IMPACT OF MATERIAL DEGRADATION ON THE RESIDUAL LIFE OF A COMPOSITE BIMETALLIC PLATE AT HIGH TEMPERATURE

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A mathematical model has been developed to calculate the remaining service life of a composite bimetallic plate, accounting for material degradation under high-temperature conditions. The model is based on a differential equation that describes high-temperature creep crack propagation and incorporates material degradation parameters. The residual life of a plate composed of 12H1MF steel and IN-100 alloy has been assessed.

Keywords: mathematical model, material degradation, composite bimetallic plate, high-temperature creep

Introduction. Material degradation in structural elements during long-term operation leads to the deterioration of their physical and mechanical properties, resulting in reduced strength and durability. Moreover, under complex service conditions, cracks may initiate and propagate within structural components, causing unpredictable failures. Although various well-developed methods exist for predicting the residual life of structural elements based on local damage, there is a lack of approaches that consider volumetric damage (i.e., material degradation), especially in heterogeneous components composed of different materials. Therefore, a computational model is proposed to evaluate the residual life of a composite bimetallic plate subjected to prolonged static loading and high-temperature conditions.

Model development. Considered in this study is a bimetallic plate with a rectilinear crack of initial length $2l_0$, subjected to a long-term external static load of intensity p under high-temperature conditions T (see Fig. 1.a). The plate consists of two half-planes, labeled 1 and 2, with similar elastic moduli but different mechanical properties. The load is applied perpendicularly to the crack line, resulting in a symmetric stress–strain state with respect to the crack location. During operation, the material of the plate degrades due to the propagation of a high-temperature creep crack. The objective is to determine the period of subcritical crack growth, after which the plate loses its functional integrity. The problem is solved using an energy-based approach [1].

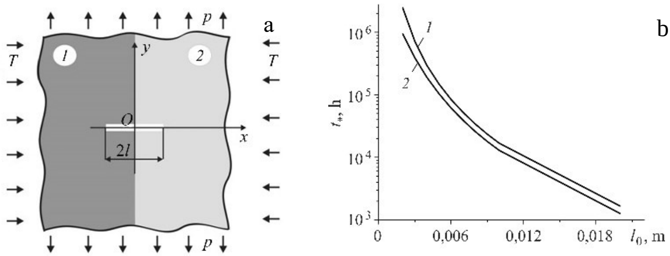

Fig. 1. a – Loading scheme of the composite bimetallic plate,
b – Residual life of the plate: 1 – with material degradation; 2 – without degradation.

The system of differential equations [1] defines the propagation kinetics and the subcritical growth period of the crack tips $l_1(t)$ and $l_2(t)$.

$$\frac{dl_i}{dt} = A_i(t_1)[K_{iI}(l_i)K_{iIC}^{-1}(t_1)]^{2m_i(t_1)}[1 - K_{iIC}^{-2}(t_1)K_{iIC}^{2}(l_i)]^{-1}, \quad (1)$$

$$t = 0, l_i = l_0, \ t = \ l_i, = \ l_{i*}, \ i = 1,2 \quad (2)$$

where A_i, m_i – characteristics of high-temperature creep of plates materials; K_{iIC} – crack resistance, $K_{iI}(l_i)$ – Stress intensity factor at the *i*-th crack tip, t_1 – degradation time.

Assumed that the plate consists of two infinite half-planes: the first made of high-alloy IN-100 alloy, and the second of 12H1MF steel, which undergoes degradation during operation. The material degradation parameters of the plate were chosen according to [1]. The mathematical problem (1), (2) was solved numerically. Fig. 1. b presents the graphical dependence of the plate's residual life on the initial crack length. Observed that degradation leads to a reduction in the residual life of the plate, especially for small initial crack sizes (Fig. 2, curve 2).

Conclusions. Based on the energy approach, a computational model has been developed to evaluate the effect of material degradation on the residual life of a composite bimetallic plate made of IN-100 alloy and 12Kh1MF steel. Mathematical models of material degradation were constructed using experimental data. The negative impact of degradation on the residual life of the plate has been identified.

1. *Andreikiv O.Ye., Dolinska I.Ya., Babii A.V., Liubchak M.O. Residual life of the folded bimetal plate taking into account degradation of materials at high temperature and under long-term loading // Mater. Sci. – 2025. – 60. – P. 650–656. https://doi.org/10.1007/s11003-025-00932-9*