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Influence of Rest in Stress Alternation on the Fatigue Properties of a Low Carbon Steel at Elevated Temperatures*

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Experiments were carried out with a low carbon steel to study the influence of rest in stress alternation on the fatigue properties of a low carbon steel at elevated temperatures. The test temperatures were 450 and 300°C and the frequency of alternating stress was 1500 c. p. m. The tests were performed under the condition of constant strain amplitude in the rotating bending fatigue test. The rest in stress alternation was realized according to two sorts of programs. In the one, a rest of 0.5~30 hours was given after the stress alternation of one half of the number of cycles to fracture, and in the other, rests of about 8 and 16 hours were given alternately after the stress alternation of every one fifth or one tenth of the number of cycles to fracture. The temperature during the rest was maintained at the test temperature.

As a result, it was found that the influence of rest on the fatigue strength of a low carbon steel was little and the distribution of hardness through the cross section of specimen showed little difference between the two cases with and without rest.

1. Introduction

It is known that rest in stress alternation does not alter the fatigue strength at room temperature⁽¹⁾⁽²⁾. At elevated temperatures, however, very little is known on this problem. The authors have proposed an analytical consideration of fatigue at elevated temperatures with special reference to the relation between the fatigue strength and the static creep rupture strength and to the influence of frequency on the fatigue strength⁽³⁾⁽⁴⁾. As a part of the general program of investigations including the above, the study of the influence of rest on the fatigue properties is also under way. In this report, the test results with a low carbon steel at the temperatures of 450 and 300°C are presented. The tests were conducted in rotating bending fatigue. To prescribe the condition at the surface of specimen accurately, and to take account of the case when the strain cycling of constant

amplitude is applied to the material as in the case of thermal fatigue etc., the rotating bending fatigue tests in this study, as well as in the previous study on the influence of frequency, were made under constant deflection and the results are discussed on the strain amplitude basis.

2. Testing apparatus

The testing machine employed was of a rotating load type⁽⁵⁾, which facilitated the accurate measurement of temperatures by means of the thermo-couples attached to the surface of minimum section of specimens. Each test was carried out under constant deflection amplitudes, which were read with a microscope. The temperatures of specimens were controlled to within $\pm 2^\circ\text{C}$ by an automatic controller of the thyatron type.

3. Test material and specimen

The material tested was a 0.15 percent carbon steel. Its chemical composition, condition of heat treatment and mechanical properties at room temperature are presented in Table 1. The dimensions of the specimen employed are shown in Fig. 1.

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Table 1 Chemical composition, condition of heat treatment and mechanical properties at room temperature

Composition	C	Si	Mn	P	S	Cu	Fe
%	0.15	0.26	0.43	0.013	0.007	0.09	bal.
Heated after machining at 900°C for one hour in vacuum with subsequent cooling in furnace							
Yield point	23.2 kg/mm ²						
Tensile strength	39.4 "						
Elongation	34.6 %						
Reduction of area	68.5 "

Fig. 1 Test specimen

Table 2 Test conditions and test results
0.15 % carbon steel, frequency of alternating stress 1500 c.p.m.

No.	Test temperature	Strain amplitude	Mode of test		Duration of rest**	Cycles to fracture
1	450°C	1.6×10^{-3}	continuous loading (without rest)		0	7.74×10^4
2					0	1.507×10^5
3					0	9.13×10^4
4					0	9.96×10^4
5			with a rest $N_1^* = 4.6 \times 10^4$		30 min	1.048×10^5
6					60 min	1.387×10^5
7					60 min	1.404×10^5
8					6 hr	1.808×10^5
9		1.45×10^{-3}	continuous loading (without rest)		0	3.975×10^5
10					0	4.596×10^5
11					0	4.719×10^5
12			with a rest $N_1 = 2.35 \times 10^5$		2 hr	4.832×10^5
13					5 hr	5.532×10^5
14					5 hr	5.492×10^5
15					8 hr 20 min	4.388×10^5
16					10 hr	4.536×10^5
17					15 hr	3.304×10^5
18					20 hr	3.182×10^5
19					30 hr	3.071×10^5
20			intermittent loading (with repeated rest)	$N_2^* = 9.4 \times 10^4$	37 hr	3.314×10^5
21					44 hr	3.911×10^5
22				$N_2 = 4.8 \times 10^4$	84 hr	3.516×10^5
23					107 hr	4.093×10^5
24		1.35×10^{-3}	continuous loading		0	1.520×10^6
25					0	3.243×10^6
26					0	2.074×10^6
27			with a rest $N_1 = 1.25 \times 10^6$		10 hr	2.538×10^6
28					20 hr	1.742×10^6
29					30 hr	1.589×10^6
30	300°C	1.8×10^{-3}	continuous loading		0	1.809×10^5
31		1.7×10^{-3}			0	1.905×10^5
32		1.6×10^{-3}			0	2.481×10^5
33		1.5×10^{-3}			0	8.569×10^5
34		1.45×10^{-3}			0	1.052×10^7 not fractured
35		1.4×10^{-3}			0	1.162×10^7 not fractured
36		1.7×10^{-3}	intermittent loading (with repeated rest)	$N_2 = 4.8 \times 10^4$	60 hr	2.623×10^5
37		1.5×10^{-3}		$N_2 = 9.6 \times 10^4$	191 hr	1.725×10^6
38		1.45×10^{-3}		$N_2 = 2.83 \times 10^5$	180 hr	10^7 not fractured

* N_1 : Number of stress cycles applied before the rest in the case with a rest N_2 : Number of stress cycles applied at one time in the case of intermittent loading

** Sum of the duration of rests in the case of intermittent loading (with repeated rest)

4. Test results

The test conditions and results are tabulated in Table 2. The test temperatures were 450 and 300°C which were the same as those employed in the tests conducted to study the influence of frequency⁽⁶⁾. As discussed in the previous report on the influence of frequency, the low carbon steel shows characteristics related to strain aging in the range of temperatures near 300°C⁽⁷⁾⁽⁸⁾ and the elevated temperature fatigue characteristics appears at the temperatures above this range. The test temperature of 450°C was selected to study the influence of rest in the temperature range of elevated temperature fatigue and 300°C was chosen to study the influence in the temperature range of strain aging. The rest in stress alternation was realized according to two sorts of program as shown in Fig. 2. In the one, a rest of 0.5~30 hours was given after the continuous stress alternation of one half of the cycles to fracture under continuous loading and in the other, rests were given repeatedly after the stress alternation of every one fifth or one tenth of the cycles to fracture under continuous loading. The tests at 300°C were made according to the latter program only.

Figs. 3 to 5 are the graphical representations of the results tabulated in Table 1. Fig. 3 is the

Fig. 2 The program of the test with a rest and with repeated rest

diagram showing the relation between the cycles to fracture and the duration of rest (or sum of rest in the repeated pause test), both in a logarithmic scale. The results of tests without rest (continuous loading) are illustrated by the open circles on the abscissa. The results are composed of three groups, i.e. those for strain amplitudes of $\epsilon_a = 16.0 \times 10^{-4}$, 14.5×10^{-4} and 13.5×10^{-4} , respectively. The broken lines in the figure indicate the maximum and minimum of the results under continuous loading. As seen in this figure, the results for the tests with rest lie in the scatter band of the results for continuous loading. In the case of the strain amplitude $\epsilon_a = 14.5 \times 10^{-4}$, a slight influence of rest on the decrease of fatigue life seems to exist. However, this statement is not conclusive because the scatter band for this amplitude would be wider than that shown in the figure, if the wider scatter bands in other strain amplitudes were taken into consideration. Fig. 4 is a representation of the results in Table 2 as ϵ_a - N diagram. In this figure, only the maximum and the minimum values of each of the three groups of test results, i.e. the results of the continuous tests, of the tests with a rest and of the repeated pause test, are presented. The broken lines indicate the limiting values of all of these test results. From this figure it may be stated that the influence of rest on the fatigue life is little at 450°C.

Fig. 5 is the ϵ_a - N diagram for the results at 300°C. In this figure, the number of cycles to fracture in the repeated pause test seems to be

Fig. 3 Relation between number of cycles to fracture and duration of rest at 450°C

somewhat larger than that under continuous loading, but the difference between them is very little. So, in this case also, as in the case of the tests at 450°C, it may be contended that rests in stress alternation little influence the fatigue strength.

5. Discussions

(1) The results at 450°C

As described in the introduction, the authors have studied the strength of material under the combined static and alternating stress on the basis of the idea that the fatigue failure is a rate process, and established formulae which agree well with the experimental results⁽³⁾⁽⁴⁾. From the analysis it is concluded that the rest in stress alternation would not influence the fatigue life. This deduction is in accordance with the test results described above and it substantiates the validity of the basic idea of the analysis. Fig. 6 shows the distributions of hardness numbers in the cross section of a fractured specimen in the vicinity of the fractured surface. As is apparent from the figure, the distribution of hardness numbers in both specimens, i.e. subjected to the continuous loading and the intermittent loading, respectively, is not appreciably different from that of the annealed material. The results may be regarded to show that the structure of the material does not vary much during the test, and this is in accordance with the authors' opinion that the above analysis is valid at least in the case of the material with a stable structure.

(2) The results at 300°C

In the tests conducted to study the influence of frequency on the fatigue properties of a low carbon steel at 300°C, the authors have found the fact that the higher frequency resulted in less cycles to fracture for a definite strain amplitude and they interpreted this as caused by the strain aging⁽⁷⁾⁽⁸⁾ due to the anchoring of dislocations by solute atoms. According to the idea, the hardness of a material subjected to alternating stress in this range of temperatures would be expected to increase owing to the interaction between solute atoms and dislocations, since the number of dislocations is increased by plastic deformation. Fig. 7 is the distribution of hardness numbers after the test at 300°C. Contrary to the results of tests at 450°C, the hardness in this case is appreciably higher than that of an annealed material. With the increase of hardness the fatigue strength also increases, and it has been found that the peak of fatigue strength appears around the temperature of 300°C⁽⁷⁾. As any

Fig. 4 ϵ_a - N Diagram for the temperature of 450°C

Fig. 5 ϵ_a - N diagram for the temperature of 300°C

Fig. 6 Distribution of hardness in the specimen fractured at 450°C

difference is not found between the tests with and without rest, the slight strengthening effect of rest seen in Fig. 4 can not be attributed directly to the strain age hardening of material, but it is likely that the strengthening effect has some relation to strain aging.

In all the tests conducted, the temperatures

during rests were maintained at a constant value. As the change in the test material, if any, would be greater at the higher temperatures, the influence of rest in the case with temperature decrease during rest would be still smaller than that found in this study.

6. Conclusion

Experiments were carried out with a 0.15 percent carbon steel to study the influence of rest in stress alternation on the fatigue properties at elevated temperatures. The test temperatures were 450 and 300°C, and the frequency of alternating stress was 1500 c.p.m. The tests were conducted under the condition of constant strain amplitudes. It was found from the test results that the influence of rest on the fatigue strength is small and is practically negligible. This result is in accordance with the idea of the authors which has been used in analysing the dynamic creep rupture.

The results reported here are of an annealed low carbon steel, and those of other materials are needed. It is planned to carry out the studies especially with heat resistant materials of precipitation hardening type with special reference to the relation with dynamic creep and rupture characteristics.

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Fig. 7 Distribution of hardness in the specimen fractured at 300°C

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