REPORT

ON

INFLUENCE OF 32,000 HOURS OF SERVICE AT 1040° AND 1090°F ON THE RUPTURE-TEST CHARACTERISTICS OF 3 Cr - 1 Mo SUPERHEATER TUBES

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INFLUENCE OF 32,000 HOURS OF SERVICE AT 1040° AND 1090°F ON THE RUPTURE-TEST CHARACTERISTICS OF 3 Cr - 1 Mo SUPERHEATER TUBES

An investigation of the influence of service for 32,000 hours at 1040° and 1090°F on the properties of 3 Cr - 1 Mo Superheater tubing (ASTM A213 Grade T21) was carried out. Evaluation of the effects of prior service were based on rupture tests at 1050° and 1100°F. The 2.5-inch O.D. x 0.5-inch wall tubing operated under a pressure of 1500 psi which indicates a hoop stress in the tube wall of 3750 psi.

SUMMARY AND CONCLUSIONS

The 32,000 hours of service reduced rupture strengths for short time periods at 1050° and 1100°F. The resulting flatter stress-rupture time curves indicated little difference between unused material and the tubes after service in 100,000 hour rupture strength. There apparently was a slight reduction at 1100°F. The load carrying ability under the estimated operating stress of 3750 psi had therefore not been significantly altered by the 32,000 hours of service.

The unused material had rupture strengths on the high side of published ranges in rupture strength for 3 Cr - 1 Mo steel. The used tubes were close to or within the lower side of the range at short times and well within the probable range for time periods longer than 10,000 hours.

The data indicate that the major effect of the prior service was structural changes, commonly classified as spheroidization, induced by prolonged exposure to the service temperatures. The amount of rupture life used up in 32,000 hours under 3750 psi by creep was negligible in comparison to that available in either the new or used tubes. The reduction of short time strength and reduced slope of the stress-rupture time curves is the usual effect of so-called spheroidization.

TEST MATERIAL

Machined specimens having a diameter of 0.250-inch and a gage length of 1.0 inch were supplied from three 2-1/2-inch O.D. x 0.5-inch wall (ASTM A213 Grade T21) tubes. Specimens were taken lengthwise to the tubes. One set of samples was stated to be representative of the tubing before service. Another had been in service for 32,000 hours at an average temperature of 1040°F with an occasional maximum of 1080°F. The third tube had operated at 1090°F (maximum of 1130°F) for 32,000 hours.

Each tube was chemically analyzed and the following results were reported by the Timken Roller Bearing Company:

Service Conditions	C	Mn	P	S	Si	Ni	Cr	Mo
Unused	.12	.46	.014	.011	.36	.24	2.97	.80
1040°F average service	.105	.50	.014	.010	.38	.26	3.13	.96
1090°F average service	.10	.50	.012	.011	.38	.25	3.02	.93

Timken also reported the following results from tensile tests at room temperature:

Service Conditions	Tensile Strength (psi)	0.2% Offset Yield Strength (psi)	Elongation (% in 1.5 in)	Reduction of Area(%)
Unused	72,250	51,250	33.6	72.2
	72,000	50,500	32.9	73.4
1040°F average service	68,750	48,750	30.7	65.8
	69,000	47,500	30.0	65.7
1090°F average service	67,000	46,250	31.4	67.8
	66,750	43,750	32.9	68.3

RESULTS

The results of the tensile and rupture tests at 1050° and 1100°F are given in Table I and shown as stress-rupture time curves in Figure 1. Rupture strengths derived from Figure 1 are summarized in Table II.

The prior service reduced tensile strengths. Rupture strengths were reduced at short time periods with the amount of reduction decreasing with time until there was little difference at 100,000 hours. The tubes which had been in service exhibited stress-rupture time curves which had somewhat less slope than the unused material. Thus, even though the prior service reduced strength at short time periods there was little effect at longer time periods.

All specimens had high elongation in the tests.

Test results were quite uniform with little scatter considering that the specimens were cut from tubing.

The original microstructure, Plate 1, showed fine grained, ASTM 8 grain size, ferrite and spheroidized carbides. The 32,000 hours of service resulted in a slight increase in the degree of spheroidization, Plates 2 and 3.

DISCUSSION OF RESULTS

The general effect of the prior service was to reduce strength at short time periods with little effect on properties obtained by extrapolation to 100,000 hours. This is the usual effect of prolonged heating and is usually attributed to spheroidization. The microstructures indicated that some spheroidization took place, although the changes were not as pronounced as the reduction in short time strength might suggest. All of the evidence points to the major effect of the service having been to flatten out the stress rupture time curve, through reduction of short time strength. As will be discussed later the changes in strength induced by prolonged heating and not exhaustion of creep-rupture life was probably the main cause.

The rupture strengths of the unused tubing tended to be on the upper side of the range of values, Table II, compiled by the ASME-ASTM Joint Committee on the Effect of Temperature on the Properties of Metals. The high ductility in the rupture tests and absence of breaks in the stress-rupture time curves was in accordance with known behavior of the steel in rupture tests.

The material which had been in service had strengths on the low side of the range for unused steel until the time periods exceeded 10,000 hours. It is important to note that even at the shorter time periods, particularly at 1100°F, the strengths were close to the range for new materials. It would not be surprising to find similar values for new materials if a larger number of products were tested.

Some speculation regarding the relation of the rupture strengths to the service stress are possible with the data. Under the estimated hoop stress of 3750 psi the rupture time indicated by Figure 1 at 1050°F for the original material would be nine million hours and at 1100°F would be 900,000 hours. In both cases the 32,000 hours of service represents a negligible amount of the total available rupture life. The used tubes indicated remaining available rupture life under 3750 psi to be 9-1/2 million hours at 1050°F and 500,000 hours at 1100°F. This bears out the contention that the amount of life used up due to creep during service was negligible at 1050°F. The prolonged exposure to 1090°F apparently was sufficient to slightly reduce long time strength as well as short time strength.

Since the amount of rupture life used up is indicated to be negligible, any effect of prior service would be due to structural changes in the metal induced by prolonged time at temperature. The flatter stress-rupture time curve at 1050°F indicates that long time strength was unchanged supporting the indication that no significant amount of the rupture life had been used up by creep. The data for tests at 1100°F are more difficult to interpret since there was some reduction in long time strength. Because 32,000 hours was only 3 percent of the original available rupture life of 900,000 hours indicated for the new material, it does not seem possible that the lower strength could have been due to this cause. It is therefore presumed that the major effect of the 1090°F service was to cause structural changes which were extensive enough to slightly reduce long time strength at 1100°F.

It is therefore concluded that the major effect of the 32,000 hours of service was to alter the structure of the metal in a manner which reduced strength at short time periods. This was not sufficient to reduce long time strength when the service temperature was 1040°F. The structural alteration was most probably precipitation and agglomeration of compounds during the prolonged exposure to temperatures in the range of 1040° to 1100°F. This is the known general effect of spheroidization, the term generally used to describe the effect of such prolonged heating.

TABLE I

Stress-Rupture Data at 1050° and 1100°F for 3 Cr - 1 Mo Steel

(A213 Grade T21) Tubes

Test Temp. (°F)	Stress (psi)	Rupture Time (hours)	Elongation (% in 1 in.)	Reduction of Area (%)
	Original Material as Shipped from Mill			
1050	43,000	S.T.T.T.	48.0	83.0
	26,000	45.5	77.0	82.0
	19,000	401.	66.0	82.0
	13,000	3542	58.0	80.5
1100	38,400	S.T.T.T.	55.0	87.0
	22,000	28	68.0	84.0
	15,000	254	71.0	86.5
	9,000	5146	78.0	85.0
	Tubing in Service 32,000 hours at an Average Service Temperature of 1040°F			
1050	34,800	S.T.T.T.	53.0	81.0
	23,000	13.2	59.0	84.0
	18,000	128	72.0	84.0
	14,000	567	58.0	81.0
	11,000	3583	73.0	80.5
1100	31,500	S.T.T.T.	44.0	81.0
	Tubing in Service 32,000 hours at an Average Service Temperature of 1090°F			
1050	35,300	S.T.T.T.	47.0	78.0
1100	30,500	S.T.T.T.	46.0	83.0
	17,000	50	69.0	77.0
	13,000	215	75.0	71.5
	9,500	1600	55.0	70.0