat treatment on the room temperature tensile properties of D-979 alloy.



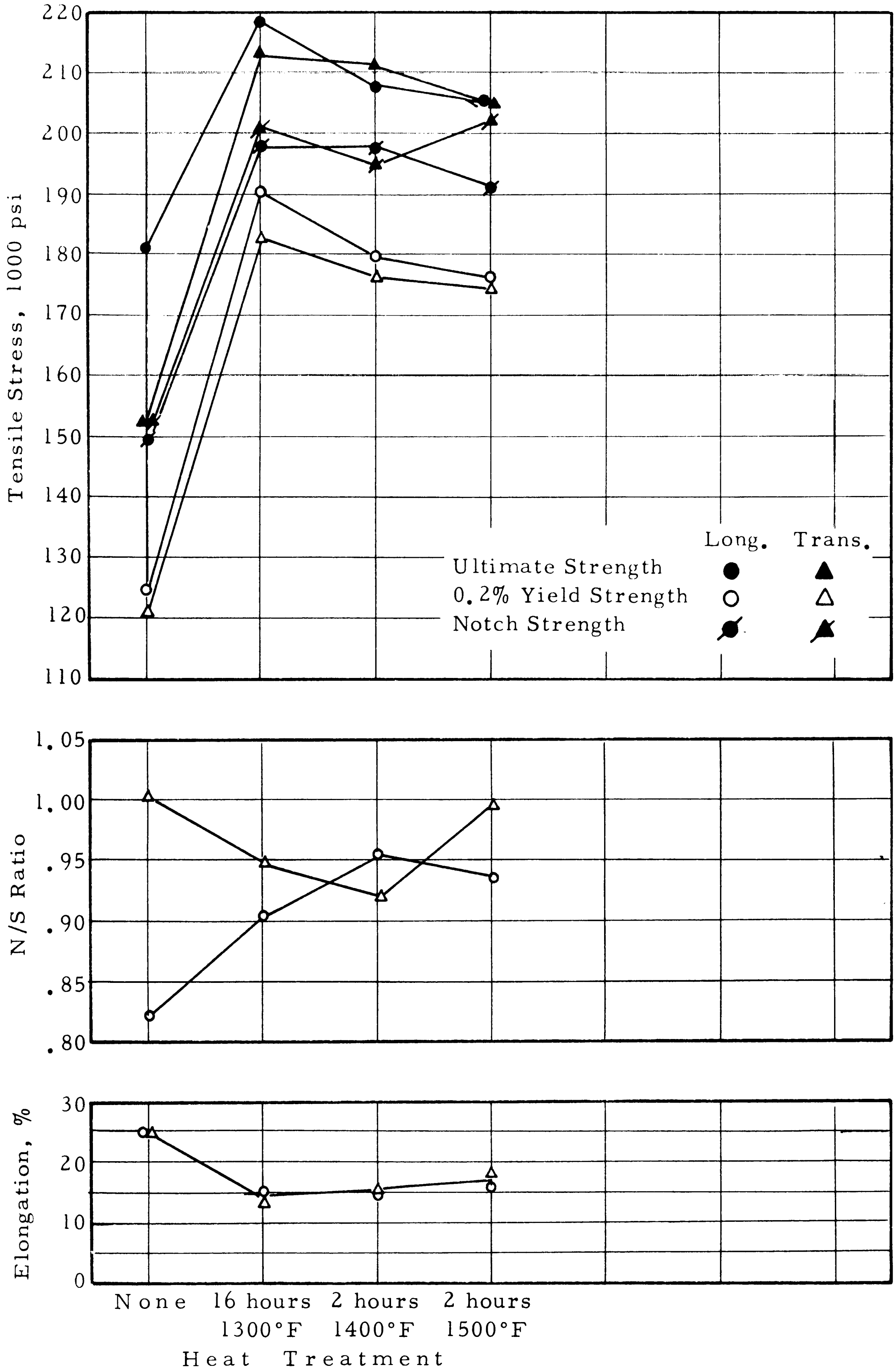
(d) Results for 80-percent cold worked strip

Figure 4 (concluded) Effect of heat treatment on the room temperature tensile properties of D-979 alloy.



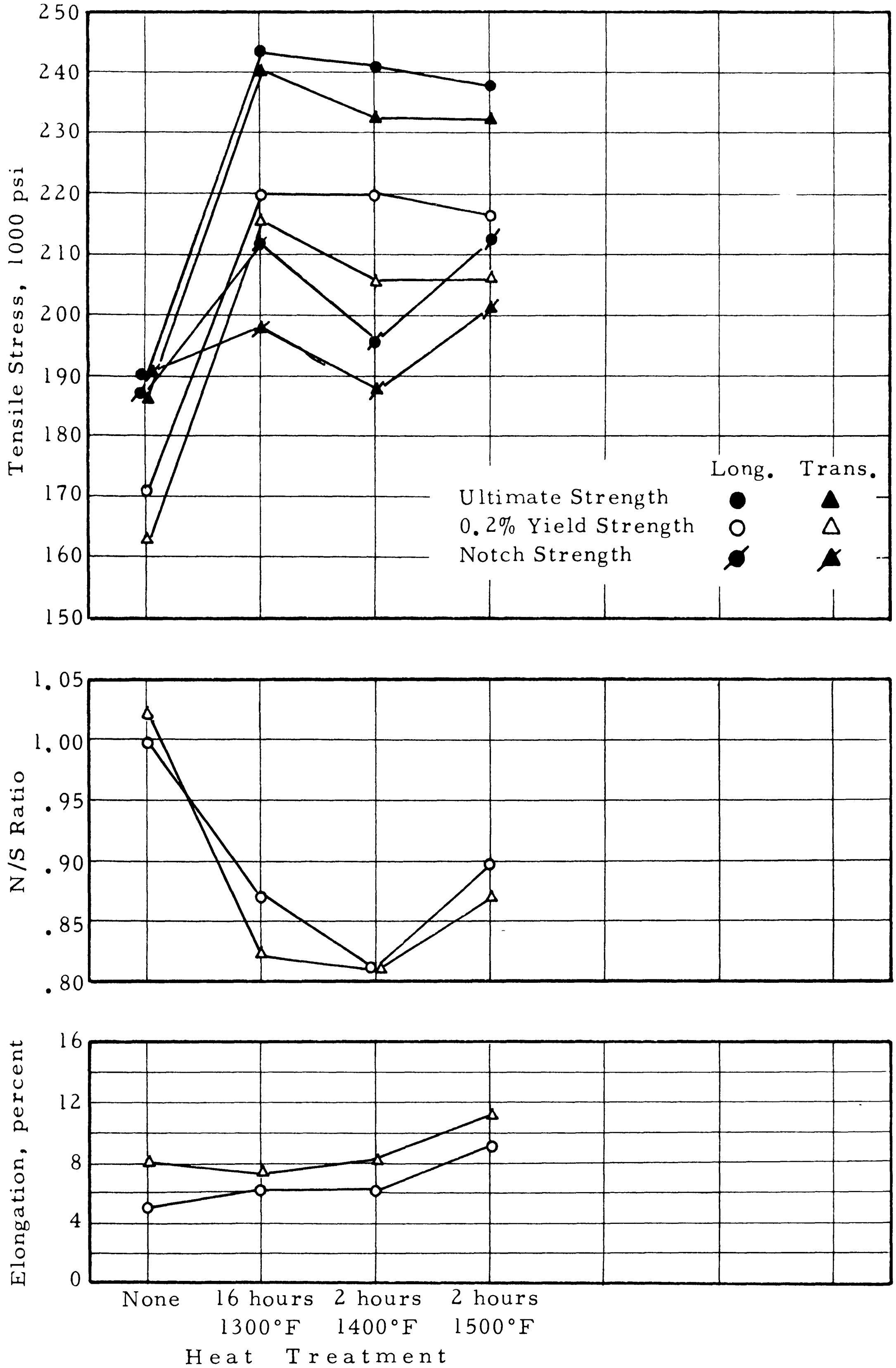
(a) Results for annealed sheet

Figure 5. Effect of heat treatment on the room temperature tensile properties of Waspaloy alloy.



(b) Results for 20-percent cold worked sheet

Figure 5 (continued) Effect of heat treatment on the room temperature tensile properties of Waspaloy alloy.



(c) Results for 40-percent cold worked sheet

Figure 5 (concluded) Effect of heat treatment on the room temperature tensile properties of Waspaloy alloy.