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REPORT ON

PROPERTIES OF A HEAVY-WALL ANNEALED TIMKEN DM STEEL TUBE AT 1000° AND 1050 °F

by

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PROPERTIES OF A HEAVY-WALL ANNEALED TIMKEN DM STEEL TUBE AT 1000° AND 1050°F

Rupture tests at 1000° and 1050°F were used to establish the properties of DM steel in the form of a heavy wall annealed tube. Limited creep data were also obtained. Directional effects were checked by testing both longitudinal and transverse specimens from the tube. Tests as long as 10,000 hours were conducted.

In common with all alloys, DM steel has creep-rupture properties which are dependent on response to heat treatment. All previously reported investigations of DM steel for Timken have been carried out on barstock. Because the response to a given heat treatment can be dependent on prior history, section size and heating and cooling rates, it was decided to investigate the properties of a production heavy wall tube. The 10.5-inch O.D. by 1.352-inch wall tube was annealed at 1575° to 1600°F and cooled at 20°F per hour to 1200°F.

SUMMARY AND CONCLUSIONS

The rupture strengths of the tube at 1000° and 1050°F were lower than had previously been obtained for annealed DM steel. The stresses for rupture in 100,000 hours were of the same order as has previously been reported for the normalized and tempered conditions, while shorter time strengths were much lower. Incomplete creep data suggest creep strengths on the low side of the range for DM steel but high in relation to the rupture strengths. The properties of the tube are compared in the report with those previously reported for DM steel and with published values for 1.25 Cr - 0.5 Mo + Si steel and the ASME Boiler Code Allowable Stresses. Limited stability tests indicated the usual good stability characteristic of DM steel.

Check tests indicated the rupture strength of the tube to be about the same

in the circumferential and longitudinal directions. Ductility was low, especially at 1000°F in the circumferential direction. One specimen fractured at about 1000 hours with only 3-percent elongation. The limited data suggest that the creep resistance was higher in the circumferential direction. The rupture strengths were mainly based on longitudinal specimens and creep properties on tangential specimens. This may explain the apparent high ratio of creep to rupture strengths.

The small irregular grains of ferrite and pearlite composing the microstructure suggest that the annealing temperature of 1575°-1600°F was too low to break up the structure established during working prior to final heat treatment. Other possible explanations for the unexpectedly low strength include unidentified heat-to-heat variations and the relatively slow cooling rate of 20°F per hour from the annealing temperature.

MATERIAL

Specimens were supplied from annealed 10.5-inch O.D. by 1.352-inch wall DM steel tube having the following reported heat number and composition:

	Chemical Composition (percent)							
Heat Number	C	Mn	P	S	Si	Cr	Ni	Mo
27548	0.13	0.45	0.013	0.030	0.78	1.19	0.23	0.49

The tube was cooled at 20°F per hour from 1575 - 1600°F to 1200°F. The hardness after annealing was reported to be 138 - 159 Brinell.

Specimens were supplied from both the transverse and longitudinal direction of the tube. Prior to machining the transverse sections into specimens the tube was flattened and stress relieved for 1.5 hours at 1200°F.

RESULTS

The properties of DM steel in the form of an annealed large heavy wall tube were evaluated at 1000° and 1050°F. Rupture properties and limited creep properties were used. A limited evaluation of structural stability effects during testing was included in the investigation.

Stress-Rupture Properties

Stress-rupture tests up to 6951 hours at 1000°F and 10,571 hours at 1050°F (Table I) were used to establish the stress-rupture time curves of Figure 1. Neither of the prolonged tests indicated a change in slope of the stress-rupture time curves. The data did show a break in the 1000°F curve at about 350 hours. As will be discussed in the next section a creep test at 1050°F under 8000 psi for 13,560 hours did not show any evidence of premature third-stage creep. The stress-rupture time curves are therefore considered to be quite reliable.

The stress-rupture time curves were established using longitudinal specimens from the tube. Check tests on transverse specimens gave about the same rupture times as longitudinal specimens. Elongations were much lower particularly at 1000°F (See Table I and Figure 1).

The tube had considerably lower rupture strength than had previously been obtained for annealed DM steel. This is shown by the comparative stress-rupture time curves at 1000°F from previous reports in Figure 1. The only exception was the low 100,000 hour strength of the original DM steel subjected to rupture tests. The rupture strengths of the tube are compared with those from previous reports for both annealed and normalized plus tempered material in Table II. The tube investigated had higher 100,000 hour strength than the normalized plus tempered material at 1000°F, but lower short time strength. Material normalized from 1750°F was, however, stronger even at long time periods than the tube at 1050°F.

Figure 2 compares the 100,000 hour rupture strengths of the tube with those from previous reports and published values for wrought material. ASTM Special Technical Publication Number 151 shows data for only one wrought material other than Timken data. Five values for heavy wall pipe (1) are also

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(1) "Influence of Heat Treatment on the 1000°F and 1050°F Properties of Steam Pipe Made in Japan and Germany from 1.25 Cr - 0.5 Mo and 2.25 Cr - 1 Mo Steels" J. W. Freeman and I. A. Rohrig, 1956 Annual Meeting of the ASME.

shown. The allowable stress values of the ASME Boiler Code are indicated on the figure. The features of this figure are as follows:

1. The 100,000-hour rupture strengths of the tube investigated were considerably below the average curve (This curve was mainly based on Timken data.) in STP No. 151. The figure also shows that the strengths at 1050°F were lower than would have been anticipated from previous reports even though no tests have previously been conducted at 1050°F on annealed material.

2. The tube had slightly lower strength at 1000°F than was obtained from heavy wall pipe made in Germany and Japan (1).

3. The strength of the tube at 1050°F was only 1300 psi higher than the ASME Boiler Code Allowable Stress.

Creep Properties

Creep data were taken during the longer time rupture tests and during one lower stress test at each temperature and creep rates measured as a function of testing time. Figure 3 shows stress-creep rate curves for minimum creep rates. The relation of these minimum creep rates to the variation of creep rate with testing time is shown by Figure 4 for the longer time tests. The actual creep curves are shown in Figure 5 and 6.

The lowest creep rate in the tests was 0.06 percent per 1000 hours. The curve at 1050°F is based on only two tests. Accordingly, the extrapolation to 0.01-percent per 1000 hours is excessive. Moreover the curves are based on both longitudinal and transverse specimens. The data are not clear as to whether or not the transverse specimens had different creep resistance than the longitudinal specimens. Both of the longer time tests at 1050°F showed low initial creep rates followed by a period of rapidly increasing creep rate (Figure 4). The creep rate increase fell off between 2000 and 5000 hours for the 10,500 psi test and the rate decreased after 2000 hours for the 8000 psi test. All of these factors cast doubt on the creep strengths indicated by Figure 3. Moreover the indicated creep strengths particularly for 0.01-percent per 1000 hours are high in relation to the rupture strengths, as the following comparison shows:

	1000°F	1050°F
0.1% per 1000 hour creep strength, psi	(15,000)	(8,400)
10,000 hour rupture strength, psi	17,000	10,500
Ratio creep strength to rupture strength	0.88	0.8
0.01% per 1000 hour creep strength, psi	(10,000)	(6,000)
100,000 hour rupture strength, psi	11,800	6,800
Ratio creep strength to rupture strength	0.85	0.88

General experience indicates that the ratio of the 0.1 percent per 1000-hour creep strength to the 10,000-hour rupture strength ought to be less than 0.8. The ratio for the 0.01-percent per 1000 hour creep and 100,000-hour rupture strengths ought to be less than 0.6. Otherwise premature third-stage creep will lead to more deformation in 10,000 or 100,000 hours than the one-percent predicted by the creep strengths.

Due to the unreliability of the creep strengths, comparisons have not been made with data from previous reports. The indicated creep strengths are, however, lower than have previously been established for DM steel, particularly for a rate of 0.1-percent per 1000 hours.

Stability Tests

Impact and hardness tests on specimens after testing showed practically no evidence of structural instability (See Table III).

Microstructures

The original microstructure consisted of irregular pearlite and ferrite (Plates 1 and 2). The longitudinal specimen (Plate 1) showed a more non-uniform distribution of the pearlite than the tangential specimen (Plate 2). The pearlite and ferrite grains were slightly elongated in the longitudinal direction and there was some banding.

The specimen which ruptured after 6951 hours at 1000°F under 18,000 psi (Plate 3) or the creep specimen tested at 14,000 psi (Plate 4) showed very little evidence of structural change. The usual intergranular cracks transverse to the applied stress were present near the fracture and at the surface.

The fractures of all the specimens tested at 1050°F are shown in Plates 5, 6 and 7. In addition, Plates 6 and 7 show the surface and the interior at high magnification. It will be noted that there was less internal cracking in the transverse than in the longitudinal specimens. The pearlite showed progressive spheroidization. The spheroidization had progressed to a greater degree in the specimen which ruptured in 10,547 hours than in the creep specimen discontinued after 13,560 hours (Plate 8).

The relationship of microstructure to creep-rupture properties is not very certain. The structure of the tube was considerably different than has previously been obtained with bar stock. Normally an anneal would be expected to give nearly equi-axed grains of ferrite and pearlite. The structure of the tube was, however, considerably different. The small irregular grains apparently reflect an influence from the structure established during previous working combined with austenitizing near the upper critical temperature. The annealing temperature of 1575° to 1600°F is near the critical temperature and not high enough in the austenitic region to eliminate structural effects from prior working. The material annealed at 1650°F for Report 134 had a fine equi-axed structure. The material normalized at 1800°F and annealed at 1500°F for Report 134 had a structure which slightly resembled that of the tube. Due to 1500°F being so far below the critical the pearlitic areas were smaller, less perfectly formed and fewer in number. A higher annealing temperature for the tube might have given better solution and equalization of the structure with higher rupture strengths.

The relationship of microstructures to creep-rupture properties is so imperfectly understood that it is difficult to draw conclusions. Prior history can influence both microstructure and properties when annealing temperatures are as low as 1600°F. It is not possible to be sure whether relatively low strength as was observed for the tube is due to the microstructure or to some prior history effect reflected in the microstructure. In addition, it is possible that some unidentified heat-to-heat difference was involved. The probability is, however, that the strength of the tube could be brought up to normal by a high annealing temperature or a normalizing treatment prior to a final anneal.

DISCUSSION

The investigation had two major objectives: (1) establishment of the relative properties of heavy wall tubes; and (2), determination of directional effects on creep-rupture properties.

Relative Properties of Heavy Wall DM Steel Tube

As previously shown the heavy wall tube had lower rupture strength than previous investigations of bar stock had established for annealed DM steel. The microstructures suggest that this was due to the prior history of the tube influencing the response to heat treatment rather than the size of the tube. Final heat treatment apparently should be adjusted to the prior history differences. Probably a higher temperature of annealing would have brought the properties of the tube up to the expected level.

The details of the annealing treatments for previously investigated bar stock are not known. The tube was cooled at 20°F per hour from 1575°-1600°F to 1200°F. This is a rather slow cooling rate. It is possible that the low strength was due to the slow cooling rate rather than the annealing temperature. It is also not possible to rule out an inherent heat-to-heat difference leading to the low strength.

While the creep data were incomplete the tube appeared to have high creep resistance in relation to the rupture strength. The actual values were not unduly high, however, in comparison to previously established creep strengths for DM steel. The microstructure was somewhat similar to that obtained in previous investigations by annealing between the critical temperatures, a treatment known to give high creep strengths. This could have been involved in the present results. The creep strengths were, however, mainly based on transverse specimens. If as the data suggest creep resistance was higher in the transverse direction, the abnormally high ratio of creep to rupture strength could have been due to the rupture strengths being based on weaker longitudinal specimens.

Longitudinal versus Transverse Specimens

The size of the tube offered the opportunity to check the properties transverse to the length of the tube. Under internal pressure a tube creeps circumferentially. Thus, if properties were substantially different for transverse specimens, properties based on longitudinal specimens could be misleading.

The check tests conducted on transverse specimens indicated about the same rupture strengths as for longitudinal specimens. Ductilities were, however, much lower particularly at 1000°F. Creep resistance may have been higher in the transverse specimens. This is not an unusual situation. Specimens taken transverse to the direction of working frequently show this type of difference. It is possible, however, that the cold straightening and additional stress relief at 1200°F for 1-1/2 hours could have influenced the relative properties of the two types of specimens.

Transverse specimens, therefore, indicated about the same rupture strength and probably higher creep strength than longitudinal specimens. The major difference, however, was the low ductility in rupture tests at 1000°F. One specimen ruptured with only 3-percent elongation, a value sufficiently low to cause concern. On the other hand, tests on tubes taken from service have generally shown nearly equal properties in both directions. While this could have been due to equal initial properties in both directions, it has strongly suggested that during service structural changes equalize directional properties.

As previously discussed the abnormally high ratio of creep strengths to rupture strengths could have been due to the location of the specimens used to establish the two values. The creep data for the tube were obtained mainly on transverse specimens. The rupture strengths were mainly based on longitudinal specimens. If the creep resistance of the transverse specimens was higher than for the longitudinal, as the data suggest, this could account for the high ratios. The few rupture tests on transverse specimens did not establish the slope for a stress-rupture time curve so that the rupture strengths of transverse specimens were not well established. Low ductility in rupture tests is usually accompanied by high ratios. Certainly the ductility of the transverse specimens indicated that this could be the case.

TABLE I

Stress-Rupture Data at 1000° and 1050°F for Annealed

10.5-inch O.D. by 1.352-inch Wall DM Steel Tube

Direction	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 inches)	Reduction of Area (%)
		1000°F		
L	46,000	0.5	29.0	73.5
L	38,000	20	40.0	62.5
L	29,000	385	19.5	20.5
L	24,500	1125	16.0	16.5
T	24,500	1236	3.0	3.5
T	23,000	1217	7.5	8.5
L	18,000	6951	10.5	23.0
T	14,000	Discontinued at 3,353 hours		
		1050°F		
L	25,000	121	31.5	33.0
T	20,000	370	14.0	18.5
L	16,000	1006	25.0	34.5
T	16,000	1041	23.0	28.0
L	10,500	10571	28.5	38.5
T	8,000	Discontinued at 13,560 hours		

L = Longitudinal to length of tube.
T = Tangential to length of tube.

TABLE II

Rupture Strengths of 10.5-inch O.D. by 1.352-inch Wall Tube of DM Steel with Comparative Values from Previous Reports

Temp (°F)	Form	Heat Treatment	Rupture Strengths (psi) for Indicated Time Periods					Data Source
			10-hr	100-hr	1000-hr	10,000-hr	100,000-hr	
1000	10.5" O.D. x 1.352" wall tube	Ann. 1575°-1600°F	40,000	33,500	25,000	17,000	11,800	
1000	1" round	Ann. 1550°F	48,000	46,000	44,000	20,500	9,000	*
1000	1" round	Norm. 1800°F- Ann. 1500°F	56,500	55,000	37,000	24,000	16,000	Rpt. 134
1000	1" round	Ann. 1650°F	49,500	47,500	38,000	25,000	16,500	Rpt. 134
1000	1" round	Norm. 1650°F- D. 1200°F	58,500	57,000	47,500	22,000	10,500	Rpt. 134
1050	10.5" O.D. x 1.352" wall tube	Ann. 1575°-1600°F		26,000	16,000	10,500	6,800	
1050	1" round	Norm. 1750°F + 6 hrs. at 1200°F	44,000	35,000	25,000	14,000	7,900	Rpt. 183

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* Original rupture tests on DM steel which were never included in a report.

TABLE III

Effect of Creep-Rupture Testing on the Izod Impact and Hardness Properties of 10.5-inch O.D. by 1.352-inch Wall Annealed DM Steel Tube

	Test Conditions				
Specimen Direction	Temp. (°F)	Stress (psi)	Test Duration (hours)	Izod Impact (ft-lbs)	BHN Hardness*
T	Original			28,26	138/159
L	1000	18,000	6951 R		143
T	1000	14,000	3353	26,26	137
L	1050	25,000	121 R		149
T	1050	20,000	370 R		139
L	1050	16,000	1006 R		133
T	1050	16,000	1041 R		134
L	1050	10,500	10547 R		123
T	1050	8,000	13560	21,26	137

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* = Converted from Vickers Diamond pyramid hardness.
R = Fractured.
L = Longitudinal to length of tube.
T = Tangential to length of tube.

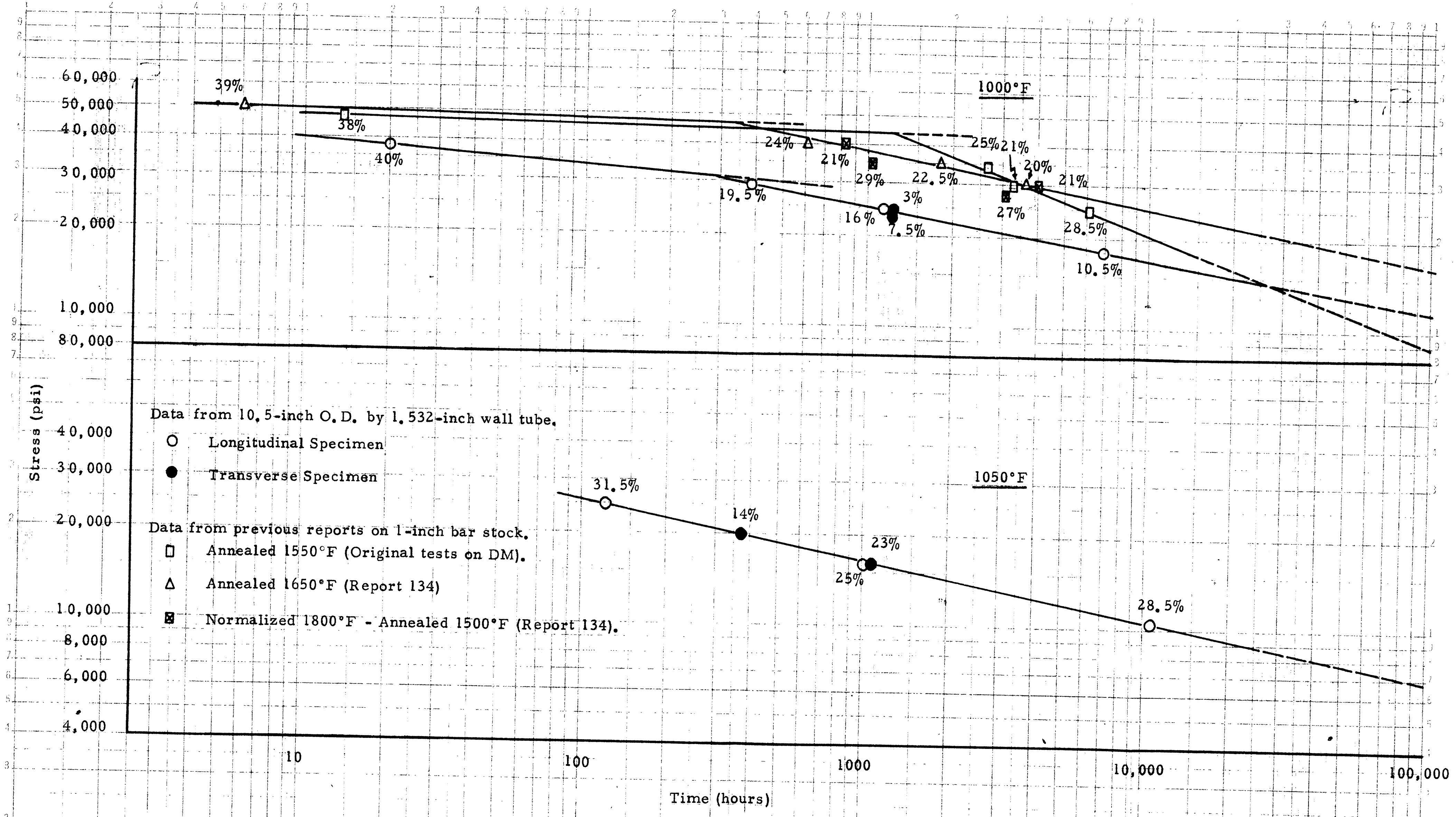

Figure 1. - Stress-rupture time curves at 1000°F and 1050°F for annealed 10.5-inch O.D. by 1.352-inch wall DM steel tube. Comparative curves for annealed DM steel from previous reports shown.

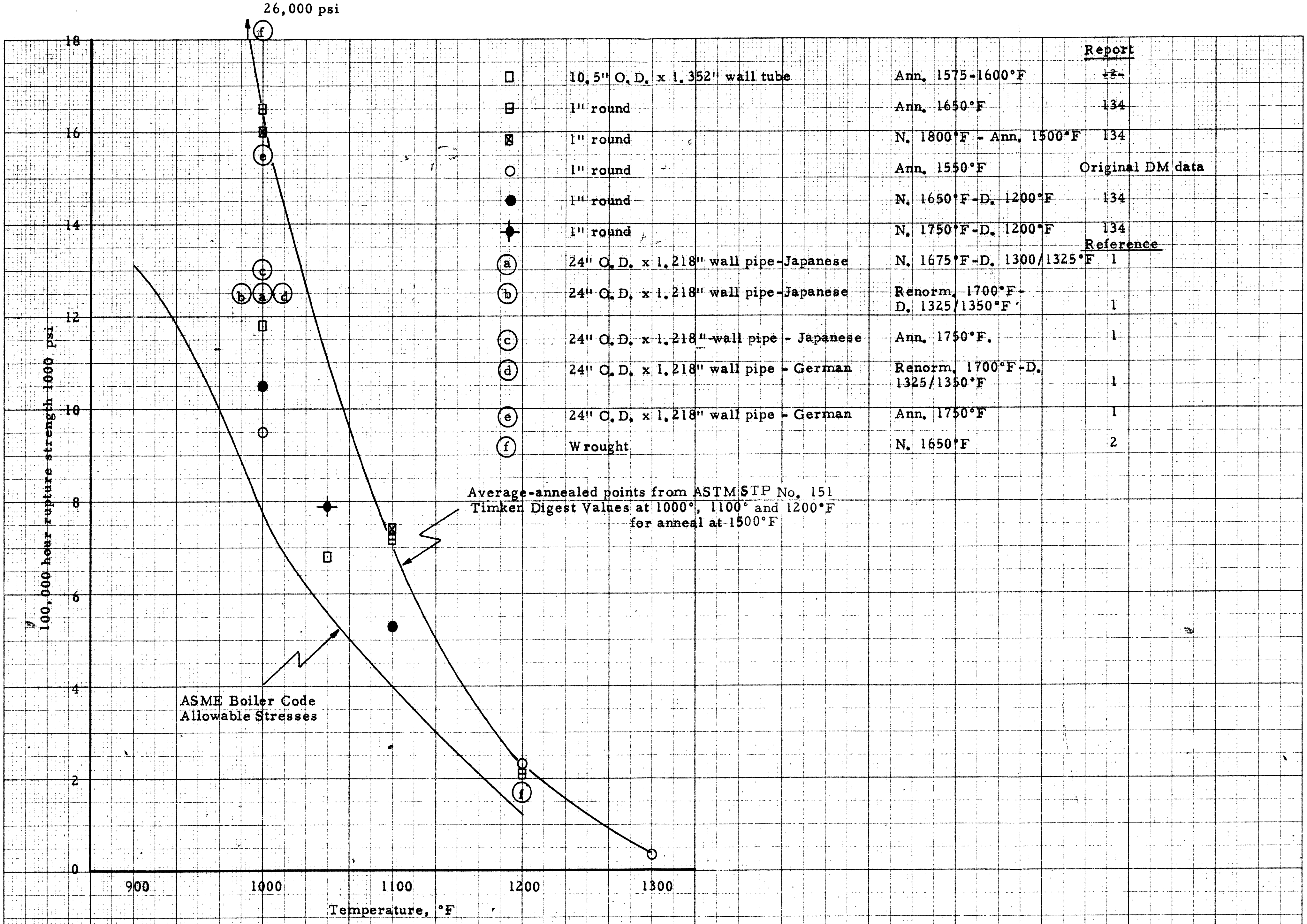

Figure 2. - Comparison of the 100,000 hour rupture strengths of 10.5-inch O.D. x 1.352-inch wall annealed DM steel tube with values from previous reports and the literature.

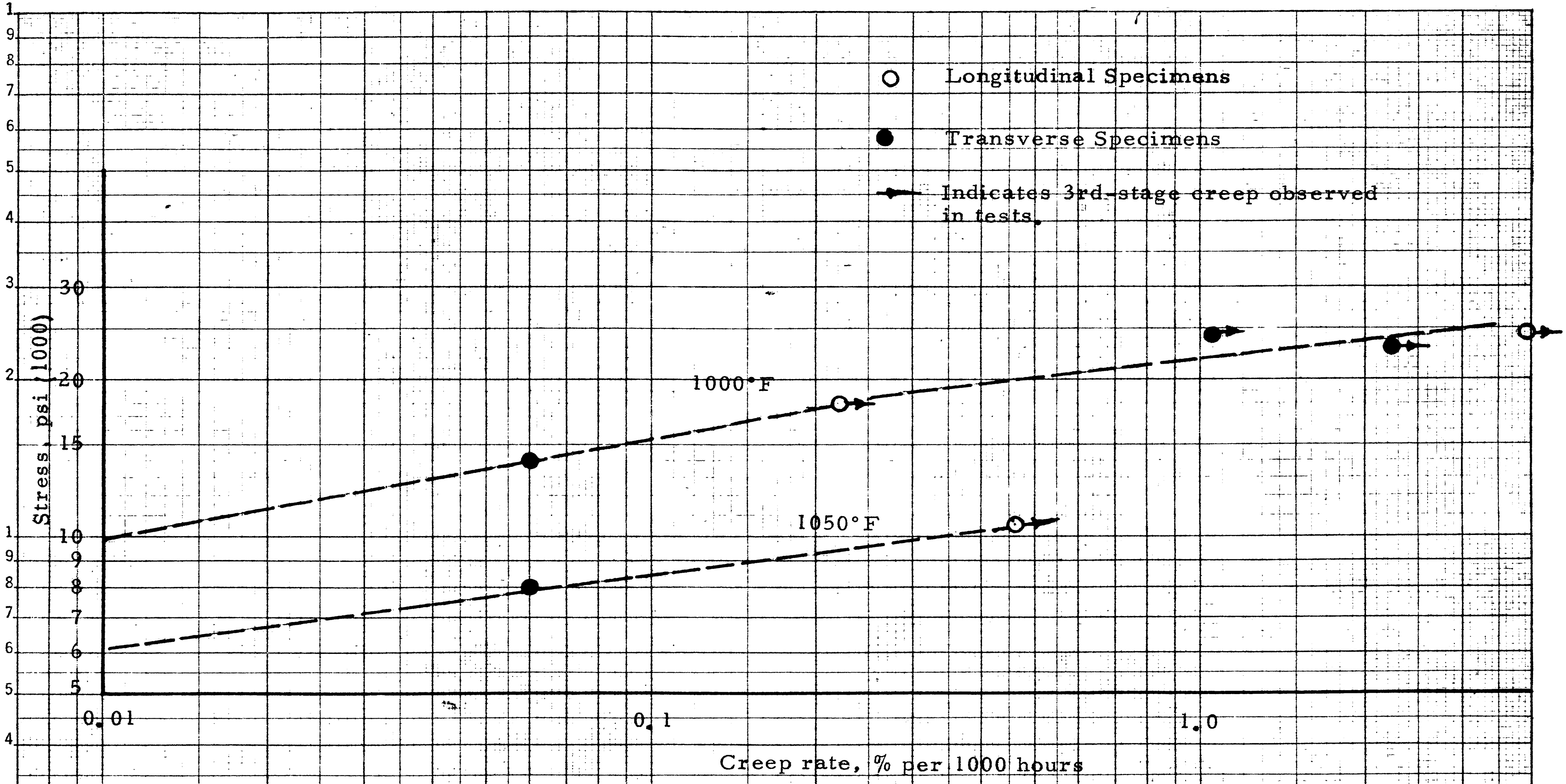

Figure 3. - Stress-creep rate curves at 1000° and 1050°F for annealed 10.5-inch O.D. by 1.352-inch wall DM steel tube.

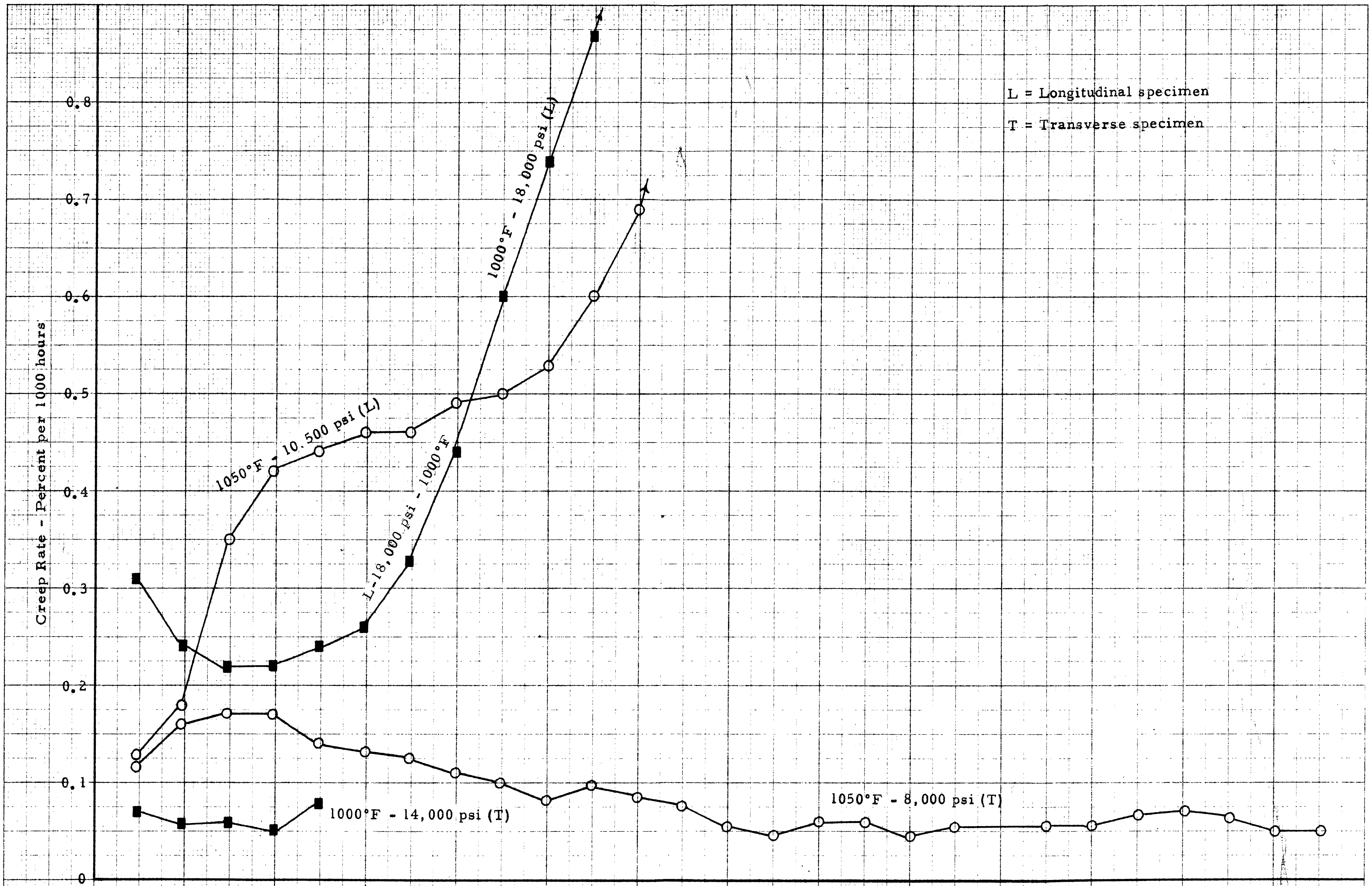

Figure 4. - Creep rate - time curves for 1000°F and 1050°F from tests on 10.5-inch O.D. by 1.352-inch wall annealed DM steel tube.

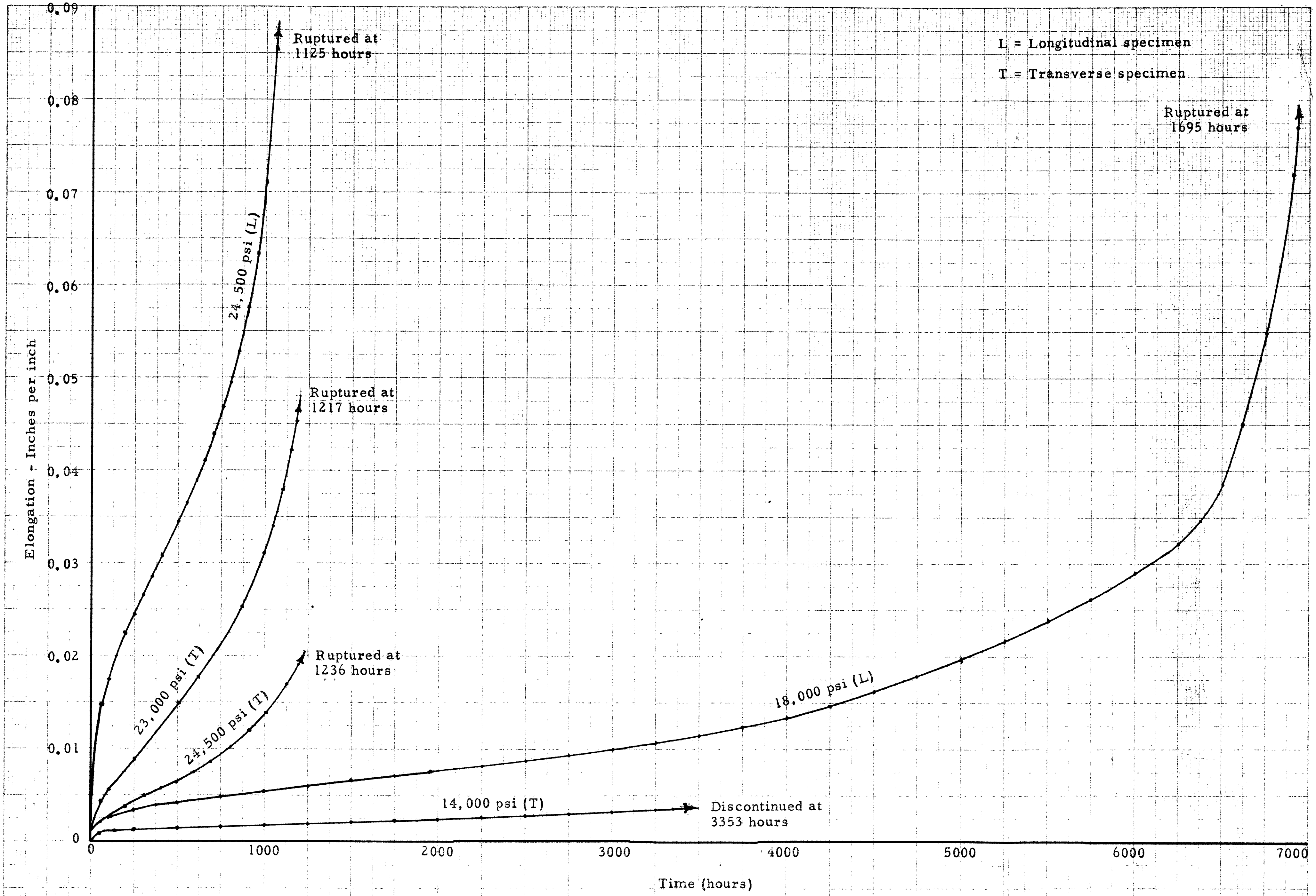

Figure 5. - Time-elongation curves at 1000°F for 10.5-inch O.D. by 1.532-inch wall annealed DM steel tube.

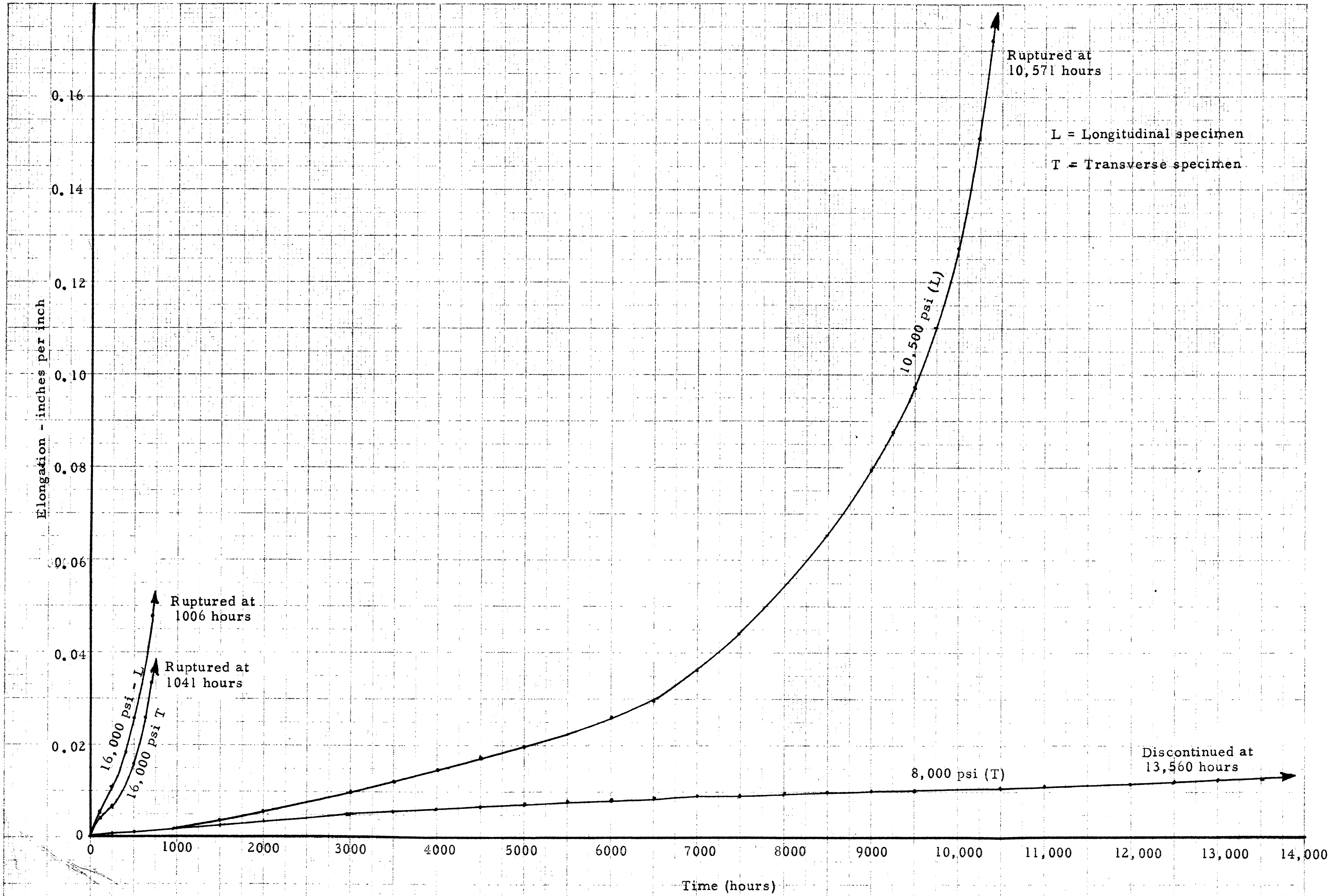

Figure 6. - Time - elongation curves at 1050°F for 10.5-inch O.D. x 1.352-inch wall annealed DM steel tube.