LOW-CYCLE STRAIN WITH HOLDING OF STEEL OKh16N15M3B UNDER CONDITIONS OF REACTOR IRRADIATION


In the operation of nuclear reactors there occur complex, combined loading regimes of elements of the active zones owing to the nonsteady state of the temperature and force conditions of reactor operation. Such regimes are, as a rule, characterized by repeated elastoplastic deformations and creep (relaxation) accompanying them in the strain cycles [1].

The present work submits the results of investigations of the resistance to simultaneous cyclic and static loading of stainless austenitic-class steel OKh16N15M3B; these tests were carried out for the purpose of evaluating the influence of reactor irradiation and holding in cycles on the nature of the strain of steel. The test temperature was 923°K. The experiments were carried out in channel No. 6 of an SM-2 reactor (Dimitrovgrad) with an installation "Neitron-5" [2]. Tests without irradiation were carried out on the same installation, with the specimens being heated in an electric resistance furnace.

The thin-walled cylindrical specimens were subjected to completely reversed elastoplastic strain in rigorous regime involving holding at the maximum parameters of the half-cycle. The length of holding in a half-cycle was 5 or 30 min.

Practically any element of a real structure under conditions of creep is connected with other elements which may be deformed only elastically [3]. Thus, under conditions of real operation, material in zones of stress concentration upon holding at high temperature operates as a rule, in an intermediate regime between creep and relaxation, where as a result of the manifestation of rheological and fatigue properties there occurs stress and strain redistribution, both at the time of separate loading and with increasing number of cycles. Such loading conditions can be reproduced on testing devices with an elastic link. In our case the tests were carried out on an installation "Neitron-5."

According to the technical conditions of carrying out in-reactor experiments, the loading and measuring units were situated at a considerable distance from the test specimen [2], and therefore the elements connecting the specimen, the measuring and loading unit have finite rigidity, and during the process of testing the specimen they can be deformed in the elastic range.

Figure 1a shows a diagram of loading a specimen. The force is applied at point A, the measuring unit recording the strain and load is situated at point B. Specimen 1 and the elastic elements 2 and 3 connecting it with the measuring and loading units have rigidities \( C_1 \), \( C_2 \), and \( C_3 \), respectively.

Upon application of force \( P_o \) (point B in Fig. 1b), the loaded chain is deformed by \( \Delta_{III} \), equal to the sum of the deformations of the specimen and of the elastic elements:

\[
\Delta_{III} = \Delta_1 + \Delta_2 + \Delta_3.
\]

Here, the specimen is deformed in the elastoplastic range, and the connecting elements in the elastic range:

\[
\Delta_1 = \Delta_{te} + \Delta_{tp} = \frac{P_o}{C_1} + \Delta_{tp};
\]

\[
\Delta_2 = \Delta_{se} = \frac{P_o}{C_2};
\]

\[
\Delta_3 = \Delta_{sp} = \frac{P_o}{C_3}.
\]

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where $\Delta_0$ and $\Delta_p$ are elastic and plastic strain, respectively.

In the stress–strain diagram (see Fig. 1b), the joint deformation of the specimen and of element 2 is recorded:

$$\Delta_{II} = \Delta_1 + \Delta_2 = \Delta_{1p} + P_0 \left( \frac{1}{C_1} + \frac{1}{C_2} \right) = \Delta_{1p} + \frac{P_0}{C_{II}}.$$  \hspace{1cm} (5)

The sum of the elastic strains of the specimen and of element 2 is expressed by the line segment $\Delta_{11}$, and the tangent of angle $\alpha$ corresponds to the total rigidity of the specimen and of element 2:

$$\frac{1}{C_{II}} = \frac{1}{C_1} + \frac{1}{C_2}.$$  \hspace{1cm} (6)

If the loading unit is locked after the load $P_0$ has been attained, then the accumulation of creep deformation in the specimen $\Delta_{III}$ will cause redistribution of stresses and strains in the loading chain with unchanged total deformation $\Delta_{III} = \text{const}$, i.e., the process of creep (relaxation) proceeds according to the arrangement with an elastic element.

Within time $t$ the force in the chain changes up to the value $P_L$ (in Fig. 1b it is point $B''$). Then

$$\Delta_{III} = \Delta_{1p} + \Delta_{in} + \frac{P_L}{C_1} + \frac{P_L}{C_2} + \frac{P_L}{C_3}.$$  \hspace{1cm} (7)

If we equate Eqs. (1) and (7), we obtain:

$$P_0 - P_L = C_{III} \cdot \Delta_{in}$$  \hspace{1cm} (8)

where

$$\frac{1}{C_{III}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$  \hspace{1cm} (9)

Thus the load during the relaxation process decreases proportionately to the accumulated creep deformation, and the proportionality factor is equal to the total rigidity of the specimen and the installation.

We determine the magnitude of $\Delta_{B'B''}$:

$$\Delta_{B'B''} = \Delta_{B'} - \Delta_{B''} = \Delta_{1p} + \Delta_{in} + \frac{P_L}{C_{II}} - \Delta_{1p} - \frac{P_0}{C_{II}} + \frac{P_0 - P_L}{C_3}.$$  \hspace{1cm} (10)

Hence follows that the tangent of angle $\beta$ corresponds to the rigidity of element 3. In real test installations the magnitude of $C_3$ is, as a rule, limited by the rigidity of the load transducer. In investigations at places where access is difficult, the rigidity of the machine is somewhat reduced on account of the lengthening of pull rods, and also in consequence of their smaller transverse dimensions, etc.

Thus, during the holding process in tests on the installation "Neitron-5," the specimen is in a regime that is intermediate between creep and relaxation, and this corresponds to real operating conditions of structural elements.

A distinguishing feature of the operation of elements of the active zone of reactors is the change of the mechanical properties of materials under the effect of irradiation in consequence of accumulated radiation damage. Radiation damage causes changes of the short-term properties (yield point, strength, change of the shape of the stress–strain diagram) and of the long-term mechanical properties (creep characteristic, long-time strength, ductility). The processes accompanying the effect of irradiation are very complex. The task of radiation materials science [4] is detailed examination of the questions, "which kinds of radiation defects in particular and in which way change the long-term and short-term mechanical properties?"

Earlier it was pointed out that reactor irradiation has a strengthening effect on the resistance to cyclic elastoplastic strain of steel 0Kh16N15M3B at 923°K, both in the case of the initial loading and on the section of stabilization of the loop [5]. With increasing flux of the preceding irradiation, the degree of strengthening of the steel increased. Holding times somewhat change the kinetics of stabilization of the loop of elastoplastic hysteresis,