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A METALLURGICAL INVESTIGATION OF A LARGE FORGED DISC OF CSA (234-A-5) ALLOY

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NACA

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A METALLURGICAL INVESTIGATION OF A LARGE FORGED DISC OF CSA (234-A-5) ALLOY

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SUMMARY

It has been found that the properties of heat-resisting alloys are dependent to a considerable extent on the conditions of fabrication. The large size of the forgings for certain types of gas-turbine rotors has introduced fabrication procedures for the alloys for which information is not available. This variable is being investigated for the better alloys. The present report is the second of a series to be issued on this subject. The first report covered a similar investigation of a 19-9 DL alloy disc. (See reference 1.)

The principal results obtained from the study of a $20\frac{1}{8}$-inch diameter by $3\frac{5}{16}$-inch thick disc of CSA alloy in the as-forged and stress-relieved condition with a surface Brinell hardness ranging from 212 to 255 were:

A. Yield Strengths

	(psi)
0.02% offset at room temperature	40,600
0.2% offset at:	
room temperature	61,300
1200° F	40,000
1350° F	34,500

B. Rupture-Test Characteristics

Stress, psi, to cause rupture at indicated temperatures in:

	(1200° F)	(1350° F)
10 hours	42,000	25,500
100 hours	35,500	19,000
1000 hours	30,000	12,500

The elongation and reduction of area of the fractured specimens were high.

C. Total Deformation Characteristics at 1200° F

Stress, psi, to cause indicated total deformations in:

	(0.1%)	(0.2%)	(0.5%)	(1.0%)	(transition to third-stage creep)
10 hours	15,750	25,000	30,000	33,500	------
100 hours . . .	13,000	21,000	27,500	30,000	32,000
1000 hours . . .	10,250	17,000	25,000	26,500	26,000

D. Creep Strength at 1200° F

	(psi)
Stress for a creep rate of:	
0.01 percent per 1000 hours	9,000
0.10 percent per 1000 hours	21,000

E. Uniformity

The properties of the disc were uniform for a forging of the size considered, although they were somewhat higher at the surface and rim due to a small amount of cold work.

F. Stability

The material was quite stable at 1200° F except for some loss in impact strength during creep tests. Structural instability was the cause of low strength at 1350° F.

The tensile and rupture strengths were low in comparison to previous data on bar stock. This was attributed to lack of hot-cold work as shown by the low hardness, and probably to the composition of the heat being low in carbon and high in columbium. The rupture strengths at 1350° F were similar to previous data for bar stock.

The rupture and creep strengths were somewhat lower than were found for a 19-9 DL alloy disc in a similar condition of fabrication. The time-deformation strengths and short-time tensile properties were similar for the two discs except that a lower stress caused third-stage creep in the CSA alloy.

Some improvement in load-carrying ability might be obtained by adjustment of chemical composition. It is probable, however, that the development of strength characteristics equivalent to those previously obtained in bar stock for time periods up to 1000 hours at 1200° F would require that such large discs be cold-worked. Equipment and procedures for this purpose have recently been developed.

INTRODUCTION

The need for improved materials for use in gas turbine rotor applications has led to the development of several alloys with good high temperature properties. One of these is CSA alloy[1] which is a 4%Mn-4%Ni-18%Cr-1.5%W-1.5%Mo-0.5%Cb analysis.

This composition was developed by the Crucible Steel Company in cooperation with the National Advisory Committee for Aeronautics. The alloy had been found to have good high temperature properties in the form of bar stock and small forgings. Since it was known that the properties of such alloys vary with fabrication conditions, an investigation was undertaken to determine the properties of a large forged disc of the type required for certain gas-turbine designs.

The disc used for this investigation was produced by the Crucible Steel Company and submitted to the University of Michigan for investigation for the National Advisory Committee for Aeronautics. This work was part of a program of development of several alloys for similar applications. A previous report on a similar disc of 19-9 DL alloy has been issued. (See reference 1.) All of these investigations have

[1]The original heats of this alloy were designated as 234-A-5 alloy and were reported under that name. The name has since been changed to "CSA" alloy.

been sponsored by the NACA as part of a general research program on the development of alloys with improved high-temperature properties for use in aircraft power plants.

EXPERIMENTAL PROCEDURE

The investigation of the disc was carried out to provide three types of data: (1) the physical properties at room temperature, 1200° and 1350° F which can be expected in large forgings of the CSA analysis; (2) the variation in properties in different locations of the large disc; and (3) the change in properties resulting from prolonged exposure to stress at 1200° and 1350° F.

The data were made as complete as possible from tension tests and are presented in a manner suitable for design purposes. Short-time tensile properties at room temperature, 1200° and 1350° F, rupture-test data up to 2000 hours at 1200° and 1350° F, and curves of stress versus time for total deformations of 0.1, 0.2, 0.5 and 1 percent at 1200° F are included. The time-deformation data were based on creep as well as rupture tests.

Hardness surveys and tensile and rupture tests at representative locations were used for uniformity studies. The completed test specimens were checked for stability by hardness, tensile and impact tests and by metallographic examination.

The details of the test procedures are summarized in the appendix.

DESCRIPTION OF DISC

The descriptive material for the disc is summarized below:

Name:

The alloy was originally developed under the designation of "234-A-5" alloy. This was later changed to the designation "CSA" alloy.

Manufacturer:

The Crucible Steel Company of America

Heat number:

Induction heat 1X2218

Chemical composition:

The analysis was reported by the manufacturer as the following percentages:

C	Mn	Si	Ni	Cr	Cb	W	Mo	P	S
0.25	4.14	0.25	5.76	18.32	0.95	1.51	1.46	0.017	0.023

Fabrication procedure:

A 15-inch short ingot was hammer cogged with a 7-ton hammer. The ingot was charged into a cold furnace, heated to 1500° F and held 1 hour, brought up to 2050° F and held 12 hours, then cogged to a 9-inch square billet. The billet was deep etched at the top and reported good. A slug, $13^1/_2$-inches long and weighing 308 pounds was saw cut for the disc.

The slug was charged into a cold furnace, heated to 2150° F and held 7 hours. The following schedule was used in forging the disc:

1. knocked off corners and upset to 10-inch thickness, recharged into furnace;

2. reheated to 2100° F and upset to 7-inch thickness and rounded;

3. reheated to 2100° F and flattened to 5-inch thickness and rounded;

4. reheated to 2100° F and flattened to $4^1/_8$-inch thickness;

5. reheated to 1750° F and flattened to $3^7/_8$-inch thickness;

6. reheated to 1850° F and flattened to $3^5/_{16}$-inch thickness by $20^1/_8$-inch diameter with a finishing temperature of 1400° F.

Heat treatment:

The as-forged disc was stress-relieved at 1200° F for 4 hours.

Sampling:

The complete disc was shipped to the University. The location of the test coupons cut from the disc and the identifying code system is outlined by figure 1. The letters X, Y and Z refer to the location of the test coupons with respect to the flat faces of the disc. One surface of coupons marked X and Z was the outside surface of the forging; while the Y coupons were taken from the center third.

Rupture tests were conducted on 0.160-inch diameter specimens obtained by splitting a $2^3/_4$-inch length from coupons, as described above, into quarters in a lengthwise direction.

RESULTS

The results are presented as a series of figures and tables setting forth the data from the hardness, tensile, rupture and creep tests.

Hardness Survey

The Brinell hardness of the tensile specimens (table I) varied from 204 to 227. The lowest hardness was found for specimens from the center plane while those from the surface plane were somewhat harder. A Rockwell "B" hardness survey of one of the coupons (figure 2) showed hardness increasing from the center towards the rim and the surface of the forging.

At the time the disc was submitted the results of a survey of the surface Brinell hardness was reported by the Crucible Steel Company. As shown by figure 3, their data indicated remarkably uniform hardness at the surface ranging from 235 to 255. Apparently the metal machined off the specimens exposed metal with somewhat lower hardness than that of the original surface.

Short-Time Tensile Properties

There was relatively little difference at room temperature in tensile properties of specimens from various locations in the disc. (See table I.) Tangential specimens had somewhat higher strength than specimens taken radially and those from the surface planes of the forging were slightly stronger than those from the center plane.

At 1200° F there was no difference between center and surface specimens taken radially from the disc.

The stress-strain curves for the tensile tests are included as figure 4.

Rupture Test Characteristics

Complete stress-rupture time data for time periods up to 2000 hours at 1200° and 1350° F are given in table II for radial specimens from the center plane at the rim of the disc. These tests were supplemented by single tests on specimens from other locations to show variation in strength throughout the disc.

The rupture strengths shown by the stress-rupture time curve (figure 5) for center-radial specimens were 35,500 and 30,000 psi, respectively, for rupture in 100 and 1000 hours at 1200° F. Corresponding values at 1350° F were 19,000 and 12,500 psi. At 1200° F the tangential specimens had somewhat higher strength than that shown by the curve for center-radial specimens. Apparently surface specimens were slightly stronger at 1350° F. High elongation and reduction of area decreasing with increasing times to fracture were shown by the broken specimens.

The 1200° F stress-rupture time curve was a straight line; but at 1350° F instability in the material caused a break in the curve.

Time for Deformation Characteristics Under Stress

Curves of stress versus the time required to reach 0.1, 0.2, 0.5 and 1 percent total deformation at 1200° F are shown as figure 6. In order to give as complete information as possible regarding the deformation characteristics of the material under tensile stresses, the stress-rupture time data have been included in this figure. A curve is also shown for the transition from second-stage to third-stage creep to indicate when rapid elongation to failure starts.

The deformation data were obtained from time-elongation curves from creep tests (figure 7) and from the rupture tests (figures 8 and 9) at 1200° F. The data from these curves used in plotting figure 6 are tabulated as table III. In general, the data from creep and rupture tests agreed quite well except that the 28,500 psi rupture specimen apparently deformed at a faster rate than the other specimens during the period of first-stage creep.

The strength of the alloy at 1350° F in rupture tests was low in comparison to other available alloys. For this reason the time-deformation characteristics were not evaluated at this temperature. The time-elongation curves for the rupture tests, however, are shown as figures 10 and 11.

Creep Strength

The creep rates at 1200° F from the time-elongation curves have been plotted to logarithmic coordinates in figure 12 as the familiar stress-creep rate curve. This figure shows creep strengths of 9000 and 21,000 psi for creep rates of 0.01 and 0.10 percent per 1000 hours, respectively. Extrapolation of the transition curve of figure 6 indicates that third stage creep would occur under 21,000 psi at about 10,000 hours. This indicates that the usual extrapolation of the 0.10 percent per 1000 hour creep strength to 10,000 hours would be reasonably safe.

Stability Characteristics

After creep testing for time-deformation data the completed test specimens were subjected to room-temperature tensile, impact, and hardness tests. The results obtained (table IV) showed some decrease in tensile properties as a result of exposure to stress at 1200° F for approximately 1000 hours. The greatest change was in impact strength which was only one-half of that of the original material. There was no change in hardness as a result of testing at 1200° F while the hardness of the 1350° F rupture specimen was slightly higher than that of the original material.

The appearance of the microstructure varied to a considerable extent as is shown by figures 13, 14 and 15. There was a large amount of excess constituent present which varied in form depending on the direction in which the metal flowed during forging with respect to the plane of the metallographic sample. Both the grains and the excess constituents reflected the amount and direction of the flow of the metal during forging. The grain size was about number 5.

There was very little change in structure in the specimens tested at 1200° F. The amount of excess constituent in the 1350° F rupture specimens increased to a rather marked extent. At both 1200° and 1350° F the grains of the rupture specimens showed considerable elongation at the fracture. The fractures were transcrystalline at 1200° F and there was no intercrystalline cracking. A slight amount of cracking was adjacent to the fracture of the 1350° F specimen.

The original material was quite magnetic. This changed very little as a result of testing at 1200° F. After testing at 1350° F., however, the response to a magnet had decreased to a considerable extent. The response to the magnet was greatly increased by room temperature tensile tests. This characteristic of the alloy indicates that the excess constituents were partly a combination of ferrite and sigma phase.

DISCUSSION OF RESULTS

The high-temperature properties of the as-forged disc have been determined over a wide range of stresses and total deformations at 1200° F. The strength properties obtained were in general lower than had been anticipated on the basis of prior investigations of bar stock. These properties may be typical for large discs finish forged at a high temperature to a low hardness. They should not be definitely considered typical as such until further information is available in which possible heat-to-heat variations and the effects of fabrication procedures are taken into consideration.

The introduction of hot-cold work by the use of a lower finishing temperature, or by reheating and working the disc at temperatures of about 1200° F, would certainly have raised the yield strength of the disc and probably the rupture and creep strength for time periods up to about 1000 hours. Evidence of this is shown by the higher tensile and rupture strengths of samples close to the surface and rim of the disc where some cold-work improved the properties. Since the disc under consideration was fabricated, equipment and production methods have been developed to hot-cold work such discs.

At 1200° F the alloy appeared to be very stable. There was practically no change in microstructure and there was no evidence of intergranular cracking in the rupture tests. The hardness, tensile properties and magnetic response were unchanged as a result of 1200° F testing. The impact strength did decrease. The data at 1350° F did show instability. The low rupture strength, intergranular cracking, large increase in excess constituents and their agglomeration, and the decrease of response to a magnet were all evidence of this.

The phase relationships for the alloy CSA composition are such that in the temperature range considered at least four constituents are possible. These are austenite, ferrite, carbides and sigma phase. The predominating constituent is the austenite of the matrix. The response of the original material to a magnet was probably due to the presence of some ferrite and perhaps magnetic carbides. The increase in magnetism after room-temperature testing was due to an increase in the amount of ferrite. The disappearance of magnetism during rupture testing at 1350° F was probably caused by the conversion of the ferrite to sigma phase. The increase in excess constituent at 1350° F was probably largely an increase in sigma phase as well as a more complete carbide or other compound precipitation.

The retention of hardness and physical properties during testing at 1200° F was probably due to any annealing effect being counterbalanced by precipitation strengthening. The decrease in impact strength was probably caused by such precipitation and possibly the formation of brittle sigma phase. The increase in low-strength sigma phase together with the agglomeration of excess constituents lowered both strength and stability at 1350° F.

The properties of the forging were uniform for an as-forged disc of the size under consideration. The disc had received more cold work at the surface and rim, as is normal, and the properties were somewhat higher in this location as a consequence.

Comparative Properties for CSA Alloy

Two heats of CSA alloy have been investigated for their high-temperature properties in the form of bar stock. The treatments used and the resulting physical properties are compared in table V with those for the large disc. These data show that variations in heat-treatment and hot-cold work, reflected in the Brinell hardness, produce rather wide variations in both tensile properties at room temperature and in rupture strength at 1200° F. In general, hot-cold work raises the yield strength to a very pronounced degree and raises the rupture strength about 10,000 psi.

There is some indication that the increase in rupture strength obtained by cold work will be lost at time periods in excess of 1000 hours because of a steeper slope to the stress-rupture time curve in comparison to materials without cold work. Bar stock cold worked during the forging or rolling operation also had high ductility to fracture in the rupture test, while those cold worked after a solution treatment had low elongation and reduction of area. This finding indicates that the latter material would have better creep properties for the same rupture strength.

Even after taking the processing differences into consideration, the rupture strength of the large disc seems to be abnormally low. Chemical composition differences may have been responsible for this. Heat 1X2218 used for the large disc was low in carbon and high in columbium as is shown below:

Type Material	Heat Number	Chemical composition (percent)							
		C	Mn	Si	Cr	Ni	W	Mo	Cb
Large disc	1X2218	0.25	4.14	0.25	18.32	5.76	1.51	1.46	0.95
Bar stock	234-A-5	.38	4.17	.30	18.52	4.55	1.34	1.35	.57
Bar stock	3678-A-2	.42	4.17	.55	18.04	5.13	1.29	1.41	.59

The combination of low carbon and high columbium would tend to reduce the effective carbon in comparison to the other two heats. The effect of this variation has not been determined for bar stock, but it might well have an adverse effect on strength properties. General metallurgical principles indicate that it would have the effect of lowering austenite stability and promoting ferrite and sigma phases which are believed to adversely affect strength characteristics. It would also decrease tungsten and molybdenum carbide formation which are believed to be beneficial to high-temperature strength.

Rupture-test data at 1350° F for the as-forged bar stock from Heat 234-A-5 described in table V are compared below with those for the large disc:

Type Material	Heat Number	1350° F Rupture Test Properties			
		100-hour		1000-hour	
		Strength (psi)	Elongation (percent)	Strength (psi)	Elongation (percent)
Large disc	1X2218	19,000	30	12,500	13
As-forged bar stock	234-A-5	22,500	26	12,500	20

There was relatively little difference in the two forms indicating that the cold-work in the bar stock was not effective at 1350° F in increasing the rupture strength.

The investigation of this CSA disc was part of a program of investigation of several alloys for service as rotors in gas turbines. The results obtained for a similar disc of 19-9 DL alloy have previously been reported as Advance Confidential Report 5C10. (See reference 1.) The properties of the two alloys in the form of large discs in the as-forged condition are compared in table VI. It should be understood that the properties of both alloys probably could be considerably improved through hot-cold work by methods and equipment now available.

The two alloys are similar in type, the difference being that CSA has higher manganese with lower nickel, the columbium is higher, and no titanium is added. Manganese and nickel have similar structural effects in many respects, as do columbium and titanium, so that the alloys are of a similar nature. Both were fabricated to a very similar condition as judged by hardness and tensile properties.

At 1200° F the rupture strength of the CSA disc was about 4000 psi lower than that of the 19-9 DL with similar ductility characteristics. At 1350° F the 19-9 DL was again superior by 3000 to 4000 psi. There was very little difference in time-deformation strengths at 1200° F between the two discs except for the higher stress to cause transition to third-stage creep for the 19-9 DL disc. The 19-9 DL disc had slightly higher strengths at the smaller total deformations and at the longer time periods. This tendency is borne out by the somewhat higher creep strength of the 19-9 DL material.

The properties of both 19-9 DL and CSA alloys can be altered to a considerable extent by variations in heat treatment and amount of cold work. The agreement in properties between the two discs considered above does seem to indicate that when they are forged to the same hardness with little or no cold work they have similar properties in the form of large forgings. Information is not yet available regarding their response to heat treatment and hot-cold work in the form of large forgings, although this is now being investigated for CSA alloy and will probably be undertaken for 19-9 DL alloy in the near future.

CONCLUSIONS

The properties of one large disc of CSA alloy in the as-forged and stress-relieved condition have been determined for constant-tension stress conditions. The data obtained include tensile properties, rupture test characteristics at 1200° and 1350° F, and time-deformation characteristics in creep and rupture tests at 1200° F.

The strength properties were not as high as had been anticipated on the basis of previous investigations of bar stock. This may have been due to the lack of cold work caused by the high finishing temperature, or to the composition of the heat having been low in carbon and high in columbium. While some improvement in properties may be possible by adjustment of the composition, the indications are that any appreciable improvement in properties will require hot-cold working such discs.

The rupture strength was low at 1350° F, but was no worse than hot-cold worked bar stock. This was probably due to the ineffectiveness of cold-work in improving strength at 1350° F. The low strength at 1350° F was caused by structural instability. The low carbon and high columbium contents of the disc may have lowered properties by reducing structural stability.

The properties of the disc were quite uniform for a forging of the size under consideration. There was some evidence of cold work at the rim and surface which enhanced the properties.

The properties of the CSA disc were slightly lower than those of as-forged 19-9 DL disc of the same hardness in rupture and creep tests. There was very little difference in total deformation characteristics.

Department of Engineering Research,
University of Michigan,
Ann Arbor, Michigan, April 25, 1945.

REFERENCES

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2. Freeman, J. W., Rote, F. B., and White, A. E.: High Temperature Characteristics of 17 Alloys at 1200° and 1350° F. NACA ACR No. 4C22, 1944.

APPENDIX

TESTING PROCEDURE DETAILS

Hardness Testing

The Brinell hardness values reported were made on a flat surface ground on the shoulders of the room temperature tensile test specimens. The hardness survey was made by grinding the surfaces of one of the coupons and then measuring the Rockwell "B" hardness at 1/4-inch intervals along the length of the coupon.

The hardness changes resulting from testing were made by comparing the Vickers hardness of metallographic specimens with typical original samples from comparable locations in the disc.

Short-Time Tensile Tests

Standard 0.505-inch diameter specimens with 2-inch gage lengths were used for tensile tests. The equipment consisted of a 60,000-pound hydraulic testing machine and an extensometer system with a sensitivity of 0.000003 inch per inch.

Stress-strain data were taken at increments of 2500 pounds per square inch until the 0.2-percent offset yield strength was exceeded. The extensometer system was then removed and the specimen fractured at a constant head speed of 0.03 inch per minute. At 1200° and 1350° F the test bar was held at temperature 1 hour before testing. Temperature control and distribution were in accordance with A.S.T.M. recommended practice for short-time tension tests at high temperatures.

Rupture Testing

The specimen used was 0.160-inch diameter with a 1-inch gage length. Pieces 2 3/4 inches in length were cut from the rim ends of radial bars 17Y, 17X and section DY, and center end of 20Y. Tangential specimens were taken from the rim edge of section B. These were split into four quarters lengthwise and machined into specimens.

The tests of less than 10 hours duration were made in the tensile machine with the specimens being held at temperature 1 hour before testing. Individual stationary units applying the stress through a simple-beam and knife-edge system were used for the longer duration tests. Twenty-four hours were allowed for temperature adjustments prior to application of the stress. Time-elongation data were obtained by measuring the "drop of the beam" during the tests.

Time for Deformation Data at 1200° and 1350° F

Time-elongation curves were obtained from constant-stress tension tests at stresses ranging from those of the rupture tests to those requiring 1000 hours to cause 0.1 percent total deformation. All tests except the rupture tests were made in creep-test units on 0.505-inch diameter specimens with an extensometer attached to the gage length of the specimens. The stresses were selected to cause total deformation of 0.1, 0.2, 0.5, and 1 percent in various time periods up to 2000 hours. Many of the tests were discontinued at time periods less than 2000 hours when it was evident that the next highest total deformation value desired would not be reached in 2000 hours.

The rupture-test time-elongation curves were adjusted for total deformation by correcting for initial deformation with stress-strain data from tensile tests. This procedure was necessary since the drop-of-the-beam method does not measure the deformation occurring when the stress is applied. While this method was not as accurate as the high precision creep test, it makes the rupture-test curves more useful for total deformation studies.

Stability Tests

Creep test specimens from the longer duration tests were subjected to room-temperature tensile, impact, and hardness tests. The tensile tests were run the same way as those on original samples. Impact specimens were prepared by machining the largest square bar possible from the gage length of the creep specimens, 0.365-inch square, and using a V-notch 0.050-inch deep. Two such specimens were obtained for Izod type tests. Hardness determinations were made on metallographic specimens with a Vickers machine.

Samples taken lengthwise of the specimens at the middle of the creep specimens and at the fracture of the rupture-test specimens were examined metallographically. The etching reagent used was aqua regia in glycerine.

TABLE I

SHORT-TIME TENSILE PROPERTIES OF THE CSA ALLOY FORGED DISC

Specimen number	Specimen location	Temperature (° F)	Tensile strength (psi)	Offset yield strength (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Brinell hardness
				(0.02%)	(0.1%)	(0.2%)				
17Y	C.R.	Room	106,900	37,500	50,500	56,000	22,500	35.5	40.7	204
22Y	C.R.	Room	108,800	37,500	53,500	59,500	22,500	33.0	33.8	209
19X	S.R.	Room	106,500	46,000	55,500	59,500	25,000	35.0	44.9	215
5Y	C.T.	Room	110,550	37,000	54,000	62,000	20,000	38.0	47.2	225
5X	S.T.	Room	113,300	45,000	61,500	69,500	25,000	33.5	47.2	227
20Y	C.R.	1200	52,750	------	37,000	39,500	17,500	27.5	45.8	---
23X	S.R.	1200	51,000	------	38,000	40,500	15,000	27.0	53.2	---
21Y	C.R.	1350	39,700	------	32,000	34,500	15,000	40.0	55.7	---
23Y	C.R.	1350	38,500	------	32,000	34,500	15,000	40.0	56.0	---

C.R. center plane radial specimen.
S.R. surface plane radial specimen.
C.T. center plane tangential specimen.
S.T. surface plane tangential specimen.

TABLE II

1200° AND 1350° F RUPTURE TEST CHARACTERISTICS OF THE

CSA ALLOY FORGED DISC

Specimen mark	Specimen location	Temperature (° F)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
17RY			48,000	1.09	28	41.8
DY			45,000	5.0	31	46.5
DY			35,000	127.0	32	48.3
DY	C.R.R.	1200	32,500	196.5	19	51.9
DY			30,000	974.0	18	38.8
DY			28,500	1596.0	13	33.0
20CY	C.R.C.		35,500	130.5	19	51.9
17RX	S.R.R.	1200	35,500	162.0	25	60.9
BY	C.T.R.		35,500	294.0	31	56.9
BX	S.T.R.		35,500	509.0	8	18.9
17RY			32,000	1.65	38	50.5
DY			20,000	71.5	39	48.3
DY	C.R.R.	1350	17,500	216.0	25	46.5
DY			15,000	420.0	15	22.3
DY			12,500	1080.0	13.5	12.2
20CY	C.R.C.		19,000	98.5	33	51.0
17RX	S.R.R.	1350	19,000	123.0	30	52.8
BY	C.T.R.		19,000	101.0	31	51.0
BX	S.T.R.		19,000	182.0	26	49.2

			Stress for rupture at indicated time periods (psi)				
			(1 hr)	(10 hr)	(100 hr)	(1000 hr)	(2000 hr)
----	C.R.R.	1200	48,000	42,000	35,500	30,000	28,000
----	C.R.R.	1350	33,500	25,500	19,000	12,500	11,000

C.R.R. center plane radial specimen at rim of disc.
C.R.C. center plane radial specimen at center of disc.
S.R.R. surface plane radial specimen at rim of disc.
C.T.R. center plane tangential specimen at rim of disc.
S.T.R. surface plane tangential specimen at rim of disc.

TABLE III

TIME-DEFORMATION DATA AT 1200° F FOR THE CSA ALLOY FORGED DISC

Specimen number	Stress (psi)	Initial deformation (percent)	Time in hours for indicated total deformation				Transition		Rupture Data	
			(0.1%)	(0.2%)	(0.5%)	(1.0%)	(hr)	Deformation (percent)	Time (hr)	Elongation (percent)
21X	11,000	0.057	585	---	-----	-----	----	----	----	----
15Y	12,500	.067	140	---	-----	-----	----	----	----	----
19Y	15,000	.078	22	---	-----	-----	----	----	----	----
22X	17,500	.092	0.4	750	-----	-----	----	----	----	----
15X	20,000	.107	-----	255	-----	-----	----	----	----	----
AY1	25,000	.133	-----	10	1090	-----	----	----	----	----
20X	27,000	.156	-----	1	200	665	550	0.85	----	----
DY	28,500	.151	-----	---	6	65	650	1.7	1596	13
DY	30,000	.163	-----	---	15	120	350	1.6	974	18
DY	32,500	.187	-----	---	1.4	17	75	3.0	196.5	19
DY	35,000	.219	-----	---	-----	3.5	40	3.5	127	32
BY	35,500	.220	-----	---	-----	25	160	2.5	294	31
BX	35,500	.220	-----	---	3	60	225	1.8	509	8
17RX	35,500	.220	-----	---	-----	4	----	----	162	25
20CY	35,500	.220	-----	---	-----	12	----	----	130.5	19
DY	45,000	-----	-----	---	-----	-----	----	----	5	31
17RY	48,000	-----	-----	---	-----	-----	----	----	1.09	28

TABLE IV

ROOM TEMPERATURE PHYSICAL PROPERTIES OF THE SPECIMENS FROM THE CSA DISC AFTER TESTING AT 1200° AND 1350° F

Type of test	Specimen number	Temperature (° F)	Stress (psi)	Time (hr)	Tensile strength (psi)	Offset yield stress (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)
						(0.02%)	(0.1%)	(0.2%)			
Range in tensile properties of original specimens				low	106,500	37,500	50,500	56,000	22,500	33.0	33.8
				high	108,800	46,000	55,500	59,500	25,000	35.5	44.9
Creep	21X	1200	11,000	1055	102,000	30,000	45,000	53,000	17,500	32.0	38.5
Creep	15X	1200	20,000	1055	102,500	35,000	51,000	56,500	22,500	31.0	35.4

Type of test	Specimen number	Temperature (° F)	Stress (psi)	Time (hr)	Izod impact strength[1] (ft-lb)	Vickers hardness
	17Y	Original			29, 31	238-245
Creep	AY1	1200	25,000	1078	14, 17	235
Creep	15Y	1200	12,500	980	15	233
Rupture	DY	1200	28,500	1596	------	250
Rupture	DY	1350	12,500	1080	------	259

[1]Specimens 0.365-inch sq with a 0.050-in. deep V-notch.

TABLE V

EFFECT OF PROCESSING PROCEDURE ON THE ROOM TEMPERATURE TENSILE AND 1200° F RUPTURE PROPERTIES OF CSA ALLOY

		Processing							Room Temperature Physical Properties					Rupture Properties at 1200° F			
		Heat treatment			Hot-cold work		Final treatment							100-hour		1000-hour	
Type material	Heat number	Temp. (° F)	Time (hr)	Cooling	Temp. (° F)	Reduction (%)	Temp. (° F)	Time (hr)	Tensile strength (psi)	Yield strength (psi) (0.02%)	Yield strength (psi) (0.2%)	Elongation (%)	Brinell hardness	Strength (psi)	Elongation (%)	Strength (psi)	Elongation (%)
Large disc	1X2218	As-forged			----	-----	1200	4	107,500	41,000	58,900	34.0	210	35,500	32	30,000	18
Bar stock[1]	234-A-5	As-forged			----	-----	1200	1	153,000	84,500	105,000	17.8	292	50,000	23	39,000	12
Bar stock[2]	3678-A-2	Hot-rolled			----	-----	----	----	130,500	44,000	67,000	25.2	248	48,000	20	37,000	16
Bar stock[2,3]	3678-A-2	2050	2	W.Q.	----	-----	----	----	127,000	54,500	64,000	49.0	230	47,500	12	37,500	5
Bar stock[2]	3678-A-2	2050	2	W.Q.	1200	10	----	----	147,000	83,000	114,000	27.5	314	56,000	4	32,000	3
Bar stock[2]	3678-A-2	2200	1	W.Q.	1200	10	----	----	147,750	87,000	112,750	34.0	306	46,000	1	42,000	3

[1]See reference 2.

[2]The Effect of Heat Treatment and Hot-Cold Work on the Properties of Five Alloys. By J. W. Freeman, E. E. Reynolds, A. E. White. University of Michigan Rep. No. 9, February 26, 1944.

[3]Unreported data from investigations in progress at the University of Michigan for the NACA.

W.Q. water quenched.

TABLE VI

COMPARATIVE PROPERTIES FOR LARGE FORGED DISCS OF CSA AND 19-9 DL[1] ALLOYS

Chemical Composition

Alloy	C (%)	Mn (%)	Si (%)	Cr (%)	Ni (%)	Mo (%)	W (%)	Cb (%)	Ti (%)
CSA	0.25	4.14	0.25	18.32	5.76	1.46	1.51	0.95	----
19-9 DL	0.33	1.14	0.65	19.10	9.05	1.35	1.14	0.35	0.16

Short-Time Tensile Properties

Alloy	Temperature (° F)	Tensile strength (psi)	Offset yield strengths (psi) (0.02%)	Offset yield strengths (psi) (0.2%)	Elongation in 2 in. (percent)	Reduction of area (percent)	Brinell hardness
CSA	Range at room temperature	106,500 to 113,300	37,000 to 46,000	56,000 to 69,500	33 to 38	33.8 to 47.2	204 to 227
19-9 DL	--do.--	103,250 to 107,750	38,000 to 46,500	54,000 to 62,000	19 to 34.5	19.9 to 41.8	202 to 209
CSA	1200	51,875	------	40,000	27	49.5	---
19-9 DL	1200	57,875	------	37,900	34	47.5	---
CSA	1350	39,000	------	34,500	40	56.0	---
19-9 DL	1350	38,100	------	31,100	45	69.3	---

Rupture Test Characteristics

Alloy	Temperature (° F)	Rupture test properties 10-hour Strength (psi)	10-hour Elongation (percent)	100-hour Strength (psi)	100-hour Elongation (percent)	1000-hour Strength (psi)	1000-hour Elongation (percent)
CSA	1200	42,000	32	35,500	32	30,000	18
19-9 DL	1200	46,000	35	40,000	27	34,000	16
CSA	1350	25,500	39	19,000	30	12,500	13
19-9 DL	1350	28,000	38	23,000	34	15,500	23

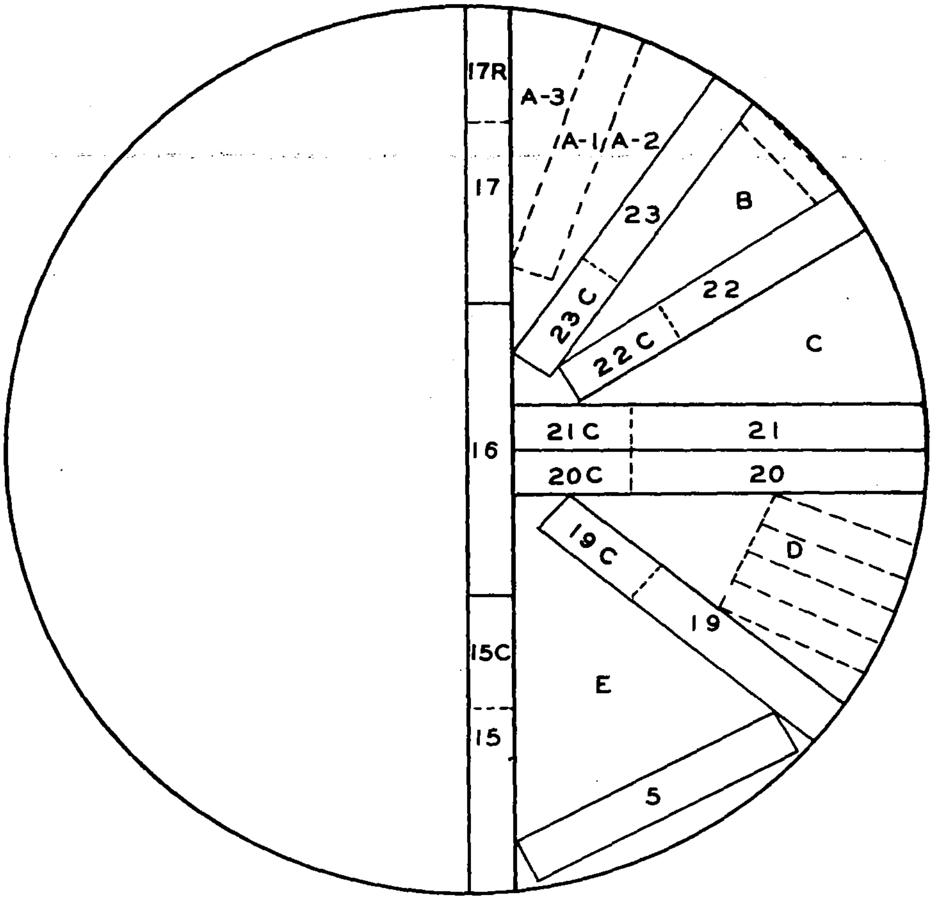
Time-Deformation Strength at 1200° F

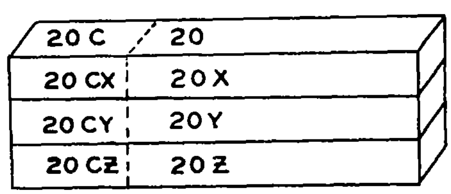
Alloy	Total deformation (percent)	Stress for total deformation in indicated time periods (psi) 10-hours	100-hours	1000-hours
CSA	0.1	15,750	13,000	10,250
19-9 DL		16,000	14,000	12,000
CSA	0.2	25,000	21,000	17,000
19-9 DL		24,000	21,000	17,000
CSA	0.5	30,000	27,500	25,000
19-9 DL		29,000	26,000	23,500
CSA	1.0	33,500	30,000	26,500
19-9 DL		32,500	29,000	26,000
CSA	Transition	------	32,000	26,000
19-9 DL		------	39,000	33,000

Creep Strength at 1200° F

Alloy	Stress for indicated creep rate (psi) (0.01%/1000 hr)	(0.10%/1000 hr)
CSA	9,000	21,000
19-9 DL	11,000	25,000

[1]See reference 1.





NUMBERING OF COUPONS

FIGURE 1.- LOCATION OF TEST COUPONS FROM THE CSA ALLOY FORGED DISC.

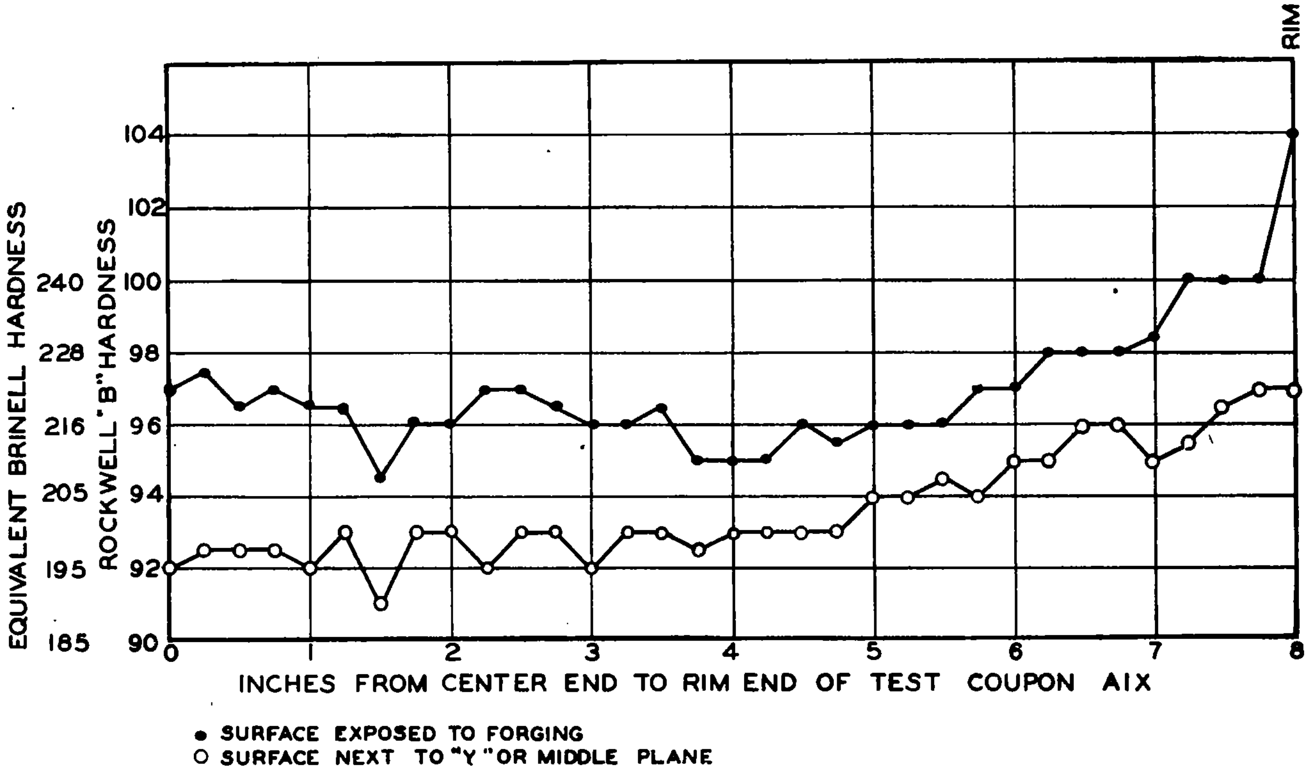
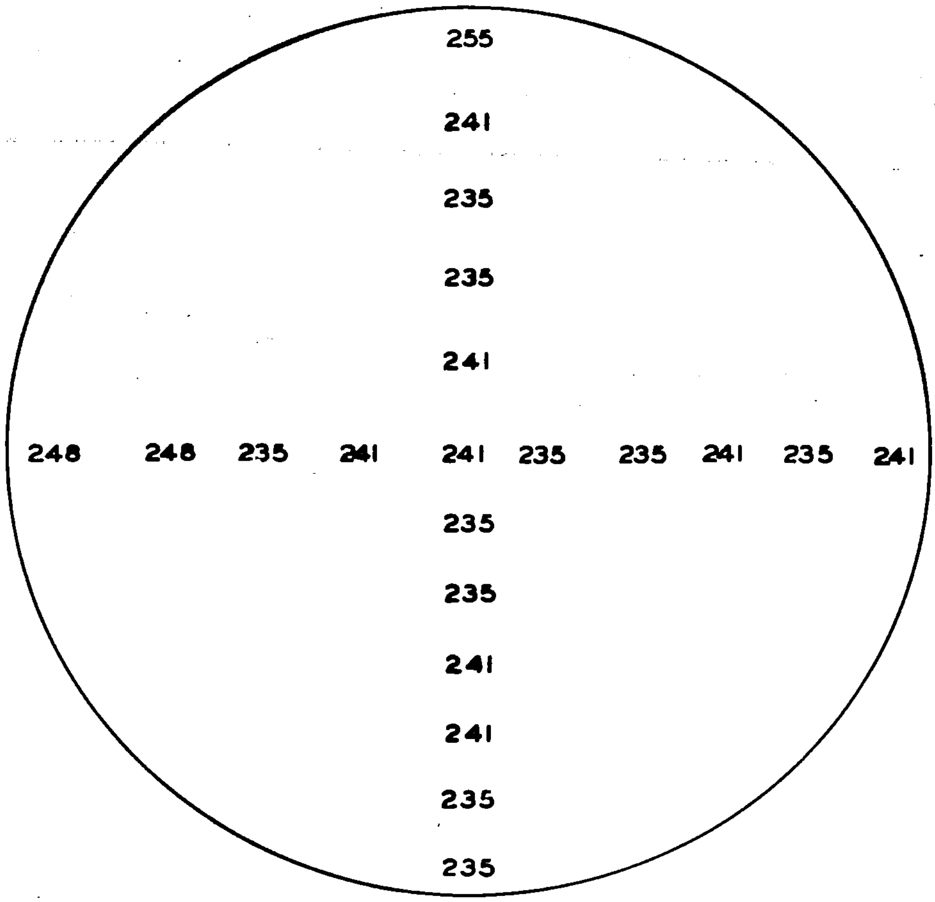


FIGURE 2.- VARIATION IN HARDNESS OF THE CSA ALLOY FORGED DISC.



CRUCIBLE STEEL COMPANY DATA

FIGURE 3.- SURVEY OF BRINELL HARDNESS ON THE SURFACE OF THE CSA ALLOY FORGED DISC.

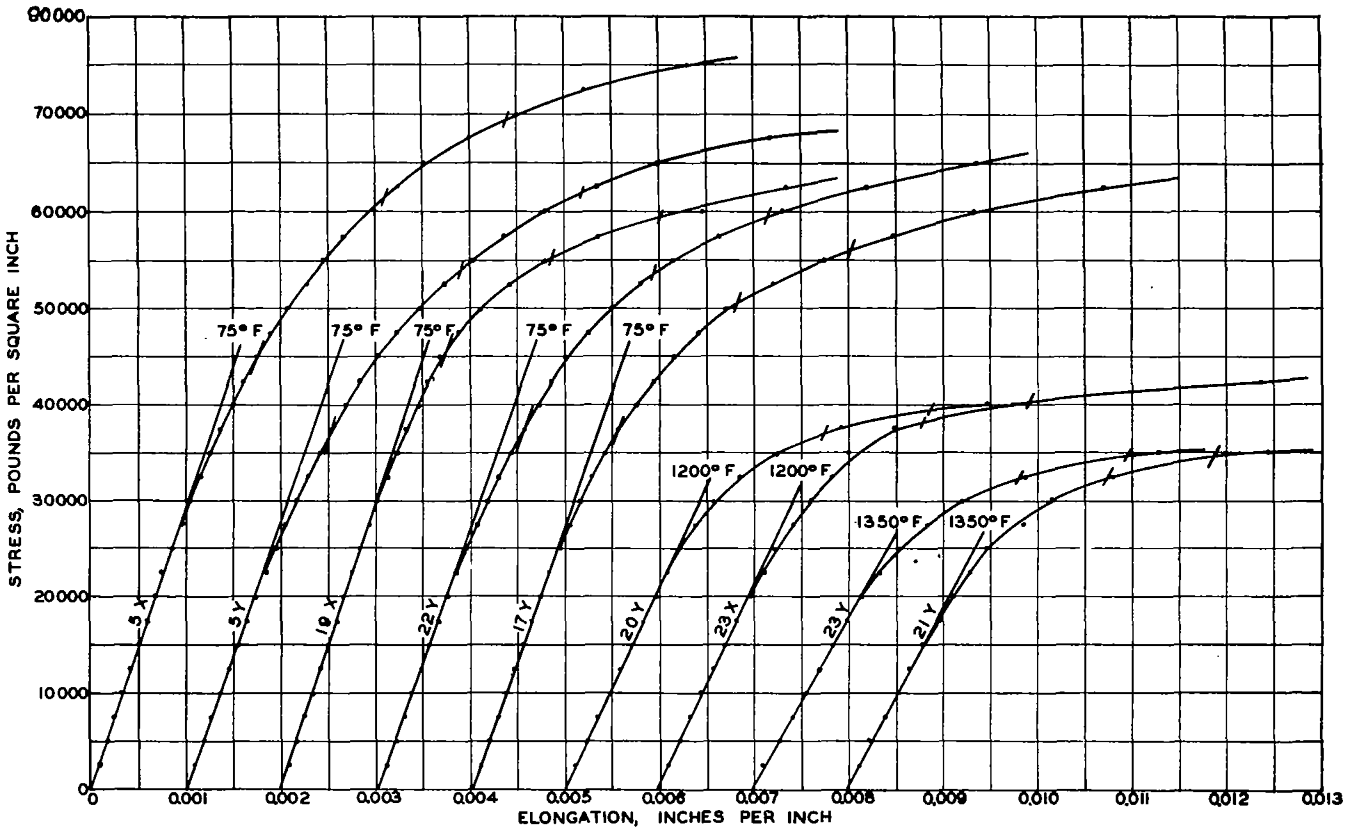
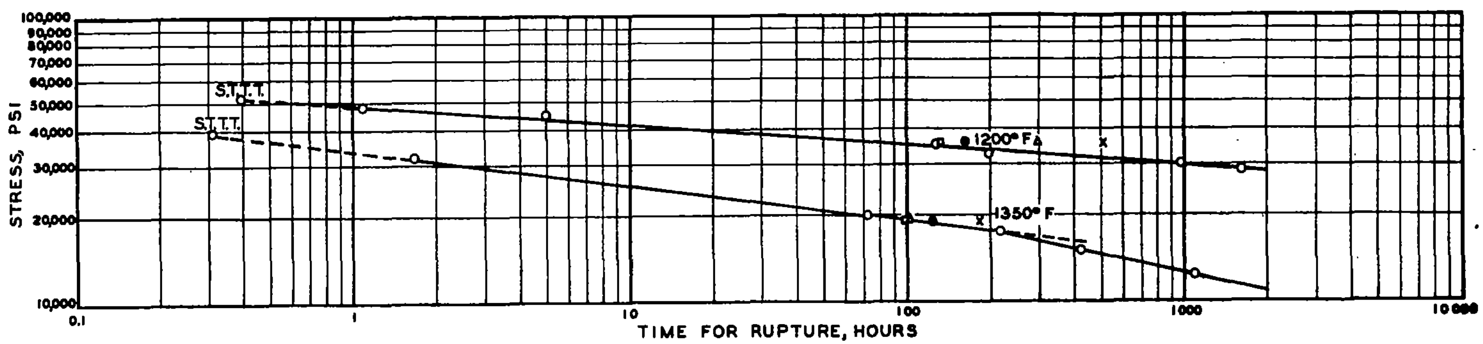


FIGURE 4.- STRESS-STRAIN CURVES FOR TENSILE TESTS ON THE CSA ALLOY FORGED DISC.



CODE	LOCATION OF SPECIMEN IN DISC
o	CENTER RADIAL SPECIMEN AT RIM
●	SURFACE " " " "
◘	CENTER " " " CENTER
x	SURFACE TANGENTIAL SPECIMEN AT RIM
▲	CENTER " " " "

S.T.T.T. SHORT TIME TENSILE TEST

FIGURE 5.- STRESS-RUPTURE TIME CURVES FOR THE CSA ALLOY FORGED DISC.

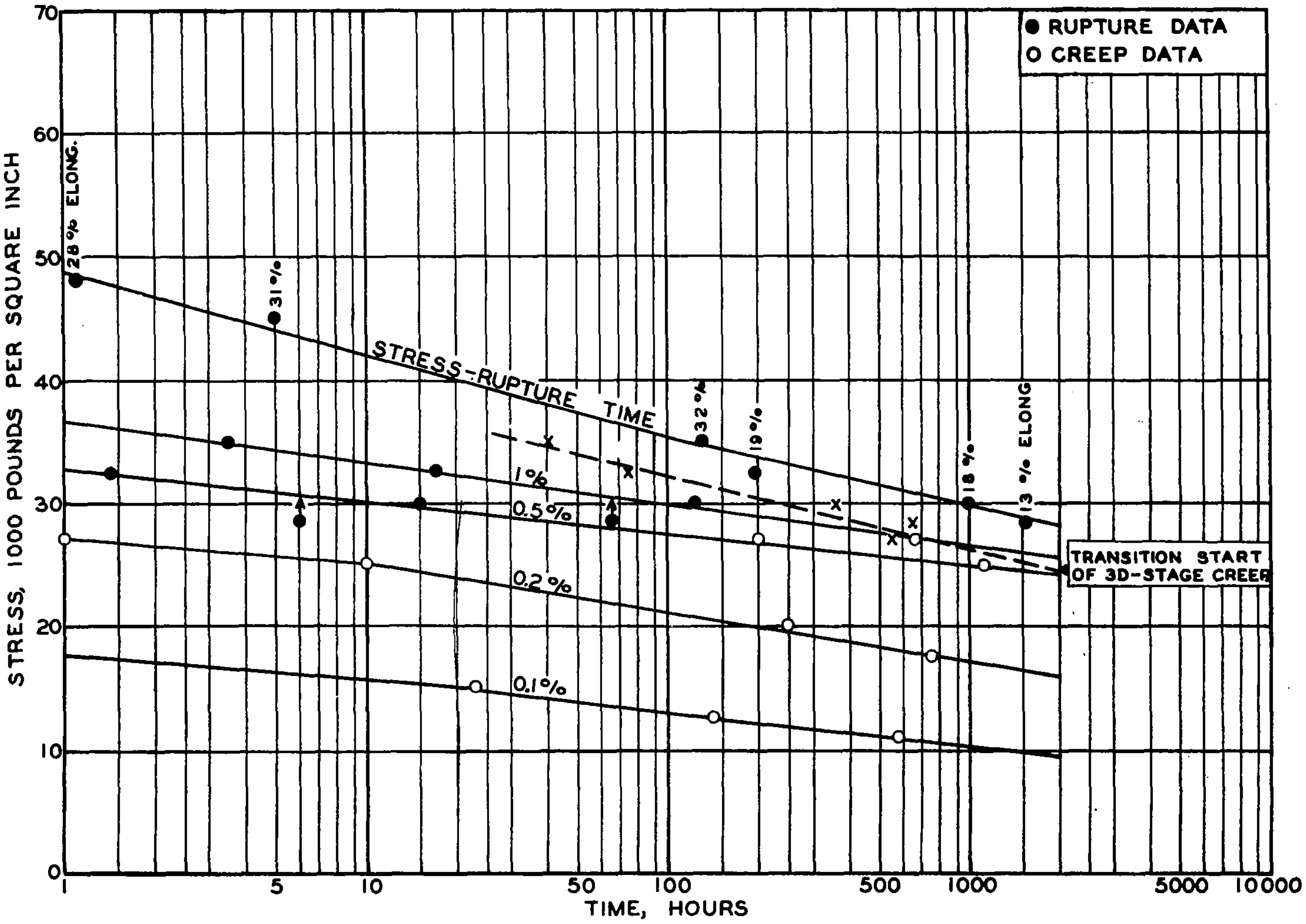


FIGURE 6.- STRESS-TIME FOR INDICATED TOTAL DEFORMATION CURVES FOR THE CSA ALLOY FORGED DISC AT 1200° F.

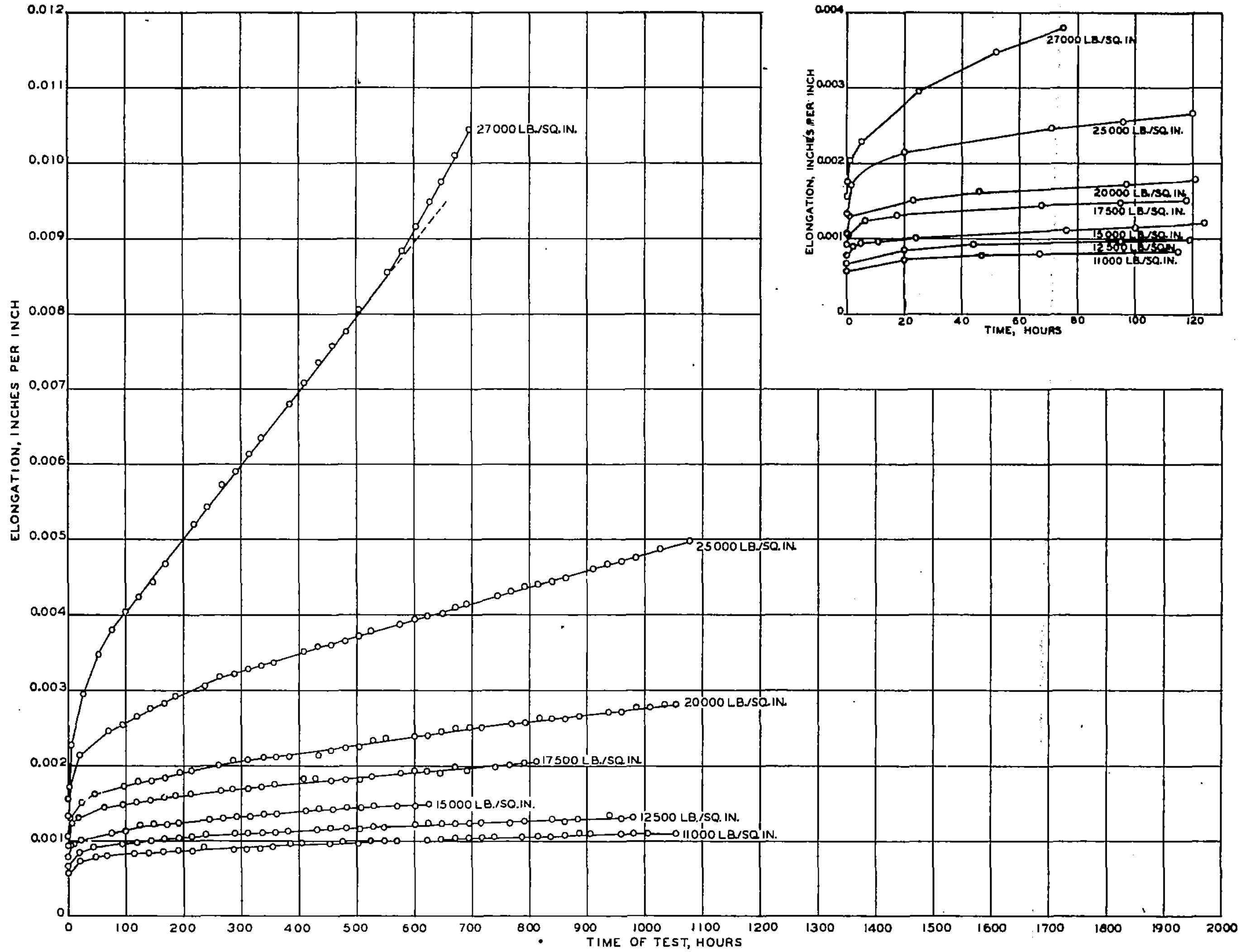
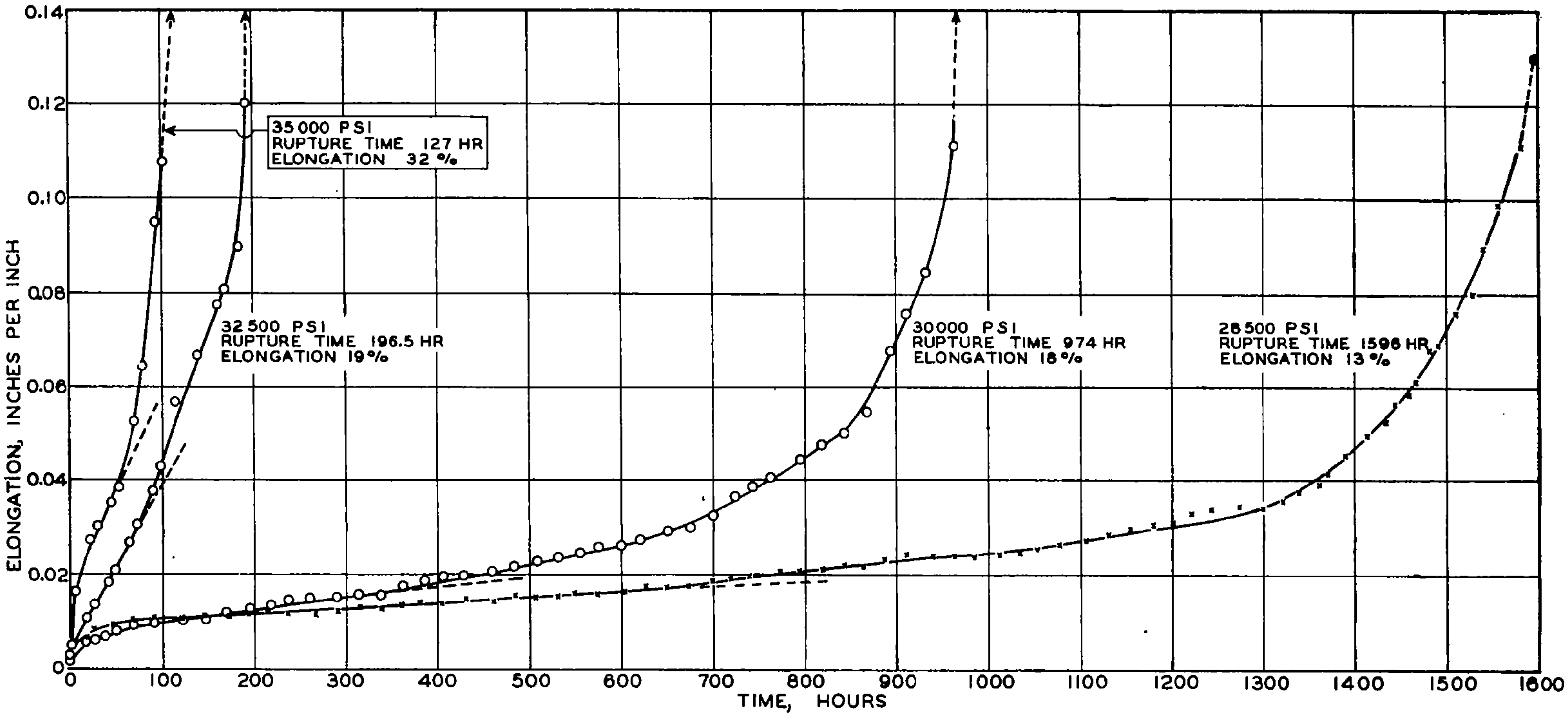


FIGURE 7.- TIME-ELONGATION CURVES AT 1200°F FOR THE CSA ALLOY FORGED DISC.



CENTER RADIAL SPECIMENS AT THE RIM OF A 20-INCH DIAMETER BY 3 5/16-INCH THICK DISC FROM HEAT 1X2218.

FIGURE 8.- TIME-ELONGATION CURVES FOR RUPTURE TESTS AT 1200° F ON AS-FORGED DISC OF THE CSA ALLOY.

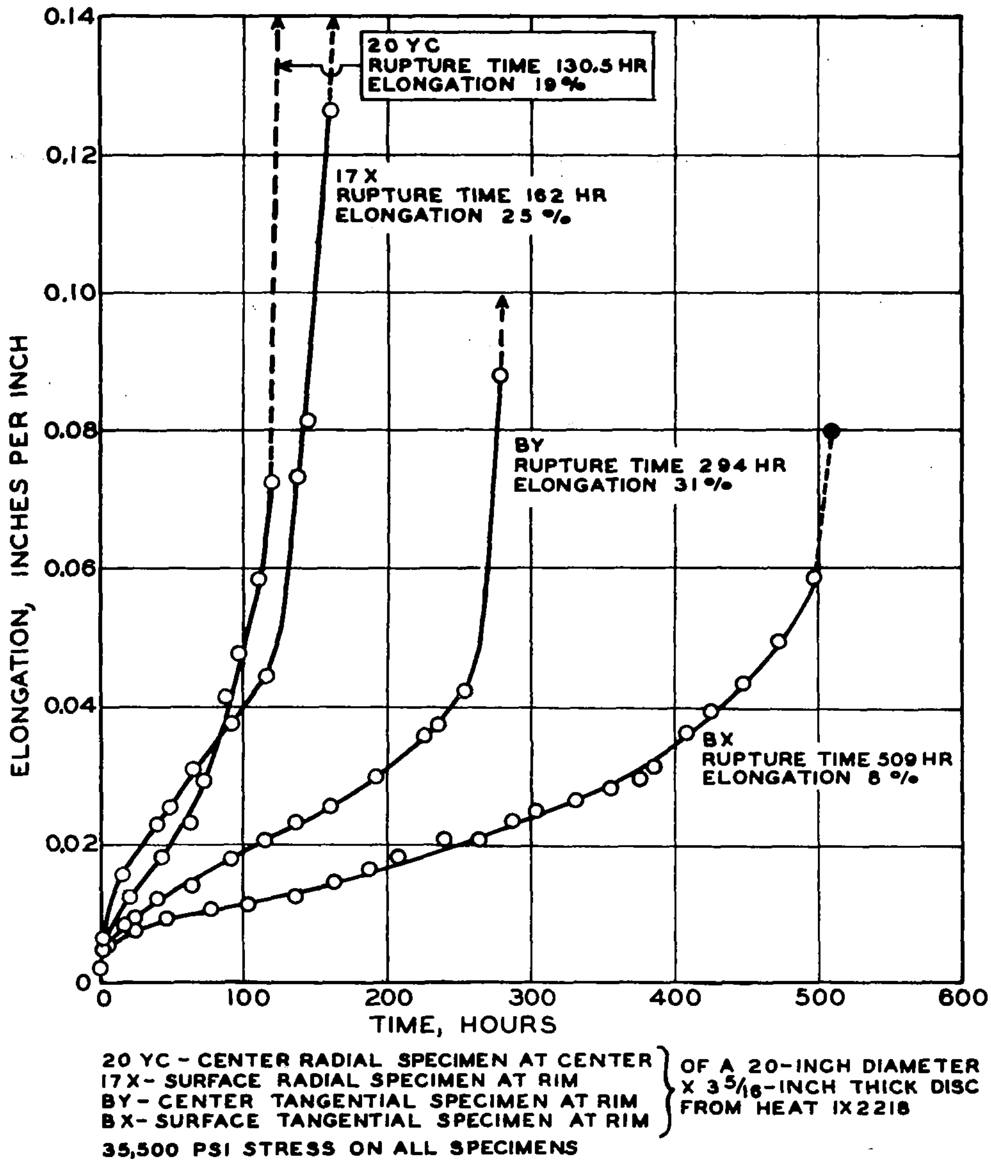
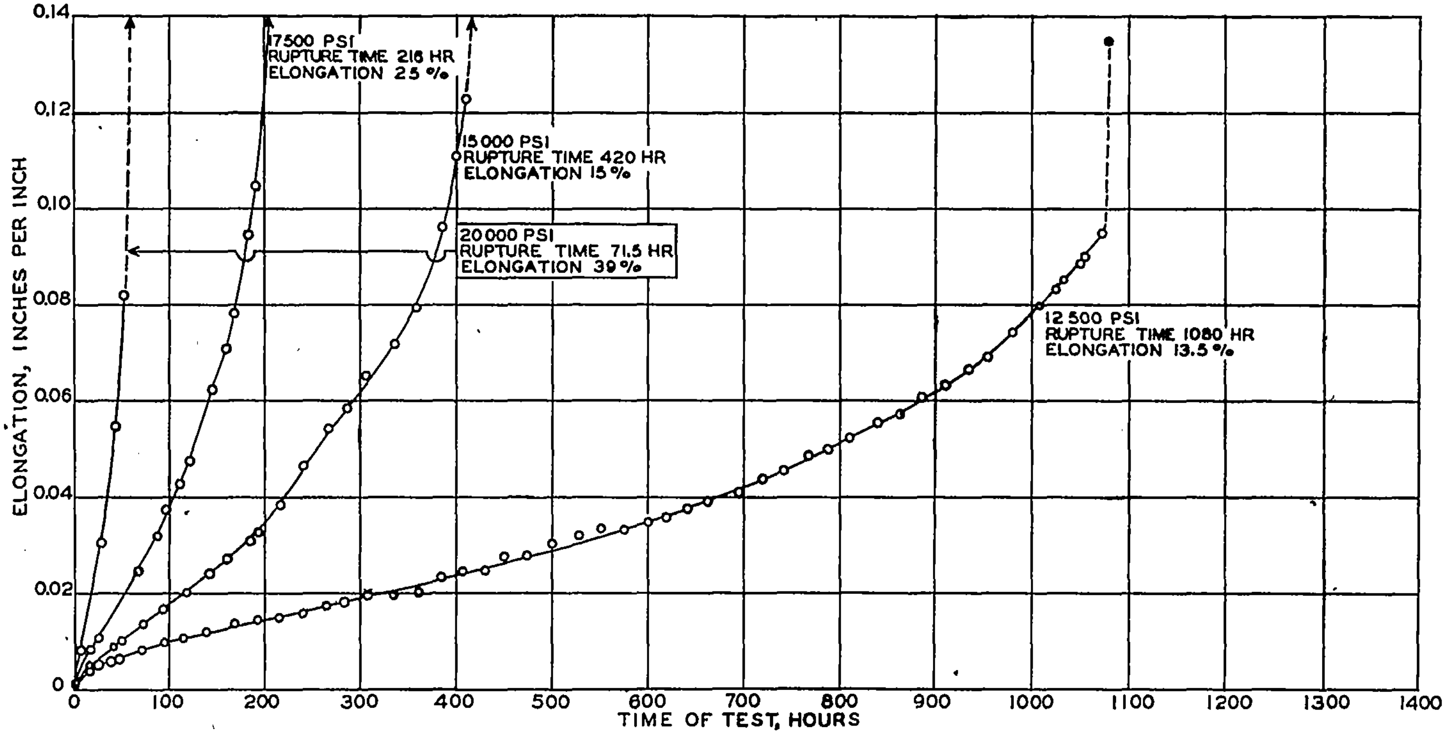


FIGURE 9-TIME-ELONGATION CURVES FOR RUPTURE TESTS AT 1200° F ON AN AS-FORGED DISC OF THE CSA ALLOY.



CENTER RADIAL SPECIMENS AT THE RIM OF A 20-INCH DIAMETER BY 3 5/16 INCH THICK DISC FROM HEAT 1X2218

FIGURE 10.- TIME-ELONGATION CURVES FOR RUPTURE TESTS AT 1350° F ON AN AS-FORGED CSA DISC.

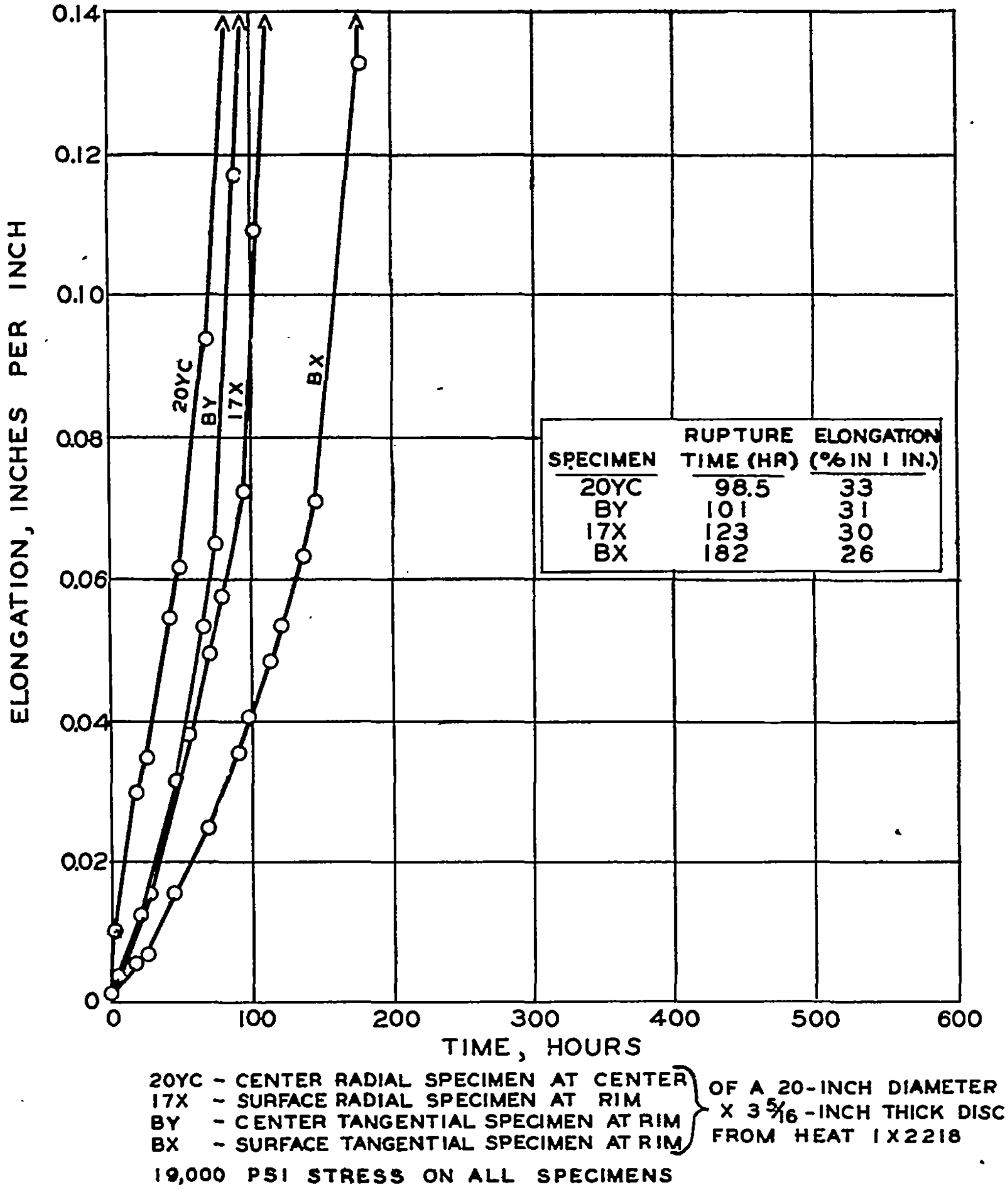


FIGURE 11.- TIME-ELONGATION CURVES FOR RUPTURE TESTS AT 1350° F ON AN AS-FORGED DISC OF THE CSA ALLOY.

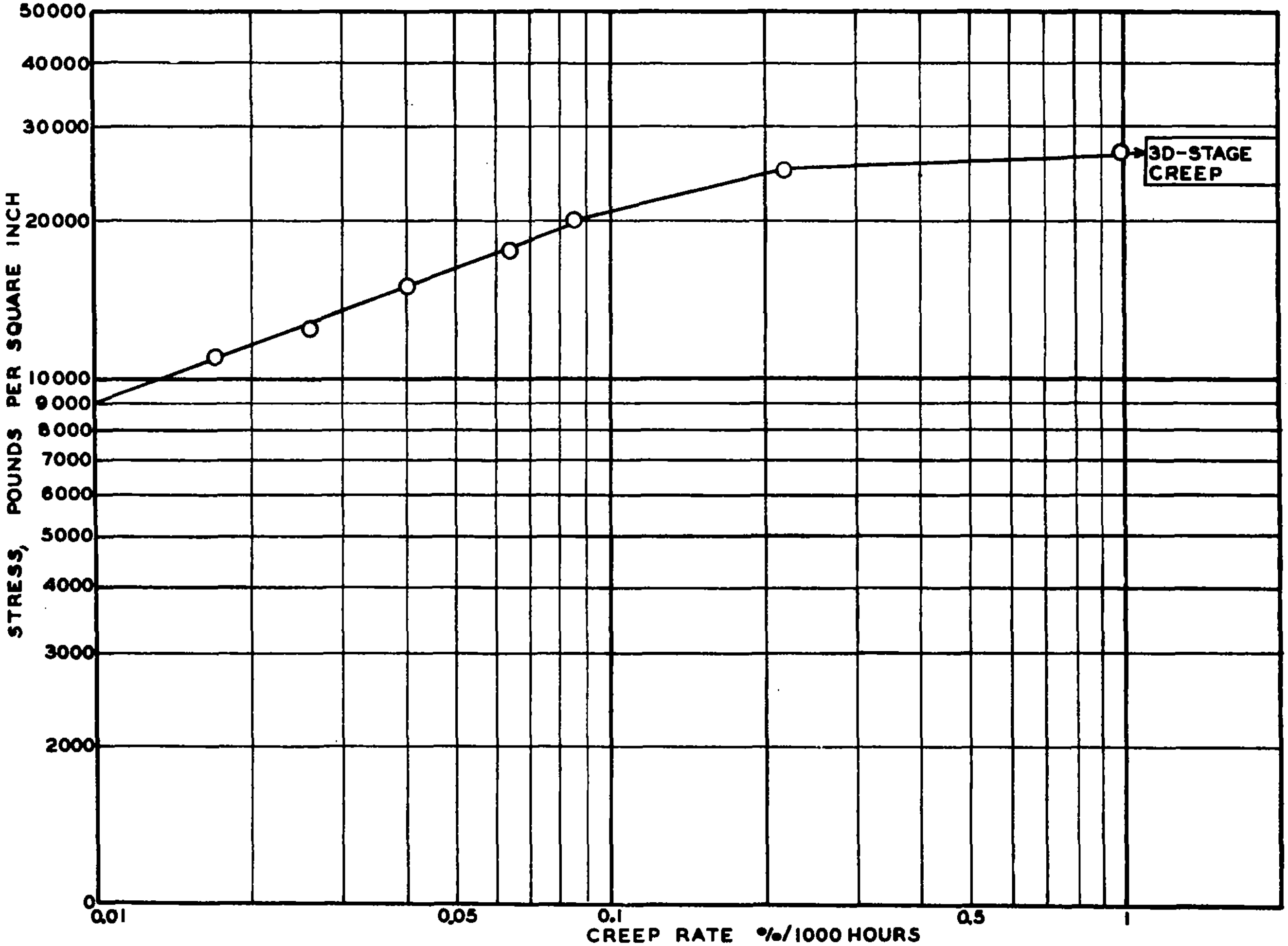
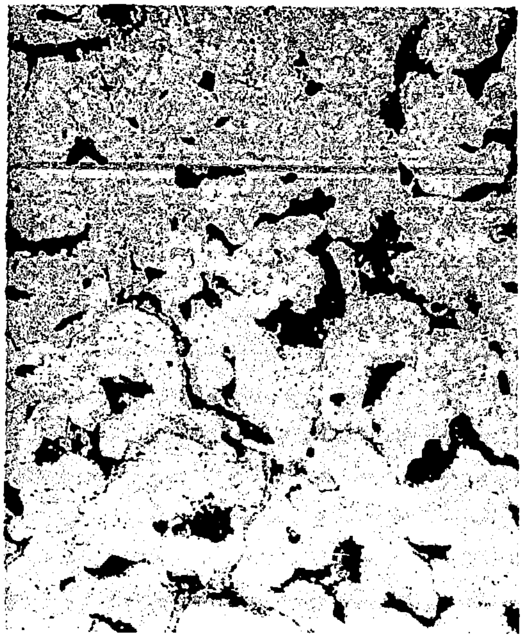


FIGURE 12.- STRESS CREEP RATE CURVE AT 1200° F FOR THE CSA ALLOY AS-FORGED DISC.



100X

1000X

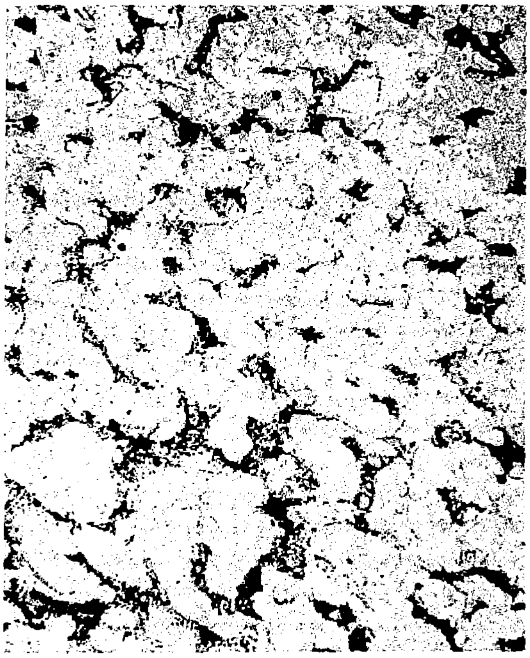
(a) Radial Section near Rim of Disc in Y Plane.

100X

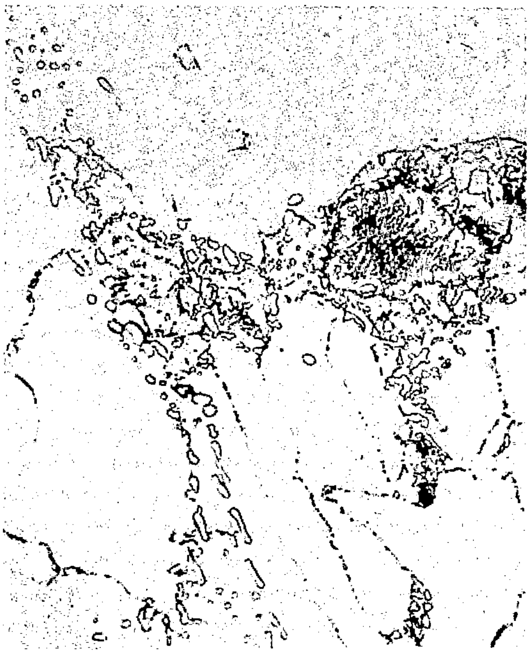
1000X

(b) Cross Section near Rim of Disc in Y Plane.

FIGURE 13.- ORIGINAL MICROSTRUCTURE OF THE CSA ALLOY FORGED DISC.



100X



1000X

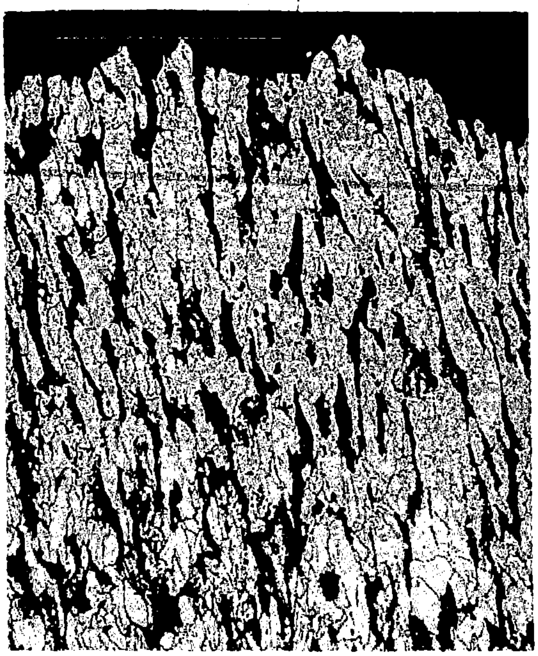
(a) Specimen 15Y - 980 Hours at 1200° F under 12,500 psi.

100X

1000X

(b) Specimen AY1 - 1078 Hours at 1200° F under 25,000 psi.

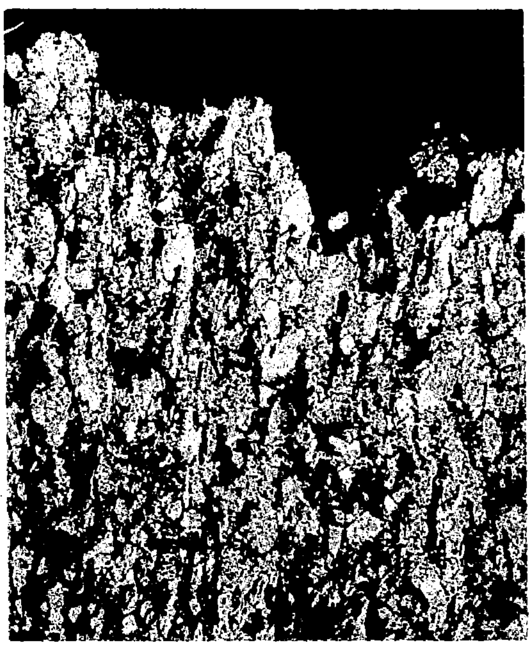
FIGURE 14.- MICROSTRUCTURE OF COMPLETED TIME-DEFORMATION SPECIMENS OF THE CSA ALLOY FORGED DISC.



Fracture - 100X

Interior - 1000X

(a) Specimen DY - 1596 Hours for Rupture at 1200° F under 28,500 psi.



Fracture - 100X

Interior - 1000X

(b) Specimen DY - 1080 Hours for Rupture at 1350° F under 12,500 psi.

FIGURE 15.- MICROSTRUCTURES OF COMPLETED RUPTURE TEST SPECIMENS OF THE CSA ALLOY FORGED DISC.

TITLE: A Metallurgical Investigation of a Large Forged Disc of CSA (234-A-5) Alloy AUTHOR(S): Freeman, J. W.; Reynolds, E. E.; White, A. E. ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C. PUBLISHED BY: (Same)	ATI- 7296 REVISION (None) ORIG. AGENCY NO. ARR-5H17 PUBLISHING AGENCY NO.

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Oct '45	Unclass.	U. S.	Eng.	33	photos, graphs, diagrs, tables

ABSTRACT:

High temperature properties over wide range of stresses and deformations at 1200°F for a large forced disc for use in certain gas turbine rotor designs were determined. CSA (234-A-5) alloy with good high temperature properties was developed. Results of investigation are presented as series of figures and tables setting forth data from hardness, tensile, rupture, and creep tests. Strength properties were not as high as anticipated because of lack of cold work caused by high finishing temperatures.

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