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MODELLING OF SHORT CRACK GROWTH IN A LOW-CARBON STEEL SUBJECTED TO ROTATION-BENDING FATIGUE, I. CRACK GROWTH DATA

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ABSTRACT

Short crack experiments are carried out under rotation-bending fatigue in a rolled low-carbon, low alloyed Bulgarian standard 09Г2 steel (RLCLAS) used for off-shore application. RLCLAS 09Г2 shows a microstructure of clearly seen alternating ferrite and perlite bands, looking like composite material structure.

The experiments include replica monitoring of short crack growth on smooth hour-glass specimens subjected to different symmetric cycling loading, and length measuring of propagating cracks. A comparison is made between the rotation-bending and pull-pull fatigue behaviour of RLCLAS 09Г2.

The conducted experiments of rotation-bending fatigue are the first experiments carried out on a table model fatigue-machine FATROBEM–2004 that is designed, constructed and assembled in the Laboratory of Plastic Deformation of the University of Chemical Technology and Metallurgy-Sofia.

Key words: Rotation-bending fatigue, Short fatigue crack growth, Table-model rotation-bending fatigue machine

INTRODUCTION

Although the enormous progress in fatigue investigations and the understanding achieved during the last years, fatigue phenomenon stays as an important problem concerning strength of metals, their life and structural integrity of engineering constructions.

Fatigue researchers use classical and new methods and develop continuously modern tools of investigations, from observations and techniques through special apparatuses to more and more precise modelling of fatigue phenomenon. One of the useful, easy for application, and informative methods of investigation is that of short fatigue crack growth monitoring of surface crack propagation from the initiation to failure in specimens with smooth finished surface, [1,2]. Experience shows that a large part of fatigue lifetime is taken by the regime of short crack growth. Also that short cracks are much more influenced by microstructure than long ones. This influence is clearly expressed in retardation of short crack propagation as a result of consequent interactions between the elements of microstructure and propagating cracks [3, 4, 5, 6]. It is most common to present fatigue data obtained by crack length in function of cycles.

In the present study we use the Method of Short Fatigue Crack Growth Monitoring for investigating fatigue phenomenon in a low-carbon steel for off-shore applications, which is subjected to rotation-bending on a newly constructed table model fatigue-machine FATROBEM–2004. We compare these results to the results obtained previously under pull-pull fatigue in the same steel.

EXPERIMENTAL

The steel under investigation is a rolled low-carbon, low alloyed steel (RLCLAS), marked as 09Г2 according to the Bulgarian Construction Steel Standard, mostly used for off-shore applications and in shipbuilding. The chemical composition of RLCLAS 09Г2 steel is shown in Table 1 and its mechanical properties – in Table 2. The average grain size is d=25,6 μm.

Table 1. Chemical composition of 09Г2 steel

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

Table 2. Mechanical properties of 09Г2 steel

σ_B, MPa	$\sigma_{0,2}$, MPa	ψ, %	HB, MPa
482	382	62.3	148

The experiments are carried out on a table model fatigue machine for rotation-bending FATROBEM–2004, newly designed constructed and assembled in the Laboratory of Plastic Deformation of the University of Chemical Technology and Metallurgy-Sofia. The machine is shown on Fig. 1 and described in details in [7]. This is the first set of experiments carried out on FATROBEM–2004, conducted in air under symmetric rotation-bending (R-B), R = -1, at different cyclic frequency and loading conditions, Table 3. The rotation-bending data are compared to pull-pull data obtained from previous in-air testing of asymmetric pull-pull fatigue (P-P), R = 0,1, Table 4, [8]. Both kinds of fatigue use the same specimens of smooth hour-glass type with surface properly polished according to the corresponding technical standards. All experiments involve the Short Fatigue Crack Growth Method monitoring crack propagation by surface replicas. The replicas are taken during fixed intervals of cyclic loading, which record the surface specimen's state and fatigue crack length, all this examining later by light microscope in order to find crack initiation and propagation and to measure crack sizes.

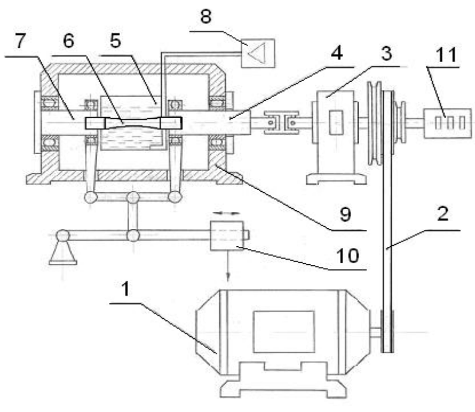

Fig. 1. Test apparatus scheme: electric engine 1, driving belt 2, ball-bearing unit 3, leading shaft 4, corrosion box 5, specimen 6, leaded shaft 7, device for circulation and aeration of corrosion agent 8, working box 9, device for loading and load changing 10, counter 11.

Table 3. Experimental conditions at R-B

Specimen number	Stress range Δσ, MPa	Frequency f, Hz
1	620	11
2	620	11
3	580	11
4	620	6,6

Table 4. Experimental conditions at P-P

Specimen number	Stress range Δσ, MPa	Frequency f, Hz
1	387	190
2	396	190
3	405	190

RESULTS AND DISCUSSION

Data obtained from both kind of fatigue – crack lengths *a*, μm and the corresponding numbers of cycles *N*, cycles – are plotted as functions "Crack length, *a* -number of cycles, *N*" and shown in Fig. 2 for R-B fatigue and in Fig. 3 for P-P fatigue.

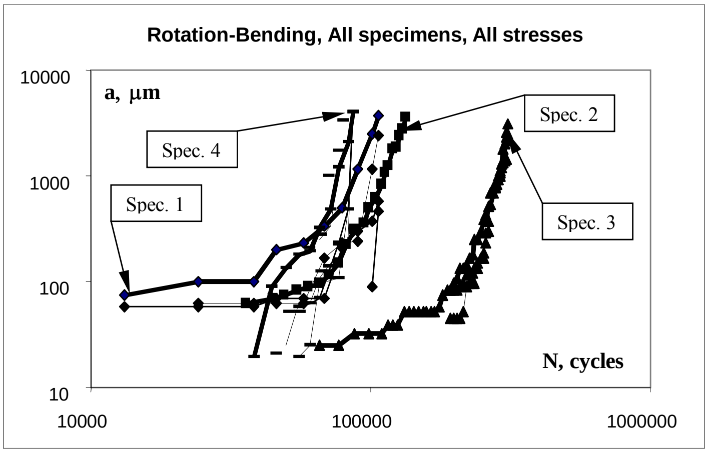

Fig. 2. Dependence "Crack length, a - number of cycles, N"

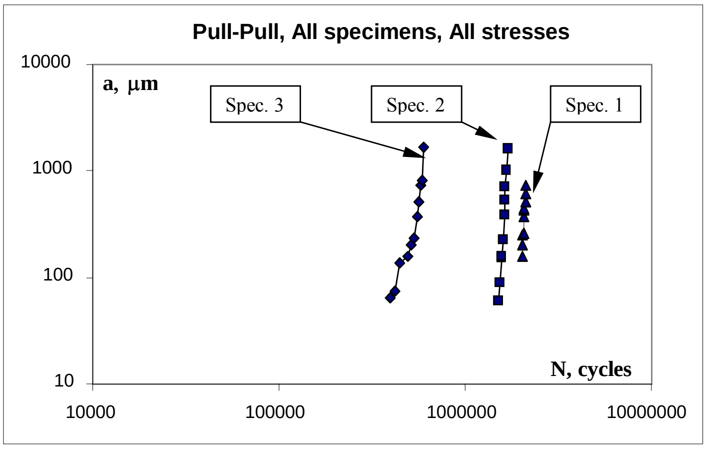

Fig. 3. Dependence "Crack length, a - number of cycles, N"

In Fig. 2 it can be seen all cracks, while the main cracks' behaviour is presented by the thickest curves. The specimen *3* subjected to the lowest stress level Δσ= 580MPa shows the longest lifetime, N=310 420 cycles. The main crack in specimen *3* starts its propagation much later in comparison to the main cracks of the other specimens. Its initial length is found to be 25μm at 66 000 cycles (comparatively late) and its growth as a short crack (GSC) takes 78.73 % of the whole fatigue lifetime. The corresponding crack parameters of the other specimens tested at the highest stress level of 620MPa are respectively: for specimen *1* – 76μm at 13 200 cycles and time of GSC of 87.62 %, and for specimen *2* – 63 μm at 30 470 cycles and time of GSC of 77.61%. After the transition "short-long crack" all cracks show similar behaviour as their curves develop almost in parallel up to failure. However, the specimen *4* shows an exception concerning the already involved crack parameters – 19μm at 38 500 cycles and time of GSC of 55.5 % at almost vertical development of its crack curve. This particular specimen is tested at a frequency of 6.6 Hz, while all of the rest have experienced a frequency of 11 Hz. No specific difference has been found between the surface of specimen *4* and those of the remaining specimens.

In Fig. 3 are shown the dependencies "Crack length, *a* - number of loading cycles, *N*" for Pull-Pull loading at a ratio of R = 0.1 and a frequency of 190Hz. The analysis already made for Rotation-Bending fatigue data is valid in this case too. But, the short crack growth for Pull-Pull loading is badly presented by only few data, because of some reasons given in [8].

To make a more precise comparison between both fatigue conditions, Rotation-Bending and Pull-Pull, we present all the dependences "Crack length, *a* - number of cycles, *N*" in Fig. 4. Now, it is clearly seen that under Rotation-Bending fatigue the cracks observed start their growth earlier than those under Pull-Pull fatigue and also have lesser life.

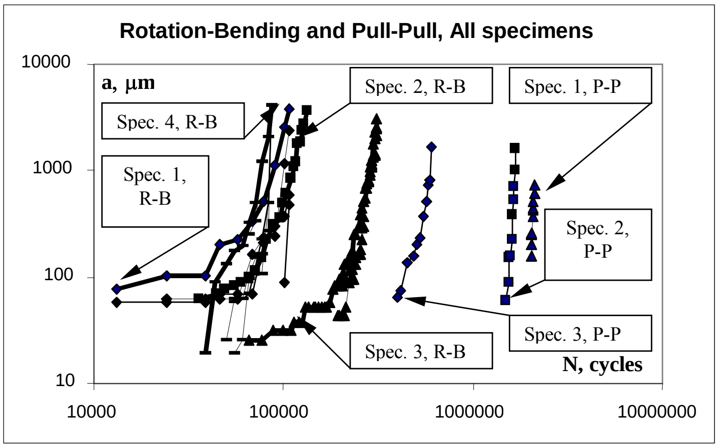

Fig. 4. Dependence "Crack length, a - number of cycles, N"

A comparison between the two specimens with longest fatigue lifetime, belonging to "Rotation-Bending" and "Pull-Pull" sets of experiments shows the following.

The specimen *3* experiences Rotation-Bending fatigue (R = -1) under a loading of σ_{max} = 290MPa and fails at 310 420 cycles, whereas the specimen *1* from the Pull-Pull set

(R = 0,1) is under a loading of σ_{max} = 430MPa and fails at 2 120 000 cycles. This fact confirms the unfavourable impact of symmetric cyclic loadings on fatigue endurance.

Another clearly evident difference between the behaviour of "Rotation-Bending" specimens and "Pull-Pull" specimens is that there always exist more than one crack in specimens under Rotation-Bending fatigue – the only exception is that of specimen *2*. A good explanation of this observation is the fact, that at Rotation-Bending fatigue the surface layers are exposed to the most unfavorable conditions: the greatest stresses arise just there [9]. In principle for our case of RLCLAS 09Г2 steel all fatigue cracks, even at Pull-Pull fatigue, start on the surface of specimens, showing that the stresses arisen on surface are greater than those existing in the bulk of specimens. This effect adds to the hard conditions characterizing Rotation-Bending fatigue.

SUMMARY

A first set of specimens is tested on a table model fatigue-machine FATROBEM–2004 that is designed, constructed and assembled in the Laboratory of Plastic Deformation of the University of Chemical Technology and Metallurgy-Sofia. The standard analyses of Rotation-Bending data obtained on a new machine show the same tendency of short fatigue crack behaviour of RLCLAS 09Г2 as that when RLCLAS 09Г2 has been exposed to Pull-Pull fatigue in all previous tests.

A comparative analysis of Rotation-Bending and Pull-Pull fatigue data show an unfavourable influence of the symmetric cyclic loading at Rotation-Bending on fatigue endurance, expressed by the earlier failure of the specimens subjected to Rotation-Bending than those experiencing Pull-Pull loading.

REFERENCES

[1] S. Suresh, Fatigue of Materials. Cambridge University Press-UK, Cambridge, 1998.

[2] N. Dowling, Mechanical Behaviour of Materials, Prentice-Hall, New Jersey, 1999.

[3] P. D. Hobson, The Growth of Short Fatigue Cracks in a Medium Carbon Steel, Ph. D. Thesis, University of Sheffield, 1985.

[4] A. Navarro, E. R. de los Rios, A model for short fatigue crack propagation with an interpretation of the short long crack transition, Fatigue Fract. Engng Mater. Struct. 10, 1987, p 169-186.

[5] K. J. Miller, The three thresholds for fatigue crack propagation, Fatigue Mechanics, 27th volume, ASTM STP 1296 (Edited by R. S. Piascik, J. C. Newman and N. E. Dowling), American Society for Testing And Materials, pp. 267-286.

[6] D. Angelova, R. Akid, A note on modeling short fatigue crack behaviour, Fracture and Fatigue of Engineering Materials and Structures, 1998; 21: 771-779.

[7] A. Davidkov, Short fatigue crack growth in 09Г2 steel, Technical Ideas, Institute of Metal Science, Sofia – in press 2005.

[8] A. Davidkov, R. Yordanova, Comparative analyses on the fatigue behaviour of low carbon steel at different loading in laboratory air, Journal of the UCTM, Sofia, volume XXXVIII, 4(2003), p 1177-1184.

[9] X. Wu, Short Fatigue Crack Behaviuor of a Submarine Hull Steel in Inert and Aggressive Environments, Ph. D. Thesis, University of Sheffield, 1995.