FEATURES OF THE FATIGUE FAILURE OF STEEL WITH METASTABLE AUSTENITE


Steels with metastable austenite belong to the TRIP steel class and possess a unique combination of strength and ductility properties [1-4].

In this work an investigation was made of the resistance to failure of a steel with metastable austenite, 36Kh9N7M4GS2 (0.36% C, 9.01% Cr, 6.95% Ni, 3.80% Mo, 1.21% Mn, 1.92% Si) under conditions of impact cyclic loading. After water hardening from 1170°C the billets were rolled into 11 x 40 mm bars on a *Duo-400* mill at 550°C in five passes with a total reduction of 60%. From the bar longitudinal samples (Fig. 1) with a gauge length diameter of 3 mm and a gauge length of 20 mm were cut for tensile testing and 10 x 10 x 55 mm ones with a notch with a depth of 2 mm and a radius of 1 mm for impact bend testing. The notches were made parallel and perpendicular to the rolling plane (Fig. 1, samples I and II, respectively). Low-cycle fatigue tests with a frequency of 626 impacts/min and a cycle asymmetry factor of R = 0 were made on a KPU-2 repeated impact machine using the method of [5].

The phase composition was determined by the x-ray diffraction method based on the known intensity of the (110) and (111) lines. In metallographic investigations, the relief method was used and also the method of staining the grain boundaries (heating the microsample at 500°C for 1 h with subsequent etching in 5% HNO₃ in alcohol).

After warm rolling and tempering at 200°C for 2 h the steel had properties of ρ₀.₂ = 1600 MPa, ρₜ = 2100 MPa, and δ = 19%.

The results of determination of impact strength of samples without a crack (a₁) and with a previously applied crack (a₀) and also the austenite content in the structure of the steel before testing and on the fracture surface after testing are:

<table>
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<tr>
<th>Type of sample</th>
<th>a₁/a₀, kJ/m²</th>
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<tbody>
<tr>
<td>I</td>
<td>110/750</td>
</tr>
<tr>
<td>II</td>
<td>620/240</td>
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</tbody>
</table>

Note: The original structure of the steel (before testing) contained 90-100% austenite and the fracture (after testing) 5-10%.

It may be seen that after warm deformation, 36Kh9N7M4GS2 steel possesses a high combination of mechanical properties.

The results of fatigue tests in impact cyclic loading of samples of 36Kh9N7M4GS2 steel are shown in Fig. 2. For comparison data for 30KhN2MFA steel (σ₀.₂ = 1560 MPa, ρₜ = 1760 MPa, δ = 12.9%, a₁ = 900 kg/m²), which possesses high

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resistance to impact cyclic loading [5], is shown. Over the whole investigated range of cyclic loads, the life of samples of 36Kh9N7M4GS2 steel is significantly higher than those of 30KhN2MFA steel. For example, with a maximum cycle load of 1300 MPa the life of samples I and II of the investigated steel is 3 and 1.5 times, respectively, greater than the life of samples of 30KhN2MFA steel. With an increase in maximum cycle stress, the difference in life of these steels increases. The different slopes of the fatigue curves is an indication of the fact that type I samples of 36Kh9N7M4GS2 steel are less sensitive to overloads than samples of 30KhN2MFA steel.

In making the fatigue tests, it was established that the character of propagation of cracks in samples I and II of the investigated steel is different (Fig. 3). For example, with a maximum cycle stress of 2600 MPa in type I samples the trajectory of fatigue crack development propagates at an angle of 60° to the direction of action of the load (Fig. 3a). In type II samples the direction of crack development coincides with the direction of application of the bending load (Fig. 3b).

It should be noted that with high cyclic stresses cracks in type I samples originate and propagate practically simultaneously in two directions to both sides of the notch. As a result of this, the effective load at the tip of each crack decreases. With relatively low cyclic stresses a crack in type I samples develops only from one side of the notch and the angle of its slope in relation to the direction of the applied load decreases. In type II samples the direction of crack development does not depend upon the amount of the cyclic stresses. Apparently this explains the increase in the difference in life of types I and II samples with an increase in cyclic stresses.

The difference in the character of development of a fatigue crack in types I and II samples, which leads to a change in the resistance of the steel to impact cyclic loading, may be explained as follows.

As a result of warm rolling, there occurs a definite orientation (texture) of the austenite grains and their form changes. Figure 4a-c shows the form of the austenitic grains in the planes A, B, and C (Fig. 1). The slip planes are located preferentially at small angles to the rolling plane (bands in Fig. 4a).

Plastic deformation in loading of a sample, accompanied by formation of martensite (in the fracture of the deformed sample only 5-10% austenite remains) and preceding crack development, occurs primarily in slip planes formed in warm rolling. In type I samples the crack development planes and slip planes practically coincide. A crack changes its direction at grain boundaries and under the action of a load changes from one level to another, as shown in Fig. 4d. In type II samples the failure surface is perpendicular to the slip planes and the direction of crack propagation coincides with the direction of the effective load.

To confirm this explanation, type I samples of 36Kh9N7M4GS2 steel were impact strength tested at 100°C (above the Md point). Since deformation martensite is not formed, the crack develops not in the slip planes but in the direction coinciding with the direction of effective load, as in type II samples.

Therefore, the features of fatigue failure of 36Kh9N7M4GS2 steel are caused both by the presence of the austenitic structure formed as a result of warm rolling and by the occurrence of the $\gamma \rightarrow \alpha$ transformation in loading.