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Abstract. Studies of fatigue crack growth in steel 2CR31 without coating and steel 2CR31 with coating NI-CR-B-SI have been carried out. The works of V.E. Panov are analyzed. On the basis of his works, studies of fatigue cracks are presented. It is shown that the process of fatigue fracture of a steel sample is accompanied by a regular decrease in the natural frequency of all recorded modes.

INTRODUCTION

In September 2020, Panov E.V., the founder of the scientific school of mesomechanics, passed away. In his works, the results of studying the stages of developing a fatigue crack under the conditions of alternating bending are presented [1-2], namely crack growth kinetics, evolution of plastic deformation and fracture processes at the mesoscale [3], change in area [4] and deformation intensity in the plastic zone at the crack tip [5].

MATERIALS AND METHODS

Contact finite elements are used to model contact conditions. They interact with ordinary finite elements of two-dimensional or three-dimensional problems, and provide the contact between the mesh nodes located on the boundary surfaces of the contacting bodies, thereby discretizing a very thin layer of pseudo-medium which is fictitious or taking place in real conditions between the contacting surfaces.

This contact layer deforms together with the interacting bodies and, due to the special nonlinear properties taken into account through step-by-step numerical simulation, can satisfy the necessary contact conditions.

RESULTS AND DISCUSSION

The first stage of fatigue failure 2CR31 (Fig. 1) is characterized by quasi-brittle growth of fatigue crack. Thus, occuring the first cracks in the near-surface layer of the samples occurs without forming a fixed deformation relief at the crack tip, and the fracture surface is built by a rivulet or faceted relief. At this stage, the plastic zone size does not exceed the average grain size of the material.

At the second stage, the quasi-brittle mechanism of fatigue crack growth is replaced by a brittle-plastic one, and the intensity of the local plastic deformations at the crack tip increases noticeably. Under these conditions, a grooved relief is formed on the fracture surface, and a plastic zone clearly identified by the deformation relief is formed at the crack tip. In this case, the region involved in the plastic flow covers rather large groups of crystallites.

At the third stage of fatigue failure, the crack propagates with a predominance of the brittle-plastic mechanism, as evidenced by the pit relief on the fracture surface and a pronounced deformation relief at the crack tip. However, the region of the plastic deformation localization reaches macroscopic dimensions and completely covers the sample residual section. Involving the entire residual section of the specimen within the fracture zone into a localized plastic flow, in fact, is a necessary condition for propagating the main crack and can be considered as a criterion for fatigue prefailure.

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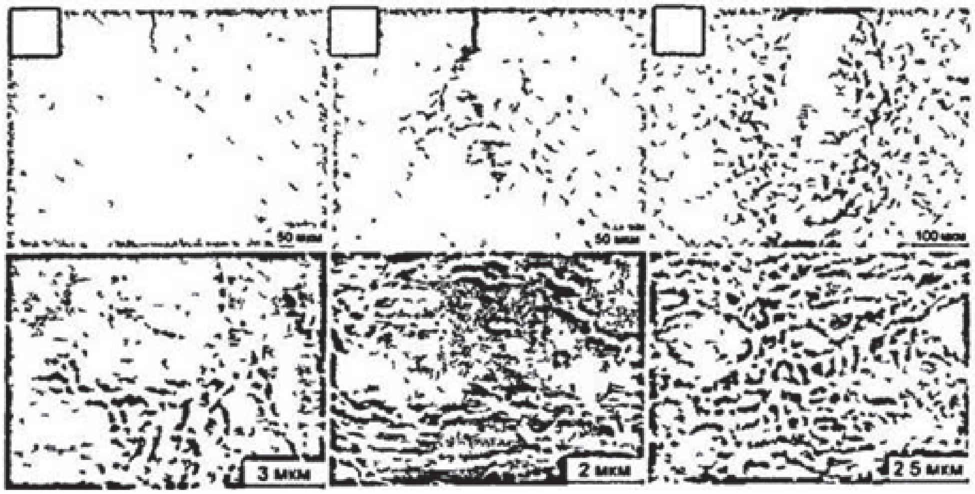


(a) (b) (c)

FIGURE 1. 2CR31. Optical images of the crack at the 1st (a), 2nd (b), and 3rd (c) stages of fatigue failure under the conditions of alternating bending and the corresponding fractograms of the fracture surface

Only 2-4% of the crack length in 2CR31 steel is formed under the quasi-brittle fracture conditions. The remaining 96-98% of the crack length is formed by the brittle-plastic mechanisms. Starting from the second stage of fatigue failure, a pair of conjugate bands of the localized plastic deformation are formed, oriented at an angle of 70° to 45° to the crack growth direction, due to which crack opening is realized. Under the conditions of bending, the strips are characterized by a curvilinear arcuate shape (Fig. 2). The intensity of plastic deformation in the plastic zone, estimated from y values, is maximum in the immediate vicinity of the crack tip and decreases rapidly with the distance from it.

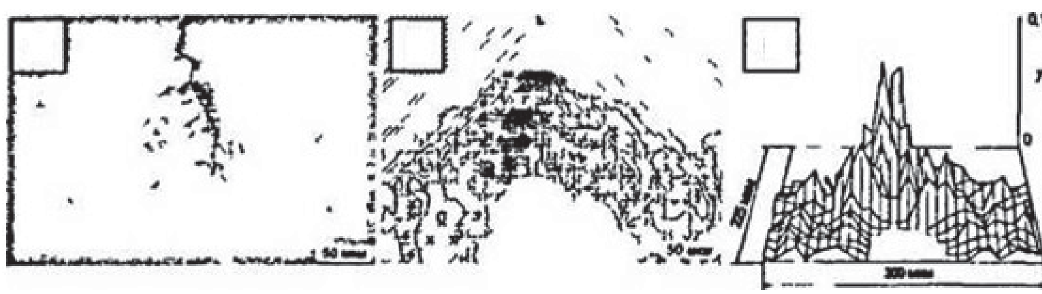
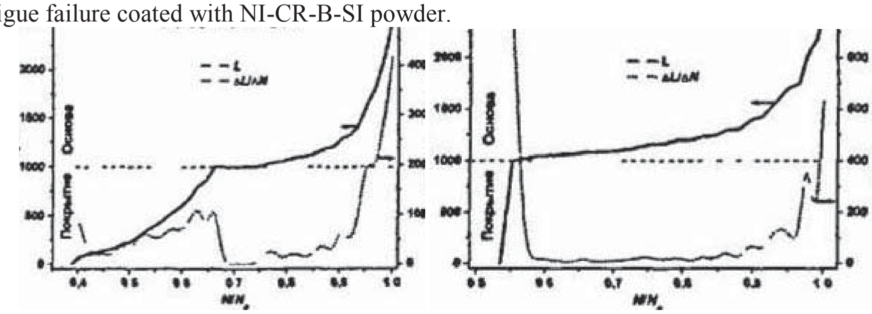


FIGURE 2. 2CR31. Optical image of the plastic zone around the crack tip area (a), displacement vector path (b) and y distribution (c) in this area N=39

Parameter measurements of the plastic zone in the process of fatigue failure 2CR31 showed that the area of the plastic zone S and the total normalized value y within its limits grew up with increasing the crack length. The test results demonstrated fundamentally different nature of kinetics (Fig. 3) and mechanisms of 2CR31 composite fatigue failure coated with NI-CR-B-SI powder.



(a) (b)

FIGURE 3. Fatigue crack growth curves in 2CR31 composite samples coated with Ni-Cr-B-Si from behind

Crack initiation in 20X13+NI-CR-B-SI steel composition occurs on the coating surface. In the direction of the "base-coating" interface, the crack develops at a relatively low rate, and its propagation is characterized by several stages of quasi-brittle (Fig. 4, a) and brittle-stochastic growth (Fig. 4, b, c). Reaching the "base-coating" interface, the crack does not pass into the base metal immediately, but undergoes deceleration in the coating layer adjacent to the interface (Fig. 5). In the given layer, characterized by a reduced level of microhardness (Fig. 1), there is a relaxation of stresses in the crack tip region due to localized plastic deformations.

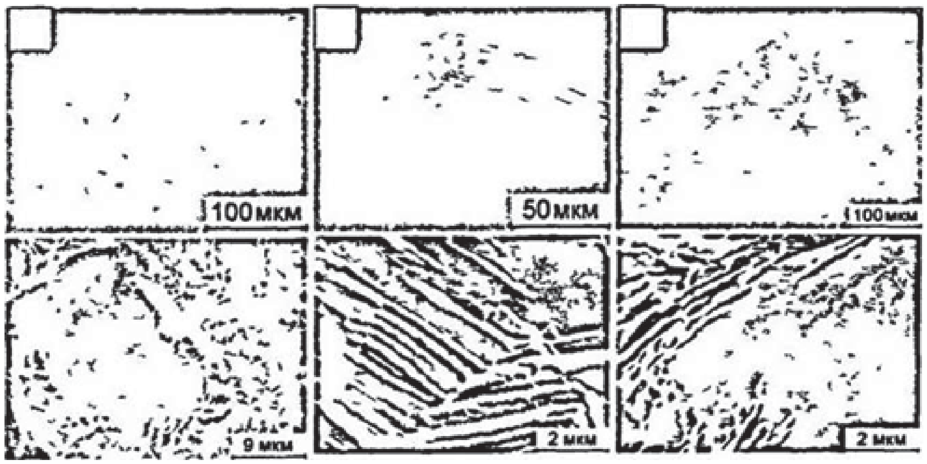
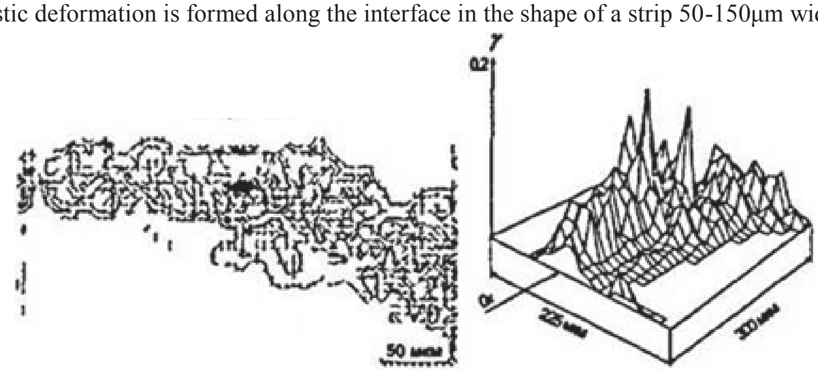


FIGURE 4. Optical images of a fatigue crack in the coating based on NI-CR-B-SI and corresponding fractograms of the fracture surface

FIGURE 5. Optical image of a fatigue crack in 2CR31 + NI-CR-B-SI composition in the "base-coating" interface region

Crack initiation in 2CR31 + NI-CR-B-SI composition occurs in a weakened sublayer in the base-coating interface region, which is associated with a high concentration of stresses during loading and a significant gradient of mechanical properties in this region. During loading, even before occurring a crack, a zone of localized plastic deformation is formed along the interface in the shape of a strip 50-150μm wide (Fig. 6).



(a) (b)

FIGURE 6. 2CR31+ NI-CR-B-SI composition. The field of mixing vectors in the "base-coating" section grant (a) and the distribution in this zone (b)

The zone area, as well as the intensity of plastic deformation in it, increase with loading. In the softened sublayer, slip marks, adhesion and cohesive cracks occur. (Fig. 7). It should be noted that these deformation damages are localized quasi periodically along the interface. In this case, the distance between adjacent sections with sliding marks and cracks has a minimum in the sample cross section, where it subsequently fails. The crack growth in the coating from the interface occurs at a high rate and is quasi-brittle, as evidenced by the absence of plastic deformation signs along the crack path and the facet relief on the fracture surface. A through crack formed in the coating almost immediately spreads into the base metal.

FIGURE 7. 2CR31+ NI-CR-B-SI composition.
Optical image of the deformation damage in the “base-coating” interface region

CONCLUSIONS

The process of 2CR31 sample fatigue failure is accompanied by a regular decrease in the natural frequency of all recorded modes. The quantitative relationship between the natural frequency and the crack length is characterized by a decreasing dependence. The relationship between the natural frequency and the loading duration is characterized by a more pronounced decreasing dependence due to increasing fatigue crack growth rate at the final stage of fatigue failure.

The change in the sample natural frequency of 2CR31 + NI-CR-B-SI compositions during fatigue failure occurs in a slightly different way. This is primarily due to the peculiarities of the kinetics of fatigue crack growth in these compositions. Thus, decreasing the natural frequency accompanied by increasing the crack length in 2CR31 + NI-CR-B-SI composition samples is characterized by a similar decreasing dependence, as in the case of 2CR31 specimen without coating. However, depending on the loading duration, the change in frequency occurs in a more complex way. At a certain stage, decreasing the natural frequency of all registered modes stops and then resumes again. When comparing the graphs with fatigue crack growth curve, it becomes obvious that this corresponds to the fatigue crack stop at the “base-coating” interface.

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