Influence of Stress Ratio R on the Fatigue Strength and Fatigue Crack Path in Metal Materials

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ABSTRACT. *Influence of stress ratio R (*$R=\sigma_{min}/\sigma_{max}$*) on the fatigue crack path and fractographic features of fatigue fractures of metal materials is investigated. As an investigated material were used aluminium alloy AK6 (2,22 %Cu, 0.6 %Mn, 0,9 %Si, 0,6 %Mg, 0,3 %Zn, 0,7 %Fe, 0,1 %Ni) and austenitic steel 110G13L (1,06 %C, 15,18 %Mn, 0,2 %Cr, 0,4 %Ni). Fatigue tests of prismatic samples were conducted under the rigid scheme of loading under constant fatigue stress range (*$\Delta\sigma$ *= const) in a wide range of ratio R.. The fracture surfaces of tested samples were investigated by macro-, microfractographic methods and also X-ray diffraction analysis. It was shown the fatigue life of samples and also quantity of loading cycles for crack propagation are stress ratio R dependent. Maximum value of these parameters takes place under symmetric loading cycle at R=-1, and minimum value – at R→1. The generalized scheme of influence of ratio R on fatigue life of samples is presented. The increase of compressing stresses at the crack tip same influence, as well as increase of stretching stresses on the fatigue life of samples, i.e. reduces both fatigue life of samples and stage of crack propagation. A micro relief of a fatigue fracture and also degree of crystal structure distortion of a material on the fracture surface are dictated by both micro mechanism of a crack propagation, and additional deformation from the compressing stresses, arising already after the fatigue crack passage.*

INTRODUCTION

It is known [1, 2], that the stress ratio R ($R = \sigma_{min} / \sigma_{max}$) exert essential control over a fatigue crack propagation in samples and components working in fatigue stressing conditions. Thus influence of stress ratio R on the crack propagation resistance under compressing cycles of loading is most poorly studied. The purpose of work was the research of influence of stress ratio R on the fatigue crack path and fractographic features of fatigue fractures of metal materials.

MATERIALS AND TECHNIQUES OF RESEARCH

As an investigated material were used aluminium alloy AK6 and manganous austenitic steel 110G13L. Aluminium alloy AK6 used in a condition of delivery (hot-rolled). Steel 110G13L was solution heat treated by heating at 1100 ^{0}C followed by water quenching. After heat treatment steel 110G13L had single-phase austenitic structure. The chemical composition of investigated materials is shown in table 1. Mechanical properties of materials studied are shown in table 2.

Table 1. Chemical composition of materials studied (wt %)

Material	C	Cu	Zn	Mg	Fe	Ni	Si	Mn	Cr
AK6	-	2,22	0,30	0,60	0,70	0,10	0,90	0,60	-
110G13L	1,06	-	-	-	-	0,40	-	15,18	0,20

Table 2. Mechanical properties of investigated materials

Material	Tensile strength $\sigma_{B,}$ (MPa)	Yield strength $\sigma_{0,2,}$ (MPa)	Percentage elongation after fracture δ, %	Reduction of area after fracture ψ, %
AK6	420	300	12	40
110G13L	820	380	40	45

Fatigue tests were conducted employing prismatic specimens with edge notch. Specimens manufactured from alloy AK6 with a thickness of $1,2\cdot10^{-2}$ m have been cut out from a plate so that a fatigue crack propagates across fibers. The thickness of specimens made from steel 110G13L is equal to $5,0\cdot10^{-3}$ m. Fatigue tests of all samples were performed by the cross-section bend under rigid scheme of loading and constant fatigue stress range ($\Delta\sigma$ = const) at the stress ratio R ranging from $-\infty$ to ∞. Obtained fracture surfaces were investigated by macro-, microfractography and X-ray diffraction analysis [3].

RESULTS OF RESEARCH AND DISCUSSION

Correlation between fatigue life of samples N and factor R for alloy AK6 and steel 110G13L is presented in Fig. 1.

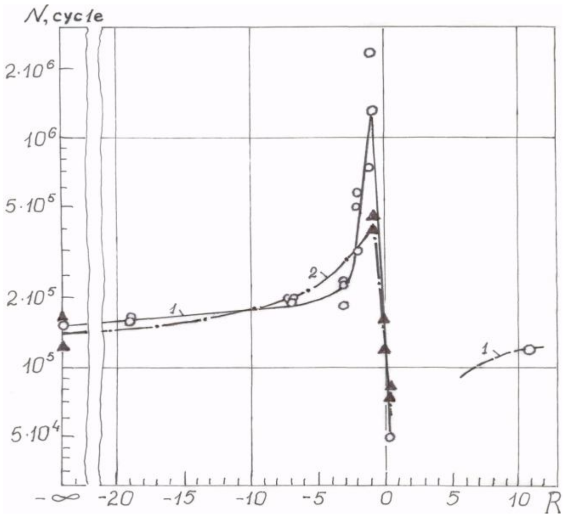

Figure 1. Correlation between fatigue life of samples N and stress ratio R for aluminium alloy AK6 (1) and steel 110G13L (2)

It is possible to allocate three regions of values of ratio R on the above correlation. With increase of ratio R from - ∞ up to-1 the fatigue life of samples made from alloy AK6 and steel 110G13L increases. And, the most intensive increase of the fatigue life of samples is observed at the stress ratio ranging from R = -3 to -1 (Fig. 1). The fatigue life of samples both from alloy AK6, and from steel 110Г13Л decreases sharply at an interval of values R ranging from -1 to 0,5. It was not possible to establish the experimental dependence of fatigue life of samples made from alloy AK6 from ratio R at the load ratio ranging from R = 1 to ∞, since in the samples tested at R = 5, fatigue crack arose on the opposite side from a notch. Such results of tests do not analyze in further, therefore only one experimental point at R = 11 shown in Fig. 1.

It is shown, the maximum fatigue life of samples takes place at R = -1, that corresponds to the loading scheme at which the maximum and minimum stress cycle have the minimum deviations from zero. The minimum fatigue life of samples takes place at R→1, when the maximum stress cycle at completely stretching loading cycles, and, apparently, and minimum stress cycle at completely compressing loading cycles (last case is noted by a dotted line in Fig. 1) achieves the maximum deviation from zero. The fatigue life of samples makes intermediate value from above at R → - ∞ or R → ∞ (Fig. 1).

The obtained results allow to present the generalized scheme of influence of load ratio R on the fatigue life of samples N in all values R ranging from - ∞ to ∞ for a case of constant fatigue stress range ($\Delta\sigma$ = const). The generalized scheme is shown in Fig. 2.

It is seen in Fig. 2 that the increase in compressing stress renders the same influence, as well as increase in stretching stress on the fatigue life of samples, i.e. reduces the general fatigue life of samples.

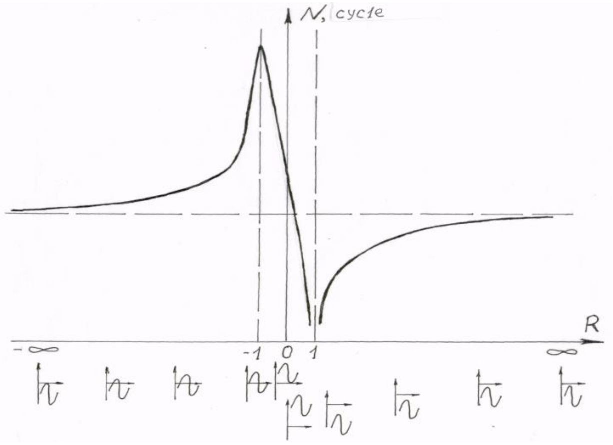

Figure 2. The generalized scheme of influence of stress ratio R on the fatigue life of samples N in all values R ranging from - ∞ to ∞ under constant fatigue stress range ($\Delta\sigma$ = const).

There are three characteristic macro zones on all obtained fractures of samples made from aluminium alloy AK6 [1-3] i) a zone of crack stable growth l_s ii) an accelerated crack extension zone l_r and iii) a fracture zone. Zones l_s and l_r form a zone of crack fatigue extension l_f ($l_f = l_s + l_r$). It is possible to observe two fatigue zones and on the fracture surface of samples made from steel 110G13L, tested at R = -1. Only one zone is observed on the fracture surface of all other samples made from this steel. Relation between zones length and stress ratio R in samples made from both alloy AK6 and steel 110G13L is similar to relation between stress ratio R and fatigue life N (see, Fig. 1). On the basis of it, it is possible to conclude, that the stress ratio R influence on the fatigue crack extension stage N_e greater, than on the crack origin stage N_o.

Let us consider influence of stress ratio R on micro fractographic features of a structure of fatigue fractures on an example of samples from alloy AK6.

Micro relief of a fracture surface of the sample tested at R = -19 (Fig. 3 a, b), specifies strong mutual compression of the interfaced fracture surfaces during a fatigue crack growth. Irregular fatigue striations, secondary cracks and steps are observed in a zone l_s, (Fig. 3 a). The micro relief of the accelerated crack extension zone l_r slightly differs from above, however looks more relief (Fig. 3 b). Irregular fatigue striations and secondary cracks are visible.

A combined fracture: ductile section, intercrystalline cleavage and irregular fatigue striations are observed in a zone of crack stable growth l_s of the sample tested at R = -1 (Fig. 3 c). Implicit fatigue striations are surrounded by the dispersed pits on flat sites of fracture and secondary cracks are visible in accelerated crack extension zone l_r (Fig. 3 d). As a whole the given fracture surface looks more relief. This suggests that compression of the interfaced fracture surfaces was less intensive.

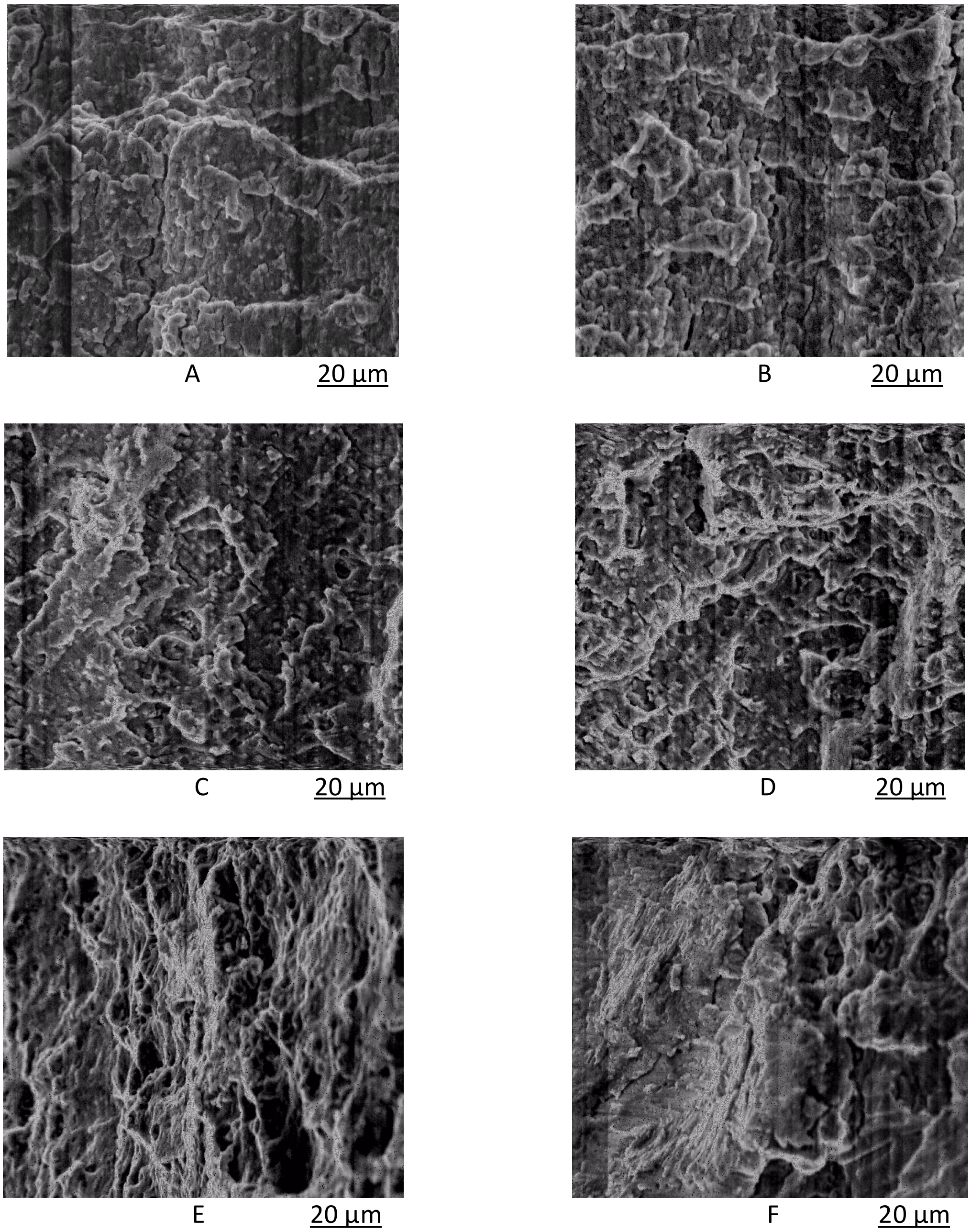

Figure 3. Fractographic surfaces of samples from aluminium alloy AK6 tested at R = -19 (a, b,), R = -1 (c, d,) and R = 0,5 (e, f,); a, c, e - crack stable growth zone l_s; b, d, f - accelerated crack extension zone l_r

Irregular fatigue striations surrounded by pits with different sizes in a zone of crack stable growth l_s on the fatigue fracture surface of the sample from alloy AK6 tested at R = 0,5 are observed (Fig. 3d). More regular fatigue striations surrounded by pits on flat sites of fracture and secondary cracks are visible in accelerated crack extension zone l_r (Fig. 3e). Traces of mutual compression of fracture surfaces are not observed.

Thus, it is visible, that at change of a stress cycle of samples made from alloy AK6 from compressing (R = -19) to symmetric (R = -1) and stretching (R = 0,5) the viscous component increases in both crack stable growth zone l_s and accelerated crack extension zone l_r that is caused by change of the relation between compressing and stretching stresses and also by degree of mutual compression of the interfaced fracture surfaces during test.

Obtained data of micro fractographic investigation is confirmed by X-ray diffraction analysis of fracture surfaces. Figure 4 presents an effect of stress ratio R on the diffraction line (311) K_α width in a zone l_s and fracture zone for alloy AK6. (фиг.4). It is visible, that with decrease of compressing stresses under change of stress ratio R from -19 to -1 the diffraction line (311) K_α width decreases in a zone l_s, that point to decrease of a degree of crystalline structure distortion on surface of the given zone.

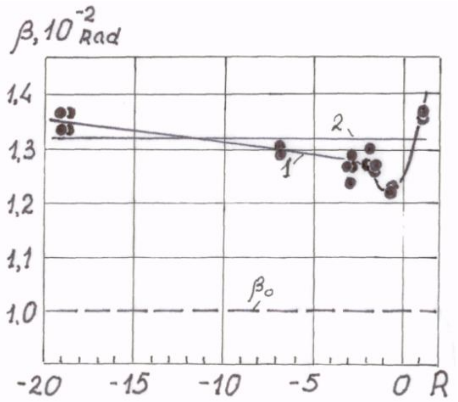

Figure 4. Effect of stress ratio R on the diffraction line (311) K_α width in a zone l_s (1) and fracture zone (2) for alloy AK6. β_0 - diffraction line (311) K_α width of standard sample

The minimum of diffraction line (311) K_α width is obtained at a symmetric cycle (R =-1), that corresponds to the loading scheme at which the maximum and minimum stress cycle in samples have the minimum deviations from zero. The diffraction line (311) K_α width again increases at R = 0,5 (Fig. 4). Attracts attention that fact, that crystalline structure distortion of a material on a surface of a zone l_s, estimated on diffraction line (311) K_α width, can be more then crystalline structure distortion in a fracture zone, that takes place at R =-19 and 0,5 (Fig. 4). Apparently, the increase of crystalline structure distortion of a material in l_s zone at R = 0,5 is connected with a big stretching stress, and, as consequence, with ductile fracture. The high degree of crystalline structure distortion of a material in the given zone at big compressing stress at R =-19 is connected, apparently, with additional deformation from the compressing stresses, arising already after the fatigue crack passage.

CONCLUSIONS

1. The fatigue life of samples and also quantity of loading cycles for crack propagation are stress ratio R dependent. Maximum value of these parameters takes place under symmetric loading cycle when the stress ratio R=-1, and minimum value – under stress ratio R→1.
2. The increase of compressing stresses at the crack tip same influence, as well as increase of stretching stresses on the fatigue life of samples, i.e. reduces both fatigue life of samples and stage of crack propagation.
3. The generalized scheme of influence of stress ratio R on fatigue life of samples is presented.
4. A micro relief of a fatigue fracture and also degree of crystal structure distortion of a material on the fracture surface are dictated by both micro mechanism of a crack propagation, and additional deformation from the compressing stresses, arising already after the fatigue crack passage.

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