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RUPTURE PROPERTIES AT 1400°F OF TYPE 304 AUSTENITIC STEEL PIPE WHICH FAILED IN SERVICE

by

T. M. Cullen
J. W. Freeman

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THE M. W. KELLOGG COMPANY
711 THIRD AVENUE
NEW YORK 17, N. Y.

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SUMMARY

An investigation has been conducted at the request of The M. W. Kellogg Company in which the rupture properties of a section of Type 304 austenitic steel pipe were evaluated at 1400°F. This pipe (12" O. D., 3/8" wall) had been in service at 1400°F for approximately 80,000 hours. In this service the pipe had been heavily carburized on its inner walls. Most of the heavily carburized layer was removed during machining of the rupture specimens.

The rupture properties of this material at 1400°F were in close agreement with the properties of virgin Type 304 steel at this temperature. This indicates that the uncarburized material of this pipe had suffered little damage as the result of service at 1400°F for an extended period of time. The rupture ductilities of the specimens were somewhat below those which new material would exhibit.

INTRODUCTION

On May 20, 1963, a section of Type 304 austenitic steel primary reformer 12" outlet piping ruptured along a longitudinal weld seam. This 3/8" thick pipe had been in service for more than nine years at an ammonia plant operated by the Shell Chemical Company in Ventura, California. A subsequent inspection of the pipe showed cracks to be present in virtually all of the longitudinal weld seams. No cracks, however, were observed in the thicker circumferential weld seams or in the parent metal.

The original operating conditions were such that a mixture of steam and natural gas entered the reformer at 1000°F and 95 psig, were reacted, with the products of reaction exiting at 1400°F and 70 psig. For some period of time prior to failure the operating conditions called for the mixture to enter at 1000°F and 110 psig and for the products of reaction to exit at 1350°F and 85 psig.

After the failure a section of the failed pipe was sent to the Shell Development Company for their examination. Their findings were as follows:

(1) The longitudinal weld seam failure was a result of high temperature stress-rupture.

(2) Heavy carburization had developed at the inner walls of the pipe.

(3) The parent metal showed a marked reduction in ductility as determined by flattening tests at both room temperature and 1450°F as compared with normal Type 304 austenitic steel.

The present investigation was undertaken to determine if any significant change in the rupture properties of the base metal had occurred during its long service, as compared with the average properties of virgin material. With this objective in mind a series of rupture tests were conducted at 1400°F on specimens taken from the failed pipe.

EXPERIMENTAL PROCEDURES

A section of the failed 3/8" thick Type 304 austenitic steel pipe was received by the University of Michigan from the Lucius Pitkin Laboratories at the request of The M. W. Kellogg Company. Specimen blanks were removed in the longitudinal direction from this section of pipe. From these specimen blanks 0.160" diameter rupture specimens were machined. These specimens had a gage length of approximately 0.64". Specimens of this size were used in this investigation because of the requirement that the rupture testing be accomplished on relatively uncarburized material. The rupture tests were conducted at 1400°F in the University's High Temperature Laboratory. Because of the relatively small loads involved in these tests the specimens were loaded directly as opposed to the utilization of a lever system.

RESULTS

A tensile test was conducted at 1400°F on a specimen of the pipe in order to arrive at the approximate range of stresses required for the rupture tests. This test showed the material to have an ultimate tensile strength of 29,450 psi at 1400°F.

Based on the results of this test, rupture tests were at 1400°F under stresses which ranged from 17,000 psi down to 7,500 psi. The results of these tests are shown in Table I. The log of the rupture times have been plotted as a function of log stress in Figure 1.

It has been assumed that a linear extrapolation of the log stress-log rupture time data of Figure 1 can be made. The extrapolated 100,000 hour rupture strength of the Type 304 steel pipe at 1400°F was 3,100 psi.

The rupture ductilities, both elongation and reduction of area, of the ruptured specimens are shown in Table I. The measured ductilities were nominal except for the longest time test. Both the elongation and the reduction of area of this specimen were well below the values recorded for the other specimens. The data shown in Table I indicate that these low values may be approximately correct, however, since a downward trend in the values is evident even when the values obtained for the longest time test are excluded.

DISCUSSION

The rupture properties of the base metal of the section of Type 304 austenitic steel pipe are in good agreement with the properties measured at the University on new material at the same testing temperature. The rupture data are very sparse at 1400°F with the consequence that only one set of results are available at that temperature. If these results (Table II) were to be plotted on the same graph as the results obtained in this investigation it would be noted that the log stress-log rupture time would be almost identical. Based on this fact it is unlikely that the uncarburized zone of the Type 304 pipe tested in this investigation had been significantly damaged as the result of the prolonged service of the pipe.

The rupture ductilities recorded for the specimens tested in this investigation were somewhat lower than the corresponding ductilities shown in Table II. No explanation for the lower ductilities can be offered other than to state that a slightly carburized layer may have remained on the specimens. It is possible that such a layer could have caused the specimens to exhibit somewhat lower ductilities than they would have shown otherwise. If such a layer did exist on the specimens, it could have been shallow enough not to appreciably influence the strength of the material. The determination of creep damage is a somewhat unknown procedure at the present time. It is therefore possible that the low ductility of the longest test could be an unrecognized indication of damage.

CONCLUSIONS

As the result of a series of rupture tests at 1400°F on Type 304 austenitic steel piping removed from service, the following conclusions have been reached:

(1) The strength properties of the relatively uncarburized region of the Type 304 pipe are in good agreement with available data on new material at 1400°F.

(2) The uncarburized pipe has not suffered appreciable damage as the result of its prolonged service.

(3) The rupture ductility of the pipe was somewhat lower than the ductility exhibited by new material tested at the same temperature.

TABLE I

Stress-Rupture Time Data at 1400°F for Type 304 Stainless Steel Piping Supplied by The M. W. Kellogg Company

Specimen Code	Stress psi	Rupture Time Hours	Elongation %	Reduction of Area, %
1	29,450	STTT	21.5	21.8
2	17,000	2.9	20.0	22.3
3	15,000	A	20.0	20.8
4	13,500	13.8	20.0	20.0
6	11,500	36.1	20.0	19.6
7	9,500	94.2	16.5	15.5
8	8,000	262.3	13.6	12.7
5	7,500	440.7	7.7	8.5

A - Timer did not shut off when specimen fractured

TABLE II

Available Data at 1400°F for Wrought Type 304 Steel

Stress psi	Rupture Time Hours	Elongation at Rupture, %
22,000	0.47	32
17,000	2.3	26
14,000	6.4	26
7,000	740	19
6,000	1112	15
5,000	3430	14