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CREEP PROPERTIES AT 1100° AND 1200°F FOR TYPE 304L AUSTENITIC STEEL WITH CONTROLLED RESIDUAL ELEMENTS

by

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CREEP PROPERTIES AT 1100° AND 1200°F FOR TYPE 304L AUSTENITIC STEEL WITH CONTROLLED RESIDUAL ELEMENTS

The properties of Type 304L austenitic steel under creep conditions have been subject to considerable uncertainty. The creep resistance of Type 304L steel is generally considered to be lower than for Type 304H with a minimum carbon content of 0.04 percent. There are some data indicating equal strengths for the "L" grade as made in production. In addition, The International Nickel Company Inc. has published data indicating that small amounts of certain elements in Type 304L steel result in creep-rupture strengths as high as those for Type 304H. These elements could be present unknown as residuals from the scrap used in the charge or be purposefully added.

The investigation covered by this report involved the determination of the creep resistance of air melted steel with 0.04% Mo, 0.10% V and 0.074% Cb as "controlled" residuals. The same stock was also remelted in a consumable arc vacuum furnace to check the effect of melting in vacuum. The V and Cb content of the vacuum melted material was not reported. The heat treatment used was 15 minutes at 1900°F, water quenched.

CONCLUSIONS

The Type 304L steel with "controlled" residual elements had creep strengths at 1100° and 1200°F close to the average for Type 304H steel. Evidently the "residual" elements brought the creep resistance up.

There was very little difference in the creep strengths of the original stock from the air arc furnace heat and the same material consumable electrode vacuum remelted. The creep rates of the vacuum melted material started out lower and changed less with increasing times of testing than did those from the air melted condition.

Both the air and the vacuum melted materials underwent very little change in tensile and impact properties at room temperature as a result of creep testing. Both had exceptionally high ductility.

EXPERIMENTAL MATERIAL

Standard 0.505-inch diameter tensile specimens were supplied from heat treated bar stock. Part of the specimens were from an air melted heat. Stock from the air melted heat was remelted in a consumable electrode vacuum furnace. The Timken Roller Bearing Company made the heats, supplied machined specimens and reported the following chemical compositions for the two materials:

	Chemical Composition (percent)									
Heat No.	C	Mn	P	S	Si	Cr	Ni	Mo	V	Cb
15356	.023	1.25	.014	.013	.72	17.94	11.26	.04	.10	.074
IV3814	.020	1.19	.012	.015	.76	17.95	11.30	.05	-	-

Bar stock from each heat was solution treated for 15 minutes at 1900°F and water quenched. The hardness of the air melted heat was 174 Brinell and 162 for the consumable electrode vacuum melted heat.

RESULTS

Creep tests up to 5,100 hours duration at 1100° and 1200°F (Figures 1 through 3) indicated the following:

(1) The tests at 9,600 psi and 1100°F were discontinued at 2,859 hours when the creep rates were down to 0.0035% per hour. The measurement uncertainty of such creep rates together with the rates being so

far below the 0.01% per hour rate showed that further testing would not be useful.

(2) There was very little difference in creep rate between the air melted and vacuum melted materials for the tests at 9,600 psi at 1100°F and 6,000 psi at 1200°F. There was a slight difference in the higher stress tests. The air melted material started with faster rates but the creep rate decreased more with time of testing.

(3) Log-log stress-creep rate curves were used to estimate the stresses for creep rates of 0.01% per 1000 hours (Figure 4):

Temperature (°F)	0.01% per 1000 hour creep strength (psi)
1100	13,000
1200	7,700

The differences in minimum creep rates were sufficiently small that there seems to be no reason to report a difference in creep strength for the air versus vacuum melted materials. Presumably continuing the 9,600 psi creep tests to longer time periods at 1100°F would have resulted in lower creep rates than those reported. This, however, would have little effect on the reported 0.01% per 1000 hour creep strength. The rates at 14,500 psi are sufficiently close to 0.01% per 1000 hours so that the creep strength would not be appreciably changed by lower creep rates at 9,600 psi.

Tensile and Impact Tests at room temperature after creep testing

The lower stress specimens from the creep tests are compared with the original material on the basis of tensile and impact tests at room temperature in Table I. The following comments are based on this data:

(1) The samples from the air melted heat had tensile strengths about 5,000 psi higher than the vacuum melted heat. Both showed about the same increase in tensile strength as a result of creep testing.

(2) The same comments apply to yield strengths except that the differential was greater between the two heats.

(3) There was little difference in ductility for either material between heats or as a result of testing.

(4) Impact strengths from the modified specimens hardly changed during testing and were about the same for both materials.

Microstructural Examination

The air melted material had a uniform fine grain size of ASTM 7-8. The vacuum melted stock had a mixed grain of ASTM 2-3 and 7-8. (See Plates 1 through 6).

Creep testing at 1100°F hardly changed the microstructure. Some precipitation occurred in the grain boundaries. Testing at 1200°F did result in some precipitation in the grain boundaries. The precipitate particles were small and scattered along the grain boundaries. Clear structure adjacent to the grain boundaries probably resulted from depletion of elements from the grains to form the precipitates, which were probably carbides with some sigma. This effect was most pronounced at stringers of particles carried over from ingot compositional segregation.

It should be noted that the structures of the original materials and the creep specimens from the 1100°F tests had to be etched far more than those tested at 1200°F to develop the structures shown. The precipitation at 1200°F resulted in the grains being outlined with far less etching.

DISCUSSION

The creep strengths for 0.01% per 1000 hours were slightly higher than the "average" for Type 304H steel reported by George Smith in reviewing the ASME Boiler Code Stresses. Presumably the small amounts of V and CB brought the stress up from that considered characteristic of Type 304L steel.

The strengths are also comparable to those for Type 304 steel in previous investigations for Timken (Table II). There was some slight tendency for the "L" heats to be slightly lower at 1200°F. Comparison with the more extensive ASME data showed that Heats 15356 and IV3814 had strengths similar to Type 304 steel and it therefore appears that factors other than carbon content controlled the level of properties.

Table II also shows the far higher creep strengths for all carbon levels when the tests were longer than 2,000 hours. The decrease in creep rate with testing time especially for air melted heats certainly increases the indicated "creep strengths" in the more prolonged tests.

There are certain features of the data which are not understood. Vacuum melting would be expected to remove nitrogen, which ought to have reduced creep resistance compared with air melted steel. Evidently some other factor was involved that is not understood. It is probably the result of interactions between trace elements.

The creep data seem to indicate that the low carbon material with controlled "trace" elements can have creep strengths equal to Type 304H steel. Furthermore such material retained ductility and impact strength at room temperature to a remarkable degree after creep testing.

The information supplied did not indicate whether the specimens were made from hot-finished or cold-worked material. It is therefore uncertain whether or not the grain size differences between the air and vacuum melted material were due to differences in the conditions of making the bar stock, or to differences resulting from air and vacuum melting. It is quite common for vacuum melting to lower grain growth temperature.

TABLE I

Room Temperature Tensile and Impact Properties of Air Melted and Consumable Electrode Vacuum Melted Type 304L Austenitic Steel after Creep Testing at 1100° and 1200°F

Temp. (°F)	Stress (psi)	Test Duration (Hours)	Tensile Strength (psi)	Offset Yield Strength 0.1%	Offset Yield Strength 0.2%	Elongation (% in 2 ins.)	Reduction of Area (%)	Impact* Value (Ft. lbs)
			Air Melted (Heat 15356)					
Original material			88,800	32,250	41,000	54.5	75.5	109, 105
1100	9,600	2,859	92,250	43,500	45,000	51.5	69.5	-
1100	14,500	5,110	-	-	-	-	-	97, 97
1200	6,000	4,943	93,125	40,250	43,250	49.0	68.0	-
1200	9,000	5,110	-	-	-	-	-	98, 87
			Consumable Electrode Vacuum Melted (Heat IV3814)					
Original material			84,000	32,000	34,250	59.5	77.5	93, 98
1100	9,600	2,859	87,500	36,000	37,750	58.5	75.0	-
1100	14,500	5,110	-	-	-	-	-	97, 88
1200	6,000	4,943	88,250	35,000	37,250	55.0	71.0	-
1200	9,000	5,012	-	-	-	-	-	95, 93

* From modified Izod impact specimens (0.365-inches square with 0.050-inch deep V-notch)

TABLE II

Creep Properties for Type 304L Austenitic Steel Air Melted and Consumable Electrode Vacuum Melted compared with Creep Properties of Type 304 Steel in Previous Investigations

Heat No.	Material	Treatment	Grain Size	Report Number	Test Duration	Creep Strength (psi) (0.01%/1000 hrs)
			1100°F			
15356	Bar - air melted	WQ1900°F	7-8	current	2800/5000	13,000
IV3814	Bar - vacuum melted	WQ1900°F	4-8	current	2800/5000	13,000
18838	Thin wall tube	WQ1950°F	5-8	230	5000	13,000
19367	Heavy wall tube	WQ1950°F	1-5	230	5000	17,000
28023	1" dia. bar stock	WQ2000°F	3	41	1000	7,950
			1200°F			
15356	Bar - air melted	WQ1900°F	7-8	current	5000	7,700
IV3814	Bar - vacuum melted	WQ1900°F	4-8	current	5000	7,700
18838	Thin wall tube	WQ1950°F	5-8	230	5000	8,500
19367	Heavy wall tube	WQ1950°F	1-5	230	5000	11,000
28023	1" dia. bar stock	WQ2000°F	3	41	1000	4,300
34736	1" dia. bar stock	AC1700°F	6-8	153	1000	3,500
22451	1" dia. bar stock	WQ2000°F +CW 20%	2-6	169	2000	6,000

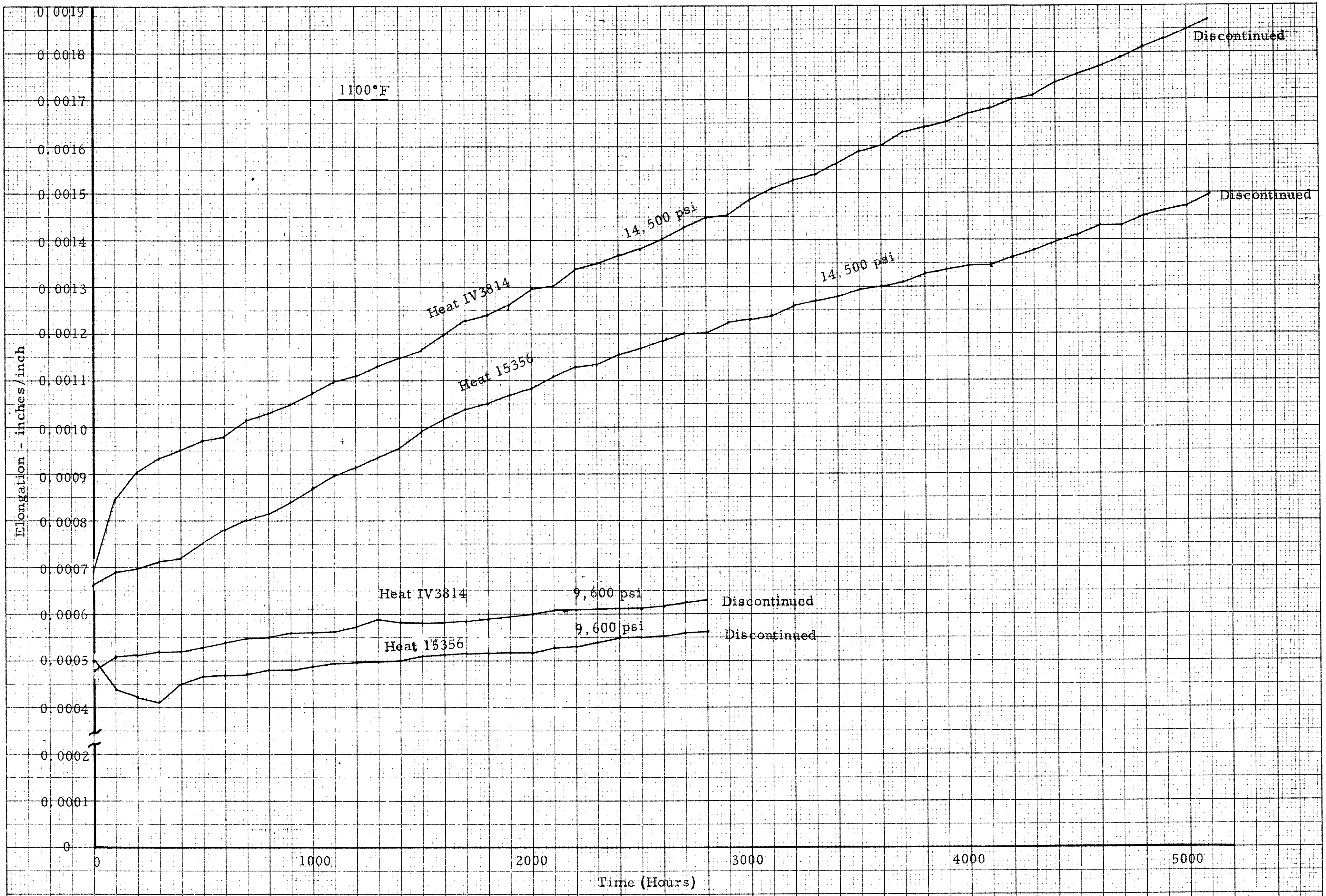

Figure 1. Time-Elongation Curves for creep tests at 1100°F for air and vacuum melted Type 304L Austenitic steel with Controlled Residual Elements

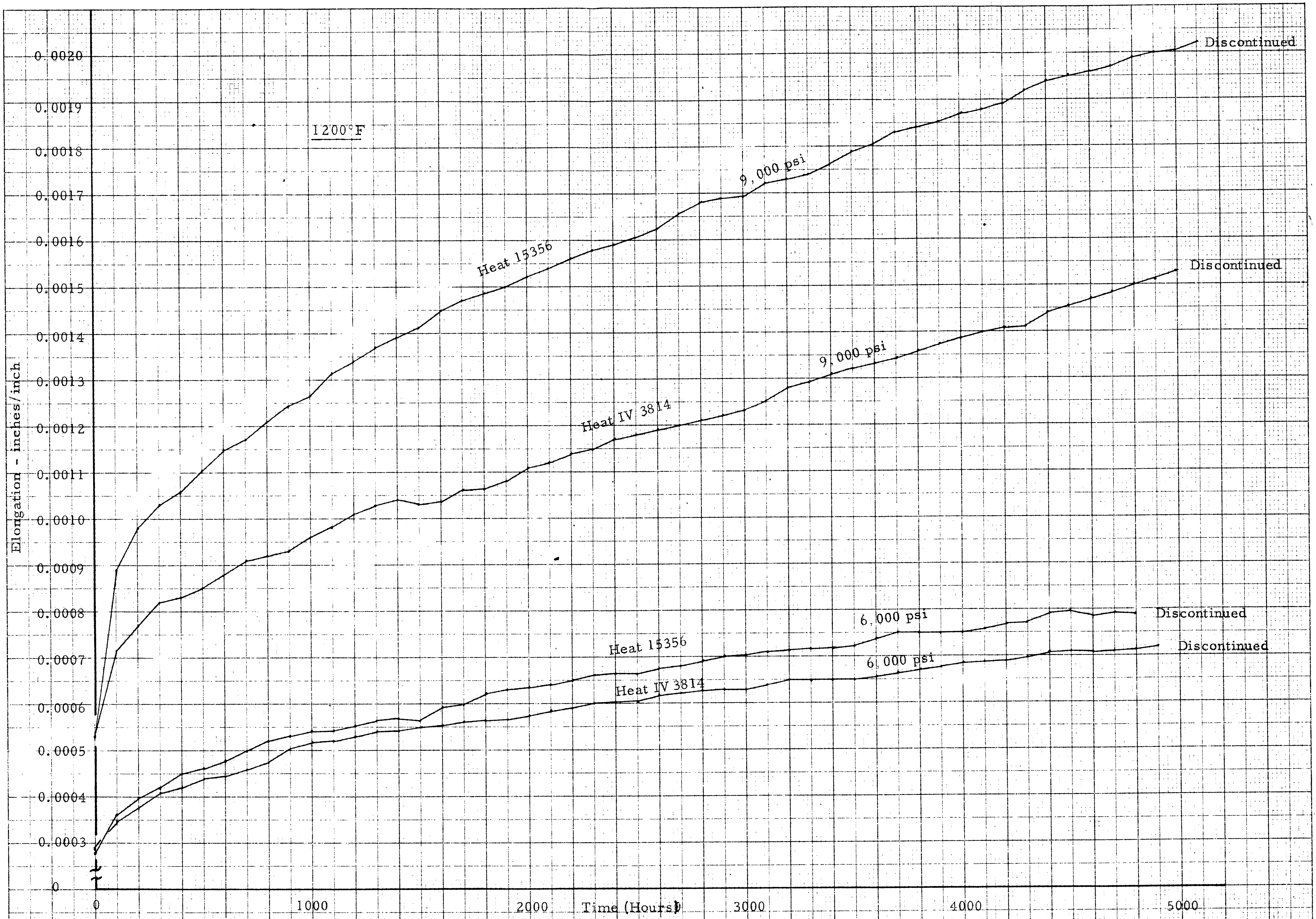

Figure 2. Time-Elongation Curves for creep tests at 1200°F for air and vacuum melted Type 304L Austenitic steel with Controlled Residual Elements

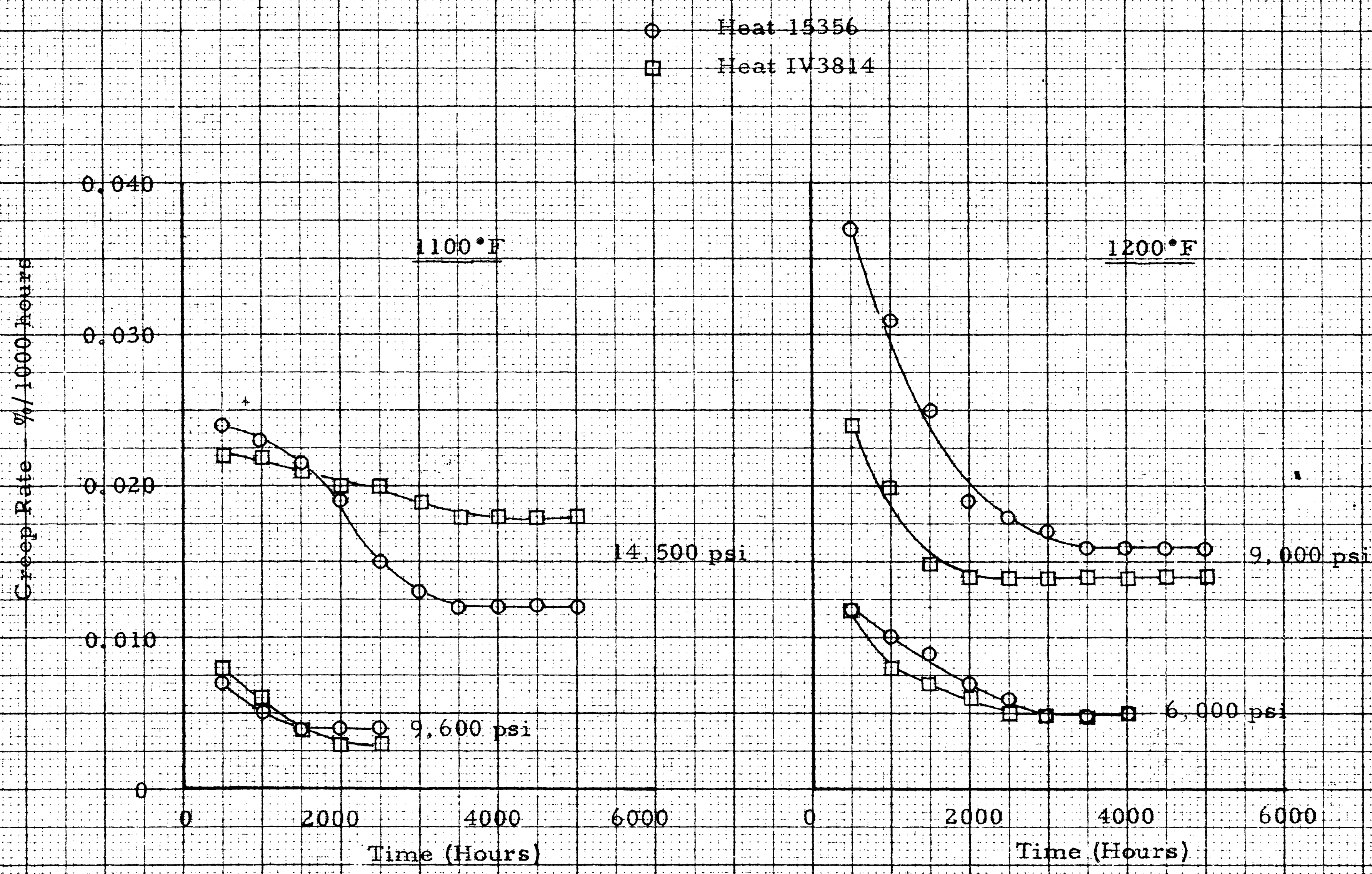

Figure 3. Creep Rate versus testing time at 1100° and 1200°F for air and vacuum melted Type 304L Austenitic steel with Controlled Residual Elements

Source		Heat No.	Water quenched from (°F)	
Current	●	15356	1900	Bar stock - air melted
Current	□	IV3814	1900	Bar stock - vacuum melted
Report 230	⊗	19367	1950	Heavy wall tube
Report 230	X	18838	1950	Thin wall tube

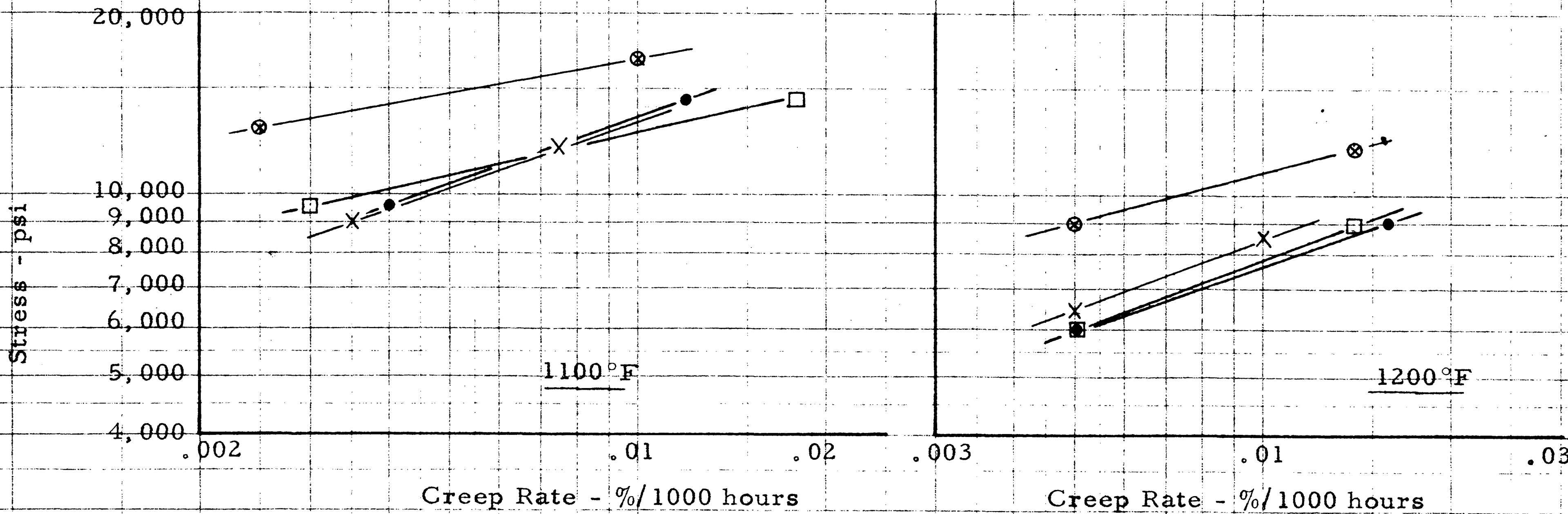

Figure 4. Stress-Creep Rate Curves at 1100° and 1200°F for air melted and vacuum melted Type 304L Austenitic steel with Controlled Residual Elements compared with those for Type 304 Austenitic steel tubing.