SOME RESULTS OF LOW CYCLE FATIGUE ON BOILER STEEL

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This paper is concerned with low cycle fatigue studies of a steel used for boilers and pressure vessels. The material is a low carbon, high manganese and low chromium steel. The results show that only a few grains undergo elastic deformation and that most grains deform plastically.

INTRODUCTION

The resistance of alloys to thermal and mechanical low cycle fatigue is one of the most important problems to be elucidated in order to promote further development of chemical reactors and power generating plants. For a better understanding of the properties of fatigue resistance of alloys Ivanova et al. (1), Ginsztler (2) and Ivanova et al. (3) studied the kinetics of fatigue crack propagation in some boiler steels, during different stages of the crack propagation process. In order to prevent the catastrophic failures of boiler plant because of unknown material properties, the critical crack length values were determined. Further studies in this field were directed toward high temperature cyclic crack growth resistance, being performed by Makhutov and Romanov (4) where deformation criteria were adopted relating to crack growth rate having a maximum strain level at the maximum crack opening displacement (COD), and minimal strain values at minimum COD.

The purpose of the work presented here was to study the low cycle fatigue behaviour of a boiler steel, being subjected to prior plastic deformation, first at room temperature and later at higher temperatures. This work presents part of a broader research program (5), (6).

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EXPERIMENTAL PROCEDURE

A carbon-manganese steel was chosen for this investigation. The chemical composition is given in table 1.

TABLE 1 - Chemical composition of the steel.

C %	Si %	Mn %	P %	S %	Cr %	Mo %
0.21	0.016	0.81	0.025	0.031	0.087	0.10

The material tested was a 17 Mn 4 steel in accordance to German DIN Standards Stoff Nr. 0916 except for carbon, silicon and manganese for which the DIN Standards prescribe carbon values to be between 0.14% and 0.20%, for silicon between 0.20% and 0.40% and finally for manganese to be between 0.90% and 1.20%. The differences in chemical composition can be tolerated, because we investigated steel killed with silicon, and for this steel the differences in chemical composition may lie in the order of 10.0%.

The specimens prepared for testing were machined from plates, having a thickness of 30.0 mm and the material was cut in a direction, which was transverse to the direction of rolling. The gage lengths were polished carefully after machining in order to minimize possible surface defects, which could possibly influence mechanical behaviour.

The results of tensile tests, being measured in accordance with the German Standard DIN 17155, are shown in table 2.

TABLE 2 - Uniaxial tensile data.

yield strength [MPa]	ultimate strength [MPa]
390	470.0

Charpy impact values were also determined and values of 41.0 and 43.5 Joules were obtained.

The results of uniaxial tensile data is in accordance with the results of metallographic structure determinations.

The metallographic structure was of a very fine grained ferrite-pearlite showing no banding. The results of quantitative determinations of the structure of the steel investigated showed 72% of ferrite and 28% of pearlite, thus showing that no heat treatment procedure was adopted. As far as non-metallic inclusions are concerned the results of metallographic structure investigations showed inclusions of manganese silicate and manganese sulphide.

Strain controlled low cycle fatigue tests were carried out on an INSTRON 1255 machine. The amplitude of alternating strain is shown in table 3. Cylindrical samples of 10 mm diameter and 100 mm length were used. The sample length was selected to suit the available extensometer for dynamic testing. The maximum amplitude of elongation was limited to ± 1.0% when slight buckling of samples was observed. Two frequencies were used namely 0.1 Hz and 0.5 Hz. As a rule, the first hundred cycles and all direct recording of hysteresis loop were carried out at the low frequency otherwise the higher frequency was used up to fracture.

EXPERIMENTAL RESULTS

During each test complete cyclic stress strain loops were recorded. Only stabilized values as shown in figure 1 were analysed.

Resistance of the tested steel to strain cycling is described as the summation of plastic and elastic components following Morrow's equation (7):

$$\varepsilon_a = \varepsilon_{a,pl} + \varepsilon_{a,e} = \varepsilon_f \, (2N_f)^c + \frac{\sigma_f}{E} \, (2N_f)^b \qquad (1)$$

The results of these investigations can be presented in a diagram, schematically presented in figure 2. Numerical results are shown in figure 3.

Analysis of the results shows that elastic strain measurements showed practically identical values with a small increase in the direction of lower number of cycles to failure. However, plastic strains always show an increase in the direction of lower number of cycles to failure.

From table 3 it can be observed that there exists good agreement between the measured and calculated elastic strain data.

TABLE 3 - Measured results of elastic and plastic resistance and calculated results of elastic strain.

strain amplitude	cycles to failure	force amplitude	stress	measured plastic strain	measured elastic strain	calculated elastic strain
$\pm \varepsilon_a$	N_f	$\pm P$	σ	$\sigma_{a,pl}$	$\varepsilon_{a,e}$	$\varepsilon_{a,e}$
-	-	[kN]	[MPa]	-	-	-
0.4	2766	23	292	0.26	0.14	0.146
0.5	1462	25	318	0.36	0.14	0.159
0.6	871	26	331	0.47	0.13	0.165
0.8	706	26.5	337	0.62	0.18	0.168
1.0	581	30.5	388	0.79	0.21	0.193
1.2	256	31.0	394	1.03	0.17	0.197

From the P-Δ curves which are not shown here, the initiation of crack and crack growth could be followed. These curves will be used as an additional method of crack initiation and crack growth measurement together with other standard methods of crack measurement.

The strain-life relationship for the investigated steel is shown in figure 3 and shows more clearly the small increase and relatively small values of elastic strain and a more definitive increase in plastic strain in the direction of low number of cycles to failure.

CONCLUSIONS

Low cycle fatigue investigations were performed on a boiler steel. The results showed that only a few grains exhibit elastic deformation and that most grains deform plastically.

The results presented here show only a small part of a larger investigation in the field of low cycle fatigue, where further investigations will be devoted to the low cycle fatigue behaviour at higher temperatures. During these investigations also the crack initiation and propagation will be studied.

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SYMBOLS USED

ε = strain

$\varepsilon_{a,e}$ = elastic strain

$\varepsilon_{a,p}$ = plastic strain

σ = stress

$\Delta\sigma$ = stress range

ε_f, c } = cyclic material properties
σ_f, b

E = Young's modulus of elasticity

N_F = cycles to failure

$2N_f$ = number of reversals to failure

σ_u = ultimate tensile strength

σ_y = yield stress under uniaxial tension

F = cyclic frequency

N = cycles

P = load

$\Delta\varepsilon_{a,pl}$ = plastic strain range

$\Delta\varepsilon_{a,e}$ = elastic strain range

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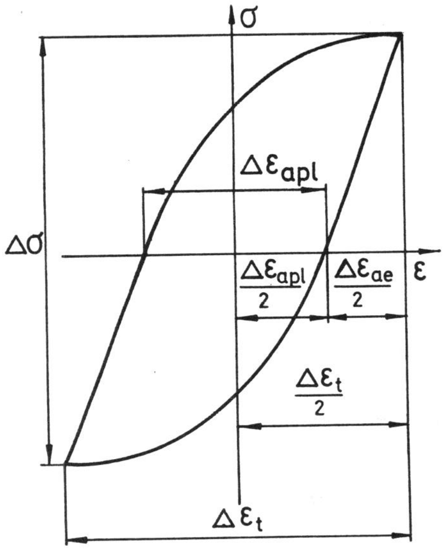

Figure 1 Schematic representation of hysteresis

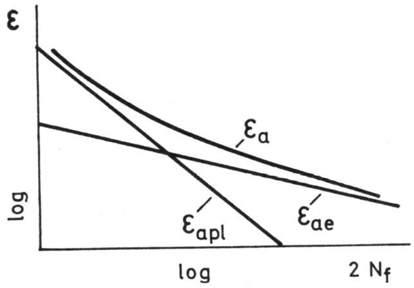

Figure 2 Strain-life relation given in equation (1)

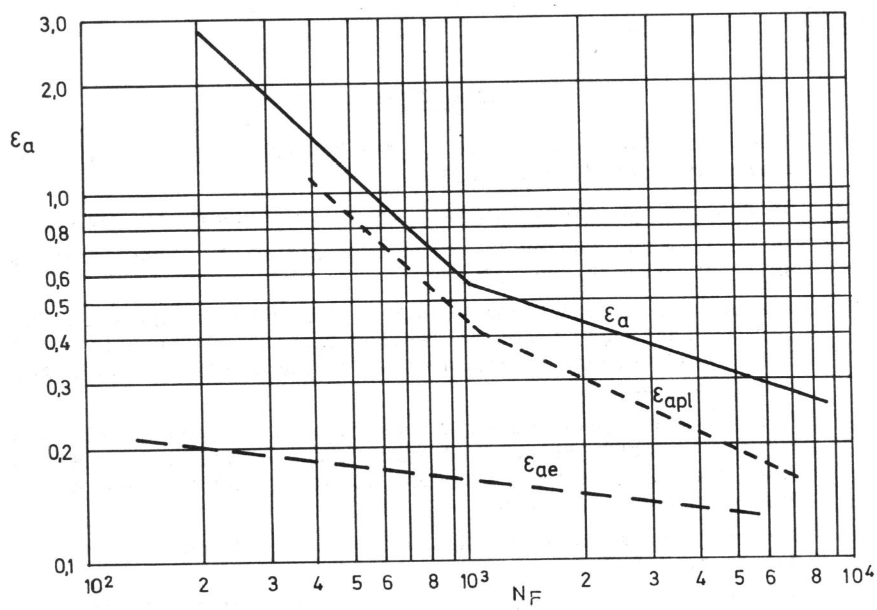

Figure 3 Strain-life relation