13th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2009, Hammamet, Tunisia 16-21 October, 2009

INFLUENCE OF FATIGUE LOAD WITH INTEGRITY OF WELDED JOINT ON X20 HIGH ALLOYED STEEL

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ABSTRACT
In the present paper, experimental investigations have included the effect of operating conditions (time and temperature of operation) on crack growth rate parameters of base metal and welded joint, steel X20 CrMoV 12-1 (X20). The effect of operating conditions was analysed by testing new material and material that had already been in service for 116000 hours. The results obtained and their analysis represent a practical contribution to the assessment of base metal and welded joint X20 quality, aimed at revitalisation and prolongation of service life of thermal power plants components, made of high alloy steels operating at elevated temperatures.
Keywords: High alloyed steel X20, crack growth rate parameters fatigue threshold.

1. INTRODUCTION

Some components of process equipment in thermal power plants, operating at elevated temperatures, are critical due to service conditions, particularly after long service period, exceeding the accepted nominal service life. Experienced failures of these components endangered not only human lives and safe operation of a plant, but affected the environment, too. In order to identify the quality and reliability of the material exposed to the effects of elevated temperatures in thermal power plants, mechanical properties of X20 steel were tested. This and similar steels of different manufacturers are largely built into steam lines of thermal plants of Electric Power Industry of ex. Yugoslavia country [1].
The effect of operating conditions (operating time and temperature) on crack growth rate parameters of base metal and welded joint, steel X20 CrMoV 12-1 (X20), designed for vital components of thermal power plant - steam lines has been analysed by testing new material and material after service of 116000 hours.

2. MATERIAL

For assessment of the effect of operating time and temperature on crack growth rate parameters of base metal and welded joint, steel X20 CrMoV 12-1 (X20), samples of new welded pipe (N) and a welded pipe that had been in service for approx. 116000 hours (U) were available. Both samples were the pipes ∅450 x 50 mm. Chemical compositions of tested pipes are given in Table 1 [2]. Chemical composition of wire CM2-1G, and electrode FOX20MVW according to certificates is given in Table 2. Mechanical properties according to certificates are given in Table 3 [2].

Table 1: Chemical composition of tested pipe samples [2]

Charge No.	**Chemical composition, mass %**								
	C	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**V**
N	0,21	0,27	0,563	0,017	0,006	11,70	1,019	0,601	0,310
U	0,22	0,31	0,539	0.019	0,005	11,36	1,033	0,551	0,314

Table 2. Chemical composition of filler metal [2]

Filler metal	Chemical composition, mass %								
	C	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**V**
CM2-1G	0,19	0,35	0,69	0,011	0,005	10,43	0,94	0,60	0,27
FOX20MVW	0,20	0,39	0,77	0.014	0,005	10,75	0,88	0,55	0,29

Table 3. Mechanical properties of filler metal [2]

Filler metal	Yield stress $R_{p0,2}$, MPa	Tensile strength, R_m, MPa	Elongation A, %	Impact energy, KV, J		
				20°C	545°C	570°C
CM2-1G	> 510	580 – 710	>14		> 47	> 47
FOX20MVW	> 510	560 –630	22 - 30			> 47

3. TEST RESULTS AND ANALYSIS

If a structural component is continuously exposed to variable loads, fatigue crack may initiate and propagate from severe stress raisers if the stress intensity factor range at fatigue threshold, ΔK_{th}, is exceeded. A basic contribution of fracture mechanics in fatigue analysis is the division of fracture process to crack initiation period and the growth period to critical size for fast fracture. The total number of cycles to fracture, N_u, is divided into number of cycles for fatigue crack initiation, N_i, and for its growth to the value critical for fracture, N_p: ($N_u = N_i + N_p$)

The development in the research of material behaviour for variable loading is achieved applying experimental and theoretical approaches. The analysis of stress and strain state at growing fatigue crack tip by applying linear elastic fracture mechanics (LEFM) enabled to develop the Paris equation for metals and alloys, which relates fatigue crack growth rate *da/dN* to stress intensity factor range ΔK through coefficient *C* and exponent *m* [3]:

$$\frac{da}{dN} = C\left(\Delta K\right)^m \tag{1}$$

The standard ASTM E647 [4] defines the testing of pre-cracked specimen for fatigue crack growth rate measurement, *da/dN*, and for the calculation of the stress intensity factor range, ΔK. Two basic requirements in ASTM E647 are: the crack growth rate should be above 10^{-8} m/cycle to avoid fatigue threshold region and load should be of constant amplitude.

Standard Charpy size specimen, fatigue pre-cracked in different welded joint constituents, and instrumented by foil RUMUL RMF A-5, of measuring length 5 mm (Fig. 1), for continuous monitoring of crack length, were tested at room temperature under variable loading for the determination of fatigue crack growth rate, *da/dN*, and stress-intensity factor range at fatigue threshold, ΔK_{th}. The testing was performed in load control, by three-points bending on the FRACTOMAT high-frequency resonant pulsator.

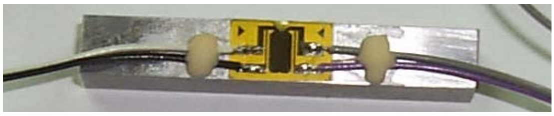

Figure 1. Charpy specimen instrumented by foil RUMUL RMF A-5 for continuous monitoring of crack length

CT specimens were tested on working temperature, since at 545°C and 570°C the measuring foils can not be used, and load line displacement is measured instead. The relations *da/dN* - ΔK are presented in

Fig. 2 for the specimens pre-cracked in the parent metal (PM), in Fig. 3 for specimens pre-cracked in the weld metal (WM) and in Fig. 4 for specimens pre-cracked in the heat-affected-zone (HAZ).

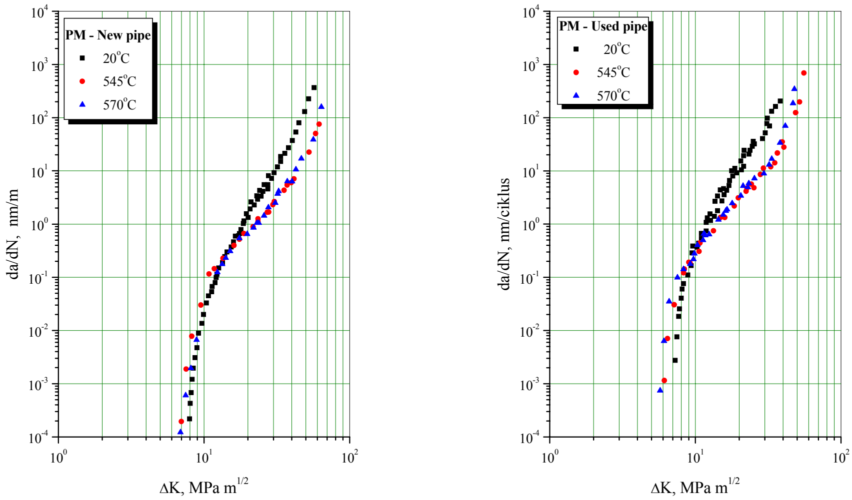

Figure 2. Fatigue crack growth rate per cycle, da/dN, vs. stress intensity factor range, ΔK, specimens pre-cracked in parent metal [2]

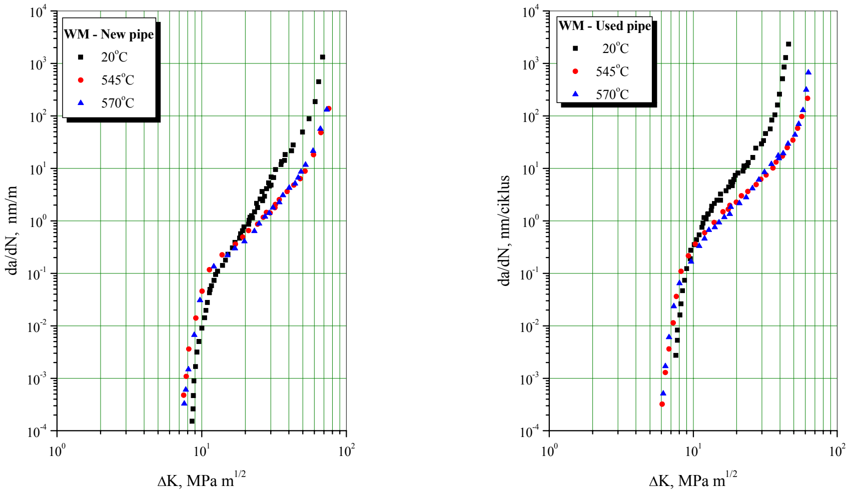

Figure 3. Fatigue crack growth rate per cycle, da/dN, vs. stress intensity factor range, ΔK, specimens pre-cracked in weld metal [2]

The dominant almost linear middle part of curve in Figs. 2-4 is covered by Paris law and is practically most important, since it allows to define the difference between fatigue crack low growth rates (initiation) close to fatigue threshold, and high rates (K_{Ic}), when fracture occurs. The application of Paris equation is very convenient for fatigue of structures produced of materials of elevated and high strength. The position of the fatigue crack-tip and the testing temperature significantly affect the ΔK_{th} values and the fatigue-crack growth [5,6]. The behaviour of welded joint and its constituents should affect the change of curve slope in validity part of Paris law. Materials of lower fatigue-crack growth rate have lower slope in the diagram *da/dN\ vs. ΔK* [6]. Slow growth is confirmed for specimens cracked in BM and WM, since for the same growth rate, greater factor intensity range is required. The maximum fatigue crack growth rate is expected when stress intensity factor range approaches to plane strain fracture toughness, when brittle fracture is possible.

In spite of significant differences in fatigue-crack growth rate, the obtained values are still low and acceptable. That means that tested steel and its welded joint exhibited acceptable level of fatigue-crack growth resistance and can be successfully applied for variable loading in case of detected crack-like defects, primarily for low-cycle fatigue [6,7].

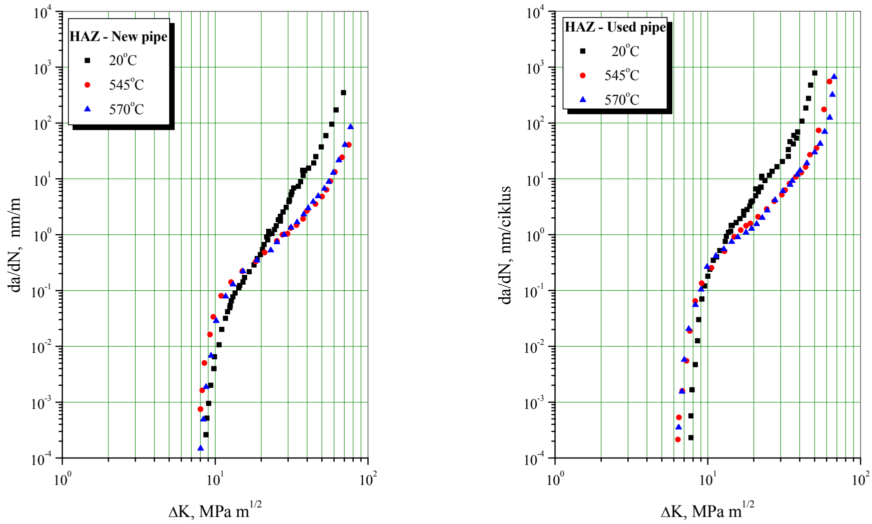

Figure 4. Fatigue crack growth rate per cycle, da/dN, vs. stress intensity factor range, ΔK, specimens pre-cracked in heat-affected-zone [2]

4. CONCLUSIONS

The following conclusions were derived:

- Notch location and crack initiation, as well as testing temperature affect values of fatigue threshold ΔK_{th} and fatigue crack growth parameters.
- The minimum fatigue-crack growth rate exhibited the specimens pre-cracked in BM, and the maximum fatigue crack-growth rate in specimens pre-cracked in HAZ. This is directly connected to the effects that microstructural heterogeneity in HAZ regions has on fatigue-crack growth rate, *da/dN*.
- Specimens of welded joint constituents at working temperature (545°C and 570°C) exhibited two to four-fold higher crack-growth rates when compared to room temperature under variable loads in tests of the fatigue threshold and fatigue crack growth parameters that this is explained by reduced material properties at elevated temperature.

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