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# CREEP-RUPTURE PROPERTIES OF 1¼Cr - ½Mo STEAM PIPING AFTER EXTENDED SERVICE AT 1000°F

by

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## INTRODUCTION

As a result of the recent reductions in the allowable stresses for P11 (1.25 Cr, 0.5 Mo) steel piping in the ASME Boiler and Pressure Vessel Code, the users of the steel in applications subject to the Code restrictions have become concerned about the possibility of accumulated creep damage in their installations. These installations have in most cases been operating many thousands of hours at the higher stresses formerly specified in the Boiler and Pressure Vessel Code.

The Detroit Edison Company has initiated an investigation to determine the influence of prolonged service at stresses formerly allowed in the Code on the remaining creep-rupture life of the P11 main steam piping. It was anticipated that the results of the investigation would not only be of significant value in determining the remaining service life of the Detroit Edison P11 piping but would also serve to guide other users of this material as to the degree of damage which might be expected to have accumulated in their own installations.

The objectives of the investigation were threefold:

(1) Determine the amount of creep damage accumulated in the P11 piping as the result of prolonged service at 1000°F.

(2) Determine the remaining service life of the material under Code Conditions of 1000°F and 7,800 psi stress.

(3) Determine the influence of reheat treatment on the creep-rupture properties of the P11 material removed from service.

The studies of the influence of reheat treatment on the creep-rupture properties of the material removed from service were carried out on the premise that if the pipe was found to have low strength it might be possible to restore the properties by either annealing or normalizing and tempering the pipe.

## CONCLUSIONS

The P11 main steam pipe removed from service after 83,403 hours at 1000°F showed no evidence of creep damage with respect to the long time properties of the material as a result of that service. The stress-rupture properties exhibited by the material removed from service were quite low at the short time periods, however, at the longer time periods they were at least as high as would be expected for virgin material. The relatively low short time strengths can be accounted for by microstructural changes which took place in the pipe during the extended service.

The rupture life remaining in the P11 pipe under the aforementioned service conditions is greatly in excess of 100,000 hours. Based on the parameter method of extrapolation, the remaining life is in excess of 1,000,000 hours.

There was no evidence of any difference in creep or rupture properties of the material removed from service as a function of the orientation in the pipe from which the specimens were removed.

Reheat treatment of the material removed from service raised the short time properties but did not significantly affect the long time properties of the material. There did not appear to be any major difference in the creep or rupture properties of the specimens heat treated in the different manners; annealing or normalizing and tempering.

## MATERIAL INVESTIGATED

The P11 steel used in the investigation was taken from a section of main steam piping in the Detroit Edison system which had operated for 83,403 hours at 1000°F under a pressure of 1,800 psi.

The material had originally been supplied as forged and bored by Midvale-Heppenstall in the normalized and tempered condition. The pipe had an outside diameter of 12 inches and an inside diameter of 9 inches.

Machined specimens from the main steam piping were supplied to the University of Michigan in the following conditions:

(1) As removed from service - longitudinal orientation - Code A.

(2) As removed from service - transverse orientation - Code B.

(3) Removed from service and heat treated - annealed at 1675°F for 1 hour, furnace cooled at 125°F per hour to 1300°F, furnace cooled to room temperature in 16 hours - longitudinal orientation - Code D.

(4) Removed from service and heat treated - held at 1700°F for 1 hour, A. C., plus tempered at 1225°F for 1½ hours, A. C. - longitudinal orientation - Code E.

## EXPERIMENTAL PROCEDURES

Machined specimens were supplied for the investigation by The Detroit Edison Company. The specimens were standard creep-rupture specimens with a diameter of 0.505-inch.

All of the creep-rupture tests were conducted at 1000°F with the exception of the longitudinal specimens in the as-removed from service condition. These specimens were tested at 1000°, 1100° and 1200°F.

The majority of the specimens were tested at 1000°F because this temperature corresponded to the service temperature of the steam piping. The tests at 1100°F and 1200°F were used to aid in the extrapolation of results obtained from the specimens of the pipe in the as-removed from service condition.

## RESULTS

Creep and stress-rupture time data have been obtained from P11 piping material in the as-removed from service condition and in the reheat treated condition. The reheat treatments consisted of: (1) annealing, and (2) normalizing and tempering the piping prior to creep-rupture testing.

### As Removed from Service

The creep and stress-rupture time data obtained from the P11 pipe are presented in Table I. The curves obtained from these data are shown in Figures 1, 2 and 3.

Stress-rupture behavior - Examination of the stress-rupture curves shown in Figure 1 shows that the 1000° and 1100°F curves are approximately parallel to one another. Limited data obtained at 1200°F suggests that the stress-rupture curve at this temperature has a slightly greater slope than the curves at 1000° or 1100°F. Linear extrapolation of the log stress-log rupture time curve indicates that the stress for rupture in 100,000 hours at 1000°F is approximately 12,500 psi. This is in close agreement with the rupture stress of 12,000 psi predicted when the data is plotted as a function of the Larson-Miller parameter. This graph is shown as Figure 2.

The similarity of the slopes of the log stress-log rupture time curves of Figure 1 lends confidence to the accuracy of linear extrapolation of the 1000°F curve out to 100,000 hours. The stress of 12,500 psi for rupture in 100,000 hours is well above the average value obtained from new material. A compilation of the available creep-rupture data for 1¼Cr - ½Mo steel lists an average stress for rupture in 100,000 hours at 1000°F of 9,400 psi. It is not surprising, however, that the material from service exhibited a rupture stress much higher than this average. In instances where materials have been in service for prolonged periods of time and where they have not sustained strain damage as the result of that service, the subsequent creep-rupture strengths exhibited by such material have usually been at least as high if not higher than the same material in its original condition.

A limited number of tests were conducted on transverse specimens removed from the pipe. As is shown in Figure 1 these specimens did not show any significantly different properties from those exhibited by the longitudinal specimens. The data points obtained from the specimens with the different orientations fell on the same rupture curve.

The data obtained at 1100°F suggests that the pipe retains a high level of strength at this temperature. Linear extrapolations of the curve at this temperature out to 100,000 hours is not considered to be justifiable because of the difference in slope between it and the 1200°F stress-rupture curve. The 1100°F stress-rupture time curve can be extrapolated, however, by assuming that the curve beyond 1000 hours has the same slope as the 1200°F curve. This should yield a conservative stress for rupture in 100,000 hours. If this assumption is made the 100,000 hour rupture strength at 1100°F is approximately 8,000 psi. This stress is much higher than the average stress of 4,300 psi expected for new material.

Creep behavior - The minimum creep rate data obtained from the specimens in the as-removed from service condition are listed in Table I. These data are plotted as a function of stress in Figure 3.

Of particular interest are the results of a creep test conducted at 1000°F and 7,800 psi, the stress formerly allowed by the ASME Boiler and Pressure Vessel Code. The specimen exhibited a minimum creep rate of 0.0065 percent per 1000 hours. This rate is below the 0.01 percent per 1000 hours permitted by the Code under the aforementioned testing conditions.

## Reheat-Treated Material

Specimen blanks were cut from the pipe removed from service in the longitudinal direction. These blanks were heat treated by either annealing or by normalizing and tempering prior to being machined into finished creep-rupture specimens.

Stress-rupture properties - The stress-rupture properties of the reheat-treated specimens are listed in Table II and are plotted in Figure 4. Linear extrapolations of the results obtained from the annealed specimens yields a value of the 100,000 hour rupture strength of 12,800 psi. As close as can be determined from the data obtained from the normalized and tempered specimens, the 100,000 hour rupture strength at 1000°F is also about 12,800 psi. The exact slope of the rupture curve beyond 1000 hours is somewhat in doubt due to the close proximity of the rupture times obtained from the specimens tested under 35,000 and 33,000 psi.

The value of 12,800 psi is approximately the same as was obtained for the 100,000 hour rupture strength of the material in the as-removed from service condition. The level of the rupture properties of the reheat-treated material was much higher at the shorter time periods than attained by samples in the unheat-treated condition. The log stress-log rupture time curves broke rather sharply downward at about 300 hours for the annealed material and at approximately 1100 hours for the normalized and tempered pipe.

As previously mentioned, the average stress for rupture in 100,000 hours at 1000°F of P11 material is approximately 9,400 psi. Since the strengths of the material from service as well as the reheat-treated specimens were considerably above this value, it is likely that the strength of the material in its original condition was well above the average for the alloy.

Creep properties - The minimum creep rates exhibited by the specimens in the two heat-treated conditions are listed in Table III. These rates are plotted as a function of the stress in Figure 5.

No creep tests, as such, were conducted on the heat-treated materials. As a consequence the stresses used in the creep-rupture tests were much too high to allow an accurate estimation of the stress required to yield a minimum creep rate of 0.01 percent per 1000 hours.

## DISCUSSION

The results obtained from the tests conducted during this investigation do not show that damage has been accumulated in the P11 main steam pipe as the result of service at 1000°F for 83,403 hours. Service under these conditions caused the short time rupture strength of the material to be reduced, however, no significant change in the long time properties of the steel was noted. The net effect was to flatten or decrease the slope of the log stress-log rupture time curve. It should be noted that the ultimate tensile strength at 1000°F of the material as removed from service was well below the value expected for new material at this temperature. This is in agreement with the drastically reduced short time rupture properties of the material in this condition.

Since the log stress-log rupture time curve has been flattened out as the result of service, no accurate estimate can be made of the remaining life of the steam line. One can only observe that the remaining life under the Code conditions of 1000°F and 7,800 psi is probably just as great as it was prior to being placed in service. This type of behavior most probably comes about because the microstructure of the material has approached equilibrium and concurrently no strain damage has accumulated in the material as the result of service.

Reheat-treatment caused the short-time rupture properties of the pipe to be restored to the level presumably present before service. The tensile properties of the reheat-treated material were also restored to a level close to the average of new material. The slope of the stress-rupture curve was much steeper than exhibited by the material in the as-removed from service condition. This strongly indicates that reheat-treatment only served to restore the microstructure of the pipe to its original level.

Microstructural stability, or instability, determines to a significant degree the slope of the stress-rupture curve. The second factor which influences the slope of this curve might be called strain damage. Strain damage may be defined as the onset of those conditions necessary for the actual formation of cracks or voids in the material. If the operating condition are such that strain damage is accumulated during service, then the stress-rupture behavior of that material after service should be parallel to the behavior observed prior to service but at a lower level.

TABLE I

Creep-Rupture Properties of P11 Material As-Removed from Service

| Specimen Code | Temperature °F | Stress psi | Rupture Time hours | Elongation percent | Reduction of Area, percent | Minimum Creep Rate, %/1000 hrs. |
|---|---|---|---|---|---|---|
| Longitudinal Orientation | | | | | | |
| A-1 | 1000 | 38,300 | STTT | 41.5 | 77.0 | |
| A-4 | 1000 | 24,000 | 72.0 | 51.5 | 68.5 | 198.0 |
| A-2 | 1000 | 22,000 | 182.6 | 44.5 | 78.0 | Rupture Test |
| A-13 | 1000 | 22,000 | 106.4 | 37.0 | 76.0 | Rupture Test |
| A-6 | 1000 | 18,000 | 1565.9 | 27.0 | 59.0 | 4.94 |
| A-8 | 1000 | 7,800 | | | | 0.0065 |
| A-5 | 1100 | 18,000 | 44.4 ± 23 | 53.5 | 74.0 | 200.0 |
| A-3 | 1100 | 16,000 | 193.6 | 48.5 | 76.0 | 53.1 |
| A-7 | 1100 | 15,000 | 424.6 | 44.0 | 67.0 | 18.0 |
| A-10 | 1100 | 14,000 | 1018.7 | 31.0 | 48.5 | 5.55 |
| A-11 | 1200 | 12,500 | 62.6 | 37.5 | 71.5 | 102.0 |
| A-12 | 1200 | 11,000 | 183.3 | 39.0 | 63.0 | 20.4 |
| Transverse Orientation | | | | | | |
| B-2 | 1000 | 24,000 | 38.8 ± 7 | 51.0 | 73.5 | 160.0 |
| B-1 | 1000 | 22,000 | 178.6 | 43.5 | 67.5 | 64.50 |
| B-3 | 1000 | 20,000 | 433.7 | 46.0 | 56.5 | 16.58 |

TABLE II

Creep-Rupture Properties of Reheat-Treated P11 Material Removed from Service

| Specimen Code | Temperature °F | Stress psi | Rupture Time hours | Elongation percent | Reduction of Area, percent | Minimum Creep Rate, %/1000 hrs. |
|---|---|---|---|---|---|---|
| Annealed | | | | | | |
| D-6 | 1000 | 52,500 | STTT | 35.5 | 79.5 | - |
| D-2 | 1000 | 45,000 | 83.0 | 32.0 | 71.0 | 53.9 |
| D-7 | 1000 | 43,000 | 95.2[a] | 31.0 | 70.5 | 45.9 |
| D-3 | 1000 | 42,500 | 187.5 | 33.0 | 70.0 | 19.0 |
| D-1 | 1000 | 40,000 | 309 ± 23 | 37.0 | 69.0 | 10.0 |
| D-4 | 1000 | 38,000 | 396.6 | 32.0 | 68.5 | 5.20 |
| D-5 | 1000 | 33,000 | 818.0 | 22.5 | 67.5 | 0.91 |
| Normalized and Tempered | | | | | | |
| E-2 | 1000 | 50,200 | STTT | 38.0 | 81.0 | - |
| E-6 | 1000 | 42,500 | 138.4 | 32.0 | 69.0 | 52.20 |
| E-4 | 1000 | 40,000 | 255 ± 5 | 30.0 | 51.5 | 18.8 |
| E-1 | 1000 | 35,000 | 1125.9 | 23.5 | 66.5 | 1.72 |
| E-7 | 1000 | 33,000 | 1173.4 | 26.0 | 64.5 | 1.63 |

a - held at temperature for 48 hours prior to loading