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ROTATING-BENDING FATIGUE IN A LOW-CARBON STEEL

ZAMOR ROTACIJA-SAVIJANJE KOD NISKOUGLJENIČNOG ČELIKA

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Keywords
- crack propagation
- low-carbon low-alloyed steel
- rotation bending fatigue
- band structure

Abstract

Short crack propagation behaviour of a low-carbon low-alloyed construction steel, ROLCLAS 09G2 is investigated under stress ranges $\Delta\sigma$=500; 540; and 580 MPa and testing frequency f = 11 Hz at rotating-bending fatigue. The applied loading scheme is symmetric with a loading ratio $R = -1$. Two groups of specimens without and with a layer are tested in air. All fatigue tests are carried out on a table model Fatigue Rotating Bending Machine, FATROBEM-2004 at UCTM–Sofia, Bulgaria. Short fatigue crack growth behaviour of ROLCLAS 09G2 in-air is presented in plots "Crack lengths, a, against corresponding numbers of cycles, N", for the two groups of specimens and compared graphically and microstructurally. The specific band structure of ROLCLAS 09G2 makes it possible to use the steel as a modelling material in relation to composite materials.

Ključne reči
- rast prsline
- niskougljenični niskolegirani čelik
- zamor pri rotaciji i savijanju
- trakasta struktura

Izvod

Istraženo je ponašanje nisko ugljeničnog niskolegiranog konstrukcionog čelika ROLCLAS 09G2, pri rastu kratke prsline u uslovima zamora pri rotaciji i savijanju, sa nivoima napona $\Delta\sigma$ = 500; 540; i 580 MPa i frekvencije f = 11 Hz. Primenjena šema opterećenja je simetrična sa odnosom $R = -1$. Ispitane su dve grupe uzoraka na vazduhu, sa i bez strukturnog sloja. Zamorna ispitivanja su izvedena na ispitnom stolu mašine sa zamornim rotacionim savijanjem, FATROBEM-2004 na UCTM–Sofija, Bugarska. Ponašanje prsline sa kratkim zamornim rastom u ROLCLAS 09G2 na vazduhu je predstavljeno na dijagramima tipa „Dužina prsline, a, i odgovarajući broj ciklusa, N", za dve grupe uzoraka i upoređeno grafički i mikrostrukturno. Specifična trakasta mikrostruktura ROLCLAS 09G2 omogućava da se može upotrebiti za modeliranje i kompozitnih materijala.

INTRODUCTION

Generally, fatigue failure occurs by propagation of sub-critical cracks ranged from several microns to a few hundred microns. Those cracks are known as short cracks or small cracks whose growth takes up a large percentage from the total fatigue lifetime of components and structures, /1/. In this respect, the short crack effect and characterisation are quite critical for accurate lifetime prediction.

In the present work short fatigue crack propagation behaviour in a low-carbon low-alloyed construction steel is investigated under rotating-bending symmetric loading conditions. Experimental data are described by using a presentation "Crack lengths, *a*–cycles, N". The results for two groups of specimens without and with a layer, /2/, are compared for two constant-amplitude cyclic loads. A plastic replica technique is used for short fatigue crack growth monitoring.

EXPERIMENTAL PROCEDURE

A cold rolled low-carbon, low-alloyed steel (RLCLAS), marked as 09Mn2 Steel (according to the Bulgarian Construction Steel Standard), used mostly for offshore applications and in shipbuilding, was subjected to rotating-bending fatigue. Two groups of specimens were under investigation: specimens without layer tested under stress ranges, $\Delta\sigma$= 500; 540; and 580 MPa; and specimens with layer exposed to $\Delta\sigma$=500; 540; and 580 MPa; the applied stress ratio was $R = -1$, and the frequency $f = 11$ Hz.

The tests were carried out on a table model Fatigue Rotating-Bending Machine, FATROBEM-2004 at UCTM-Sofia, /2/, shown in Fig. 1.

The chemical composition of the steel and its mechanical characteristics are given in Table 1.

RLCLAS steel is available in sheets of 8 mm thickness. Its microstructure revealed a sequence of long and uniform pearlite and ferrite bands, as shown in Fig. 2a. The average ferrite grain size was $d = 25.6$ μm. The bands were wider in the middle of the sheet but loose and thinner close to the surface.

Both groups of specimens without and with a layer use the same shape of smooth hour-glass type specimen shown in Fig. 2b; the microstructure of the specimens with a layer, /3/, is presented in Fig. 2c. Specimen surface was properly polished according to corresponding technical standards. All experiments employed the *Method of Short Fatigue Crack Growth* and the crack propagation was monitored by surface replicas. Replicas were taken during fixed intervals of the cyclic loading and had recorded the specimen surface state and fatigue crack length. Replicas were examined later by light microscope in order to find crack initiation and propagation and to measure crack sizes.

The surface modified layer (here the specimen is subjected to 580 MPa) is produced with expectation for better weariness and longer fatigue lifetime. That is only a first attempt for fatigue testing of RLCLAS with such a layer and for modelling of the obtained experimental results. There are some investigations of tool steels with a layer produced by the same technology that show good results.

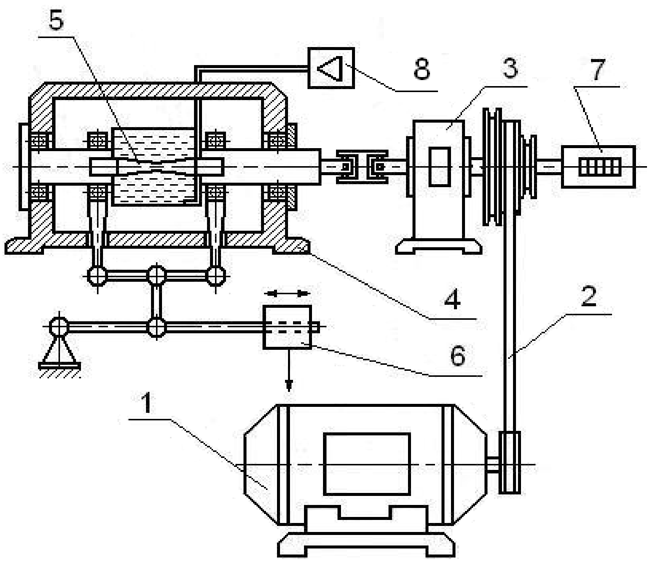

Figure 1. Table model of fatigue machine FATROBEM-2004: Schematic presentation: electric engine–1; driving belt–2; ball-bearing unit–3; testing box–4; specimen–5; device for loading–6; counter–7; device for circulation and aeration of corrosion agent–8.

Slika 1. Stoni model mašine za zamaranje FATROBEM-2004: šematski prikaz: elektromotor–1; pogonski kaiš–2; sklop kotrljajnog ležaja–3; ispitna komora–4; uzorak–5; uređaj za opterećivanje–6; brojač–7; uređaj za cirkulaciju i aeraciju korozivnog agensa–8.

Table 1. Chemical composition and mechanical properties of RLCLAS 09Mn2.
Tabela 1. Hemijski sastav i mehaničke osobine RLCLAS 09Mn2.

Chemical composition (wt. %)									
C	Si	Mn	Cr	Ni	P	S	Cu	Al	As
0.09	0.28	1.63	0.05	0.04	0.017	0.026	0.13	0.12	0.014

Mechanical properties				
Tensile strength σ_B (MPa)	Proof strength $\sigma_{0,2}$ (MPa)	Cross section contraction ψ (%)	Hardness HB	Average grain size (μm)
482	382	62.3	148	25.6

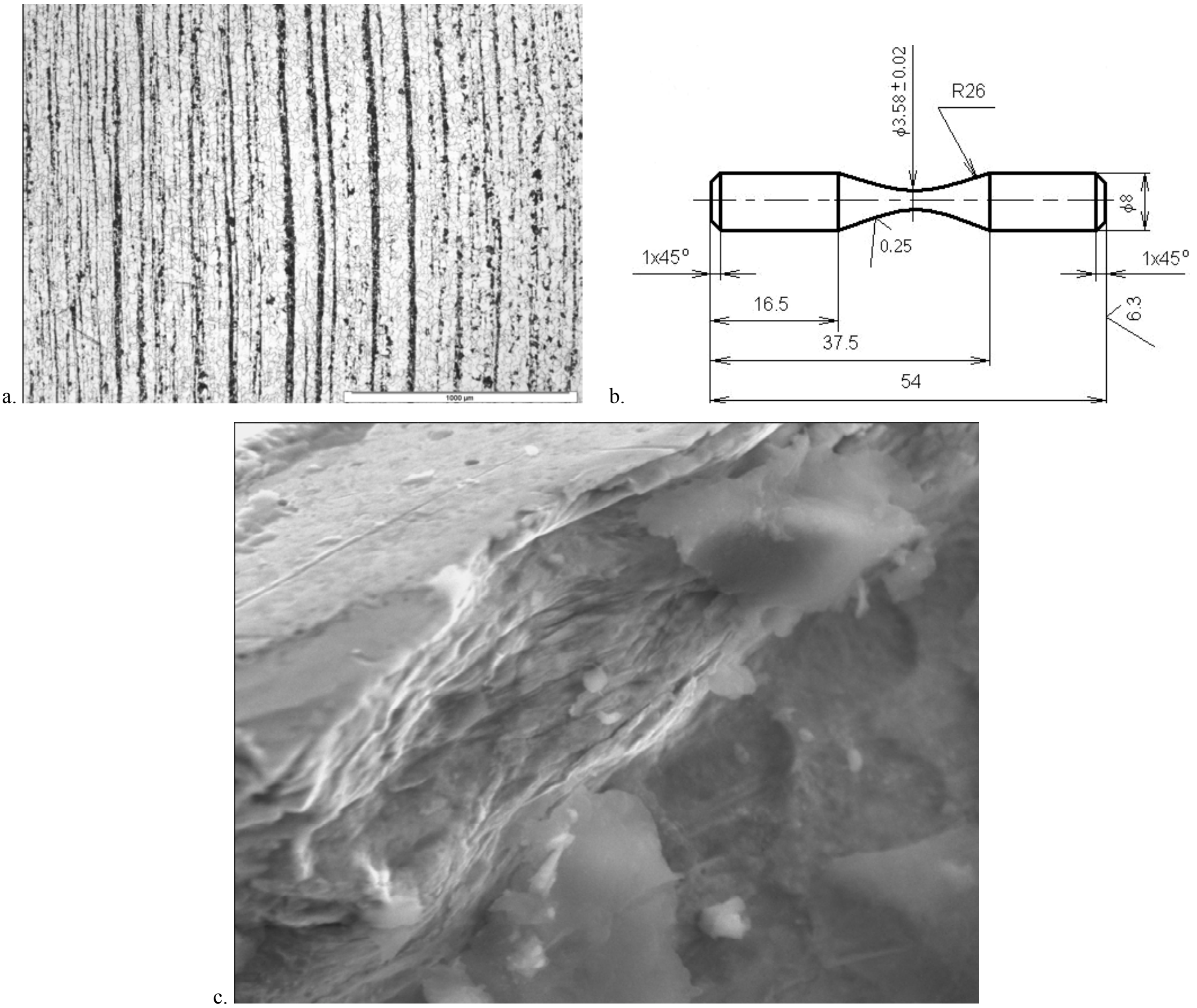

Figure 2. Microstructure of cross section of RLCLAS (a); cylindrical fatigue specimen with dimensions in mm (b); microstructure of RLCLAS with a layer (c).
Slika 2. Mikrostruktura preseka RLCLAS (a); cilindrična epruveta za ispitivanje na zamor sa dimenzijama u mm (b); mikrostruktura RLCLAS sa slojem (c).

RESULTS AND DISCUSSION

Using the well-known standard procedure for obtaining the Wohler curve of RLCLAS, /4/, has led us to results shown in Table 2 and a curve presented in Fig. 3.

Data obtained from rotating-bending fatigue: crack lengths, a (μm), and corresponding numbers of cycles, N, are plotted as “crack length, a–number of cycles, N”, and shown in Figs. 4 and 5.

Table 2. Stress ranges for plotting the Wohler curve of RLCLAS.
Tabela 2. Opseg napona za iscrtavanje Velerove krive za RLCLAS

RLCLAS, cylindrical specimens, without layer		RLCLAS, cylindrical specimens, with layer	
Stress range $\Delta\sigma$ (MPa)	Fatigue lifetimes N_f (cycles)	Stress range $\Delta\sigma$ (MPa)	Fatigue lifetimes N_f (cycles)
500	767250	500	985490
540	377080	540	300080
540	654610	580	154770
580	251656	580	280280
580	310420	620	151800
620	132990		
620	106700		
660	55550		

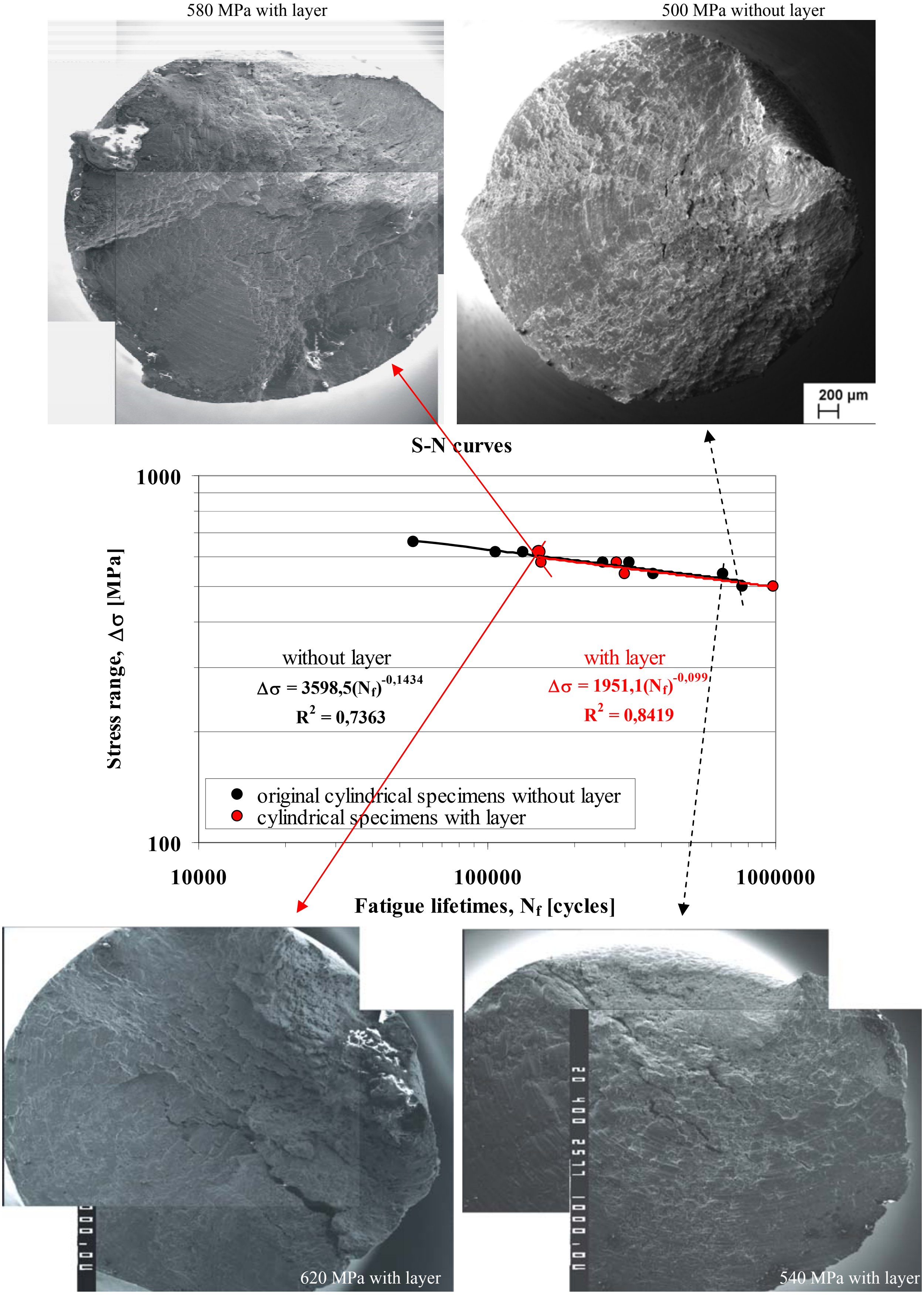

Figure 3. Wohler curve of RLCLAS with microstructure of some specimens.
Slika 3. Velerova kriva RLCLAS sa mikrostrukturom nekih uzoraka.

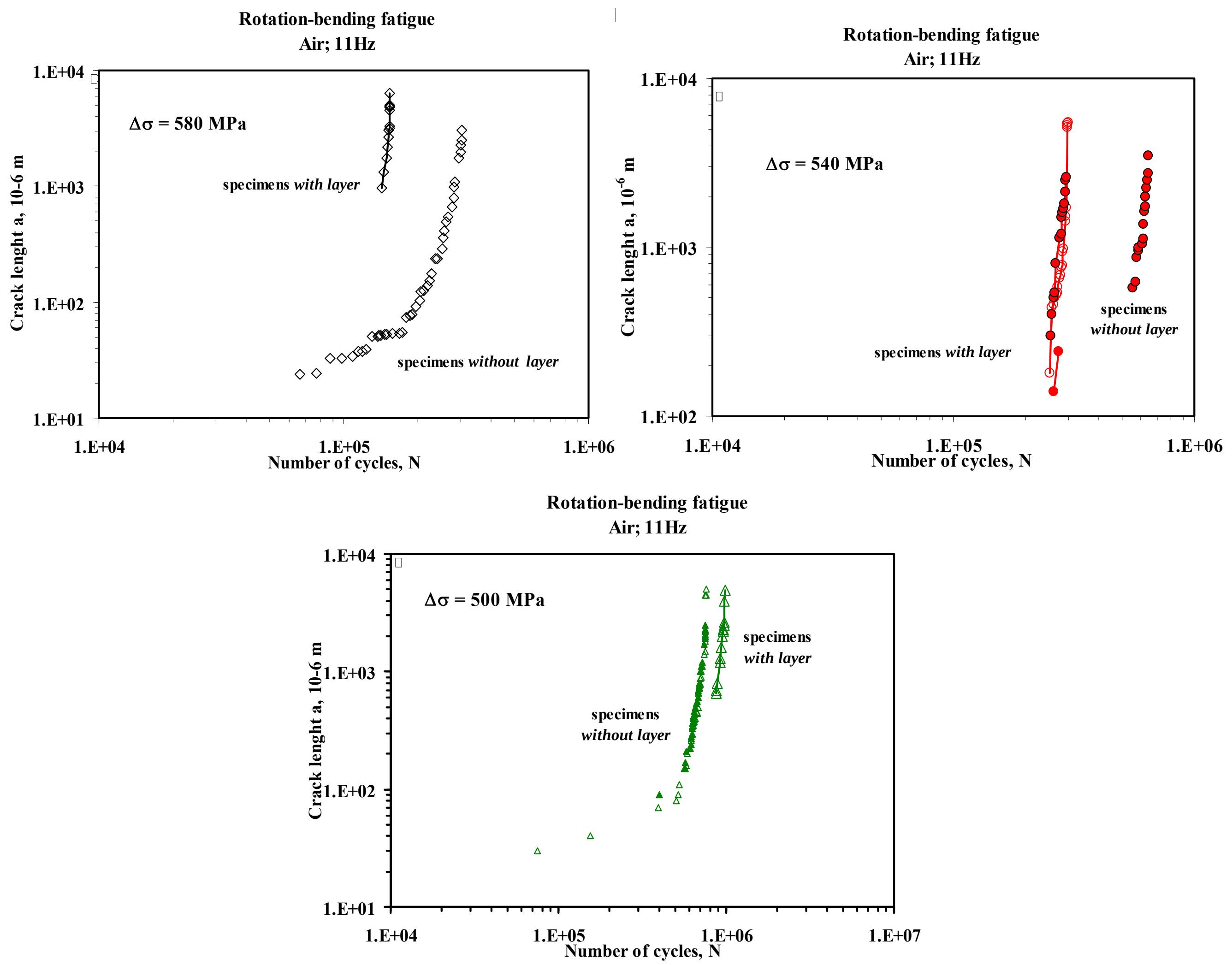

Figure 4. Plot Crack length, a–Numbers of cycles, N, at stress ranges $\Delta\sigma$= 500; 540; and 580 MPa for specimens with and without layer.
Slika 4. Dijagram dužina prsline, a–broj ciklusa, N, za napone $\Delta\sigma$= 500; 540; i 580 MPa za uzorke sa i bez sloja.

The analyses in Fig. 4 show that at the lowest range, $\Delta\sigma$= 500 MPa, the specimen with a layer have a prolonged fatigue life compared to those without a layer. Its crack has been observed late in the specimen life and has developed very quickly. At the same time under the higher ranges, 540 and 580 MPa, the picture is just the opposite – the layer facilitates failure. That fact has to be carefully investigated and proved with more experiments.

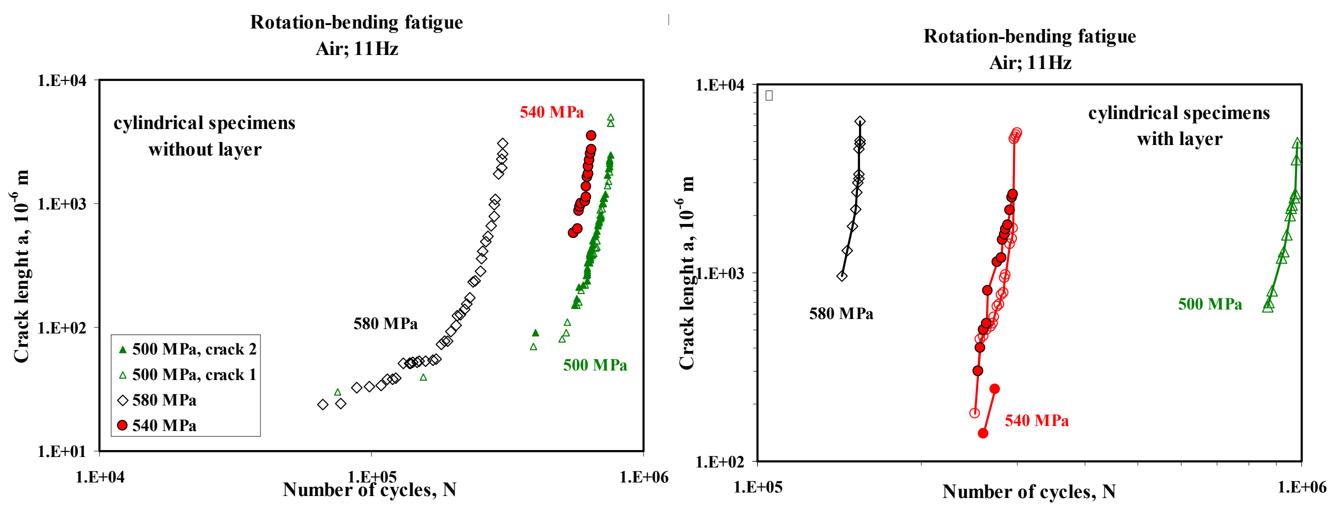

Figure 5. Plot Crack length, a–Number of cycles, N, for specimens with and without layer.
Slika 5. Dijagram dužina prsline, a–broj ciklusa, N, za uzorke sa i bez sloja.

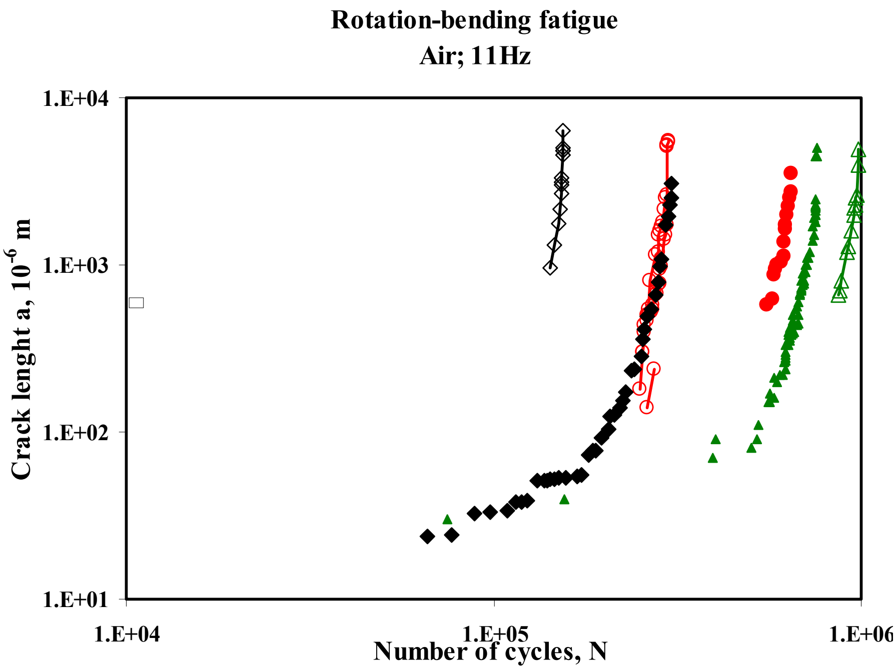

Figure 6. Comparison between specimens without layer (solid symbols) and specimens with layer (open symbols).
Slika 6. Poređenje uzoraka bez sloja (ispunjeni simboli) i uzoraka sa slojem (šupljі simboli).

Results from Figs. 5 and 6 show a classical tendency for both groups of specimens: longer fatigue time at low stress ranges. At the same time the family of crack curves for specimens without the layer forms the multitude of obtained curves, while the family of crack curves for the ones with the layer is presented by more dispersed curves. That tendency of dispersion or scatter of the results, from testing of the specimens with layer can be seen on the Wohler curve as well.

SUMMARY

Two groups of specimens of a low-carbon steel without and with a modified surface layer are subjected to rotating-bending fatigue at three different loadings. In each group the specimens tested at lower stress ranges show higher fatigue lifetimes. However, the specimens with the layer show a family of more dispersed crack-curves following the tendency of the larger scatter for the same group of specimens in comparison to the specimens without layer, as can be seen on the Wohler curve. Also the specimens with layer show shorter fatigue lifetimes than those without layers at the lowest stress range, which has to be carefully investigated and proved.

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