INFLUENCE OF PERLITE DISPERSION OF CARBON STEEL ON THE FATUGUE PROCESSES

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Abstract

Using the example of carbon steel with perlite structure it was determined the influence nature of the ferrite layer thickness of perlite on the angular coefficient of tangent at a certain point of the fatigue curve. Based on the analysis of the obtained dependencies, it is determined that the value of angular coefficient of the tangent can be used to evaluate the resource of limited endurance of the metal under conditions of cyclic loading.

1.Problem state.

Based on the analysis of experimental studies of carbon steel it is determined that the ferrite layer thickness of the perlite colony to a large extent affects not only the level of fatigue endurance limits but also the appearance of the cyclic loading diagram itself [1]. At the same time, taking into account the existence of a certain conjugation of the crystal lattices of ferrite and cementite with the growth of the pearlite colony, the decrease in the ferrite layer will be accompanied by a corresponding thinning of the cementite plates. Taking into account the additive contribution of structural components to the overall level of strength characteristics of carbon steels, one should expect the effect of the dispersion cementitious plates of perlite on the development of fatigue phenomena.

The presented influence acquires the determined value, especially under conditions of evaluation of the limited endurance value of the metal material on the degree of cyclic over loading. Conditional distribution of the fatigue curve at the area of low- and high-cyclic fatigue is caused by the qualitative changes in the mechanism of forming the sites of metal destruction. On this basis the determined sensitivity of the metal material to the conditions of cyclic loading is in fact caused by the dependence of the development of structural transformation processes on the border of transition from one area to another. It is evidenced by existence of violation of the monotonous form of the fatigue curves.

2.Material and methodology of research.

The carbon steel of a rail way wheel containing 0.62% C; 0.68% Mn; 0.49% Si was used as a material for research. Different perlite dispersion was obtained using accelerated cooling of the metal to certain temperatures of isothermal holding, with the duration sufficient to complete the perlite transformation. The thickness evaluation of the ferrite layer of the perlite colony (λ) was carried out according to the methodologies of quantitative metallographic. The change interval of λ was 0.14 - 0.5 μm. The dislocations density (ρ_{211}) was measured by the interference (211), using the methodology of X-ray structural analysis. Fatigue tests were carried out under conditions of the machine Saturn-10, at room temperature on the samples of flat shape with symmetrical cycle of alternating bending. Load frequency was 1000 min^{-1}. Using the analysis of the constructed cyclic loading curve in the coordinates of the cycle amplitude – the number of cycles to fracture, it was determined the value of limited endurance, angular coefficient of the tangent for a certain curve point, position of the transition border from a low- to high-cyclic fatigue.

3.Results and discussions.

The Fig. 1 presents the influence of the ferrite layer thickness of perlite on the form of cyclic loading diagram for the investigated carbon steel. For the range of λ values under study, the characteristic feature of the cyclic loading curves is the occurrence of violation in the monotonous decrease in the cycle amplitude (σ_a) on the number of cycles to the destruction of sample. In the literature the above-mentioned anomalies on the fatigue curves are often referred to as "breakpoints" [2]. Depending on the features of the internal structure of the metal, the conditions of cyclic loading, the position of such anomalies on the abscissa axis is changed. The appearance of extremums itself is significantly different: from significant fluctuations in the cycle amplitude with concentration in a narrow range of cycles (Fig.1a), to the almost horizontal section (Fig. 1e). For the corresponding conditions of cyclic loading, origin of such sections is caused by combined action of various factors. Thus, according to the work [1], the cause of the anomaly is violation of uniformity in the development of structural transformation processes under cyclic loading, in the deformation distribution homogeneity [2], or change of active crystallographic systems of dislocations glide [3].

The explanations based on the change in the stress state of the metal ahead of the growing fatigue fracture have become sufficiently widespread. It is believed that under conditions of low-cyclic fatigue, in the crack mouth a plain stress condition Is realized and the fatigue area at the destruction surface of the fracture occupies relatively small area. Other conditions of the crack growth are performed for the area of high-cyclic fatigue. Based on the analysis of the destruction surface, for the mentioned area the presence of characteristic features during displacement and delay of the growing crack front indicates formation of the forced plain stress condition. The obtained results for the position in go on the abscissa axis of the border between the areas of low-and high-cyclic fatigue (N_1) for the investigated dispersion interval of the perlite colony showed the existence of the dependence on λ.

After pair plotting of N_1 against the corresponding values of λ, an unambiguous, directly proportional relationship between them was determined (Fig. 2). According to the given dependence increase in the ferrite layer thickness of perlite is accompanied by a significant shift of the value N_1 in the direction of increasing the number of cycles.

Thus, increase in the ferrite layer thickness of perlite colony against the background of increase of N_1 (Fig. 2) is in fact accompanied by a steady decrease in the cycle amplitude in the area of the limited endurance of carbon steel (Fig. 1).

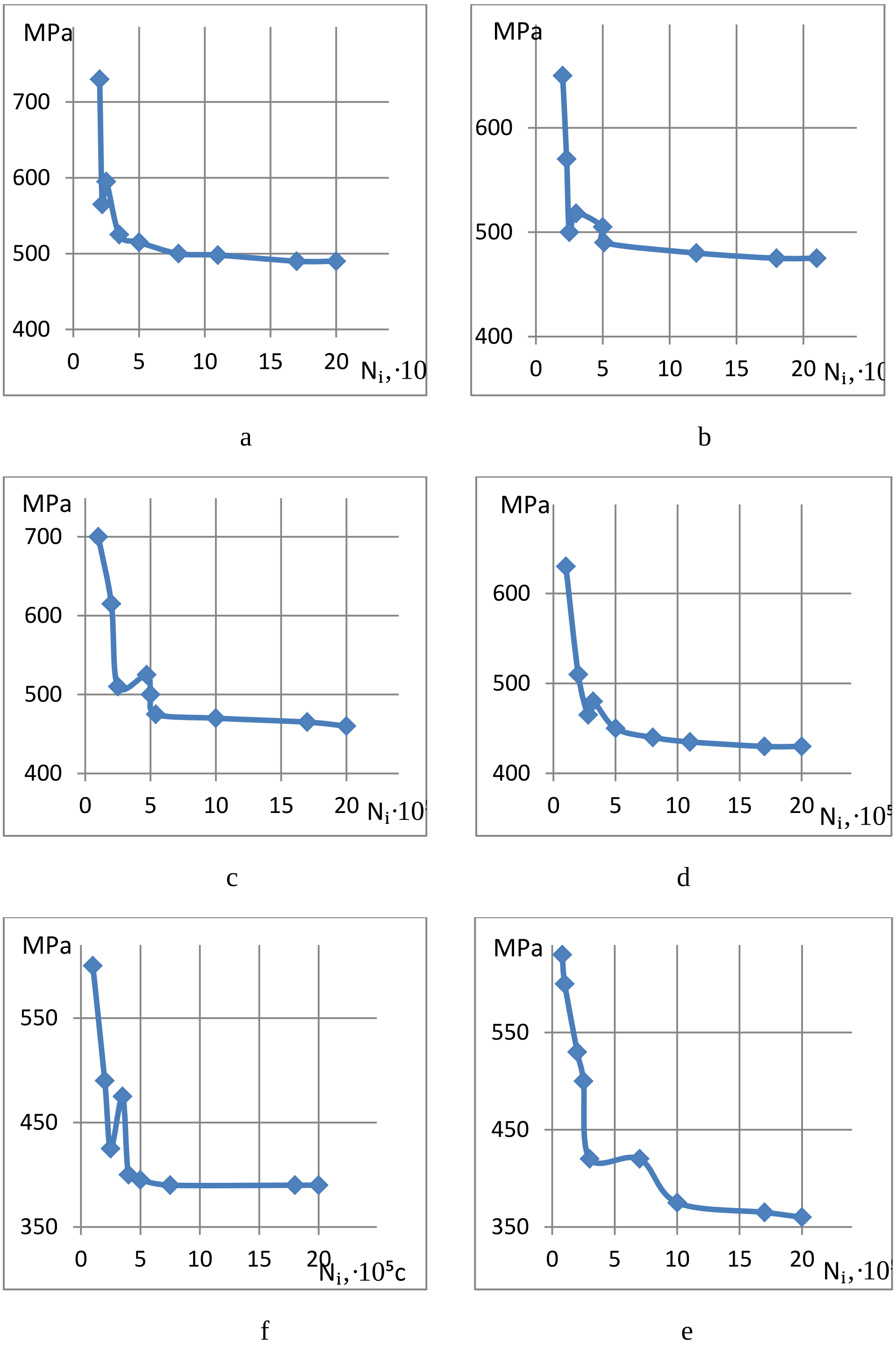

Fig.1. *Influence of the ferrite layer thickness of the perlite colony (a-0.14;b-0,19; c-0,26; d-0,3; f-0,33; e-0,5* μ *) on the fatigue curve.*

Despite rather complex nature of the relationship $\sigma_a = f(N_i)$ (Fig. 1), the use of analytical dependencies can make it possible to a certain extent to predict the behavior of metallic materials under conditions of different degrees of cyclic overloading.

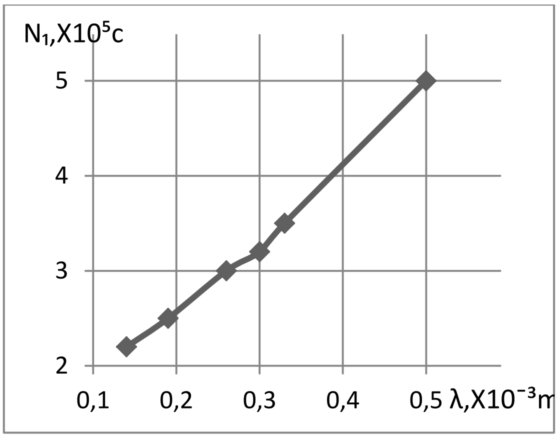

Fig.2. Influence of the perlite dispersion on the border position between the areas of the curve with the low- and high-cyclic fatigue

To analyze dependence the amplitude of cycle - limited endurance, used the relation [2,3]:

$$\sigma_a = K_a(N_i)^{-n}, \quad (1)$$

where K_a - is the constant, n - is the degree exponent. After transformation (1), a dependence for determining the angular coefficient of tangent of the fatigue curve ($d\sigma_a / dN_i$) was obtained [4]:

$$\frac{d\sigma_a}{dN_i} = -\frac{n \cdot \sigma_a}{N_i}, \quad (2)$$

Formally, them mentioned characteristic is a measure of change in the cycle amplitude under conditions of increasing the cyclic endurance for one cycle.

Taking into account existence of different correlation in the development of the processes of nucleation and annihilation of crystalline structure defects to support the conditions for the continuous distribution of plastic deformation during fatigue, one can assume that $d\sigma_a / dN_i$ should be a structurally sensitive characteristic. Dependence of value $d\sigma_a / dN_i$ on λ for the qualitatively different parts of the fatigue curve is shown in the Fig. 3. For the area with the low-cyclic fatigue (curve 1), the relation between $d\sigma_a / dN_i$ and λ has an inverse proportional form.

According to the given dependence it should be considered that the cruder the plate structure of the perlite colony, the lesser should be reduced the cycle amplitude to increase the fatigue endurance. If for the transition area from the lowto high-cyclic fatigue, in appearance there is almost no influence of λ on the value $d\sigma_a / dN_i$ (curve 2), then for the high-cyclic fatigue there is a unique directly proportional dependence (curve 3). According to the relation (2), under conditions of unlimited endurance, when $N_i \to \infty$, and $\sigma_a = \sigma_{-1}$, where σ_{-1} - is the fatigue stress limit, $d\sigma_a / dN_i \to 0$ (Fig. 1).

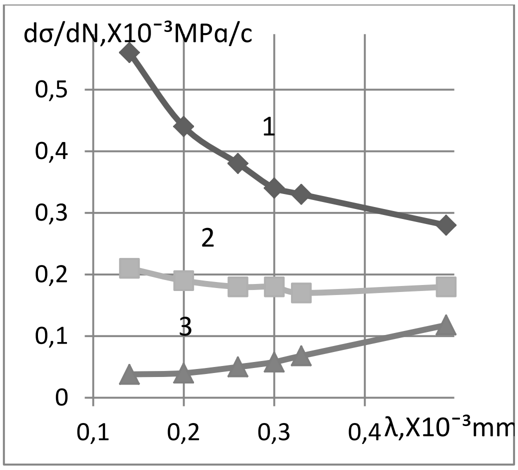

Fig.3.Dependence of $d\sigma_a / dN_i$ on λ for different level of the limited endurance $2{\cdot}10^5$ – (1),$5{\cdot}10^5$c – (2), $5{\cdot}10^6$c - (3).

Taking into account the dislocation mechanism for the distribution of plastic deformation during cyclic loading, it is fully justified to expect the existence of dependence of the number of accumulated dislocations in a metal on the degree of its cyclic over loading. The evaluation made for λ = 0.14 µm and two values $d\sigma_a / dN_i$ 0.05 and 0.5 10^{-3} MPα/c showed that the accumulated density of dislocations (ρ_{211}) in the metal after the samples destruction was 19 and 7.5 $10^{10} cm^{-2}$, correspondingly. Taking into account the same nature of influence of λ on the carbon steel behavior under conditions of the static and cyclic loadings [5], it should be expected that $d\sigma_a / dN_i$ may be a measure of defects accumulation in the crystalline structure under conditions of cyclic loading.

4. Conclusions.

1. From the analysis of curves fatigue carbon steel with different dispersion of perlite, the structural sensitivity of the transition border from the low- to high-cyclic fatigue, was determined.
2. Decrease of ferrite layer thickness of perlite colony contributes to the achievement of conditions to high-cyclic fatigue.
3. Under conditions of limited endurance, the existence of a qualitative inverse proportional relationship between the angular coefficient of the tangent curve of

fatigue and the density of accumulated dislocations after the destruction of the metal is determined.

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