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ESTIMATION OF CRACK GROWTH PARAMETERS IN SURFACE WELDED LAYER

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ABSTRACT
Rails, which are produced of high-carbon steel, in exploatation are exposed to complex stress state and complicated degradation mechanisms, such as wear and rolling contact fatigue. Surface welding is maintenance way to prolong exploitation life of damaged parts. Having on mind cyclic loading of rails, fatigue behavior of all parts of welded joints have to be tested. Under applied repeated loading, small crack will propagate up to critical size. For that, knowledge of the crack growth rate is imperative to be computed and it is possible to estimate number of cycles to critical crack size. In this paper, by estimation of crack growth rate da/dN and fatigue treshold value ΔK_{th} in each zone of welded joint, it is shown than deposite layer has higher resistance to the crack growth compare to base metal, so becomes desirable area of future crack initiation.
Keywords: Welded joint, fatigue, crack growth rate, fatigue treshold

1. INTRODUCTION
High-carbon steels are widely used for rails and crossings due to their high hardness and strength. Anyhow, having pearlitic microstructure, these steels have typically low toughness and crack growth resistance, being prone to wear and rolling contact fatigue, which cause rails to become unfit for service due to unacceptable rail profiles, cracking, spalling and failures. Degradation of rail depends on the complicated interaction between wear mechanisms, fatigue crack initiation and growth rates, which affect rail life [1]. Damaged parts produced from high-carbon steel can be surface welded, in spite of their poor weldability. With proper choice of welding technology, it is possible to get a microstructure with improved properties, corresponding to the new steel generation, i.e. bainitic microstructure. In that case, surface welded layer has higher resistance to the crack growth, improving overall reliability of rails and crossings.

2. FATIGUE CRACK GROWTH RATE TESTING
A few different fracture control concepts are applied in railway systems, and one of them is damage tolerance concept [2]. Within the frame of this concept, the possibility of fatigue crack growth is basically accepted. The aim is to prevent the crack to grow to its critical size during the lifetime of the component, i.e. to estimate number of cycles to critical crack size. In fatigue, crack extension is expressed as a function of stress intensity range ΔK and the crack extension rate, *da/dN*, whereby *da* denotes an infinitesimal crack extension due to an infinitesimal number of loading cycles *dN*. This dependence is described by Paris law [3]:

$$\frac{da}{dN} = C \cdot (\Delta K)^m \qquad (2.1)$$

In equation 2.1 *da/dN* is the growth in crack size a per unit cycle, *N* is cycle number, C and m are constants obtained from experiments, ΔK is stress intensity factor range in the loading cycle.

Beside crack growth rate, fatigue treshold value ΔK_{th} is also important representative parameter. That value corresponds to initiation energy in impact testing and it is good value for comparation.
Most frequently, surface welding is performing in three layers, sometimes with buffer layer. The overall thickness of final layer is 6-9 mm and that is the place in rail head with maximum stress concentration during exploatation. That much complicate estimation of crack growth rate, because it is necessary to estimate crack growth rate in base metal, in HAZ and in the each layer of weld metal.

3. EXPERIMENT AND DISCUSSION

The material used in present work is pearlitic steel, received in the form of rails. It's chemical composition and mechanical properties are given in Table 1. The steel is surface welded by semi-automatic process, with self-shielded wire (FCAW-S). Surface welding is carried out in three layers. Heat input during welding was cca 10 kJ/cm and preheating temperature was 230^0C, since the CE equivalent was CE=0.64. Controlled interpass temperature was 250^0C.

Table 1. Chemical composition and mechanical properties of base metal

Chemical composition, %							Tensile strength R_m (N/mm^2)	Elongation A_c (%)
C	Si	Mn	P	S	Cu	Al		
0.52	0.39	1.06	0.042	0.038	0.011	0.006	680-830	≥14

Fatigue crack growth tests had been performed on the CRACKTRONIC dynamic testing device in FRACTOMAT system, with standard Charpy specimens, at room temperature, under the ratio R=0.1. The specimen is part of the spring/mass system and affects by its stiffness the resonant frequency. The system produces pure bending moment and measures the crack length during test, by crack-gauge of special thin metal foil with electrical tranducer, bonded on a component, Fig. 1. A standard 2 mm V notch was locate in BM (specimen No.1), and in WM and HAZ (specimen No. 2), Fig. 2, what provides estimation parameters for both zones. In both cases, crack was initiated from surface and propagated into HAZ, in accordance with previous discussion [4], enabling calculation of crack growth rate *da/dN* and fatigue treshold ΔK_{th}.

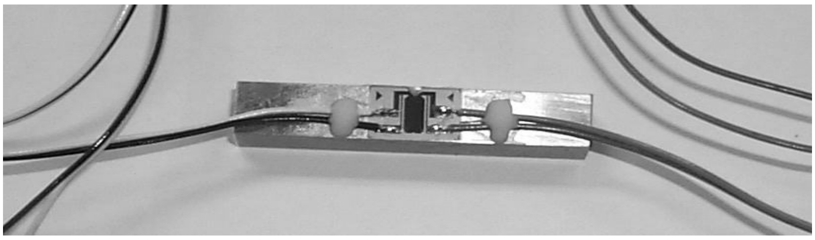

Figure 1. Prepared specimen for fatigue crack growth test

Results of crack growth resistance parameters, i.e., obtained relationship *da/dN* vs. ΔK for base metal is given in Figure 3, and for weld metal and HAZ in Figure 4. Parameters *C* and *m* in Paris law, together with fatigue threshold ΔK_{th} and crack growth rate values are given in Table 2 for base metal, surface weld metal and HAZ, as obtained from relationships given in Figures 3 and 4, respectively, for corresponding ΔK values.

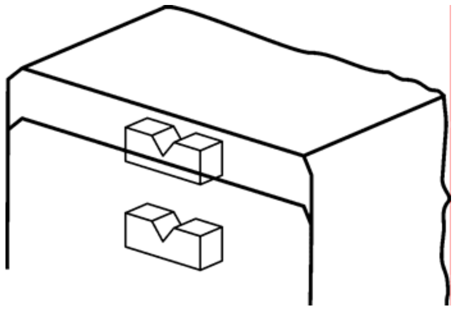

Figure 2. Specimens for estimation of crack growth rate in surface welded layer

In Figure 4 change of fatigue crack growth rate during crack propagation from WM to HAZ is clearly shown, i.e. there is obvious transition in curve slope (lower slope, lower crack growth rate in WM and higher slope, higher crack growth rate in HAZ). More precisely, because weld metal specimen consists of two layers (third layer is used for V notch), two slope changes can be seen and two values of crack grow rate have been estimated. The crack growth rate in base metal is 3-4 times higher than in both weld metal layers, i.e. the growth of initiated crack will be slower in weld metal layers. This means that for the same value of stress intensity factor rang ΔK, base metal specimen needs less number of cycles of variable amplitude than weld metal specimen, for the same crack increment [5].

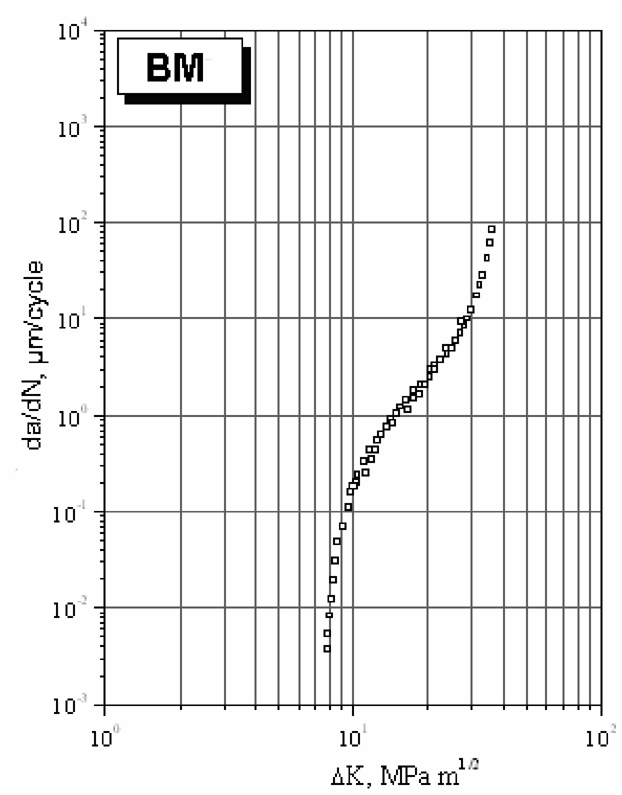

Figure 3. Diagram da/dN vs. ΔK for base metal

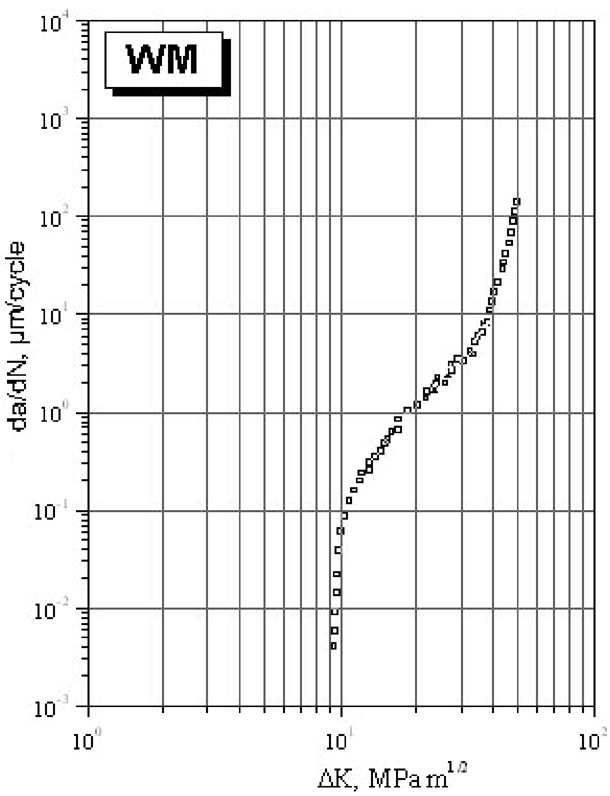

Figure 4. Diagram da/dN vs. ΔK for WM and HAZ

Beside crack growth rate, fatigue treshold value ΔK_{th} is also representative parameter for comparation. Fatigue treshold value ΔK_{th} in base metal (ΔK_{th} =8 MPa $m^{1/2}$) is lower than fatigue treshold value ΔK_{th} in weld metal (ΔK_{th} =9.5 MPa $m^{1/2}$). It means that crack in base metal will be initiated earlier, i.e. after less number of cycles, than in weld metal.

Table 2. Parameters C, m, ΔK_{th} and crack growth rate values for all zones of surface welded joints

Zone of surface welded joint	Fatigue threshold ΔK_{th}, MPa $m^{1/2}$	Parameter C	Parameter m	Crack growth rate da/dN, m/cycle			
				ΔK = 10 MPa $m^{1/2}$	ΔK=15 MPa $m^{1/2}$	ΔK=20 MPa $m^{1/2}$	ΔK=30 MPa $m^{1/2}$
BM	8,0	$3.31 \cdot 10^{-11}$	3.28	$6.31 \cdot 10^{-08}$			
WM 1	9,5	$4.45 \cdot 10^{-13}$	3.74		$1.11 \cdot 10^{-08}$	-	-
WM 2		$3.78 \cdot 10^{-13}$	3.61		-	$1.88 \cdot 10^{-08}$	-
HAZ		$4.07 \cdot 10^{-13}$	3.79		-	-	$1,61 \cdot 10^{-07}$

4. CONCLUSIONS

Considering performed examinations the following is concluded:

1. The crack growth rate in base metal is 3-4 times higher than in both weld metal layers, i.e. the growth of initiated crack will be slower in weld metal layers. This means that for the same value of stress intensity factor rang ΔK, base metal specimen needs less number of cycles of variable amplitude than weld metal specimen, for the same crack increment.
2. Fatigue treshold value ΔK_{th} in base metal (ΔK_{th} =8 MPa $m^{1/2}$) is lower than fatigue treshold value ΔK_{th} in weld metal (ΔK_{th} =9.5 MPa $m^{1/2}$). It means that crack in base metal will be initiated earlier, i.e. after less number of cycles, than in weld metal.
3. Results show that crack will initiate more likely in base metal, and that it needs less number of cycles to reach the critical size. Contrary to a typical welded joint, surface welded layer is the safest place for crack initiation.

5. REFERENCES

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