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ESTIMATION OF THE IN-SERVICE DEGRADATION OF STEEL SHAPES FOR THE BOOM OF A CLAMP-FORMING MACHINE

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Comparing the mechanical properties of the angle-bar steel used in the framed structures of a clamp-forming machine after long-term operation with the initial state of the steel, we discover that its strength and plasticity do not undergo significant changes but the impact toughness became lower almost independently of the sign of variable stresses. To estimate the in-service degradation of properties, we apply the electrochemical approaches and show that the polarization resistance is a quite sensitive informative parameter.

Keywords: steel shapes, engineering state of structures, impact toughness, electrochemical methods, fractographic analysis.

As a result of the long-term operation of metal structures under severe force conditions and the action of corrosive media, one may observe not only the development of macrodefects but also a substantial degradation of the initial physicomechanical properties of the material and, in particular, the decrease in its brittle-fracture resistance [1–4]. Among the force factors, cyclic loading is especially dangerous [5] because, under this loading, microplastic strains are accumulated in the metal and, as a result, its brittle-fracture resistance becomes lower. Various types of lift-and-carry mechanisms operate under conditions of this kind [6]. Among these mechanisms, we can mention continuous machines used to perform different laying works. They serve as efficient means of mechanization in open mines for the extraction of mineral resources and for the bulk storage of agricultural production, in particular, sugar beets at sugar factories. These machines are equipped with boomlike structures kept at the required angle with the help of guy-ropes fastened to a cable-stayed support. A belt conveyer used to transport the weights is mounted on the boom.

In recent years , the problem of prediction of the degradation of mechanical properties of structural materials by the methods of nondestructive testing has become much more urgent. In [7–9], it is proposed to use for this purpose the electrochemical characteristics which prove to be sensitive to changes in the state of metals after long-term operation.

In the present work, we study the influence of long-term operation on the characteristics of strength, plasticity, and impact toughness of the steel of boom frame of a clamp-forming machine and the electrochemical behavior of the metal in order to select the informative parameters of changes in its state.

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Specific Features of the Experimental Procedures

We investigate the boom frame of a BUM-65M2B3-K clamp-forming machine made of an angle bar of ST3 steel 45 × 45 mm in size and study three states of the metal: (1) intact (for an element of the frame that was almost not subjected to the action of operating loads), (2, 3) after operation under the action of tensile and compressive cyclic loads. The specimens were cut out from a leg of the angle bar after operation whose moment of resistance was lower than the working bending moment. To determine the characteristics of strength and plasticity, we used plane specimens (2 × 10 × 40 mm in size) stretched at a rate of $3 \cdot 10^{-3} \text{sec}^{-1}$. The tests for the impact toughness KCV of Charpy specimens were carried out within the temperature range from room temperature to $-60°\text{C}$ by constructing the $KCV - T$ temperature dependences (curves of cold brittleness).

Mechanical Properties of the Steel

The fractographic features of the fracture surfaces after impact testing of specimens were investigated with the help of an EVO-40XVP scanning electron microscope. We determined the electrochemical characteristics (stationary potential E_{st}, corrosion current density i_{cor}, the density of limiting diffusion current i_d, and the Tafel constants b_{c} and b_{a} of the cathodic and anodic reactions, respectively) in a 0.3% NaCl aqueous solution by taking polarization potentiodynamic curves in an IPC-Pro potentiostat for a potential sweep speed of 1 mV/sec. We used a standard three-electrode temperature-controlled electrochemical cell with a saturated chlorine-silver reference electrode and an auxiliary platinum electrode. The temperature of the corrosive medium was equal to $22 \pm 1°\text{C}$. By using the graph-analytic method, the polarization resistance R_p was found according to the Stern–Giri equation [10]:

$$\frac{\Delta E}{\Delta i} = R_p = \frac{K}{i_{\text{cor}}},$$

where $K = b_{\text{a}} \dfrac{b_{\text{c}}}{2.3(b_{\text{a}} + b_{\text{c}})}$ is a constant.

As a result of operation, the characteristics of strength and plasticity of the metal undergo insignificant changes (Table 1). However, we observe a clear trend to decrease in plasticity. The indicated properties of the metal of elements after cyclic deformation by tension or compression did not exhibit any noticeable difference. It was found that the relative narrowing ψ is the parameter most sensitive to changes in the state of the metal.

Table 1. Mechanical Properties of Steel

No. of State	σ_{u}	$\sigma_{0.2}$	δ	ψ
	MPa		%	
1	434	305	31.9	72
2	436	295	28.1	64.4
3	450	298	28.0	58.2