EFFECTS OF FREQUENCY, TEMPERATURE AND LOADING WAVEFORM ON FATIGUE CRACK GROWTH RATE IN STEEL 15Kh13MF

P. V. Yasniy, P. O. Maruschak

Department of Material Science, Ternopil Ivan Puluj State Technical University, Ternopil, Ukraine

The influences of frequency, loading cycle waveform and temperature on the crack growth resistance of steel 15Kh13MF, have been investigated. The data were analyzed using the linear and nonlinear fracture mechanic.

INTRODUCTION

Machines roll of billet continuous moulding are subjected to severe cyclic loads during service. Under these conditions fatigue creep are of major importance in determining the life of the components. Bimaterial 15Kh13MF/25Kh1M1F are widely used due to their superior high temperature properties; good fatigue and creep resistance in addition to resistance to corrosion and oxidation under severe operating conditions. Loading spectra during service includes combinations of fatigue cycles and hold times. Hence, in component life prediction knowledge of crack growth rates under frequencies ranging from 0.1 to 0.01 Hz and hold time at different temperatures is required.

MATERIAL

The tests were carried out on bimaterial single edge notch tension specimens made of steels 15Kh13MF/25Kh1M1F (Fig 1), and cut out from the machine roll of billet continuous moulding, produced by the centrifugal moulding. Specimens were tested under cyclic tension, the crack growth being perpendicular up to the bimaterial interface.

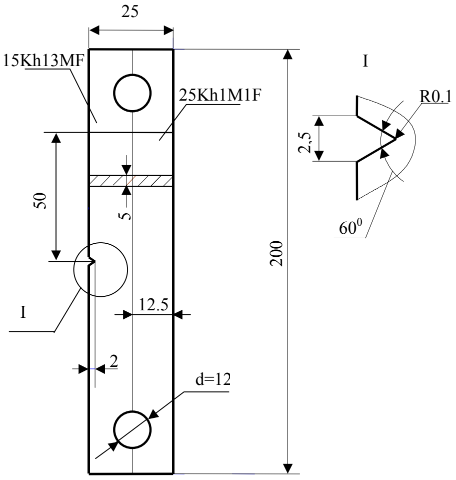


Fig. 1 Geometry and dimensions of test specimens (mm).

Table 1. Tensile properties of tested materials

Material	**Temperature ^{0}C**	**Yield strength (MPa)**	**Ultimate strength (MPa)**	**Elongation %**	**Reduction of area %**
15Kh13MF	20	338	456	6.0	4.80
	375	467	262	12.7	15.5
	600	242	334	24.2	56.6
25Kh1M1F	20	509	718	21.7	47.6
	375	431	582	21.5	48.5
	600	321	369	21.0	64.5

EXPERIMENT

The effects of frequency on fatigue crack growth (FCG) rate have been studied in steel 15Kh13MF. Fracture mode and FCG rate were studied at frequencies ranging from 0.1 to 0.01 Hz using a balanced triangular waveform. Fatigue testing was performed using a servo-hydraulic machine equipped with a micro-console and a data acquisition system. Tests were carried out under constant applied load, i.e. increasing ΔK as the crack growth, with and without hold-time, with a stress ratio R=0. An electric furnace chamber was used to achieve heating of the central part of the specimen at a uniform temperature of 375 and 600 ^{0}C. The temperature was controled by the Chromel-alumel thermocouple. A heat resistant glass window was designed to make possible video camera observations on the surface of the illuminated by a high intensity spotlight. Hold time of 10 s was performed at the maximum tensile stress giving trapezoidal waveform of frequency 0.1 Hz.

Crack lengths were monitored using optical microscope. Before commencement of high temperature testing, specimens were pre-cracked at room temperature using a 25 Hz triangular wave at an R = 0.1 to ensure subsequent crack growth during high temperature testing begins from a microscopically sharp crack away from any machining effects of the notch.

FCG rate in bimetal was described according to Paris equation:

$$\left(\frac{da}{dN}\right)_F = C\Delta K_{bi}{}^{m} \qquad (1)$$

here ΔK_{bi}- stress intensity factor (SIF) range [1];

FCG rate at high temperature was calculated using J – integral range ΔJ_f according to [2]

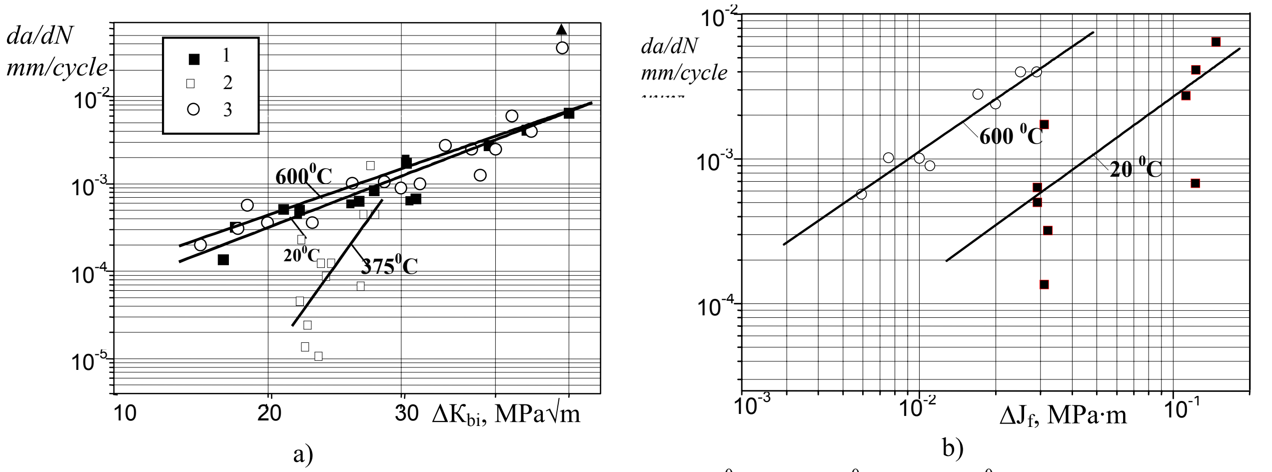
$$\frac{da}{dN} = C_I\left(\Delta J_f\right)^n \tag{3}$$

Here C_1, n, C and m-material parameters depending on the mechanical properties – coefficient and index of the power correspondenly

The experimental procedure has been described in detail in a previous paper [2]. Only a brief description is given here.

RESULTS AND DISCUSSION

In Fig.2. dependencies of the FCG rate on the SIF range at different temperatures are built. Analysis of the dependencies shows that at +20 ^{0}C, +600 ^{0}C experimental points match well in scattering area. Decrease of fatigue crack growth rate was noticed at +375 ^{0}C, for ΔK_{bi}<28,6 MPa√m.



a) b)

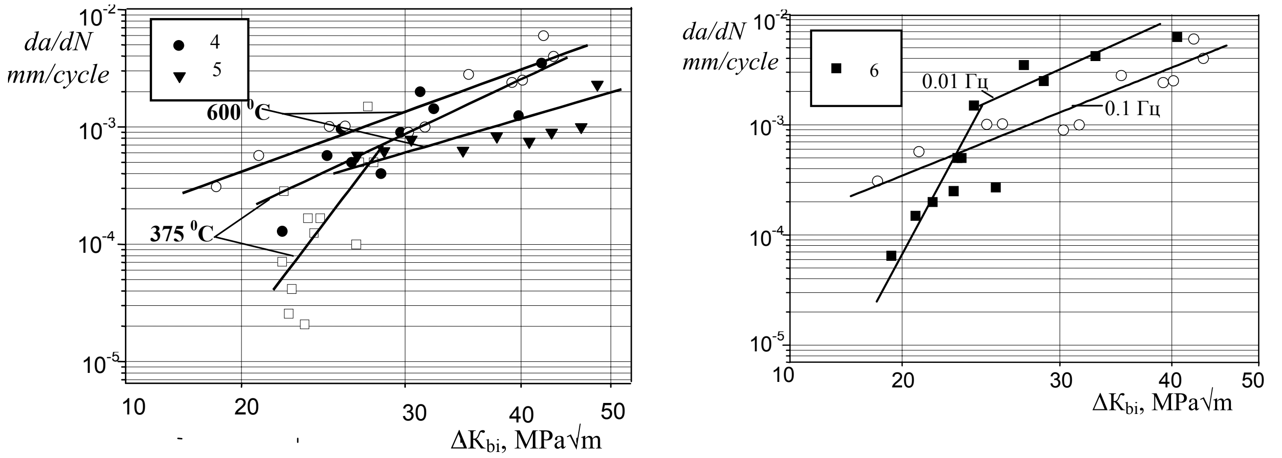
Fig.2 Dependence of the FCG rate in the bimetal specimen at +20 ^{0}C(1), +375^{0}C(2), +600 ^{0}C (3) on the SIF range (a) and the fatigue J_f-integral (b).

SIF range ΔK_{bi} is known to be used for the description of the FCG rate with the sufficient accuracy only when the size of the plastic zone at the crack tip is small.

That is why in order to describe FCG rate of non-linear fracture mechanics J_f- integral range was used. ΔJ_f- integral was calculated according to the technique [2] using the program "Fatigue". Dependencies of the FCGR on the temperature in da/dN-ΔJ_f coordinates are presented in Fig. 2b.

According to the data presented in Fig. 2b, FCG rate increases in 6 times when the testing temperature increases from +20 ^{0}C till +600 ^{0}C.

Crack growth rate under trapezoidal cycle form at +375 ^{0}C increases, at +600 ^{0}C FCG rate increases in 2-3 times (Fig. 3a).



a) **b)**

Fig. 3. Dependences of the FCGR on the SIF range ΔK_{bi}. under tempering 0 sec (1,2) and 10 sec (3,4); b) at frequency 0,1 Hz and 0,01 Hz (6)

The decrease of the loading frequency from 0,1 to 0,01 Hz causes the decrease of the FCG rate for ΔK_{bi}<26…28 MPa√m (Fig. 3).

When SIF range increases, the testing frequency influence decreases. The influence of the testing frequency at $\Delta K_{bi}\approx$26,6MPa√m is not available.

While testing the crack opening displacement as well as the photography of the crack at the bimaterial interface. were carried out.

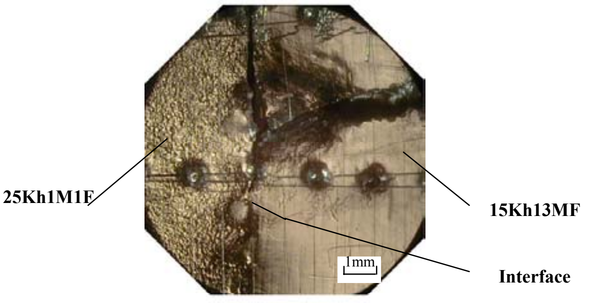


Fig. 4 Optical micrographs showing the bifurcation of the crack in steel 15Kh13MF, T=20 ^{0}C, ΔK_{bi}=55 MPa √m

For all experiments decrease of the crack growth rate before bimaterial interface was obtained. but it did not grow in steel 25Kh1M1F.

Table 2. Constant values used in formulae (1-2) for description of fatigue crack growth rate in 15Kh13MF steel.

Steel	t_h, s	T, ^{0}C	f, Hz	Fracture mechanics parameter			
				da/dN-ΔK_{bi} equat. (1)		da/dN-ΔJ_f equat. (3)	
				C, $\frac{mm/cycle}{(MPa\sqrt{m})^m}$	m	C_1, $\frac{mm/cycle}{(MPa\cdot m)^n}$	n
15Kh13MF	0	20	0.1	$2.67\cdot10^{-8}$	3.16	0.046	1.23
	0	600	0.1	$8.97\cdot10^{-8}$	2.84	0.36	1.25
	10	600		$4.93\cdot10^{-6}$	1.45		
	10	375		$2.64\cdot10^{-9}$	3.73	-	
	0	600	0.01	$5.08\cdot10^{-6}$	1.92	-	

SUMMARY AND CONCLUSIONS

Decrease of the loading frequency from 0,1 to 0,01 Hz leads to the decrease of the FCG rate at the SIF range ΔK_{bi}.<26 MPa√m.

In coordinates da/dN-ΔK_{bi} FCG rate in 15Kh13MF steel is not sensitive to the testing temperature (+20,+600^{0}C). But FCG rate increases in 5...7 times when the temperature raises from +20 ^{0}C to +600 ^{0}C depending on the crack tip opening range and the range of J-integral. Tempering causes the increase of crack growth rate at +375 ^{0}C, tempering at +600 ^{0}C causes the decrease creep-fatigue crack growth rate in 5-6 times as compared with the triangle form of loading cycle.

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