THE EFFECT OF THERMOMECHANICAL PROCESSING VARIATIONS ON THE MECHANICAL PROPERTIES AND STRUCTURAL CHARACTERISTICS OF UNITEMP C-300

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Abstract

Unitemp C-300 is an experimental nickel-base high temperature alloy which has displayed very promising strength capabilities. The alloy was developed as a modification of the original NASA IIb alloy system, and was designed specifically for optimum properties in the 1200°F temperature range. In addition, recent studies have indicated the alloy responds favorably to full solution heat treatment and improved properties at higher temperatures. This paper summarizes studies conducted to establish the effects of several thermomechanical processing variations on mechanical properties, and also establishes the versatility of Unitemp C-300 for high and low temperature applications. In addition to the mechanical property data, supporting structural studies are described including optical microscopy and X-ray diffraction of extracted residues.

Introduction

Although turbine engine technology has grown tremendously during its nearly thirty year existence, further advancements have some limitations. This situation can be attributed primarily to the lack of viable superalloy development programs. Engine designers have theoretically realized increased thrusts by: 1) increasing engine operating temperatures and developing advanced superalloys capable of maintaining current property levels at the higher temperatures, or 2) maintaining current operating temperatures and developing advanced superalloys capable of improved properties at the same temperatures. As a result, further significant advancement in turbine engine technology is greatly dependent upon advanced superalloy development efforts.

Both approaches noted above for increasing thrust capabilities are being explored by the various engine manufacturers. For example, some manufacturers have designed engines to operate at rather low temperatures - up to 1200°F in the hot section. Accordingly, these manufacturers are striving for wheel and disk alloys which exhibit very high 1200°F strength and rupture properties. On the other hand, other major producers have designed engines to achieve increased thrusts by increasing operating temperatures to the area of 1400°F and above in the hot section. Others would like to further increase operating temperatures to the 1500° and 1600°F range. These manufacturers desire superalloys which exhibit high strength and rupture properties at 1400°F and above.

This wide variety of property requirements clearly defines the need for versatile superalloys. In exploring the capabilities of current alloys, it is apparent that a variety of heat treatments and processing methods have been developed to optimize the properties of an alloy for a given application. Alloys developed for applications up to 1200°F such as Rene' 95 employ processing at low working temperatures in conjunction with a partial solution heat treatment (below the recrystallization temperature). This results in optimum strength and rupture characteristics up to 1200°F; however, while tensile strength is maintained beyond 1200°F to a degree, rupture characteristics decline severely. Alloys such as Udimet 700 were developed for applications up to 1400°F. Alloys of this type employ a full solution heat treatment which produces a fully recrystallized grain structure. Although tensile capabilities are decreased as compared with partial solution heat treated material, this treatment permits retention of desirable stress rupture characteristics at 1400°F and above.

Unitemp C-300 is an experimental nickel-base superalloy developed by Universal-Cyclops Specialty Steel Division under NASA sponsorship.(1,2) Preliminary indications are that this alloy displays a greater degree of versatility than any alloy developed to date. The alloy exhibits properties superior to Rene' 95 for partial solution heat treatment applications, and also responds favorably to full solution heat treatment displaying better strength characteristics than Udimet 700. This report summarizes studies conducted to determine the effect of processing variables on the mechanical properties of Unitemp C-300. To investigate the versatility of the alloy, the effects of all processing variables were determined for both full and partial solution heat treated material.

Procedure

Melting

The material used for this study was double vacuum melted. Initially, one 50 pound heat was vacuum induction melted to the nominal chemical analysis for Unitemp C-300 shown in Table I. The heat was cast into a 2-1/2 inch diameter electrode, then consumable-arc remelted into two 3-1/8 inch diameter ingots weighing approximately 25 pounds each.

Processing

The two 3-1/8 inch diameter ingots were sectioned in half, machined to 2-1/2 inches in diameter and canned in 1/2 inch thick mild steel in preparation for extrusion. The four canned billets were extruded to 1.065 inch diameter bars after soaking for one hour at temperature. One billet was extruded from a 2050°F temperature and the remaining three were extruded from 2150°F.

To provide material for the rolling studies, nine pieces approximately six inches long each were sectioned from the bars extruded from 2150°F, and three pieces of the same length were sectioned from the bar extruded from 2050°F. The material extruded from 2150°F was rolled in groups of three pieces each from rolling temperatures of 1950°, 2025°, and 2100°F. In addition, the three pieces extruded from 2050°F were also rolled from a temperature of 2025°F. All bars were soaked at temperature for one-half hour prior to rolling. The bars were processed by the same method to 1/2 inch diameter product using increasing percentage reductions per reheat from 10 to 22 percent with intermediate reheating at desired rolling temperatures for seven minutes. No additional canning was necessary for rolling, as a 1/8 inch thick layer of mild steel can remained following extrusion.

This processing schedule permitted a determination of the effects of the following variations on final properties:

- Effect of extrusion temperature on as-extruded material
    - 2050°F extrusion (#1)
    - 2150°F extrusion (#2)

- Effect of extrusion temperature on extruded plus rolled material
    - 2050°F extrusion + 2025°F rolling (#3)
    - 2150°F extrusion + 2025°F rolling (#4)

- Effect of rolling temperature on extruded plus rolled material
    - 2150°F extrusion (as-extruded) (#2)
    - 2150°F extrusion + 1950°F rolling (#5)
    - 2150°F extrusion + 2025°F rolling (#4)
    - 2150°F extrusion + 2100°F rolling (#6)

A total of six individual variations were evaluated.

Heat Treatment

Material for mechanical property testing was subjected to both full and partial solution heat treatments. The specific treatments chosen were as follows:

Full solution heat treatment:
2250°F/2 hours/RAC + 1600°F/16 hours/RAC + 1400°F/16 hours/AC

Partial solution heat treatment:
1600°F/16 hours + increase to 2000°F/1 hour/OQ + 1400°F/16 hours/AC

These treatments were chosen as the result of a study conducted during the development of the alloy.(2) Heat treatments for material representing each of the processing variations were held constant in an effort to maintain the direct effects of the processing variations.

Mechanical Property Testing

A total of twenty-four specimens were sectioned and machined representing each of the six processing variables previously listed. Twelve were subjected to the full solution heat treatment and the partial solution heat treatment was applied to the remaining twelve. Testing was the same for both full and partial solution heat treated material. Duplicate tensile tests were conducted at room temperature, 1200° and 1400°F. In addition, duplicate stress rupture tests were conducted at 1200°F/175,000 psi, 1300°F/125,000 psi, and 1400°F/90,000 psi.

Structural Examinations

Structural examinations were conducted on material representing each of the six processing variations in both the full and partial solution heat treated conditions. The examinations included metallographic studies and X-ray phase analyses.

Samples were prepared for metallographic examination by mechanical polishing through various abrasive grit papers and diamond polishing wheels. Etching was performed in a combination of the following two solutions, depending upon the response of the material and the desired effect:

1) 60 percent water
   15 percent sulfuric acid
   15 percent hydrofluoric acid
   9 percent nitric acid
   1 percent hydrogen peroxide

2) 85 percent water
   14 percent hydrochloric acid
   1 percent hydrogen peroxide

Sample preparation for X-ray phase analysis involved machining to a standard size, then sand blasting at low pressure. An electrolytic cleaning operation for ten minutes in a ten percent solution of hydrochloric acid in methanol preceded the actual extraction. Extractions were conducted in a new mixture of the same hydrochloric acid/methanol solution for one-half hour using a current density of approximately 0.25 amp per square inch. The extracted residues were cleaned in methanol, dried, mounted on glass slides and subjected to X-ray diffraction analysis to identify the phases present.

Results

Melting and Processing

The actual chemical composition of the 50 pound vacuum induction heat melted for this study is listed in Table I. The overall workability of the heat was rated good. The material extruded from 2050°F experienced slight cracking at the nose and tail areas of the bar; however, this marginal workability was anticipated. Past work has shown this 2050°F temperature to be very near the lower limit for primary hot working, and it was chosen in this study only to provide a valid experimental extrusion temperature variation. Extrusion workability from the 2150°F extrusion temperature was good.

Although the 2150°F temperature resulted in the best extrusion workability, the studies indicated that subsequent workability during rolling of material extruded from 2150°F was slightly inferior to the rolling workability of material extruded from 2050°F. With respect to the rolling (or secondary working) temperature variations conducted on material extruded from 2150°F, low rolling temperatures resulted in the most favorable workability. For example, rolling from 1950°F effected the best workability, while increasing amounts of cracking were observed as the rolling temperature was increased to 2025°F, then to 2100°F.

Mechanical Property Testing

Effect of Extrusion Temperature on As-Extruded Material - The effects of two extrusion temperatures (2050° and 2150°F) on the tensile and stress rupture properties of as-extruded Unitemp C-300 subjected to partial solution heat treatment are summarized in Figures 1 and 2. In general, tensile and rupture strength levels were higher for material extruded from 2150°F. Ductility values were similar but generally slightly higher for material extruded from 2150°F, except for several stress rupture reduction of area values. Figures 3 and 4 depict the effects of the same extrusion temperature variations on material subjected to a full solution heat treatment. With respect to tensile and rupture strengths, the material extruded from 2150°F again displayed slightly higher strength levels; however, no definite trends were established with regard to ductility, all values being relatively similar.

A comparison of properties displayed by material in the partial solution heat treated condition as opposed to material in the full solution heat treated condition revealed several interesting effects. The partial solution heat treatment normally results in higher room temperature ultimate and yield strength from room temperature to 1400°F. However, while ultimate strength at room temperature and yield strengths at room temperature and 1200°F were higher for partial solution heat treated material, full solution heat treated material displayed higher 1200° and 1400°F ultimate and 1400°F yield strengths. Tensile ductility was better at room temperature for partial solution heat treated material, while elevated temperature ductility was higher for material subjected to the full solution heat treatment. As anticipated, 1200°F rupture strength was slightly better for partial solution heat treated material, while full solution heat treated material displayed the best rupture strengths at 1300° and 1400°F.

Effect of Extrusion Temperature on Extruded Plus Rolled Material - The effects of two initial extrusion temperatures (2050° and 2150°F) on the tensile and stress rupture properties of Unitemp C-300 subsequently rolled from 2025°F are shown in Figures 5 and 6 for material subjected to a partial solution heat treatment. Ultimate tensile and yield strength values and rupture strength values from room temperature to 1400°F were superior for material extruded from 2150°F. Although this general trend was observed previously for as-extruded material, the superiority of the material extruded from 2150°F is much more pronounced after rolling. Although room temperature tensile ductility was higher for material extruded from 2050°F, tensile ductility at elevated temperatures (i.e., 1200° and 1400°F) and rupture ductility at all temperatures evaluated were superior for material extruded from 2150°F.

As shown in Figure 7 and 8 for full solution heat treated material subjected to the same processing variations, the 2150°F extrusion temperature was again superior. Ultimate tensile and yield strengths, rupture strengths and tensile and rupture ductilities were improved over those displayed by material extruded from 2050°F over the entire range of temperatures investigated.

A comparison of tensile and stress rupture properties displayed by full versus partial solution heat treated material revealed the general trends anticipated. For example, the partial solution treated material exhibited considerably higher ultimate tensile and yield strength levels than were displayed by full solution heat treated material from room temperature to 1400°F. In addition, the rupture strength of the partial solution heat treated material was better at 1200°F; however, at 1300° and 1400°F, rupture strengths displayed by full solution heat treated material were superior. With respect to tensile ductility, no definite trends were observed at room temperature; but, at 1200° and 1400°F, full solution heat treated material displayed higher ductility values. The effects observed for rupture ductility were opposite for the two heat treatments; partial solution heat treated material displayed low ductility values at 1200°F and steadily increasing values to 1300° then 1400°F, while full solution heat treated material displayed high values at 1200°F and steadily declining values to 1300°, then 1400°F.

Effect of Rolling Temperature on Extruded Plus Rolled Material - The effects of three rolling temperatures (1950°, 2025°, and 2100°F) on the tensile and stress rupture properties of Unitemp C-300 initially extruded from 2150°F are shown in Figures 9 and 10 for material in the partial solution heat treated condition. Also included on each figure for comparison are the properties of as-extruded material. The general effects for ultimate tensile and yield strengths indicated increasing strength with decreasing rolling temperatures, although all rolled material showed a very significant increase in strength compared with as-extruded material. For example, room temperature ultimate tensile strength values increased from approximately 240,000 to 280,000 to 290,000 to 300,000 psi for as-extruded material, material rolled from 2100°F, material rolled from 2025°F and material rolled from 1950°F, respectively. In addition, decreased rolling temperatures also resulted in increased ductility at 1200° and 1400°F. Little variation with regard to rupture strength at all test temperatures resulted from the rolling temperature variations. As-extruded material displayed lower rupture strength at 1200°F than the rolled materials, but the extruded material displayed considerably higher rupture strength than any of the rolled materials at 1300° and 1400°F. (The higher rupture properties at 1300° and 1400°F are explained later in that the 2150°F extrusion temperature resulted in a recrystallized fine grained structure simulating full solution heat treated material.) Observation of the stress rupture ductility curves indicated rolled material realized considerable ductility improvements over as-extruded material. With respect to the rolled materials, little ductility variation was observed at 1200°F, but material rolled from 1950° and 2025°F appeared to exhibit higher ductility at 1300° and 1400°F than material rolled from 2100°F.

The effect of rolling temperature variations on the tensile and stress rupture properties of material subjected to a full solution heat treatment is depicted in Figures 11 and 12. Tensile strength values were generally higher for materials rolled from 1950° and 2025°F, while material rolled from 2100°F displayed lower strengths. One very interesting feature concerns the tensile strength properties of as-extruded material. While ultimate strength values for as-extruded material were low at room temperature and 1200°F, the 1400°F ultimate tensile strength of the as-extruded material was higher than displayed by any of the rolled materials. Perhaps more surprising were the yield strength values for the as-extruded material which were higher than observed for any of the rolled materials over the entire temperature range investigated. Tensile ductility values for as-extruded material were lower than observed for any of the rolled materials. Material rolled from 2100°F displayed ductility values slightly improved as compared with as-extruded material, but inferior to the values displayed by the materials rolled from 1950° and 2025°F which exhibited the best ductilities. With respect to rupture strength, the as-extruded material displayed higher strengths than material rolled from 2100°F. However, strength values displayed by material rolled from 1950° and 2025°F were superior. The same trends observed regarding tensile ductility were also apparent for rupture ductility. As-extruded material displayed the lowest values. Material rolled from 2100°F displayed better ductility than as-extruded material, but values were not as high as those observed for materials rolled from 1950° and 2025°F.

With respect to partial versus full solution heat treated materials, trends observed were similar to those described previously for rolled materials. Ultimate tensile and yield strengths were superior for partial solution heat treated material over the entire temperature range. Partial solution heat treated material also displayed higher rupture strength at 1200°F; but, at 1300° and 1400°F, higher rupture strengths were displayed by full solution heat treated material. With respect to tensile ductility at room temperature, no definite trends were apparent; however, full solution heat treated material displayed better ductility at 1200° and 1400°F. Again, opposite effects were observed for rupture ductility with partial solution heat treated material displaying increasing ductility with increasing temperature, and full solution heat treated material displaying decreasing (but adequate) ductility with increasing temperature.

Structural Examinations

Metallographic examination of samples representing each of the processing variations subjected to a full solution heat treatment revealed similar microstructures as shown in Figure 13 for material extruded from 2150°F and rolled from 2025°F. Although general microstructures for all full solution heat treated samples were similar, grain size variations were apparent. These grain size effects as a function of processing variables are summarized in Table II. Extrusion temperature variations had no effect on the grain size of as-extruded material, but the 2150°F extrusion temperature as opposed to 2050°F resulted in a finer grain structure after rolling from 2025°F. With respect to rolling temperature variations, all rolled material displayed finer grain structures than extruded material, with decreasing rolling temperatures from 2100° to 1950°F resulting in progressively finer structures.

A typical partial solution heat treated microstructure is depicted in Figure 14 for material extruded from 2050°F. This unrecrystallized microstructure was representative of all material with the exception of material extruded from 2150°F. As shown in Figure 15, this higher extrusion temperature effected some degree of recrystallization. Although grain size was quite fine, the degree of recrystallization was much too advanced for a partial solution treatment to achieve the desired effects. However, the rolling temperature variations from 2100°, 2025° and 1950°F conducted on material extruded from 2150°F resulted in grain refinement and partial solution heat treatment of these materials resulted in structures similar to that illustrated in Figure 14.

Results of the X-ray diffraction studies conducted on full solution heat treated material subjected to the six processing variations are summarized in Table III. The only carbide phase detected in any of the materials was an MC type. Data scatter for the extrusion temperature variations did not permit any definite conclusions; however, rolling studies revealed a definite trend towards larger quantities of MC carbides with decreasing rolling temperatures from 2100° to 1950°F.

X-ray results for material processed according to the same variations and subjected to a partial solution heat treatment are summarized in Table IV. In this case, three carbide phases were detected including the same MC carbide found in full solution heat treated material. In addition, a lower parameter MC carbide (designated MC') and a M_6C carbide were discovered. Again, no definite trends were established as a function of extrusion temperature, although the relative amount of carbides was proportionally lower. However, rolling temperature variations revealed the same trends as observed for the MC carbides in full solution heat treated material. The three carbide phases present all increased in amount with decreasing rolling temperatures from 2100° to 1950°F.

Summary

The primary objective of this study was to determine the optimum processing methods for producing Unitemp C-300 for low temperature applications using a partial solution heat treatment and for higher temperature applications using a full solution heat treatment. A secondary objective was to establish the versatility of the alloy as compared with Rene' 95, the best alloy currently available for low temperature applications, and compared with Udimet 700, one of the best alloys currently available for high temperature applications. As discussed earlier, while each of these alloys performs well for its specific application (low or high temperature), neither is versatile enough to respond favorably to both full and partial solution heat treatments.

A review of the processing studies conducted here indicated the optimum extrusion (or primary working) temperature for Unitemp C-300 was 2150°F. This temperature yielded superior properties for both full and partial solution heat treated material. With respect to the optimum rolling (or secondary working) temperature, similar properties were displayed by materials rolled from 2025° and 1950°F; however, the 1950°F rolling temperature was rated to yield the best overall combination of tensile and stress rupture characteristics for both full and partial solution heat treated material.

A comparison of tensile and stress rupture strength capabilities displayed by Unitemp C-300 processed by the optimum method determined and by Rene' 95 is depicted in Figure 16. Both alloys were partial solution heat treated for optimum low temperature properties. As shown, ultimate tensile strength values for Unitemp C-300 of 300,000 psi at room temperature and 265,000 psi at 1200°F represent approximately 30 percent increases beyond the corresponding ultimate strengths exhibited by Rene' 95. Unitemp C-300 yield strength values of 265,000 and 240,000 psi at room temperature and 1200°F, respectively, represent nearly 40 percent increases beyond corresponding yield strength values for Rene' 95. In fact, tensile and yield strength values for Unitemp C-300 at 1400°F exceed the 1200°F strength levels for Rene' 95. Rupture strength levels attained by Unitemp C-300 were also significantly improved beyond Rene' 95 capabilities. For example, average rupture life at 1200°F/175,000 psi for Unitemp C-300 was about 80 hours compared to 15 hours for Rene' 95 -- more than a 400 percent improvement.

Figure 17 illustrates a similar comparison for Unitemp C-300 processed by the optimum method determined and for Udimet 700. In this case, both alloys were full solution heat treated for optimum high temperature properties. Unitemp C-300 displayed considerably higher ultimate tensile and yield strength values over the range from room temperature to 1400°F. At 1400°F, the critical temperature for full solution heat treatment applications, the ultimate tensile and yield strengths of 185,000 and 155,000 psi exhibited by Unitemp C-300 represent 25 to 30 percent increases with respect to corresponding Udimet 700 properties. The superiority of Unitemp C-300 was more apparent with regard to rupture strength. Again, at stress rupture conditions of 1400°F/90,000 psi, the average rupture life exhibited by Udimet 700 was approximately 20 hours, while the corresponding rupture life for Unitemp C-300 was approximately 30 times longer at nearly 600 hours.

These studies have resulted in the development of optimum processing parameters for Unitemp C-300, and clearly establish the exceptional versatility of the alloy for both high and low temperature applications. The strength characteristics exhibited by the alloy significantly exceed those of the best currently available alloys.

Conclusions

Based upon the work conducted during this investigation, the following conclusions have been formulated:

1) Extrusion workability was better for material extruded from 2150°F; however, material extruded from 2050°F displayed better workability during subsequent rolling operations.

2) With respect to rolling temperature variations after initial extrusion, the 1950°F temperature resulted in the best workability. Increasing rolling temperatures to 2025° and 2100°F resulted in decreasing workability.

3) Extrusion from 2150°F as opposed to 2050°F resulted in generally higher tensile and rupture strength capabilities and higher ductilities for both full and partial solution heat treated material. These effects were observed for as-extruded material and extruded plus rolled material.

4) Secondary working via rolling imparted much higher strength capabilities for partial solution heat treated material than were attained after primary working via extrusion; however, rupture strengths beyond 1200°F were generally higher for as-extruded material.

5) Rolling also resulted in higher ultimate strengths and slightly better rupture strengths for full solution heat treated material, although yield strengths were higher for as-extruded material. Rolling also effected significant ductility improvements beyond as-extruded levels.

6) With regard to the effects of secondary rolling temperatures on resultant properties, decreasing rolling temperatures resulted in generally better strength and ductility values for both full and partial solution treated material.

7) In general, partial solution heat treatments effected higher tensile strength capabilities up to 1400°F, and higher rupture strength at 1200°F; however, rupture strengths at 1300° and 1400°F were significantly higher for full solution heat treated material.

8) Full solution heat treated material extruded from 2150°F resulted in a finer grained microstructure after secondary rolling operations than material initially extruded from 2050°F.

9) For full solution heat treated material, extruded plus rolled material displayed generally finer grained microstructures than as-extruded material; and, decreasing rolling temperatures resulted in progressively finer grained structures.

10) An MC carbide was the only carbide phase detected in full solution heat treated material. Decreasing rolling temperatures from 2100° to 1950°F resulted in increased amounts of the MC carbide.

11) Two MC carbides (varying parameters) were detected in partial solution heat treated material in addition to an M_6C carbide phase. Again, decreasing rolling temperatures resulted in increasing amounts of all carbide phases.

References

1) Kent, W. B., "Wrought Nickel-Base Superalloys", NASA CR-72687, Universal-Cyclops Specialty Steel Division, Cyclops Corporation, March 1970.

2) Kent, W. B., "Development Study of Compositions for Advanced Wrought Nickel-Base Superalloys", NASA CR-120934, Universal-Cyclops Specialty Steel Division, January 1972.

TABLE I

Aim and Actual Chemical Composition for Experimental Heat of Unitemp C-300

Alloy Designation	Chemical Composition (Weight Percent) for: C	Cr	Co	Mo	W	Ta	Al	Ti	V	Hf	B	Zr
UT C-300 (Aim)	0.12	8.70	9.00	2.00	7.60	10.00	3.35	0.70	0.50	1.00	0.02	0.10
UT C-300 (Actual)	0.11	8.10	9.18	1.87	8.07	10.20	3.35	0.68	0.49	0.99	0.02	0.10

TABLE II

ASTM Grain Size Measurements for Full Solution Heat Treated Unitemp C-300

Processing Variation	ASTM Grain Size
Extruded from 2050°F	80% #4, 20% #3
Extruded from 2150°F	80% #4, 20% #3
Extruded from 2050°F + Rolled from 2025°F	80% #4, 20% #5
Extruded from 2150°F + Rolled from 2025°F	90% #5, 10% #6
Extruded from 2150°F	80% #4, 20% #3
Extruded from 2150°F + Rolled from 1950°F	90% #5, 10% #6
Extruded from 2150°F + Rolled from 2025°F	90% #5, 10% #6
Extruded from 2150°F + Rolled from 2100°F	90% #4, 10% #5

TABLE III

X-Ray Diffraction Data For Full Solution Heat Treated Unitemp C-300

Processing Variation	Relative Amount* of Minor Phases Present MC-Type Carbide
Extruded from 2050°F	140
Extruded from 2150°F	120
Extruded from 2050°F + Rolled from 2025°F	144
Extruded from 2150°F + Rolled from 2025°F	160
Extruded from 2150°F	120
Extruded from 2150°F + Rolled from 1950°F	208
Extruded from 2150°F + Rolled from 2025°F	160
Extruded from 2150°F + Rolled from 2100°F	144

*Relative amounts are indicated by X-ray peak heights of a selected line.

TABLE IV

X-Ray Diffraction Data for Partial Solution Heat Treated Unitemp C-300

	Relative Amount* of Minor Phases Present		
Processing Variation	MC-Type Carbide	MC'-Type Carbide	M_6C-Type Carbide
Extruded from 2050°F	29	21	2
Extruded from 2150°F	39	30	8
Extruded from 2050°F + Rolled from 2025°F	69	38	7
Extruded from 2150°F + Rolled from 2025°F	59	30	15
Extruded from 2150°F	39	30	8
Extruded from 2150°F + Rolled from 1950°F	>84	59	20
Extruded from 2150°F + Rolled from 2025°F	59	30	15
Extruded from 2150°F + Rolled from 2100°F	70	24	10

*Relative amounts are indicated by X-ray peak heights of a selected line.

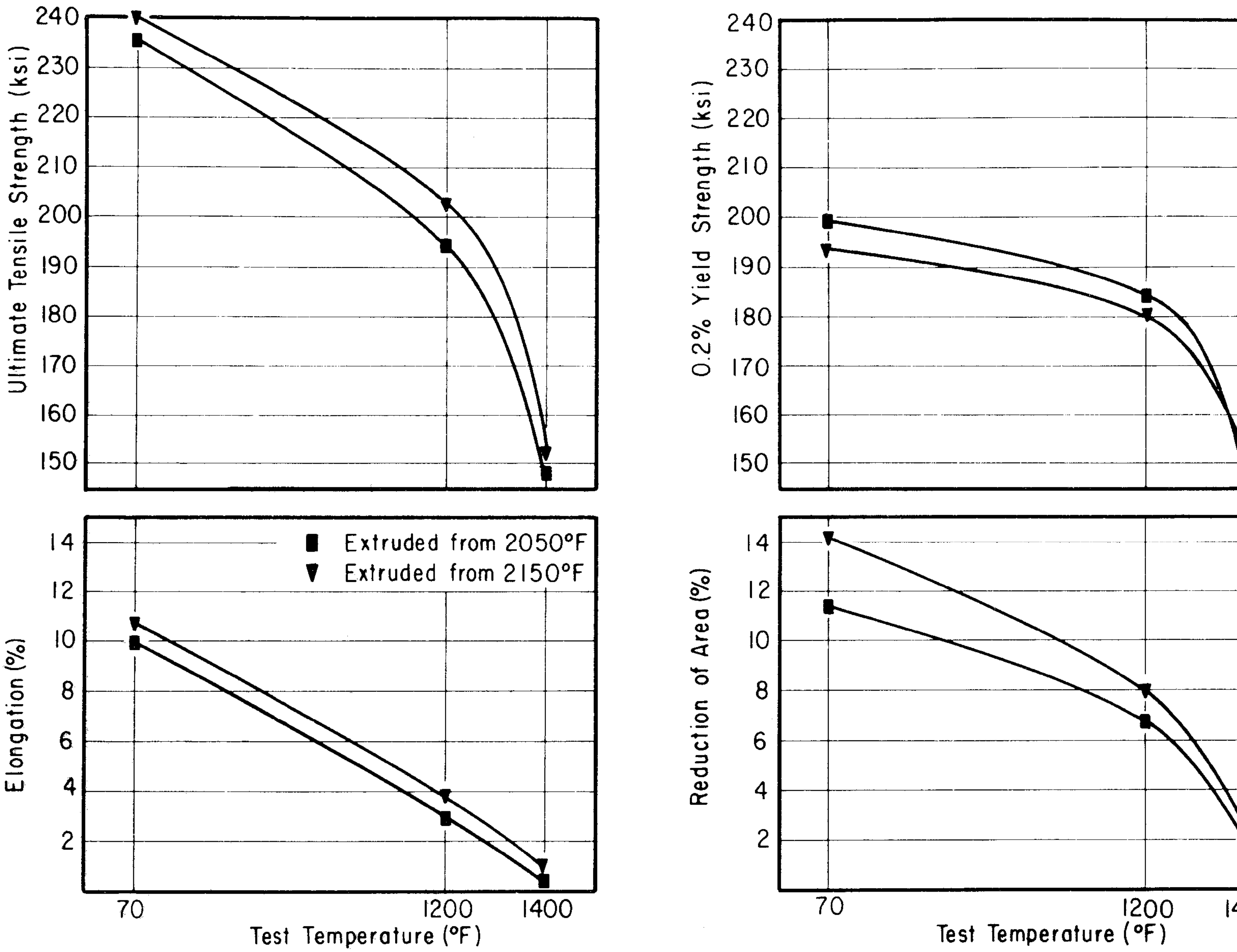


Figure 1 Effect of Extrusion Temperature on the Tensile Properties of As-Extruded Unitemp C-300 in the Partial Solution Heat Treated Condition

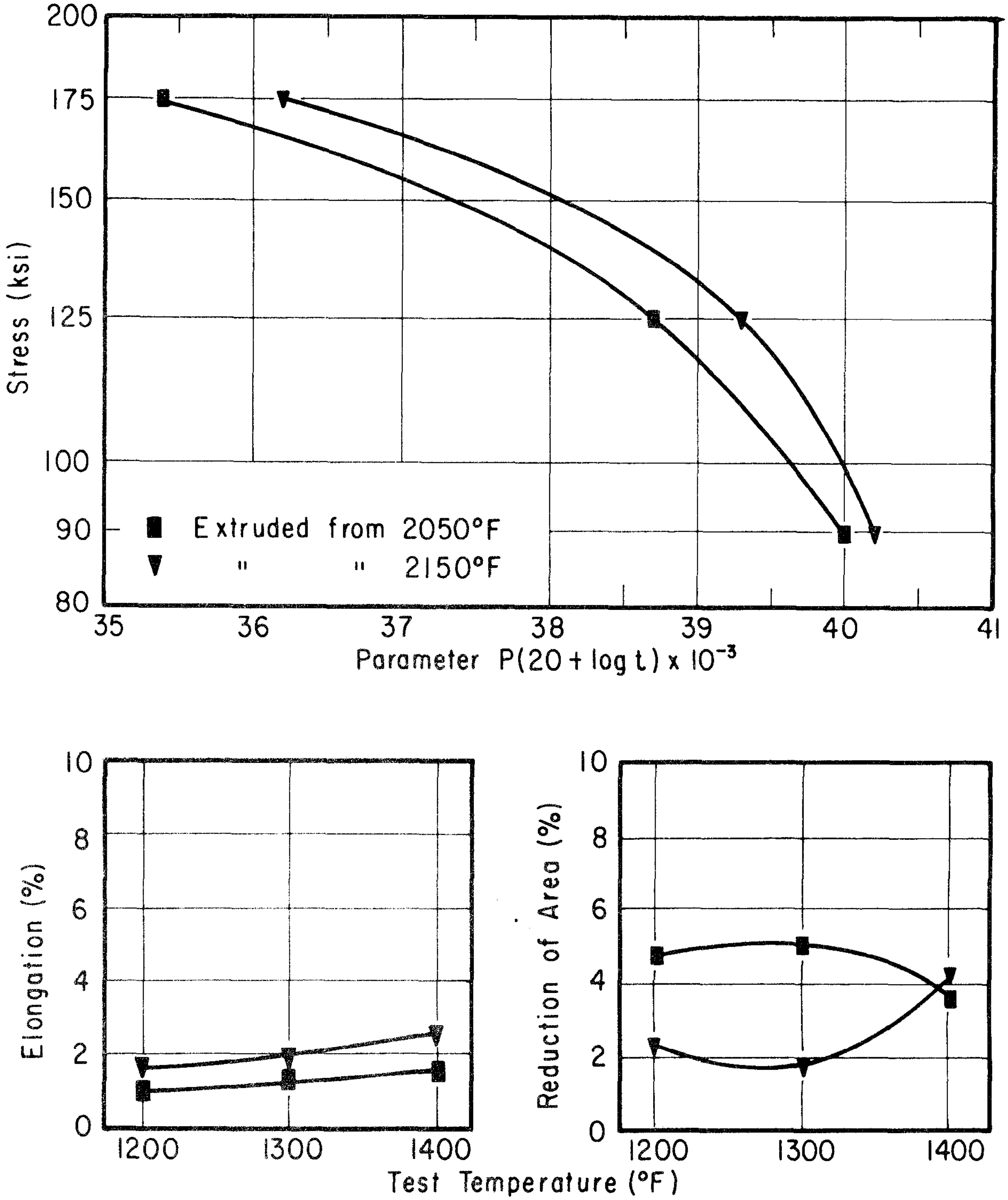


Figure 2 Effect of Extrusion Temperature on the Stress Rupture Properties of As-Extruded Unitemp C-300 in the Partial Solution Heat Treated Condition

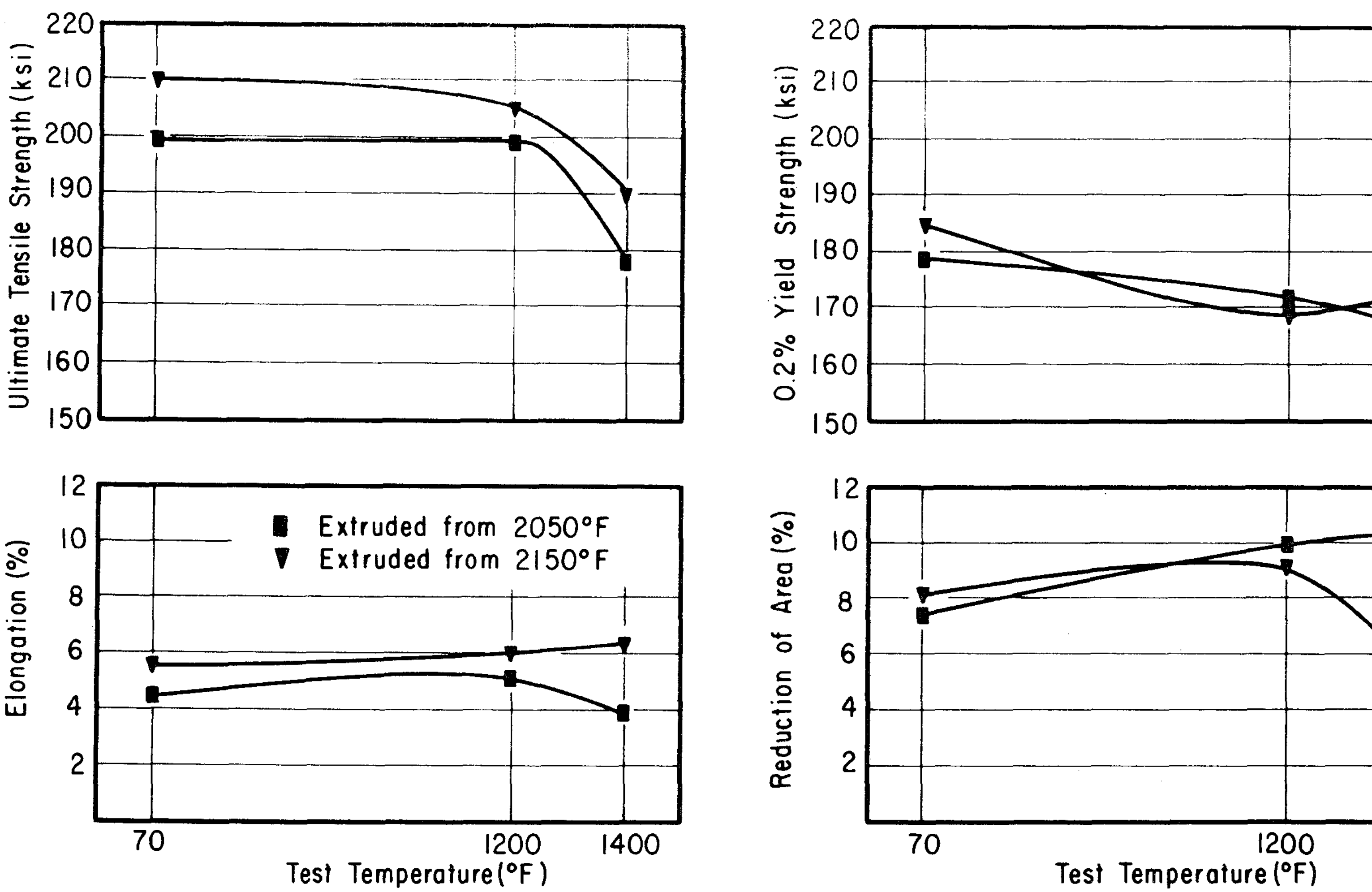


Figure 3 Effect of Extrusion Temperature on the Tensile Properties of As-Extruded Unitemp C-300 in the Full Solution Heat Treated Condition

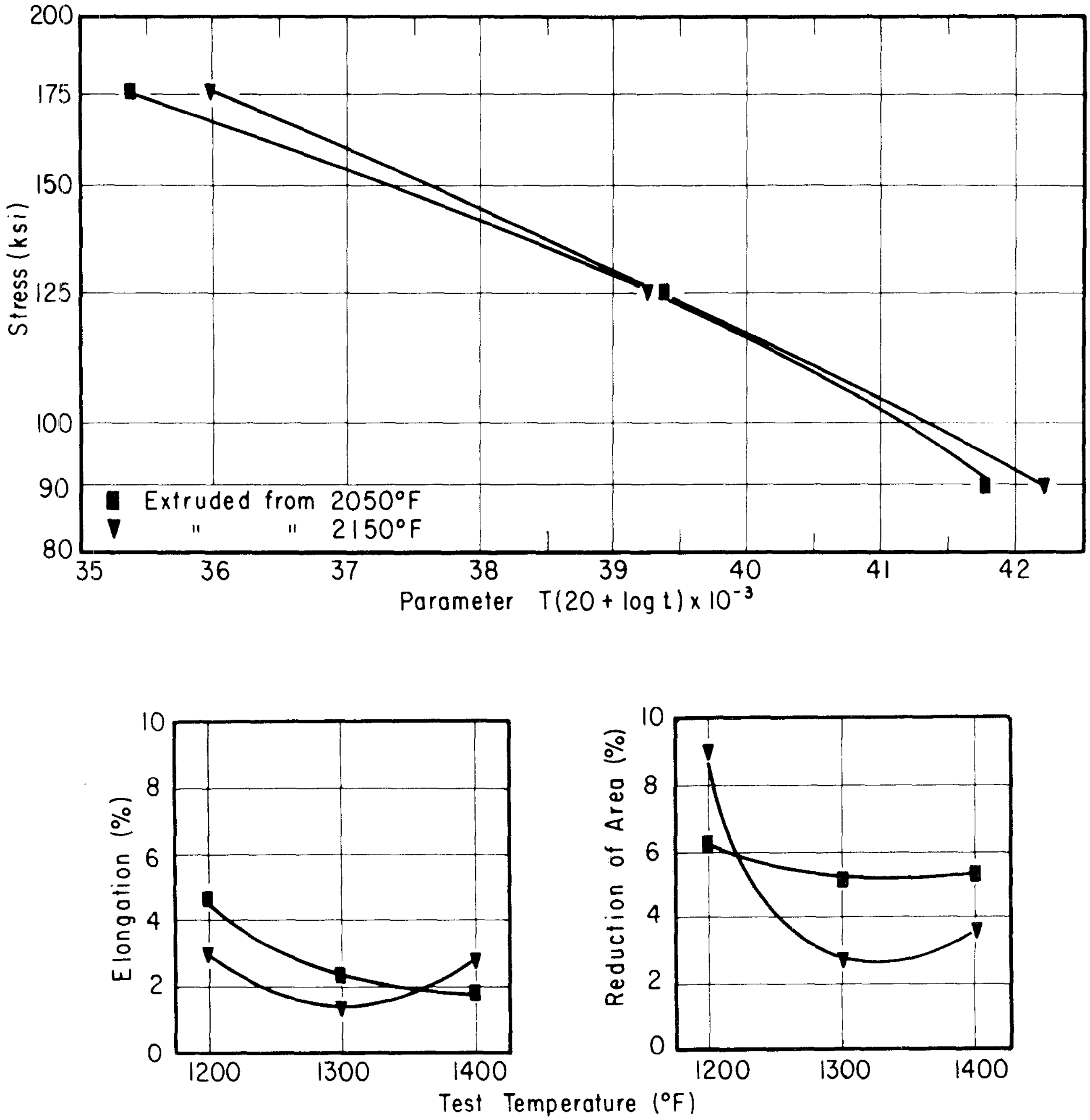


Figure 4 Effect of Extrusion Temperature on the Stress Rupture Properties of Unitemp C-300 in the Full Solution Heat Treated Condition

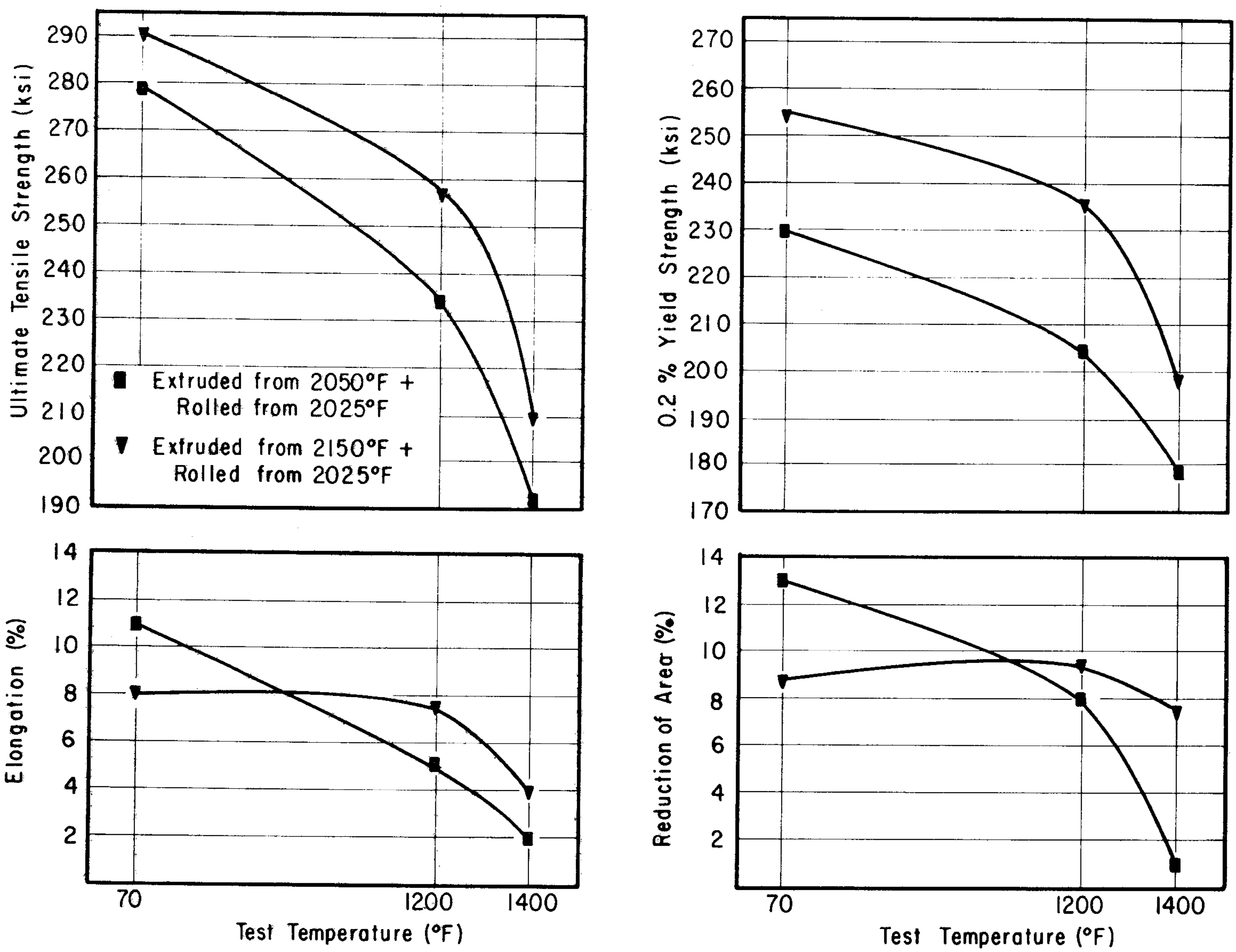


Figure 5 Effect of Extrusion Temperature on the Tensile Properties of Extruded Plus Rolled Unitemp C-300 in the Partial Solution Heat Treated Condition

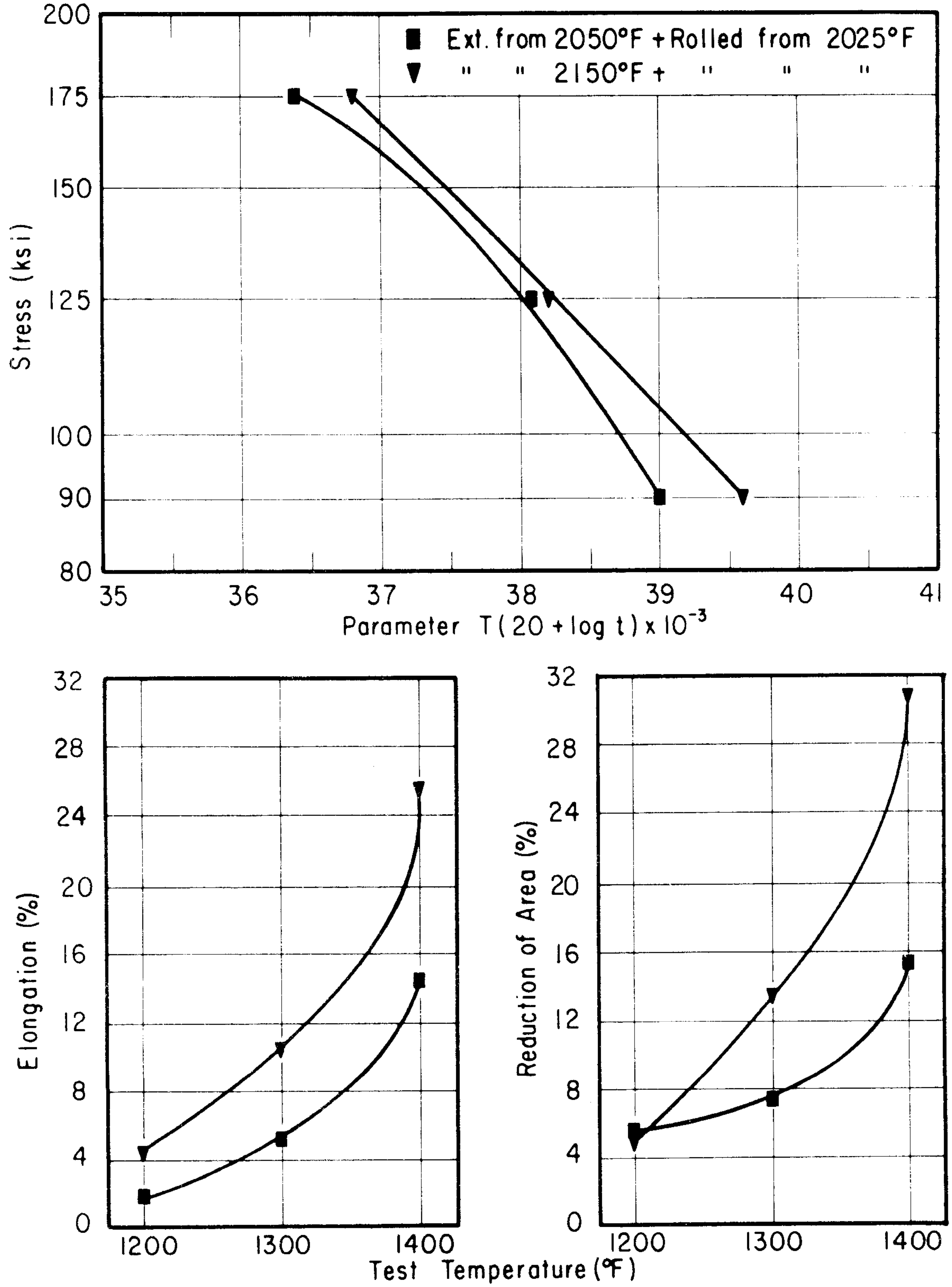


Figure 6 Effect of Extrusion Temperature on the Stress Rupture Properties of Extruded Plus Rolled Unitemp C-300 in the Partial Solution Heat Treated Condition

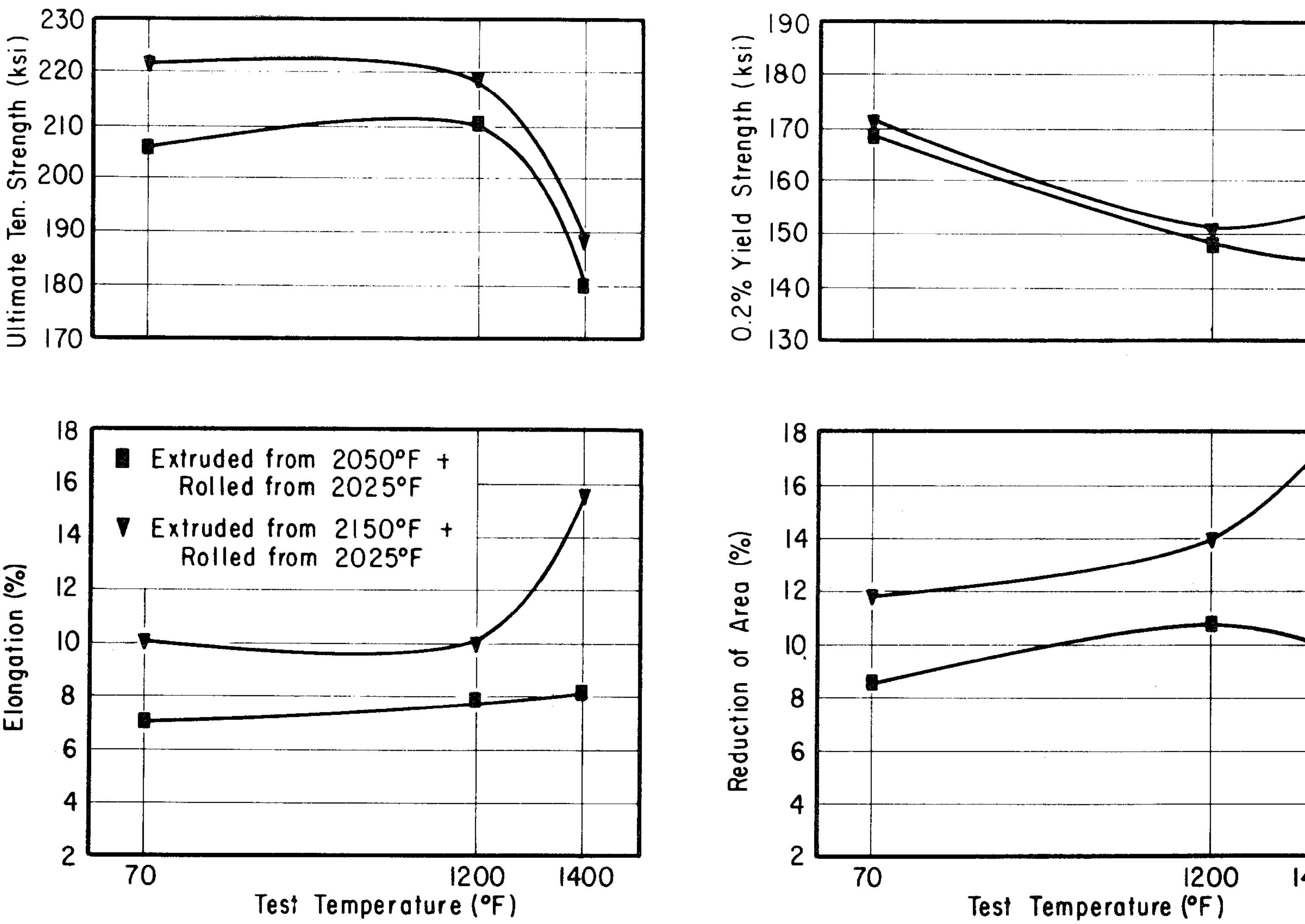


Figure 7 Effect of Extrusion Temperature on the Tensile Properties of Extruded Plus Rolled Unitemp C-300 in the Full Solution Heat Treated Condition

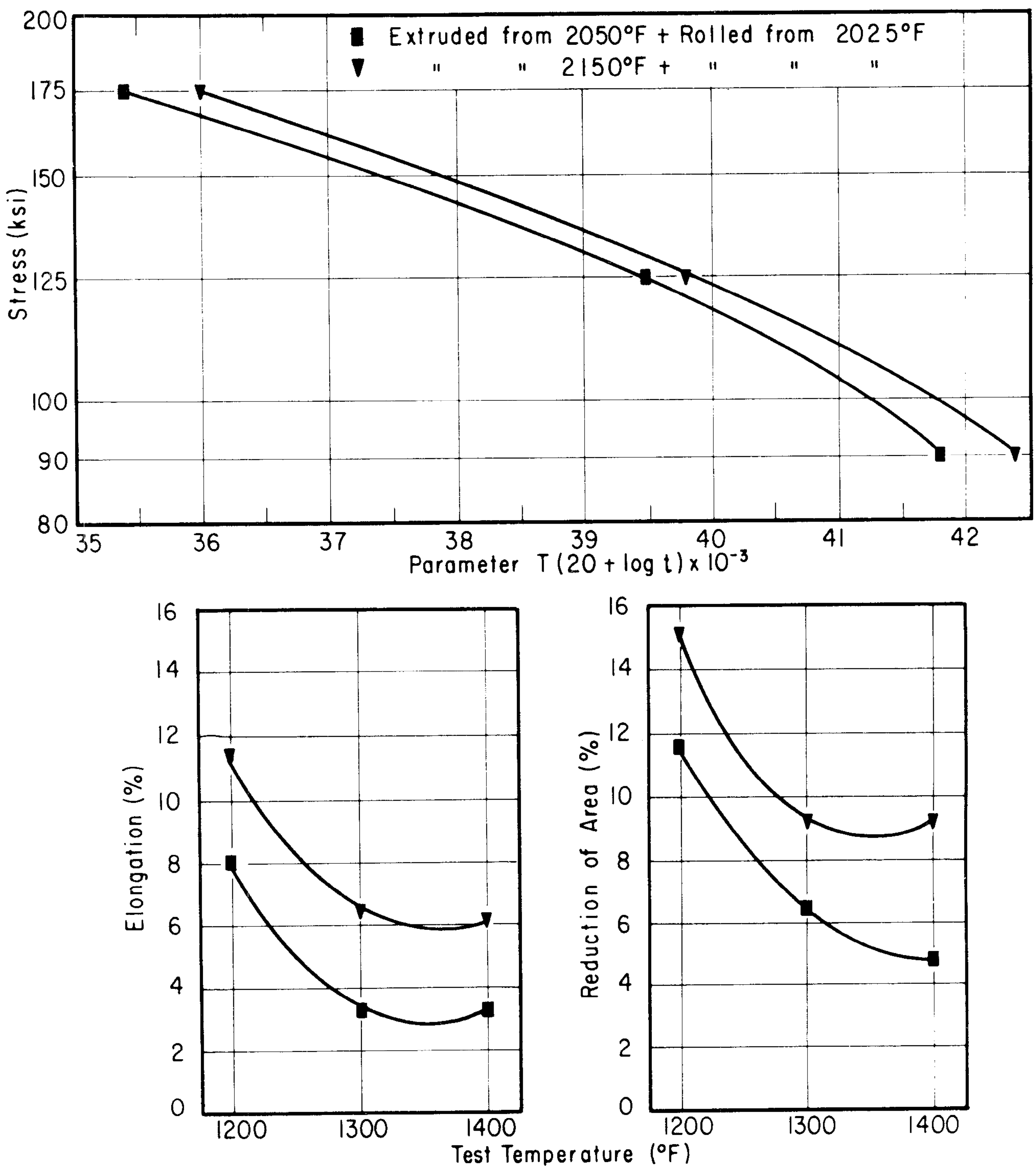


Figure 8 Effect of Extrusion Temperature on the Stress Rupture Properties of Extruded Plus Rolled Unitemp C-300 in the Full Solution Heat Treated Condition

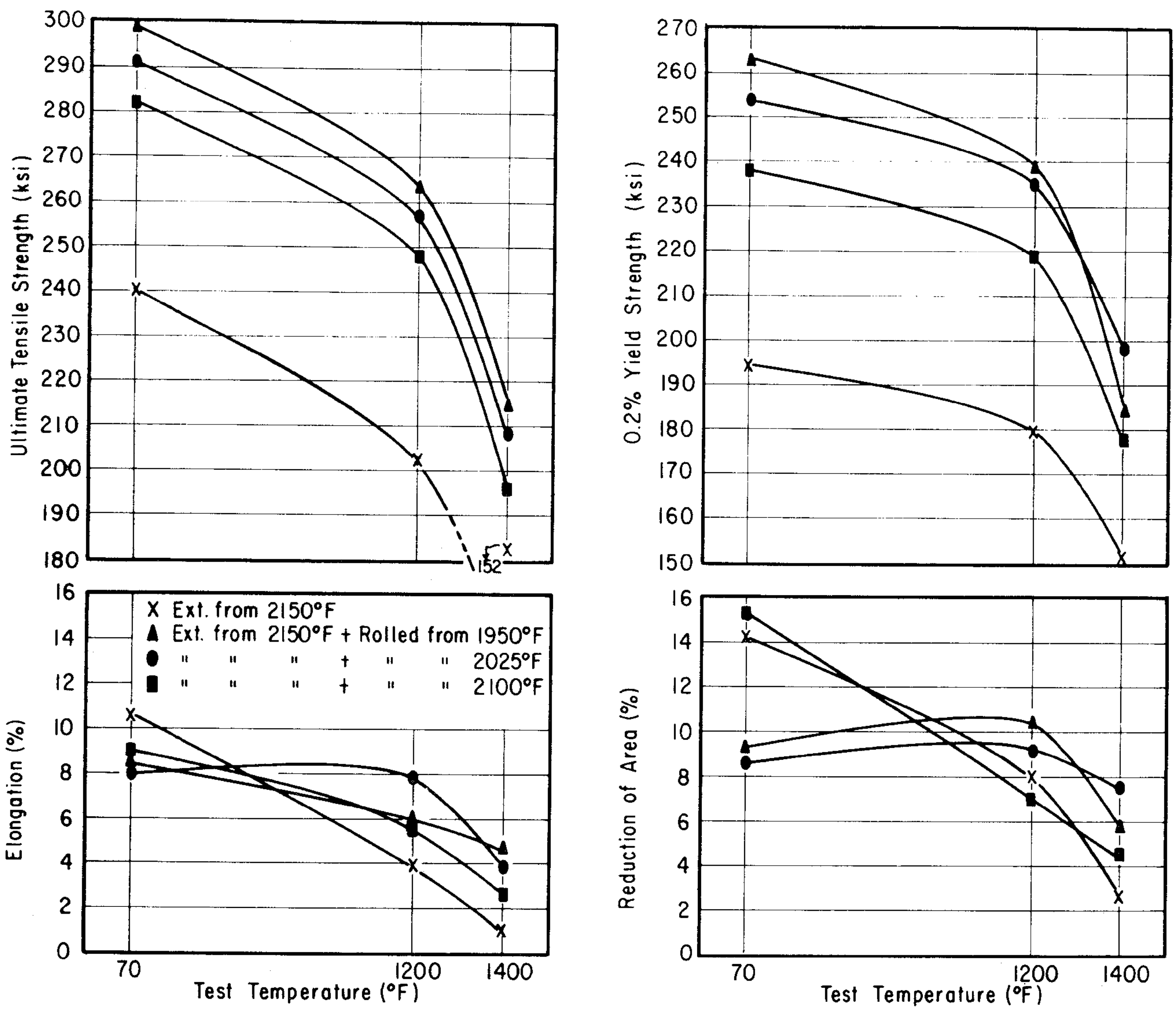


Figure 9 Effect of Rolling Temperature on the Tensile Properties of Extruded Plus Rolled Unitemp C-300 in the Partial Solution Heat Treated Condition

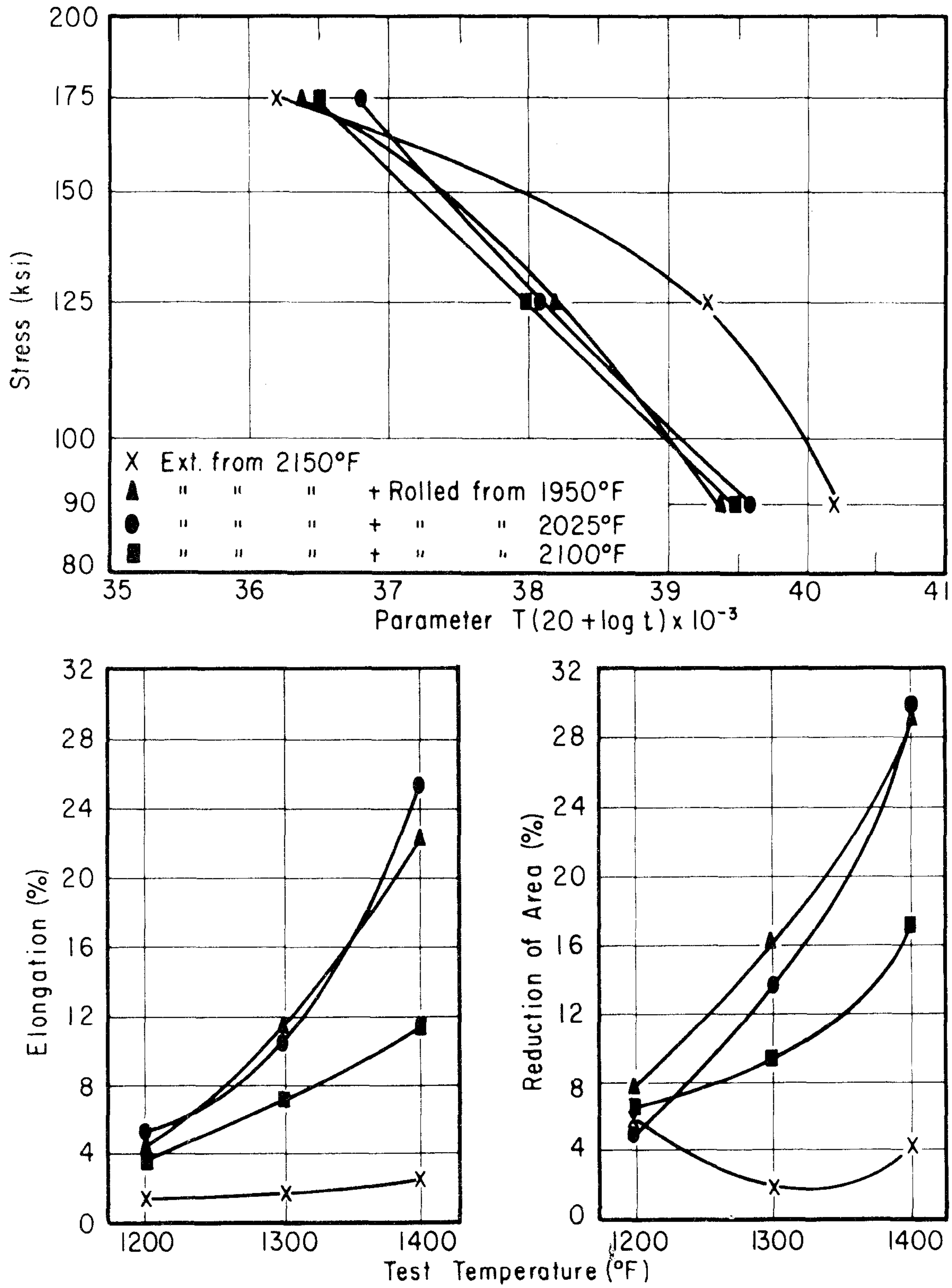


Figure 10 Effect of Rolling Temperature on the Stress Rupture Properties of Extruded Plus Rolled Unitemp C-300 in the Partial Solution Heat Treated Condition

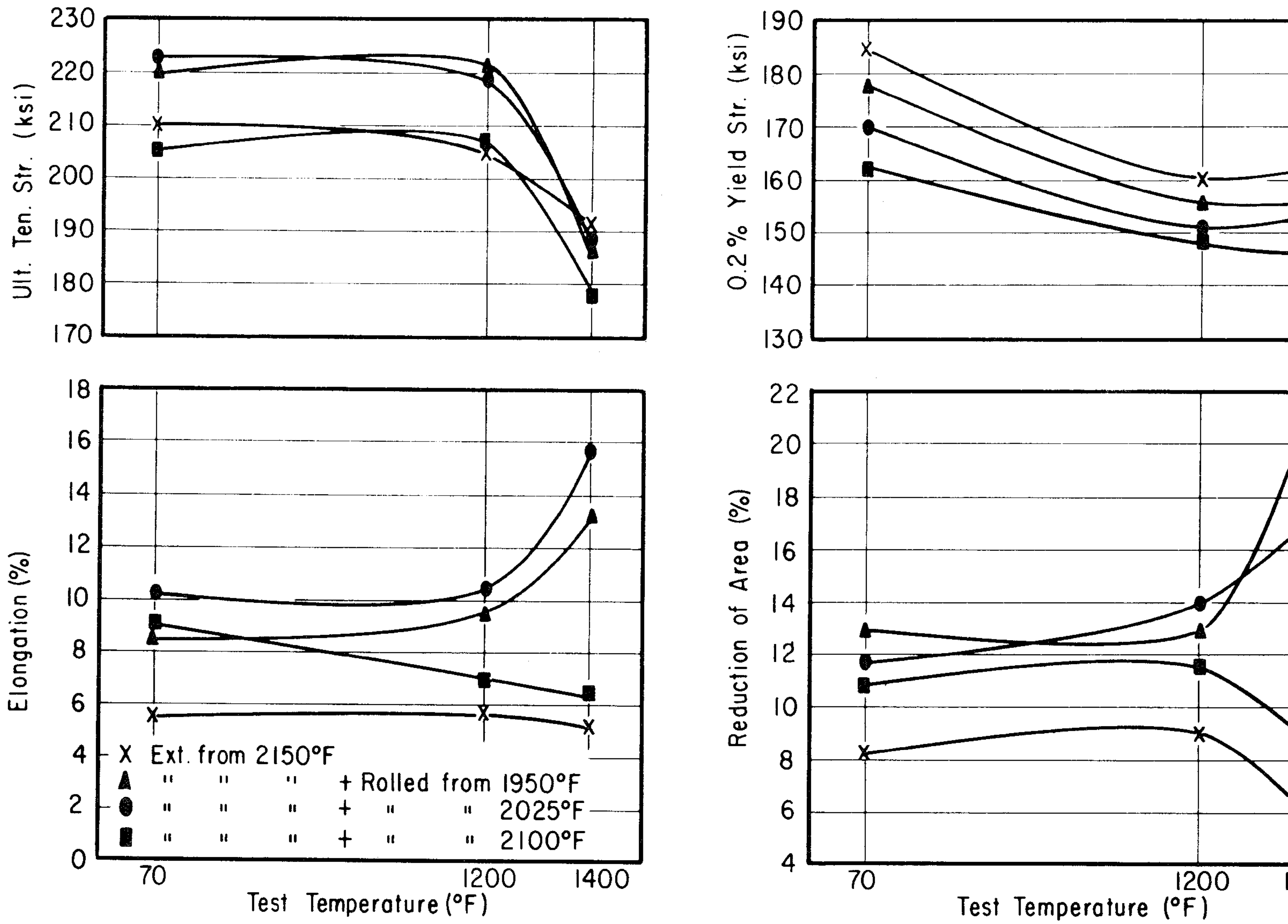


Figure 11 Effect of Rolling Temperature on the Tensile Properties of Extruded Plus Rolled Unitemp C-300 in the Full Solution Heat Treated Condition

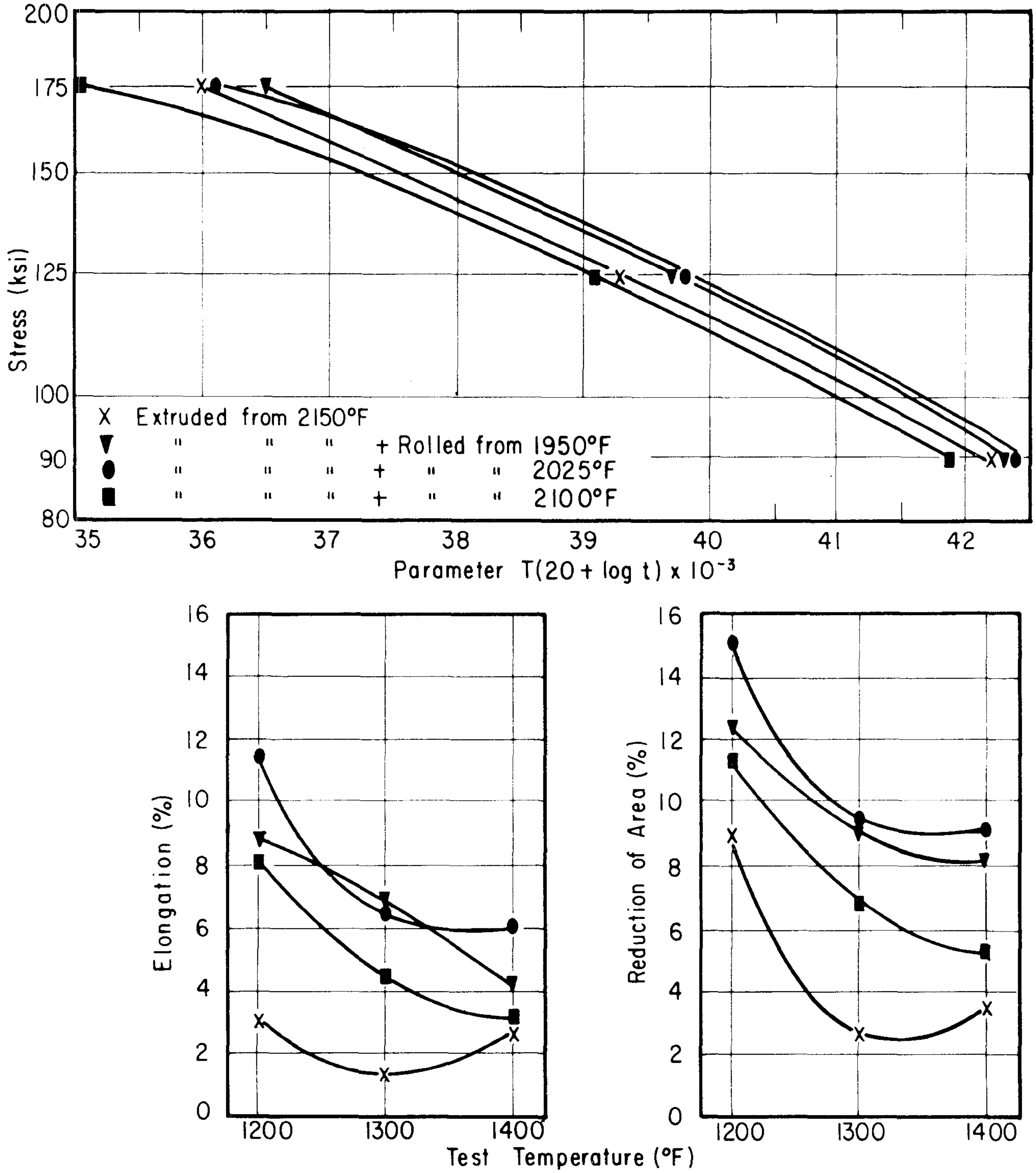
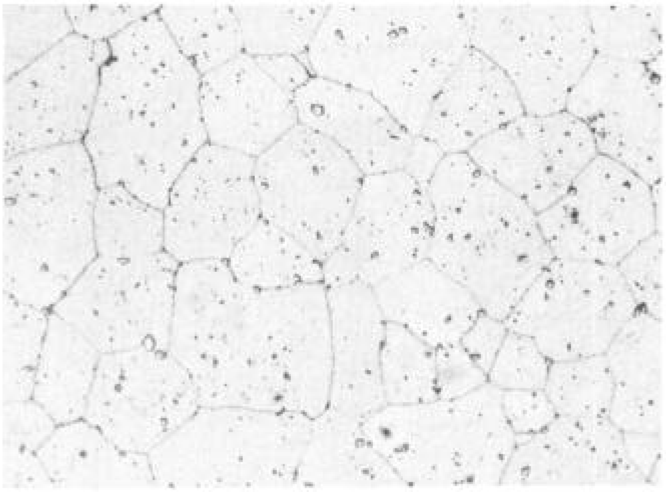


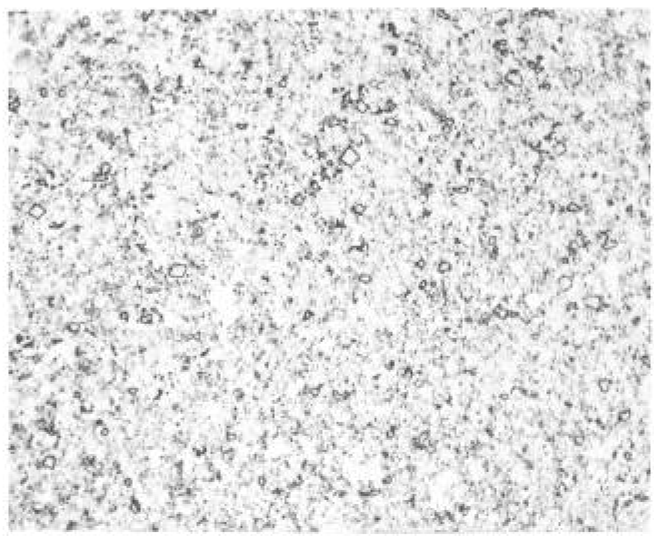
Figure 12 Effect of Rolling Temperature on the Stress Rupture Properties of Extruded Plus Rolled Unitemp C-300 in the Full Solution Heat Treated Condition



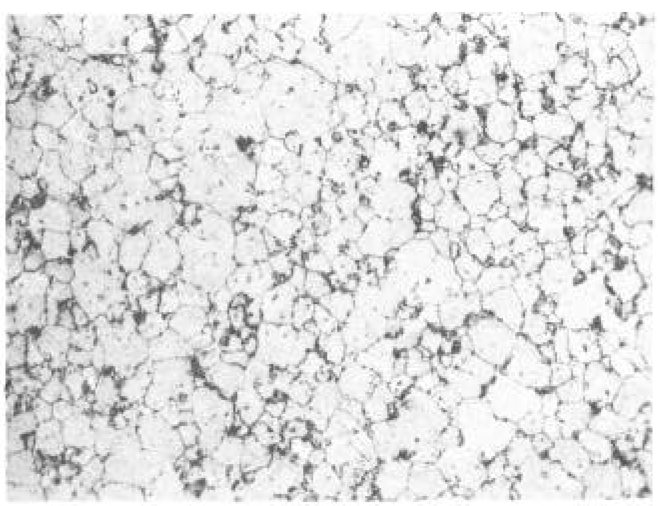
200X R24201

Figure 13. Photomicrograph Illustrating Full Solution Heat Treated Microstructure for Unitemp C-300 Extruded from 2150°F and Rolled from 2025°F

Figure 14. Photomicrograph Illustrating Partial Solution Heat Treated Microstructure for Unitemp C-300 Extruded from 2050°F



200X R24203



200X R24205

Figure 15. Photomicrograph Illustrating Microstructure for Unitemp C-300 Extruded from 2150°F then Subjected to a Partial Solution Heat Treatment

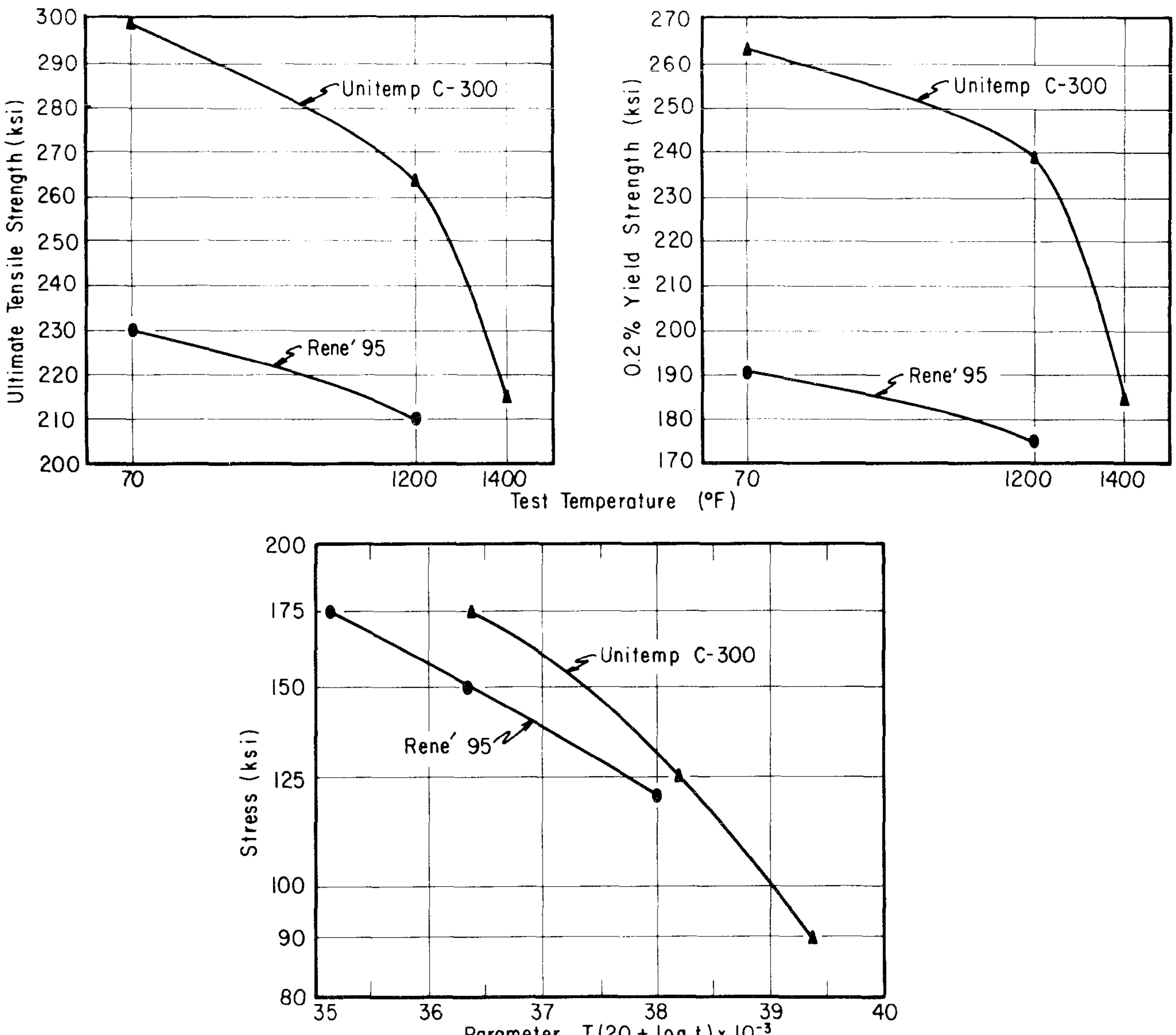


Figure 16 Comparison of Tensile and Stress Rupture Strength Capabilities for Unitemp C-300 and Rene 95 (Unitemp C-300 was Processed by the Optimum Method Determined from this Study and Both Alloys were Partial Solution Heat Treated.)

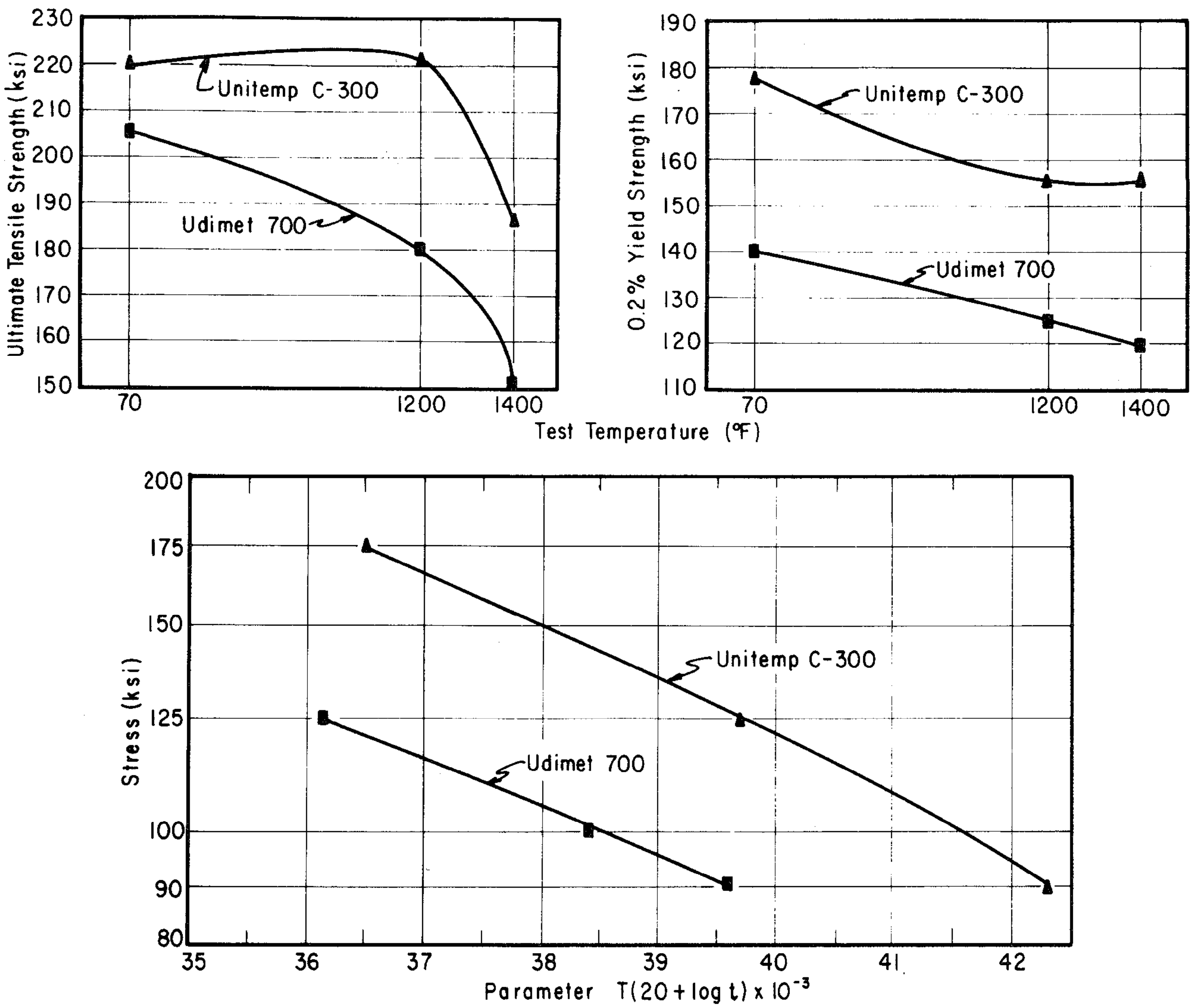


Figure 17 Comparison of Tensile and Stress Rupture Strength Capabilities for Unitemp C-300 and Udimet 700 (Unitemp C-300 was Processed by the Optimum Method Determined from this Study and Both Alloys were Full Solution Heat Treated.)