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FINAL REPORT

TO

THE GENERAL ELECTRIC COMPANY
AIRCRAFT GAS TURBINE DIVISION

ON

EFFECT OF OVERHEATING ON THE CREEP-RUPTURE PROPERTIES OF UDIMET 500 ALLOY AT 1600°F AND 28,500 PSI

by

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SUMMARY

Overheating of Udimet 500 alloy was carried out during the course of creep-rupture tests at 1600°F and 28,500 psi, the stress normally causing rupture in 90 hours. In most of the tests a stress of 15,000 psi was present during the overheats.

In one series of tests, the specimens were overheated every five hours. When the stress was removed during the overheats the rupture time at 1600°F was progressively reduced by increasing temperatures of overheating. When a stress of 15,000 psi was present during the overheats, there was little additional effect at 1800°F because the total time at 1800°F was not a significant proportion of the total rupture life under 15,000 psi. At 1900°F, the creep substantially further reduced life, and at 2000°F, 15,000 psi was near the tensile strength and caused fracture during the first overheat.

In another series of tests, specimens were overheated for fractions from 0.1 to 0.6 of the rupture time at 1800°F and 1900°F under 15,000 psi after 1 and 50 hours at 1600°F under 28,500 psi. The reduction of life was greater for the specimens overheated after one hour than after 50 hours at 1600°F. This was mainly due to only the remaining 40 hours of life after 50 hours being influenced by the overheats. When overheated after one hour at 1600°F, practically all the life was influenced by the overheat. There was evidence, particularly at 1800°F, that the temperature damage mainly occurred in a few minutes of overheating and was not a function of the total time of overheating.

Creep data are included to show the effects on deformation characteristics as well as on rupture times.

Due to the complexity of the factors controlling the effects of overheating, care is necessary in extending the results to other conditions at 1600°F.

EFFECT OF OVERHEATING ON THE CREEP-RUPTURE PROPERTIES OF UDIMET 500 ALLOY AT 1600°F AND 28,500 PSI

INTRODUCTION

An investigation was carried out to determine the effects of exposure to temperatures above normal operating temperatures on the creep and rupture properties of Udimet 500 alloy. This was accomplished by experimentally determining the effect under several conditions. The effects were evaluated in terms of the change in the creep and rupture characteristics at 1600°F under 28,500 psi, the stress causing rupture in about 90 hours in a constant temperature constant load test.

The experimental program included the study of the effect of repeated brief overheats as well as the effect of the duration of single overheats applied after either 1 or 50 hours of testing at 1600°F.

The repeated brief overheats were two minutes in duration and were applied every five hours until rupture occurred. The stress during these overheat periods was either completely removed or reduced from 28,500 psi to 15,000 psi. Overheat temperatures of 1800°, 1900°, 2000° and 2200°F were studied in the absence of stress and temperatures up to 2000°F considered under the reduced stress of 15,000 psi.

All of the single overheat tests were conducted with the stress level reduced to 15,000 psi during the overheat period. Temperatures of 1800° and 1900°F were included, with the overheat durations extending up to about 0.6 of the rupture time at the overheat temperature under 15,000 psi.

This investigation was carried out under the sponsorship of the General Electric Company, Aircraft Gas Turbine Division.

PROCEDURE

The experimental program to evaluate these effects involved the following general steps:

1. Establish the stress-rupture time curve at 1600°F for the material out to 100 hours, and the scatter to be expected at the stress selected for use in the investigation.

2. Establish the time for rupture at 1800°, 1900° and 2000° under 15,000 psi.

3. Conduct tests at 1600°F under the 100-hour stress as determined in step (1) above which were overheated in the absence of stress for two minutes every five hours to 1800°, 1900°, 2000° and 2200°F until rupture occurred.

4. Repeat (3) above with a stress of 15,000 psi present during the overheats.

5. Start tests at 1600°F under the 100-hour rupture stress, after one hour of testing reduce the stress to 15,000 psi and overheat to 1800° or 1900°F for fractions from less than 0.1 to about 0.6 of the total-rupture life at these overheat conditions as determined in step (2) above. Following the desired period of overheating, return the test to the original conditions and continue to rupture.

6. Repeat step (5) with a delay of 50 hours before introducing the overheat.

Except for the rupture testing at 1900° and 2000°F in step (2), in which the rupture times were very short making creep measurements difficult, creep data were taken for all of the tests. All of the loads applied during the testing were calculated on the basis of the original cross-section of the sample before testing.

MATERIAL

The material for the investigation was supplied by the General Electric Company in the form of 12-inch lengths of 5/8-inch bar stock. The bars were in the as-rolled condition from Heat UDF 5301.

Before machining into test specimens the stock was heat treated as follows:

Treatment	Temperature (°F)	Time (hr)
Anneal	2150	2, air cool
Solution	1975	4, air cool
Age	1550	24, air cool
Age	1400	16, air cool

The bars were of sufficient length to permit cutting four samples from each length.

EXPERIMENTAL TECHNIQUES

Testing Equipment

The creep-rupture testing was carried out in conventional beam-loaded creep-rupture units using specimens with a 0.250-inch diameter by 1-inch gage length. Each sample was accurately measured before testing. Time-elongation data were taken during testing by the use of a modified Martens-type optical extensometer with a sensitivity of ± 0.00001 inch. The units were equipped with automatically controlled resistance furnaces. Temperature variations along the gage length were held to ± 3°F. For all tests the furnaces were turned on and allowed to come to equillibrium overnight. The specimens were then placed in the hot furnace, brought on temperature and loaded in a maximum of four hours.

For the overheats, the conventional units were modified to permit resistance heating of the specimens by passing heavy direct current through the sample. A 400-ampere direct current generator was used as a power supply. In order to avoid disturbing the specimen during a test, insulated terminal blocks were fastened to the frame of the unit level with the top and bottom of the furnace. From these terminals, short leads were fastened to the top and bottom specimen holders before the test was started. Then, for overheating, it was necessary to attach the power supply leads only to the terminal blocks, completing the circuit to the generator field switch. The top specimen holder was insulated from the frame by means of a transite insert in the pin hole. The whole circuit was grounded both through the knife edges of the beam, and through an attached ground wire. A photograph of a unit is shown as Figure 1.

In order to follow the temperature accurately during an overheat, it was necessary to attach the chromel-alumel thermocouple wires to the sample by welding, so that they would remain intimately attached to the specimen as reduction in cross-section occurred by creep during the tests. This was done with a percussion type welder. In welding the wires on the sample, however, any minute error in the positioning of either wire caused the direct current from the generator to impress an emf on the thermocouple circuit. This would have appeared on the electronic indicating potentiometer which was used to follow the temperature during the overheats as a temperature effect, the magnitude of which would have varied with the magnitude of the placement error. To avoid this problem, a welding technique was employed (ref. 1) employing two alumel wires, one deliberately placed on either side of the single chromel wire. By connecting these two alumel wires to the extremes of a variable resistance, the variable tap could be adjusted so that the two emfs produced cancelled each other leaving only the thermal emf impressed on the indicator. A schematic sketch of this arrangement is shown as Figure 2.

Previous work has shown that this system gave accurate temperature measurements as installed. The overheating did not change the calibration of the thermocouples by more than 1°F at any of the conditions used in this investigation.

Overheating Procedures

For all overheat tests the specimens were prepared with a thermocouple welded at the center as described above and an additional couple mechanically attached at each end of the reduced section to check on temperature distribution along the gage length. They were placed in the creep furnace and started exactly as a normal creep test except the short power leads were attached before applying the load. The test was then allowed to run exactly as a normal creep test for the desired time period before overheating. The following overheat procedure was followed for most of the tests:

1. Temperature was checked and an elongation reading was made. At this time the power leads from the generator were attached to the unit and the welded thermocouple attached to the indicating potentiometer.

2. The thermocouple circuit was checked, the load was adjusted to the level desired for the overheat period, and the heat input to the furnace was reduced.

3. The heating cycle was initiated by applying the maximum generator output of 400 amperes to the specimen. When the desired overheat temperature was attained, the generator output was cut back to a value just sufficient to maintain temperature.

4. At the end of the desired time, the power supply was shut off and the specimen allowed to cool. No forced cooling was employed other than that supplied by having allowed the furnace temperature to fall below 1600°F when the input was reduced in step 2.

5. When the temperature reached 1600°F, the furnace input was manipulated to quickly re-establish equillibrium, and the load was increased again to the same level as before the overheat.

6. An elongation reading was made and the test continued to the next cycle or to rupture as the case may have been.

7. Typical time-temperature changes for overheats to each of the temperatures employed are shown by Figure 3.

For the tests which were overheated to 1800°F for time periods greater than 30 minutes, the following modification of the above procedure was followed:

1. Same as step 1 above.

2. Instead of reducing the furnace input in this step, the control point and input were increased in order to raise the furnace temperature to 1800°F as quickly as possible.

3. Same as step 3 above.

4. As the furnace temperature increased the generator ouput was reduced, until after about ten minutes the furnace temperature had reached 1800°F. The temperature was then maintained with the creep furnace alone until ten minutes from the end of the desired time period. At this time, the furnace controls were readjusted to the 1600°F control point and the furnace shut off. As it cooled, the specimen temperature was again maintained by applying power from the generator.

5. At the end of the overheat period the power supply was shut off and the specimen allowed to cool as in step 4 above. This technique gave the same cooling characteristics as that obtained with tests which had been held at the overheat temperature for the entire time with the generator.

6. Same as step 5 above.

7. Same as step 6 above.

This modification of the procedure permitted automatic temperature control for most of the duration of the tests which required prolonged overheat periods to 1800°F.

RESULTS

Exposing Udimet 500 alloy to higher temperatures during a 100-hour rupture test at 1600°F results in a decrease in the remaining rupture life for all of the conditions considered in this investigation. The effect in a given test appears to be the combination of the effect of a temperature change alone on the structure of the material, together with the effect of stress using up a portion of the available rupture life when stress was present during the overheat period.

Creep-Rupture Properties of Test Material

Rupture tests were conducted at 1600°F to establish the stress-rupture curve at 1600°F to define the stress for rupture in 100 hours to be used for the experimental studies of the effects of the overheating. In addition, tests were conducted under 15,000 psi at those overheat temperatures where this level of stress was to be employed to define the performance of the material at the overheat conditions to be studied.

Rupture Properties

The results of these tests appear in Table I and are shown on Figures 4 and 5. The stress-rupture time curve at 1600°F (Fig. 4) indicates that the average time for rupture under 28,500 psi, the stress selected for the basis of the study, is about 90 hours. Although the intent of the program was to use the 100 hour stress at 1600°F, the testing program was begun before the true nature of the scatter at this temperature had been completely evaluated and 28,500 psi had been estimated as the 100-hour strength in order to begin the overheat testing. The results of the four tests run at this stress indicate that the scatter of rupture times at this stress extends from about 77 to 100 hours. The level of strength appears to be normal for this alloy.

The results of the higher temperature rupture tests under 15,000 psi are shown on Figure 5 as a plot of temperature of testing versus rupture time. It may be seen from this figure that the rupture time at this stress level falls off rapidly with temperature. No tests were run at temperatures higher than 2000°F because 15,000 psi was higher than the tensile strength.

It can also be noted from Table I that the elongation and reduction of area for the rupture tests increased as the temperature increased. At 2000°F the material is extremely ductile, showing about 100-percent elongation at fracture.

Creep Properties

Time-elongation data were taken for the creep-rupture tests at 1600° and 1800°F (Figs. 8 a and b). The curves from the tests at 1600°F and 28,500 psi indicate the effect of the previously noted scatter in results at these conditions on the rupture properties of the test material. The curves for three tests run at 1800°F and 15,000 psi indicate about the same reproducibility in creep properties as in rupture times.

Effects of Overheating

The results of the tests which were overheated are presented in Tables II, III and IV and on Figures 6 through 11. These include the effects of overheating cyclically both in the presence and in the absence of a stress and the results for overheating once for various time periods with stress present during the overheats.

Effect of Cyclic Overheating

Tests were conducted in which the temperature and load were cycled for two minutes every five hours, with the cycle repeated until the specimen failed. Overheating to 1800°, 1900°, 2000° and 2200°F was carried out with the stress removed during overheating. Tests were made to 1800°, 1900° and 2000°F with the stress lowered from the 28,500 psi used at 1600°F to 15,000 psi during the overheats. In every case the time for rupture at 1600°F and 28,500 psi was reduced as a result of the overheating.

Overheats in the absence of stress. - The results of the tests overheated with all stress removed during the overheat periods (Table II and Fig. 6) indicate that as the overheat temperature was increased, the time for rupture, and consequently the number of overheat cycles before rupture, decreased. The rupture times decreased from the average value of about 90 hours in a constant-temperature test at 1600°F to 53 hours when periodically overheated to 2200°F.

The curve of Figure 6 for overheating with the stress removed can be considered as a measure of the damage to rupture strength at 1600°F and 28,500 psi introduced by temperature alone. It, however, requires careful interpretation to be properly understood. The number of overheats applied decreased with rupture time due to the fixed schedule of overheating. Thus on an average the damage per overheat was three times as much for overheating to 2200°F (reduction in rupture time was 37 hours for 11 overheats) as for overheating to 1800°F (reduction in life 16.5 hours for 15 overheats). However, experience with the same type of test on other alloys suggests that an average damage per overheat can be very misleading. As the overheat temperature increases, the first few overheats may become far more damaging than the subsequent overheats. It is, therefore, not possible to be sure how much the curve would be changed if the amount of overheating had been kept constant for each temperature of overheating; or if only a few overheats had been applied at each temperature.

The main conclusion which can be derived from the results is that the damage from overheating increased markedly with the temperature of overheating over the temperature range considered. This appears to be well fixed by the data even though the inherent scatter in rupture times raises some question as to the exact location of the curve in Figure 6.

While the rupture time was reduced by increasing temperature of overheating, the elongation and reduction of area were also reduced (Table II) when overheated to 1900°F or higher. Creep was accelerated by overheating to 1800° and 1900°F (Fig. 9a) but was not accelerated by overheating to 2000° and 2200°F. It, therefore, appears that the damage to rupture strength when overheated to 1800°F was mainly due to accelerated creep; when overheated to 1900°F due to accelerated creep and to reduced ductility; and to 2000° and 2200°F, to reduced ductility alone. Moreover, the data suggest that 1800° and 1900°F overheats mainly accelerated third-stage creep while 2000° and 2200°F prevented third-stage creep. The stress and consequently the creep rate at 1600°F are so high that these generalities are not well established.

Overheats with a stress of 15,000 psi. - Reducing the stress to 15,000 psi during the cyclic overheats from the basic stress of 28,500 psi at 1600°F gave the test results of Table III and Figure 6. The stress did not appreciably accelerate rupture when the overheat temperature was 1800°F. When it was 1900°F, it did significantly reduce rupture time below that of simple overheating without stress. The sample fractured during the first overheat to 2000°F.

The data for the stressed overheats closely reflect the strength of the test material at the overheat temperatures under 15,000 psi:

1. The total time accumulated at 1800°F under 15,000 psi in the 14 cycles of two minutes was 28 minutes. The average rupture time at 1800°F and 15,000 psi was 16.2 hours. The 28 minutes at 1800°F during the overheats, therefore, represents only about 2.8 percent of the total available rupture life at 1800°F. This is less than the reproducibility of rupture times and as would be expected the results only reflect the damage due to temperature as defined by the curve for tests overheated with the stress removed.

2. The total time at 1900°F under 15,000 psi in the 10 cycles was 20 minutes. The average rupture time at 1900°F under 15,000 psi was 22 minutes. Thus, the time at stress at 1900°F was the main cause for reduced rupture life. The actual time for rupture was longer than would have been anticipated from addibility of the temperature damage and the fractions of rupture life at 1600°F and 1900°F. The inherent variation in properties may have been the main reason for the apparent discrepancy. However, it has been noted in other alloys of the same metallurgical type that the rupture life tends to be longer than would be anticipated from addibility of the three factors for reasons which have not yet been established.

3. The average rupture time in rupture tests at 2000°F and 15,000 psi was found to be about 15 seconds. This is less than the two minutes of the overheat cycles. Consequently, the specimen ruptured the first time it was heated to 2000°F with the stress of 15,000 psi present.

The creep curves, Figure 9b, show the acceleration in creep caused by the presence of 15,000 psi during the overheats. There was little difference between the stressed and the unstressed (Fig. 9a) curves for overheats to 1800°F. The creep during overheating to 1900°F, however, was a large percentage of the total creep. Both creep curves for the samples overheated with stress present suggest that the particular samples had strength on the high side of the range for the test materials.

Effect of Schedule and Duration of Single Overheats

Tests were conducted in which single overheats of varying duration were applied to specimens after either 1 or 50 hours of elapsed testing time at 1600°F and 28,500 psi. Overheat temperatures of 1800° and 1900°F were investigated with the stress reduced to 15,000 psi. The durations of the overheats represented fractions of the constant temperature rupture life at the overheat temperature under 15,000 psi ranging from less than 0.1 to 0.6.

Effect on rupture time. - The results of the tests are given in Table IV and Figure 7. The data are interpreted as follows:

1. Overheating to 1800° and 1900°F with stress present, reduced rupture life at 1600°F. The total time at 1600°F was reduced less in most cases when the overheat was delayed until 50 hours at 1600°F and 28,500 psi had elapsed than when it was applied after one hour at the 1600°F condition.

This occurs because the effect of the temperature change on strength at 1600°F can influence only the life remaining when the overheat was delayed until 50 hours. When the overheat was applied after one hour at 1600°F almost the whole rupture life at 1600°F was affected.

2. When overheated to 1800°F, a relatively short time of overheating was almost as damaging as much longer times. For instance, the reduction of life was the same for 325 and 25 minutes at 1800°F under 15,000 psi when the overheat was applied after one hour at 1600°F. There was also little difference between 25 and 100 minutes when the overheats were applied after 50 hours at 1600°F.

There appeared to be a slight reduction in the damage for overheating at 1800°F for overheat times in the range 75 to 200 minutes. Because the data for such overheats after both one and 50 hour delays both indicate less damage, it probably is real and does not reflect data scatter.

3. When the overheats to 1800°F were delayed 50 hours, the specimens overheated more than 100 minutes all fractured during the overheats. The reason for this is uncertain. The most probable explanation is a change in strength at 1800°F introduced by a structural change during the prolonged exposure to 1600°F. Even though there had been 50 hours exposure to 1600°F under 28,500 psi, the remaining 40 percent of the rupture life was more than the percentage of the

rupture life at 1800°F under 15,000 psi represented by the overheat conditions. It is, therefore, assumed that the strength at 1800°F had been reduced by the exposure at 1600°F.

4. The data for overheating to 1800°F after one hour at 1600°F showed little change between 10 and 300 minutes at 1800°F, as previously described. Apparently this represented a temperature damage effect that reached saturation between 10 and 25 minutes. Reference to Figure 6 shows that the reduction life due temperature alone was somewhat less than is indicated by Figure 7. This could be due to all of the overheat being early in the life of the test rather than spread out during the tests as for Figure 6. It will be noted that when the time at 1800°F under stress begins to be a significant part of the total available rupture time at 1800°F, more than 300 minutes, the creep damage rapidly reduced life.

It could also be noted that when the overheats were delayed 50 hours, the damage was closer to that which would be estimated by adding temperature and creep damage effects -- at least for overheats longer than 100 minutes. This apparently is due to the delayed overheat averaging effects closer to the data of Figure 6.

5. When the overheating was at 1900°F, temperature damage was apparently less a factor so that creep damage was a substantial part of the total damage for all of the cases considered. Consequently, there was a progressive increase in damage with increasing exposure. It will be noted, however, that the damage was more than would be anticipated from percentage of rupture time at 1900°F when the overheating occurred after one hour at 1600°F. This reflects both the temperature damage and the fact that the material was damaged for almost all its life rather than the temperature damage being spaced throughout the test as in the data for Figure 6.

When the tests were delayed 50 hours, the rupture times were closer to those to be anticipated from creep and temperature damage at 1900°F. The actual times were actually longer than would have been anticipated. It is probable that either the strength at 1900°F was improved by the prior exposure at 1600°F or the damage effect was reduced by delaying the exposure.

6. The elongations and reductions of area, Table IV were about the same as for normal rupture tests at 1600°F. Even prolonged exposure at the higher temperatures did not increase the elongation as occurred in normal rupture tests at 1800° and 1900°F.

Effect on creep curves. - The plots of the time-deformation data appear as Figures 10 and 11. The following points of interest may be noted from these figures:

1. The curves for the tests which were not overheated until 50 hours had elapsed at 1600°F, (Figs. 10b and 11b) show that there was good agreement in the creep rates up to the point at which the overheating was introduced.

2. The amount of deformation which occurred during the overheat period was greater the longer the duration of the overheat. The creep rates following the overheats did not, however, follow this same pattern for the tests overheated to 1800°F (Fig. 10a and b). In this case the rate at which creep occurred followed the same general pattern as was exhibited by the rupture data after the overheat period was completed. That is, those tests which had longer rupture times also showed lower creep rates following the overheat.

3. In general these curves indicate at both overheat temperatures that the effect of the deformation during the overheat period was to increase the rate at which creep occurred after the temperature had been returned to 1600°F.

It should be kept in mind with reference to Figures 7, 10 and 11 that the times indicated at 1600°F for rupture and deformation do not include the time that the tests were held at the overheat temperature. The times indicated are only the time that the tests were actually at 1600°F during their life. On the time scales used this is not as significant for the tests which were overheated to 1900°F since the maximum overheat time used was only 13.5 minutes. At 1800°F, however, there is a significant difference in the total time that any given tests was running and the time that it was actually at 1600°F during the test. It is for this reason that the creep curves show a vertical line at the time when overheating occurred even though the overheat may have lasted for several hours.

Limitations of Results

Insofar as the actual test conditions are concerned, the data are believed to be reliable! The normal scatter in strength of the specimens was perhaps not as well established for the curves as would have been desirable. However, the major trends are believed to be correct.

The creep data and the ductility values measured may be somewhat in doubt. The specimens were overheated by electrical resistance. The heat, therefore, would tend to concentrate at the minimum diameter as creep progressed. There was, however, very little necking and this effect was minor. Even if it had occurred it would only influence the creep curve after considerable creep had occurred. There would be little effect on rupture time but it would reduce elongation.

The main limitation of the results involve their extrapolation to other conditions of stress at 1600°F and the overheat temperatures. The discussion of the causes for the observed effects indicate that they are not simple. Thus if the stress level at 1600°F was different they could have quite different effects. The same could be true for other conditions of exposure to the overheat temperatures. The detailed discussion of the causes for the observed effect has been included to aid in estimating the effects of overheats under other conditions.

It seems evident that more information on the temperature damage for limited amounts of overheating and at other portions of the creep-rupture life would be useful. The stress damage seems to be relatively easy to estimate. The temperature damage appears less clear because it apparently can be more for short times of exposure than would be anticipated for the larger times covered by this investigation.

CONCLUSIONS

Udimet 500 alloy underwent reduction in rupture life at 1600°F and 28,000 psi (90-hour rupture life) from overheating to 1800°, 1900°, 2000° and 2200°F. This appeared to be due to changes in properties introduced by the temperature induced structural changes and, when stress was present during overheating by the rapid increase in creep at the higher temperatures.

In general, the damage from stress during an overheat can be estimated from normal creep-rupture data at the overheat temperature. The major exception noted to this was an apparent reduction in the strength at 1800°F from 50 hours prior exposure at 1600°F before overheating.

Higher temperature alone can introduce substantial reduction of rupture life at 1600°F. Some of the data suggest that this may under some circumstances occur for rather short times of overheating. In other words, the exposure temperature and not the total time of exposure may be the important factor. The data for exposure to 1800°F were particularly suggestive of this. For this reason, it appears as if more data on the influence of time of exposure would be desirable.

The limited data on the influence of overheat temperature indicated that the damage increased with the overheat temperature up to 2200°F.

The reduction in rupture life for overheating to 1800° or 1900°F in the absence of stress appeared to be due mainly to reduction in creep resistance at 1600°F. Overheating at 2000° and 2200°F mainly reduced ductility with little effect on creep resistance.

REFERENCES

1. High Heating Rate Strength of Three Heat-Resistant Metals, NAVORD Report 2017, NOTS 670, Mar. 1953.

TABLE I

RESULTS OF RUPTURE TESTS

Temp (°F)	Stress (psi)	Rupture Time (hours)	Elongation (%)	Reduction of Area (%)
1600	33,000	43.7	7	9
	30,000	68.8	9	7
	28,500	99.7	8	9
		90.8	9	7
		78.5	11	12
		77.6	10	9
1800	15,000	18.9	15	16
		16.1	20	20
		13.6	14	16
1900	15,000	0.40	24	28
		0.35	24	36
2000	15,000	0.0042(15 sec.)	116	>99
		0.0038(13.5 sec.)	96	>99

TABLE II

RESULTS OF CYCLIC OVERHEATS WITH STRESS REMOVED

Overheats were applied for two minutes at five-hour intervals.

Tests run under 28,500 psi at 1600°F - average rupture time 90 hours.

Overheat Temp. (°F)	No. of cycles	Rupture Time (hours)	Elongation (%)	Reduction of Area (%)
1800	15	72.8	9	9
1900	15	71.5	6	7
	13	60.2	6	6
2000	13	63.9	5	3
2200	11	53.2	4	2

TABLE III

RESULTS OF CYCLIC OVERHEATS WITH STRESS REDUCED TO 15,000 PSI

Overheats were applied for two minutes at five-hour intervals.

Tests run under 28,500 psi at 1600°F - average rupture time 90 hours.

Overheat Temp. (°F)	No. of cycles	Rupture Time (hours)	Elongation (%)	Reduction of Area (%)
1800	14	70.4	9	9
1900	10	49.5	10	10
2000	<1 (1)	3.8	41	98

(1) Sample ruptured after 12 seconds at 2000°F on first cycle.

TABLE IV

RESULTS OF TESTS OVERHEATED ONCE UNDER 15,000 PSI

Tests run under 28,500 psi at 1600°F - average rupture time 90 hours

Overheat Temp (°F)	Time at 1600°F before overheat (hours)	Duration of overheat (min)	Total Time at 1600°F(hrs)	Elongation (%)	Reduction of Area (%)
1800	1	630	21.7	12	12
		490	20.4	12	11
		315	61.6	11	12
		210	62.6	7	9
		105	66.1	7	8
		50	55.6	10	9
		25	61.9	11	10
		10	70.0	8	10
	50	276	50.0	7	12
		200	50.0	9	9
		170	50.0	9	12
		105	76	8	9
		50	66.3	8	10
		25	69.9	9	10
1900	1	13.50	42.0	5	6
		10.13	33.8	6	9
		6.75	58.3	6	7
		4.50	50.8	5	7
		2.25	76.8	7	7
		2.25	66.4	6	9
	50	13.50	63.5	9	12
		10.13	61.7	8	10
		6.75	80.0	8	8
		2.25	91.7	10	11

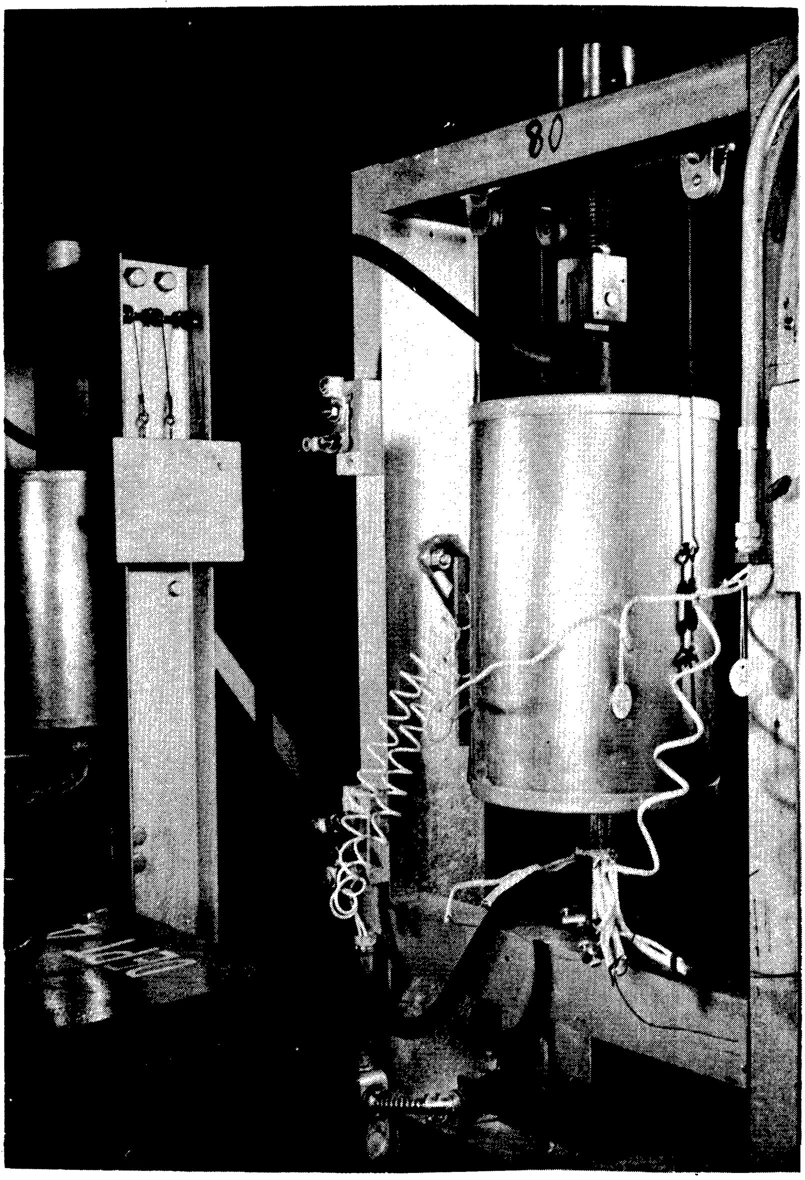


Figure 1. - Photograph showing creep-rupture unit modified for use in overheating by resistance heating.

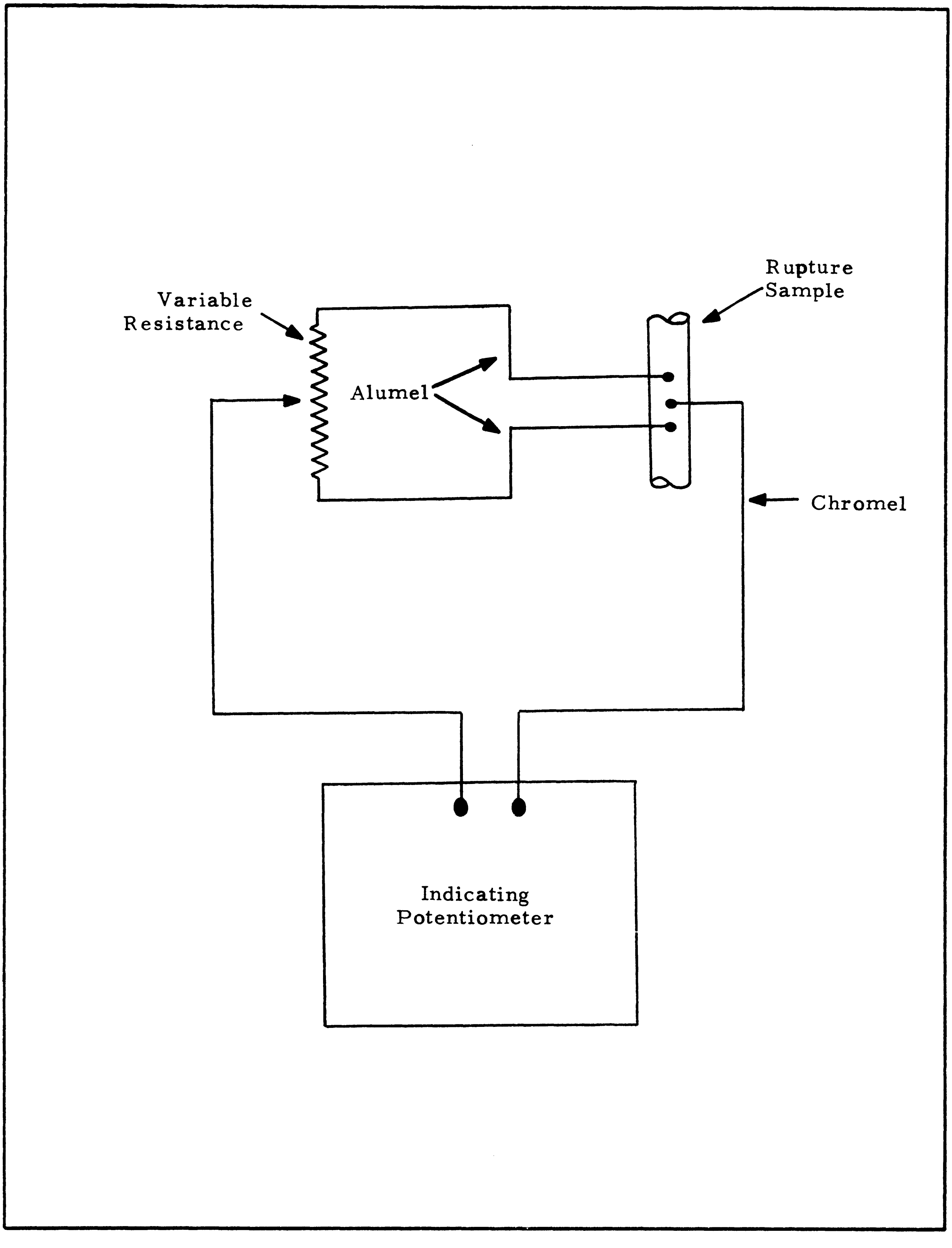


Figure 2. - Schematic wiring diagram of the system used for measurement of temperature during overheats to avoid extraneous emf from heating current.

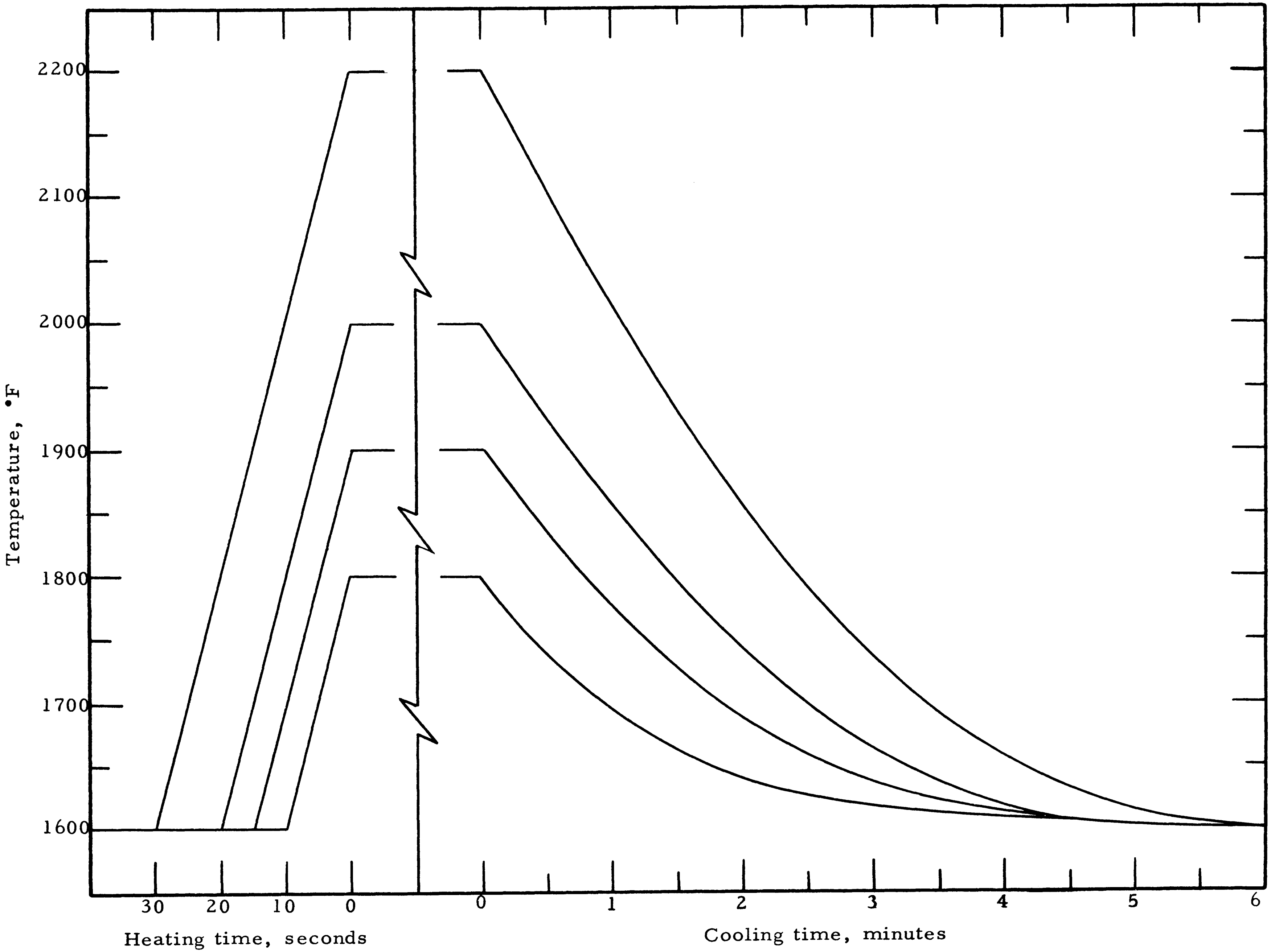


Figure 3. - Typical heating and cooling curves for overheats from 1600°F to each of the overheat temperature employed.

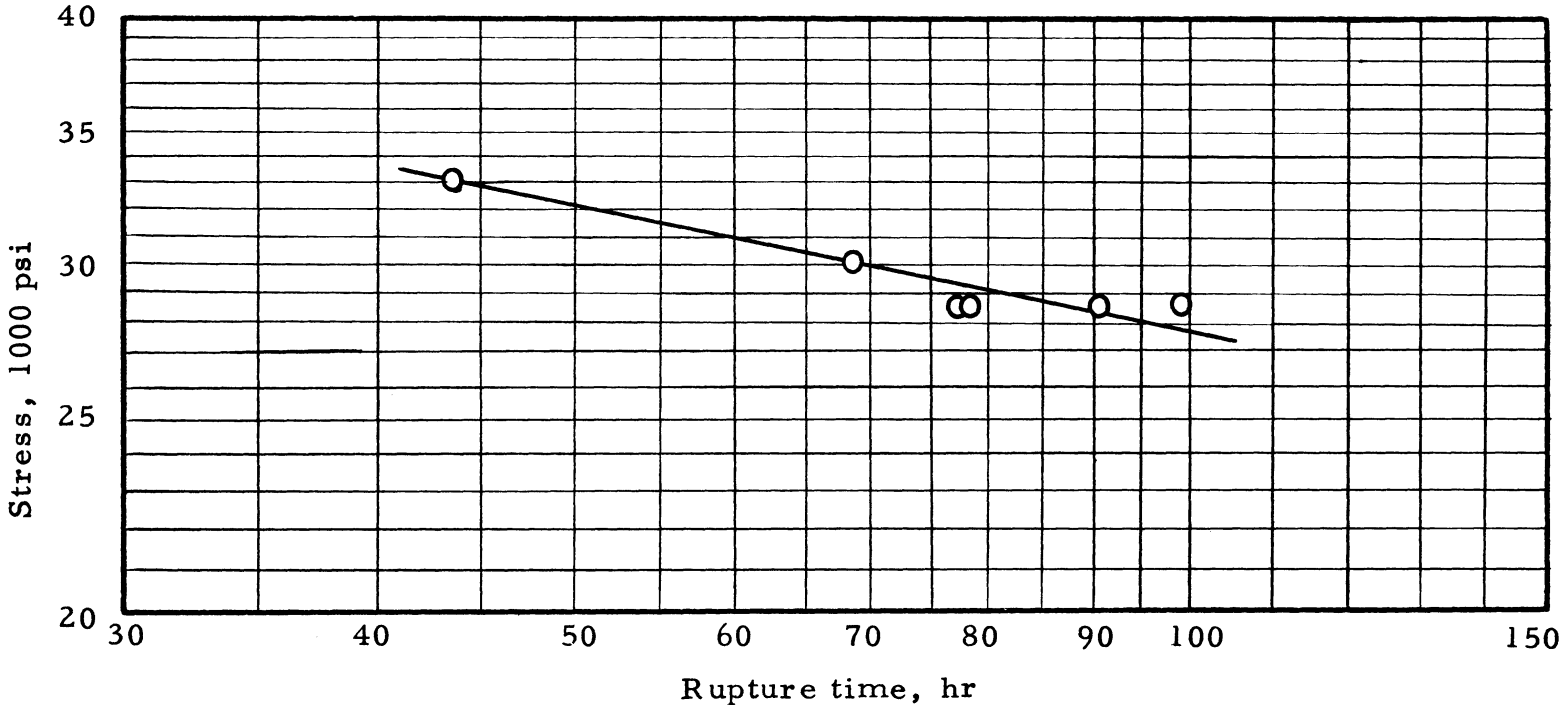


Figure 4. - Stress-rupture time data at 1600°F for the Udimet 500 used in this investigation in the as-heat treated condition (2 hours 2150°F, air cool; 4 hours 1975°F, air cool; 24 hours 1550°F, air cool; 16 hours at 1400°F, air cool).

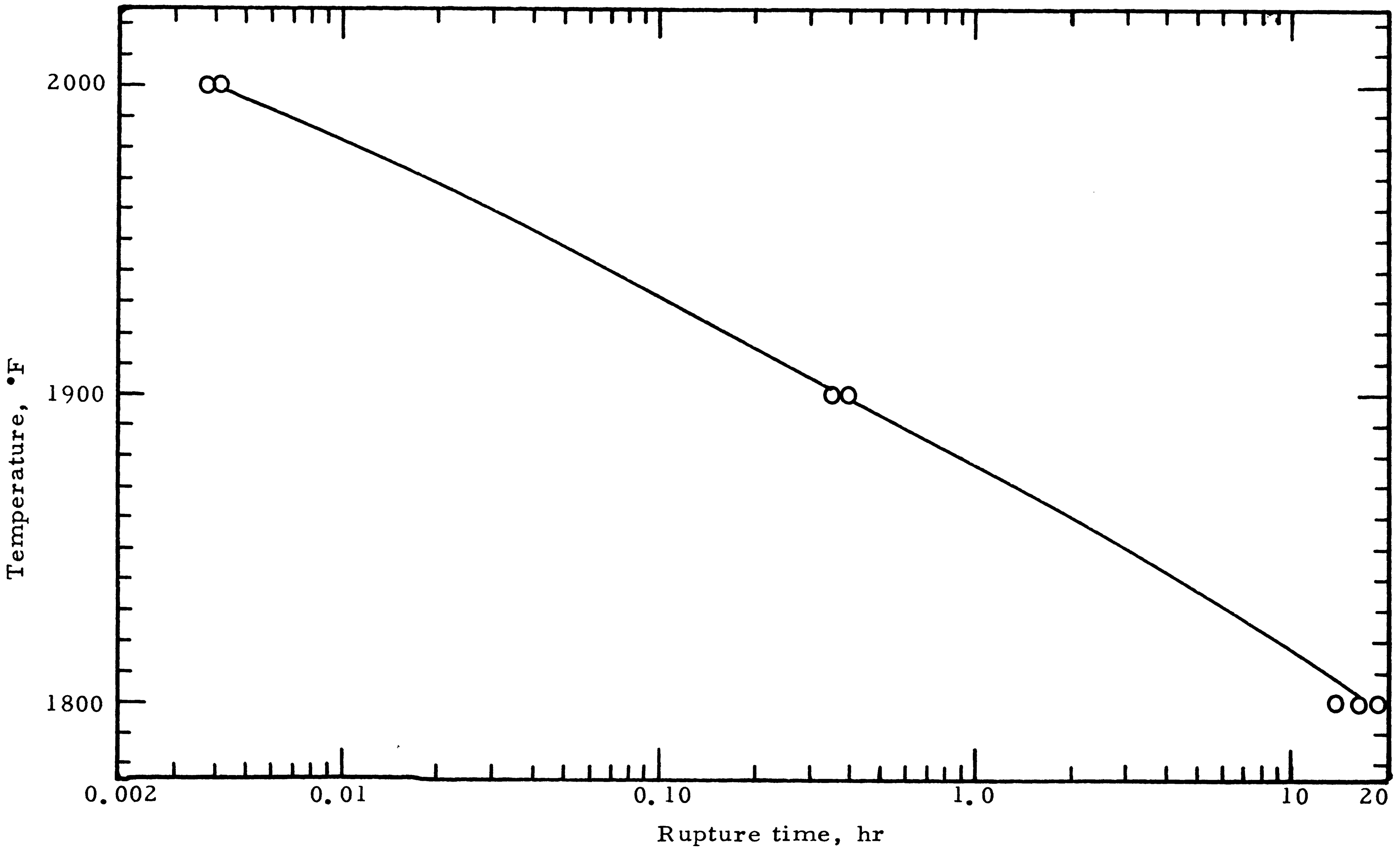


Figure 5. - Effect of temperature of testing on the time for rupture of Udimet 500 alloy at 15,000 psi in a constant load-constant temperature rupture test.

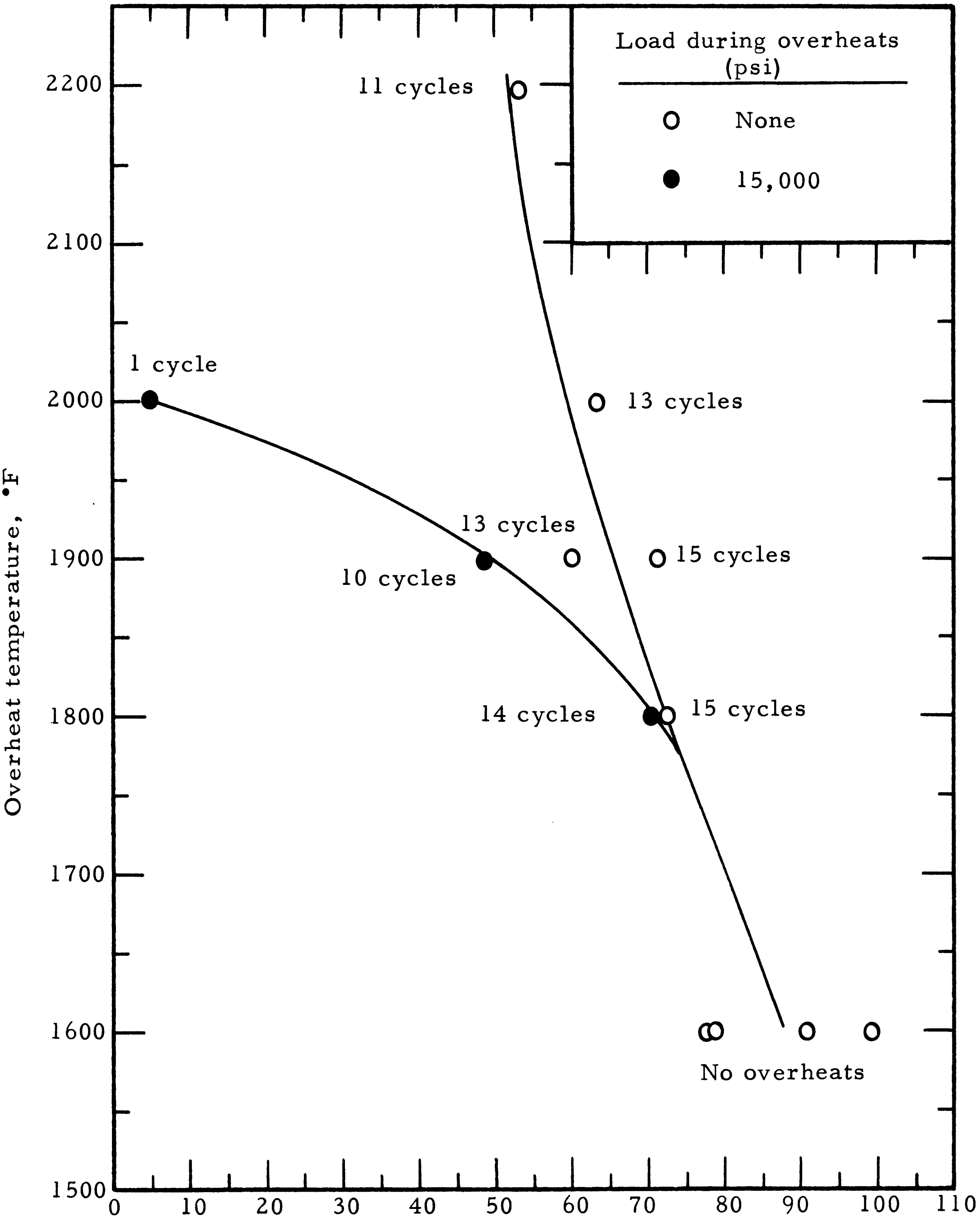
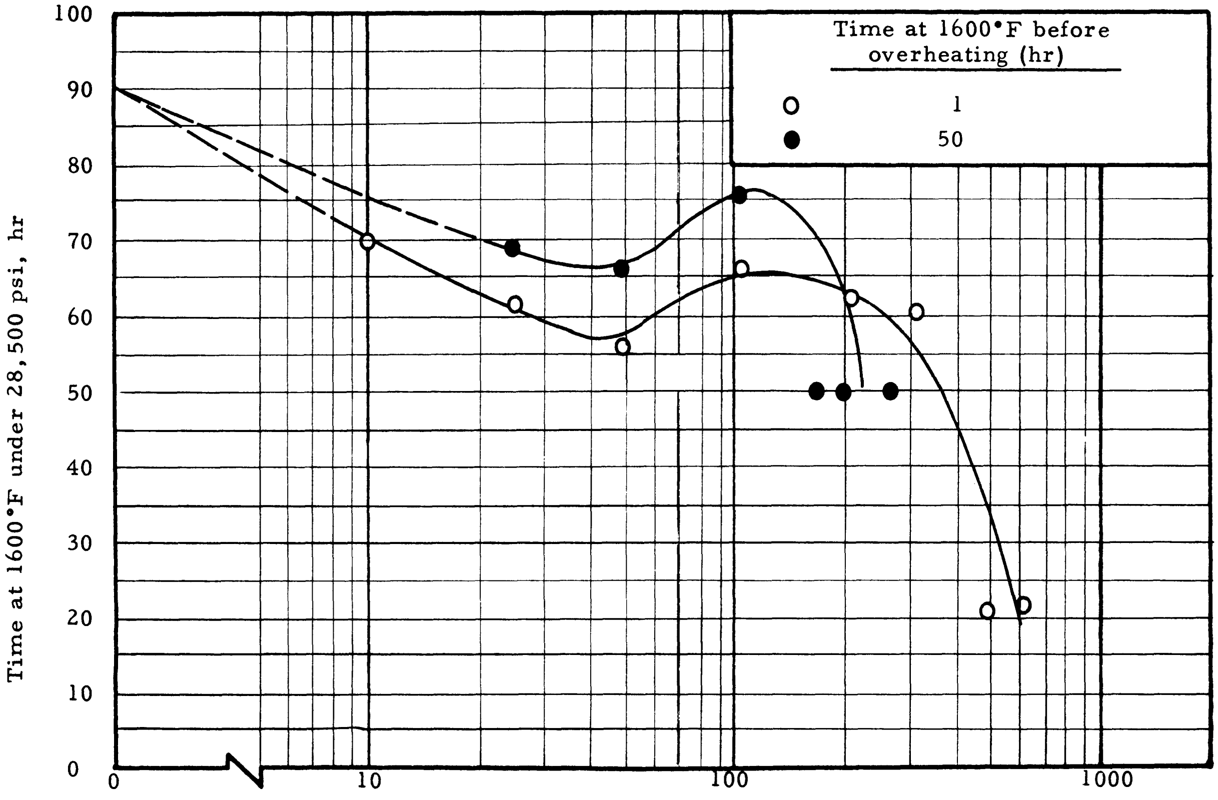
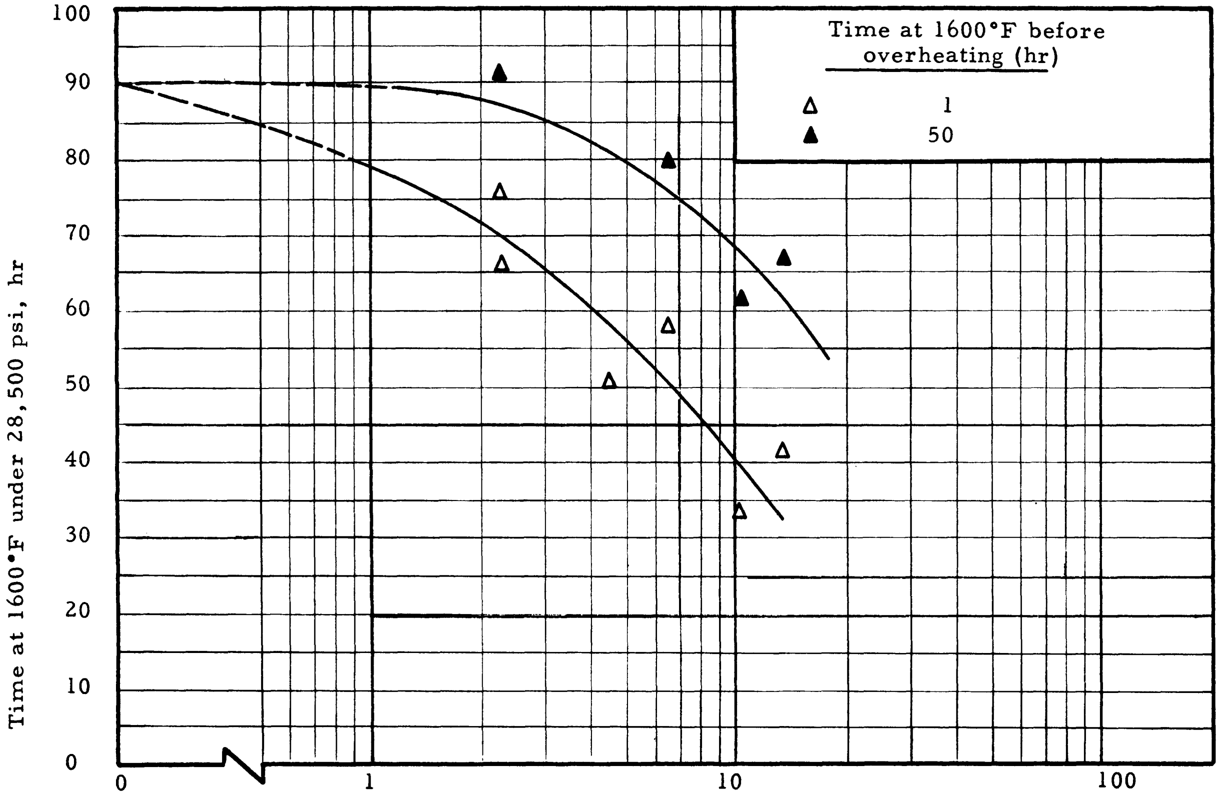


Figure 6. - Effect of overheat temperature on the time for rupture of Udimet 500 alloy at 1600°F and 28,500 psi for tests overheated to the indicated temperatures for two minutes every five hours both with no stress during the overheat period, and with 15,000 psi present during the overheat. Overheating continued until the sample ruptured after the indicated number of cycles.

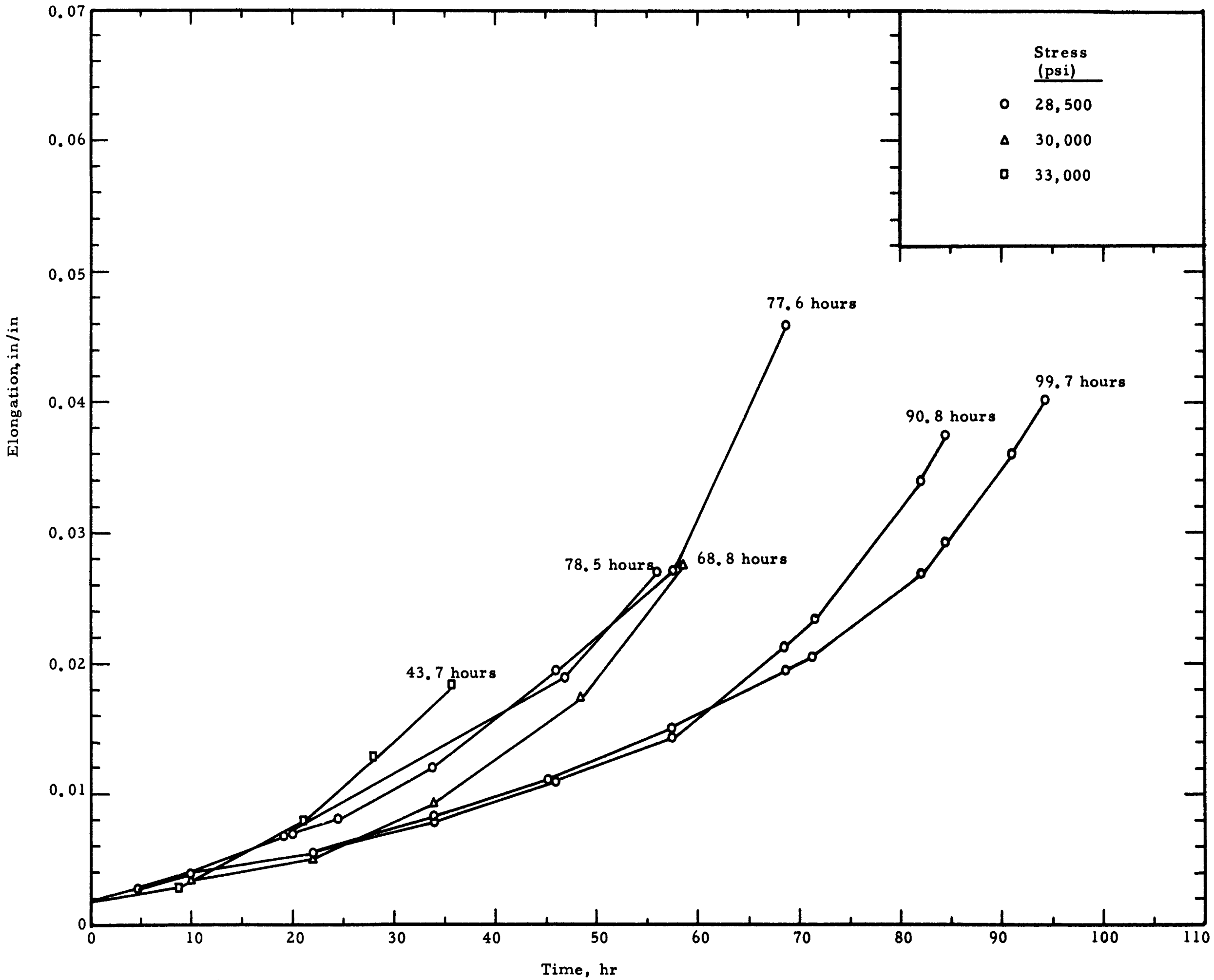


a) Tests overheated to 1800°F

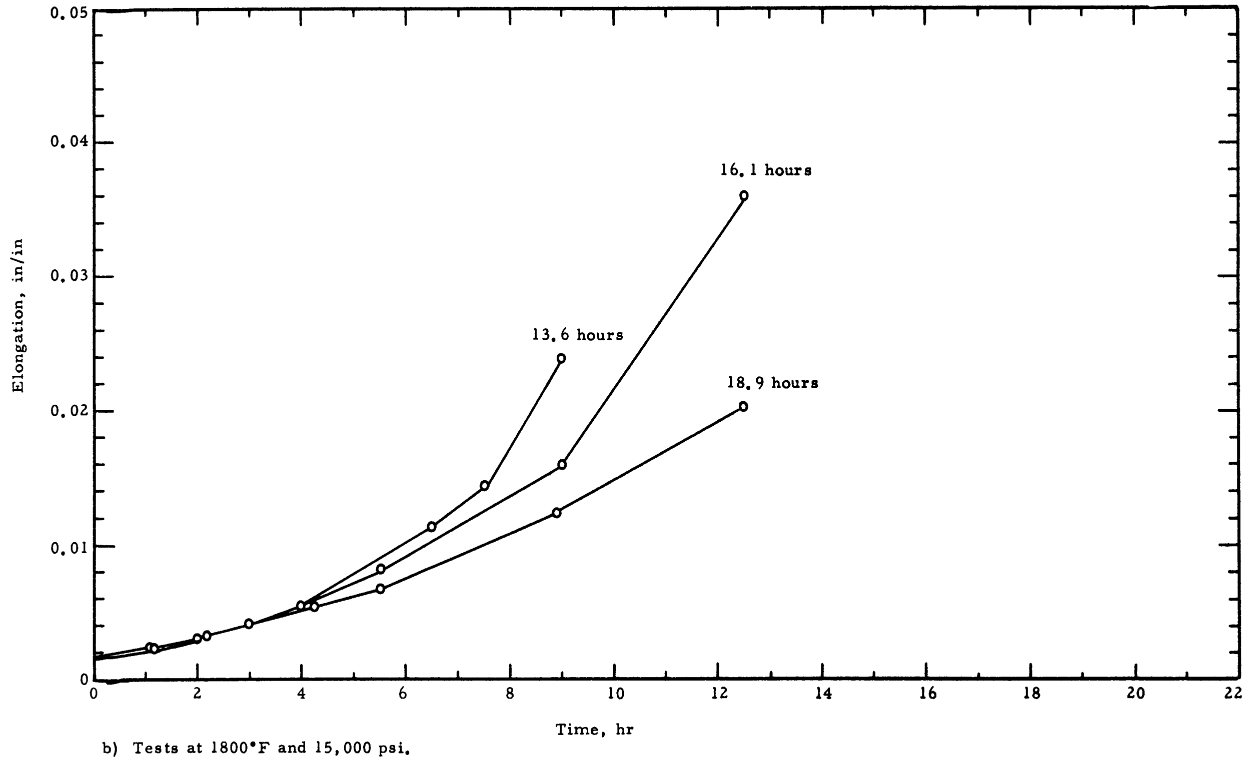


b) Tests overheated to 1900°F

Figure 7. - Effect on the time to rupture for Udimet 500 alloy at 1600°F under 28,500 psi of the duration of a single overheat to 1800° or 1900°F under 15,000 psi applied after 1 hour or 50 hours of elapsed testing time.

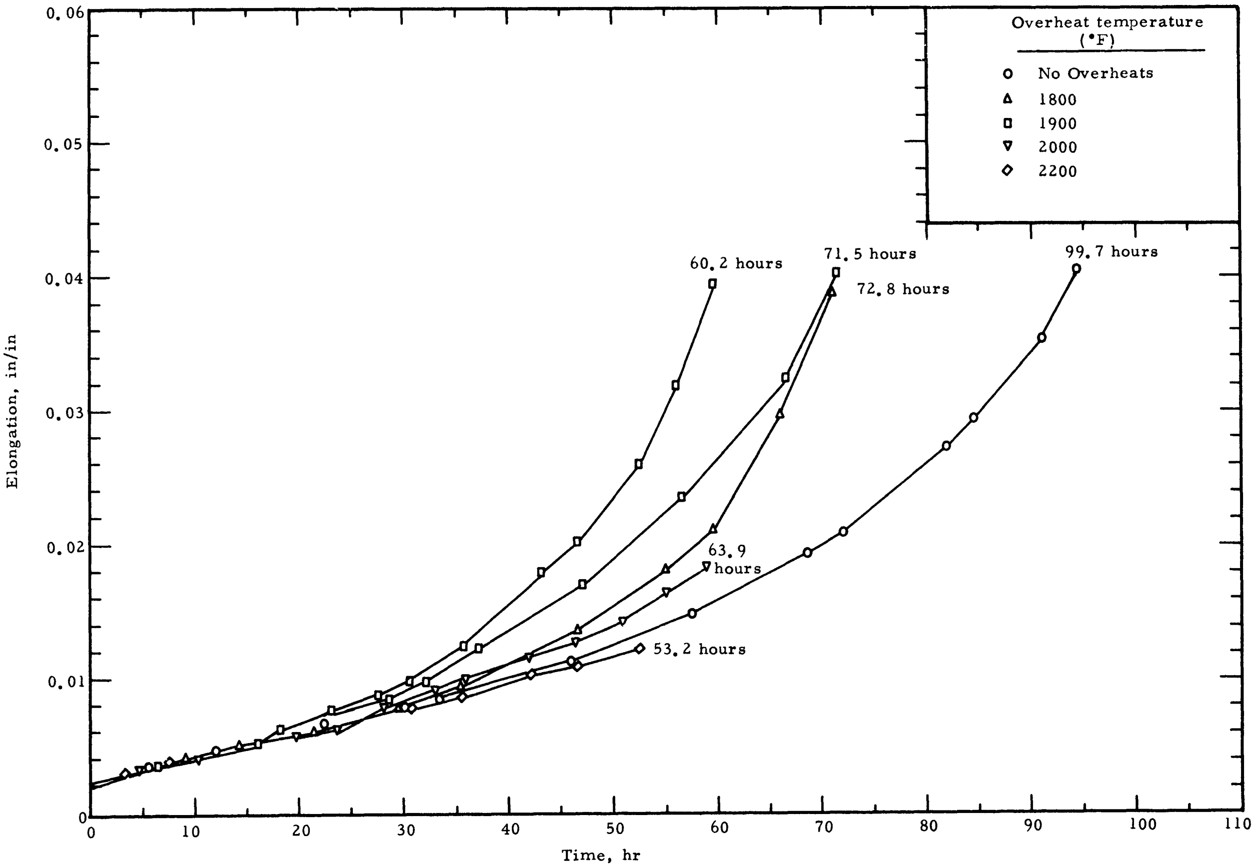


a) Tests at 1600°F and the indicated stress.

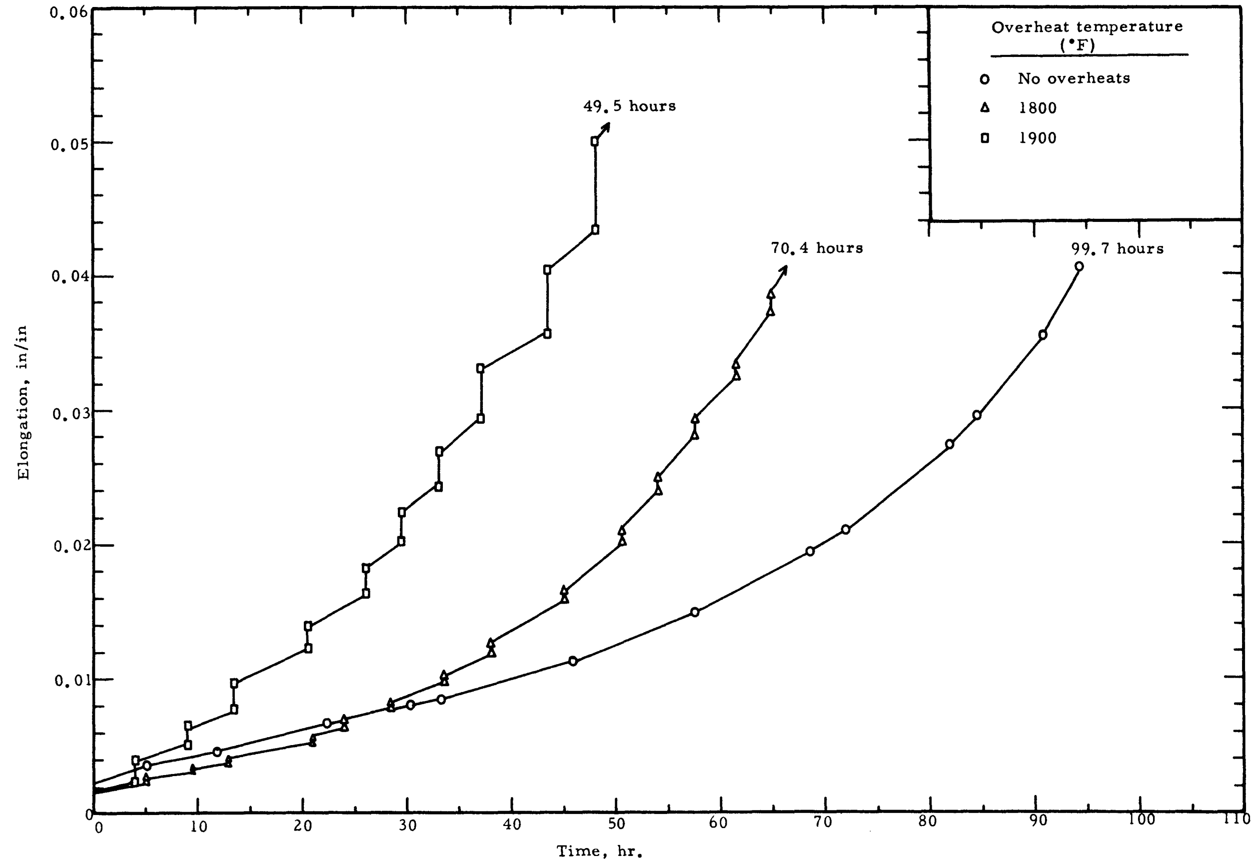


b) Tests at 1800°F and 15,000 psi.

Figure 8. - Time-elongation curves for normal constant temperature creep-rupture tests on Udimet 500 alloy. Rupture time indicated for each curve.

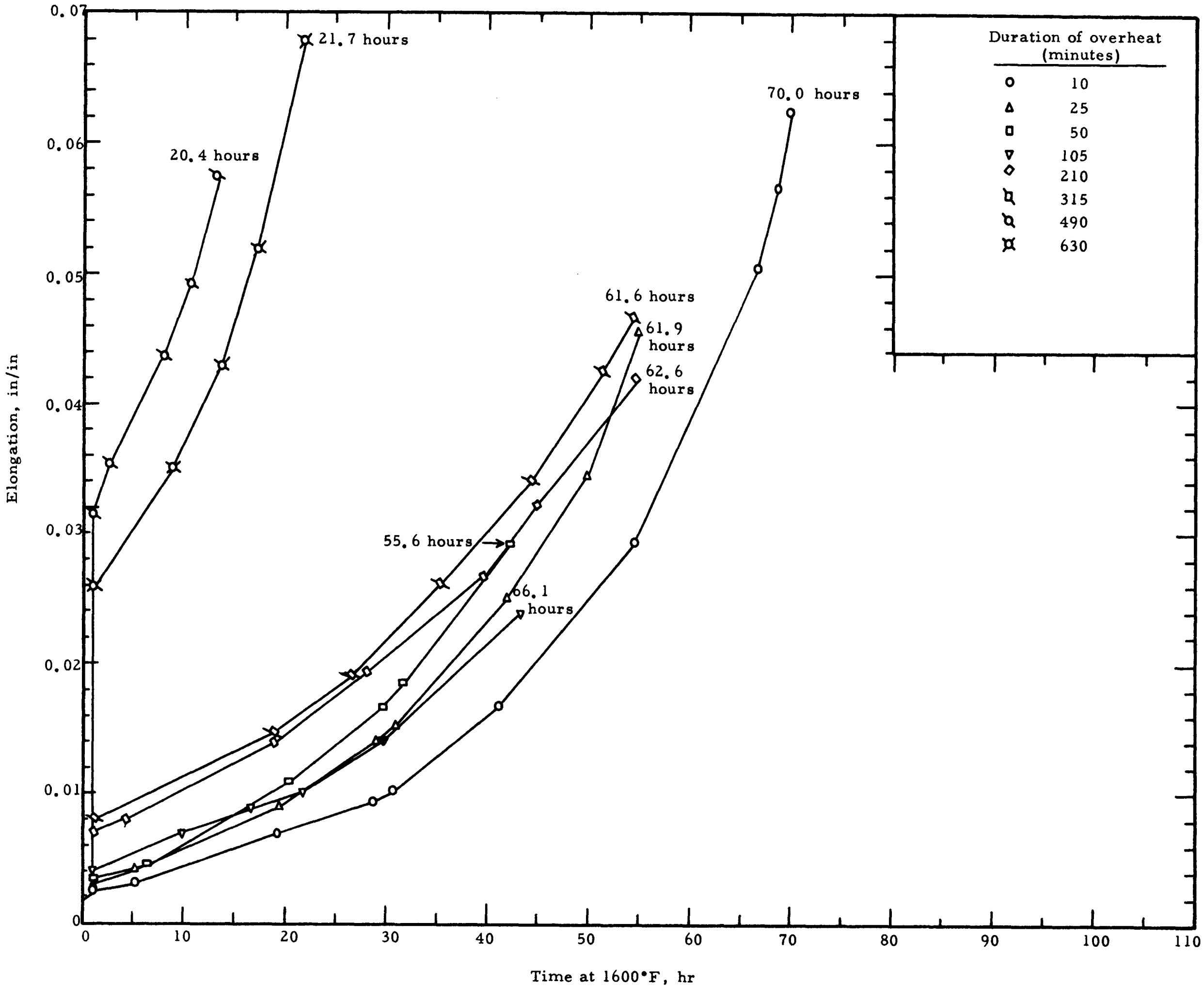


a) Tests overheated with stress removed.

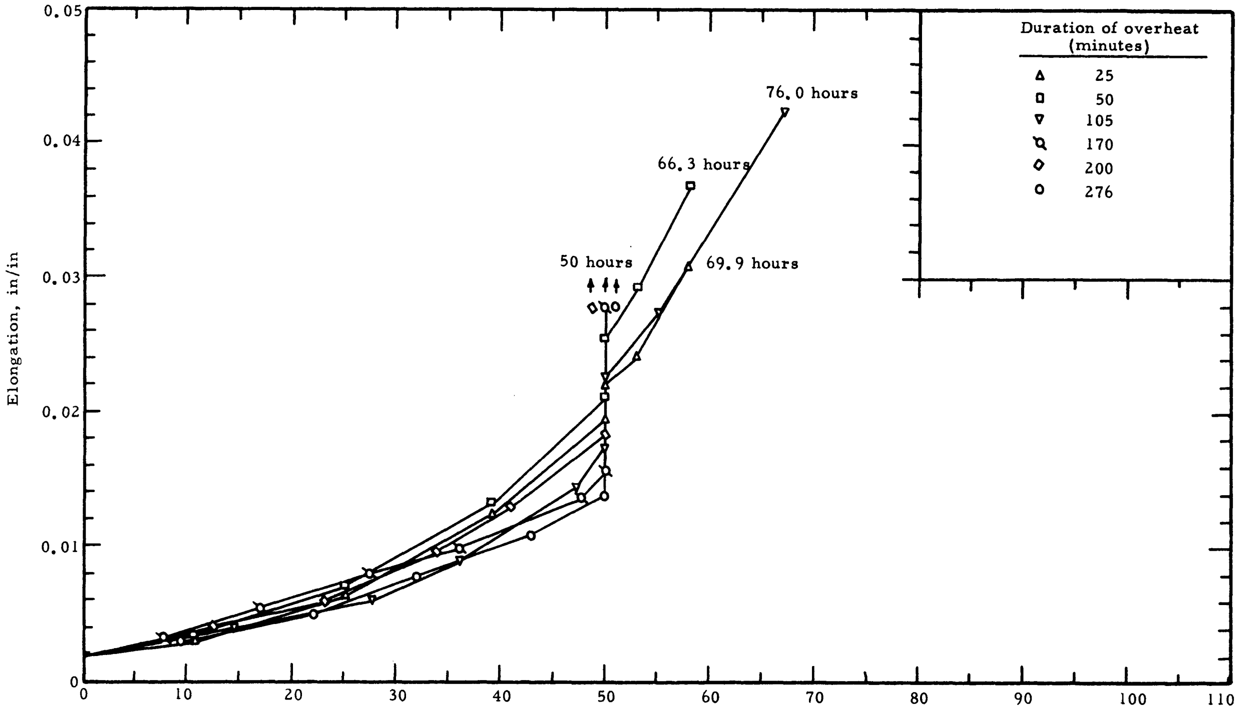


b) Tests overheated with stress reduced to 15,000 psi.

Figure 9. - Time-elongation curves at 1600°F and 28,500 psi for tests overheated to the indicated temperatures for two minutes every five hours both in the absence of stress and with stress reduced to 15,000 psi. Total time at rupture indicated for each curve.

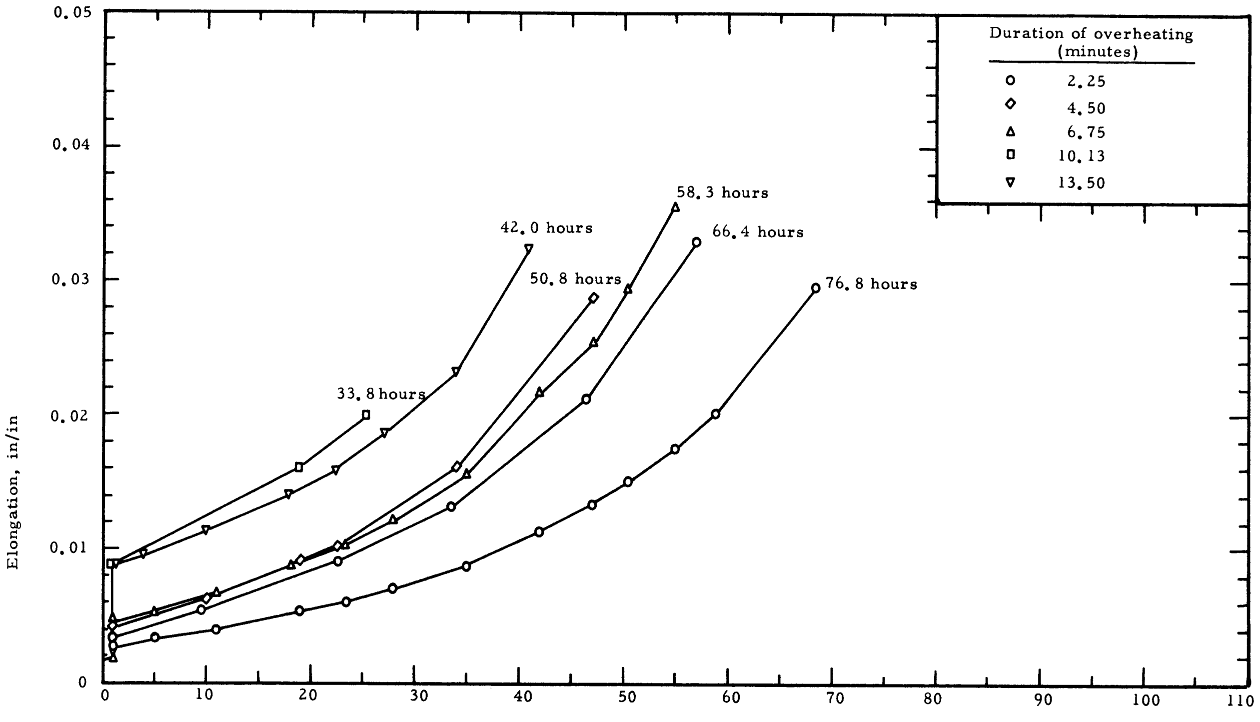


a) Tests overheated after 1 hour.

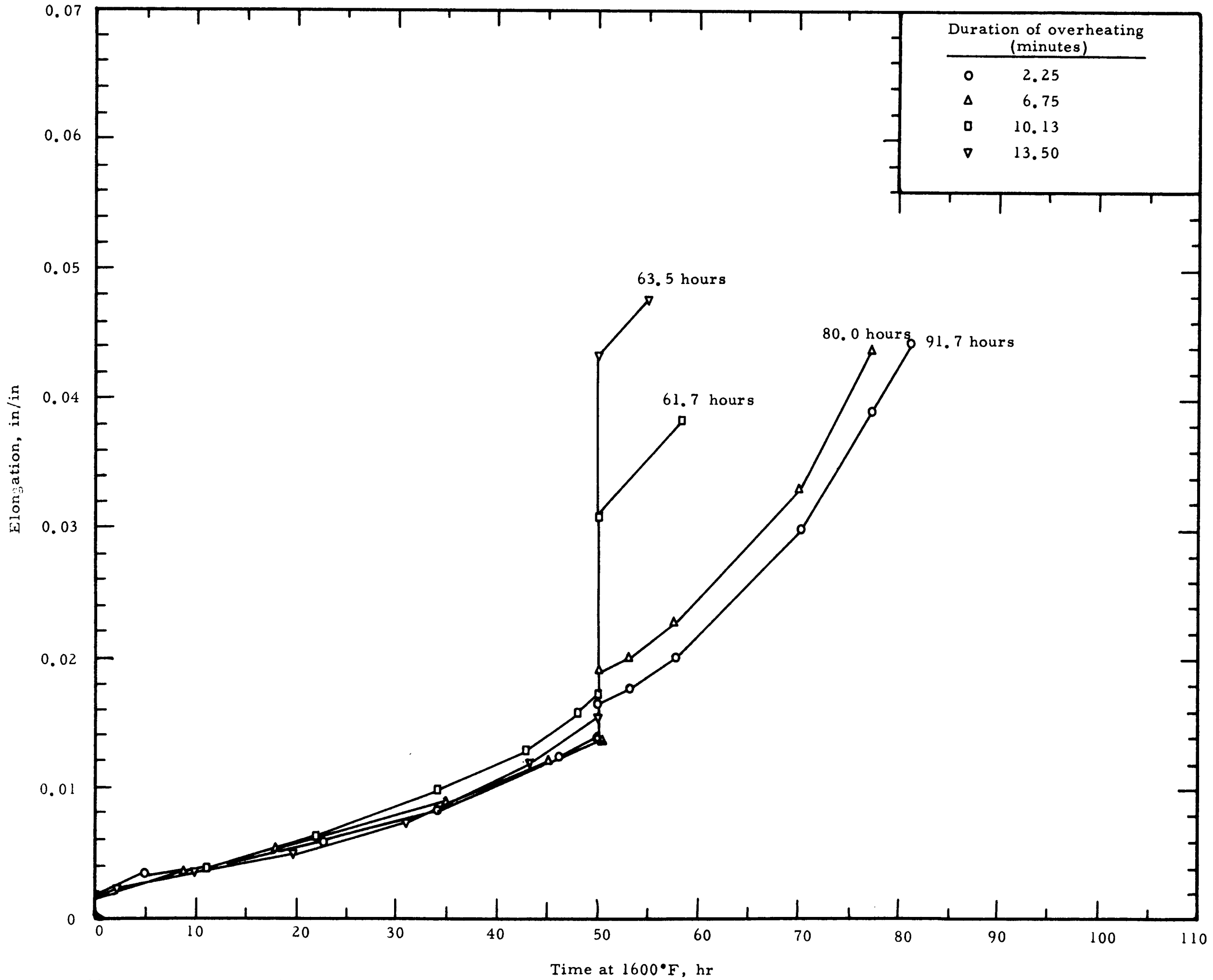


b) Tests overheated after 50 hours.

Figure 10. - Time-elongation curves at 1600°F and 28,500 psi for tests overheated for the indicated times to 1800°F under 15,000 psi after 1 hour and after 50 hours at 1600°F. Total time at 1600°F at rupture indicated for each curve.



a) Tests overheated after 1 hour.



b) Tests overheated after 50 hours.

Figure 11. - Time-elongation curves at 1600°F and 28,500 psi for tests overheated for the indicated times to 1900°F under 15,000 psi after 1 hour and after 50 hours at 1600°F. Total time at 1600°F at rupture indicated for each curve.