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SERVICEABILITY ESTIMATION OF FAST REACTOR EQUIPMENT FASTENER METAL

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ABSTRACT

The fast reactor service life estimation is possible on the base of metal serviceability investigation of high loaded components with the consideration of their radiation embrittlement, including threaded fasteners. In this case, structural materials, changing their properties in the temperature range of 623-773K by high values of fast neutron fluence (up to 10^{23} n/cm^2) are of particular interest. The traditional methods of metal serviceability estimation under as-produced and irradiated conditions without taking into account the pecularities of strain-stress state in the thread of fasteners do not permit to evaluate for certain the residual service life of reactor equipment threaded joints.
A complex of experimental investigations is presented for irradiated and model fastener materials under the conditions of short-term static and low-frequent cyclic loading of the stud-nut joint.
A calculated-experimental procedure is suggested to estimate low cycle fatigue for threaded joint with regard for loading redistribution along the screws of the thread. This method permits to define the residual service life of threaded unit metal with regard for the fluence value and high temperature irradiation effect on strength and ductility of fastener materials.

1 INTRODUCTION

The problems of nuclear reactor development and operation are associated with the provision of safety and lifetime of high loaded equipment elements. These problems are valid for threaded joints of fast reactor equipment. In the past, metal properties estimation before and after operation was carried out, basing on the test results of smooth and notched specimens on static and cyclic strength. It did not permit to define precisely the residual service life of threaded joints for reactor equipment.
Because of the difficulties to predict the behaviour of fastener metal, which is subjected to radiation and is in the unit of threaded joint, the serviceability estimation is possible by the solution of two problems.

The solution of the first problem is associated with the simulation of radiation hardening and embrittlement of fastener metal, consisting of high temperature austenization, cold work hardening and aging.
The solution of the second problem is associated with direct calculated-experimental estimation of service life of fastener metal, produced from the precipitation hardening Fe-Ni alloy (XH35BT) in various condition (as produced and with regard for dose loading) , by low cycle fatigue loading of stud-nut joint in the temperature range of 20-500°C.

2 INVESTIGATED MATERIALS

The experiments were performed on the Fe - Ni precipitation hardening XH35BT alloy. Table 1 gives its chemical composition and mechanical properties at 20°C.

Table 1

Element	Chemical composition, weigth %: investigating	Chemical composition, weigth %: GOST 5632-72
Carbon	0.06	< 0.12
Silicon	0.35	< 0.60
Manganese	1.50	1.0-2.0
Chromium	15.10	14.0-16.0
Nickel	35.60	34.0-38.0
Titanium	1.35	1.1-1.5
Tungsten	3.12	2.3-3.5
Sulphur	0.01	< 0.02
Phosphorous	0.01	< 0.03

Mechanical properties at 20°C

Yield strength MPa	Ultimate strength MPa	Elongation %	Reduction in area %
490	790	34.3	65.8

The irradiation parameters for XH35BT alloy (fast neutron fluence E > 0.1 Mev) are presented in table 2.

Table 2

no.regime	Material	$F, n/cm^2$	T_{Na}, °C	Capacity of reactor, MWt
1	XH35BT	5.7×10^{21}	450 - 500	5
2	XH35BT	3.7×10^{22}	390 - 400	60

Figure 1 illustrates the dependence of XH35BT alloy mechanical properties on neutron fluence value in the temperature range of 20-500°C.
The simulation of radiation by fast neutron fluence included the following steps:

- heat treatment of samples at 1250°C,
- plastic deformation by tension 25 - 40 %,
- aging.

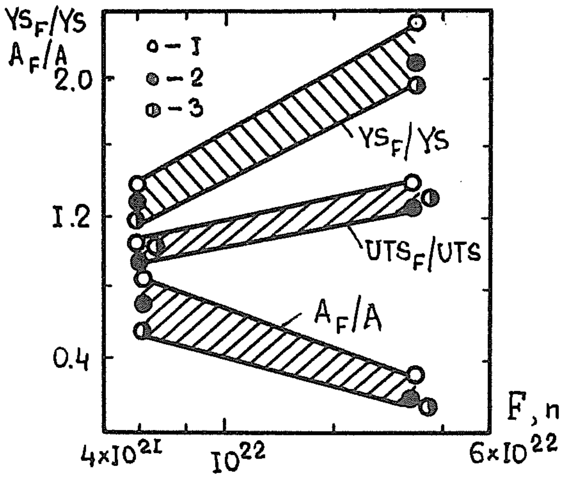

Fig. 1. The dependence of XH35BT alloy mechanical properties on neutron value: 1-3 - T_{Na}= 20, 350 and 500°C, respectively.

The developed simulation regimes of irradiated state permitted to obtain a satisfactory conformity on the level of mechanical properties. It should be noted, that the simulation of irradiation regime no.1 permitted to obtain identical strength and decreased ductility (it guarantees margin on threaded joint low cycle fatigue). In the case of irradiation regime no.2, the yield strength is 20% less, and the characteristics of strength and ductility are practically the same.

3 TESTING PROCEDURE

The tests of threaded stud-nut joints (M10 diameter) were performed in the machine with electrohydraulic drive at 20, 350 and 500 °C by the control of loading range. The frequency of cycles was equal to 0.1 Hz. The tests were carried out to complete nut failure along the thread of the first screw in the engagement with a nut.

4 STRESS CONCENTRATION FACTOR IN A THREAD

The stresss concentration factor in a thread (α_H) requires, that a great number of thread parameters should be taken into consideration. Therefore, the definition of becomes complicated. In the investigation (Gorynin et al, 1986) the dependence of α_H on the relations D, P and ρ are diameter, pitch and radius of thread hollow, correspondingly (Fig.2). This correlation permits to define the values of for the metric thread of various geometry to the critical case, when $\rho \rightarrow \infty$ and $\alpha_H \rightarrow 1.0$.

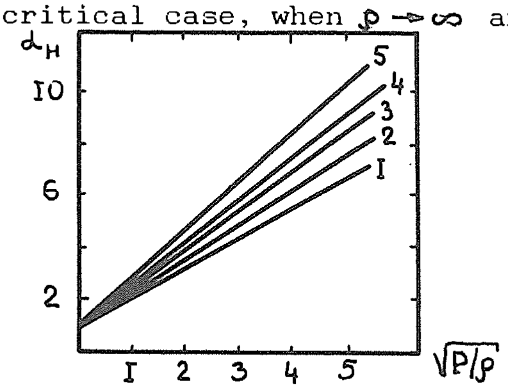

Fig.2. The dependence of stress concentration factor in thread on the relations D/P and $\sqrt{P/\rho}$:
1-5 - D/P = 8; 16; 24; 32 and 40, respectively.

As an example, let us consider value α_H in a stud thread M10x1.5 (1.5 - thread pitch) in the compaund with a nut. The parameters of thread geometry are the following: D = 10mm, P = 1.5mm, ρ = 0.20mm. Hence, we obtain P/p = 2.75 and D/P = 6.67. From Fig.2 we obtain α_H = 3.94. For the fastening of reactor equipment studs of the diameter M20 - M30 are applied. By D/p = 8.0 - 8.6 and $\sqrt{P/\rho}$ =2.7 -2.8 α_H = 4.2 - 4.3, and it is 7 - 10% greater, than for the joint M10x1.5.

5 LOW CYCLE FATIGUE RESISTANCE OF THREADED JOINT WITH REGARD FOR METAL CONDITION

The test results are given in Figure 3. It is evident, that radiation attack on fastener metal results in the reduction of threaded joint lifetime by low frequency loading. It should be noted, that A_F/A and YS_F/YS increase for the simulation of 5.7×10^{21} n/cm^2 fluence does not practically decrease the threaded joint lifetime. By the simulation of fastener metal condition by the attack of 3.0×10^{22} n/cm^2 fluence, the threaded joint lifetime is decreased by all test temperatures (especially at 500°C). It is associated with the fact, that the simultaneous decrease of metal strength and ductility is taking place.

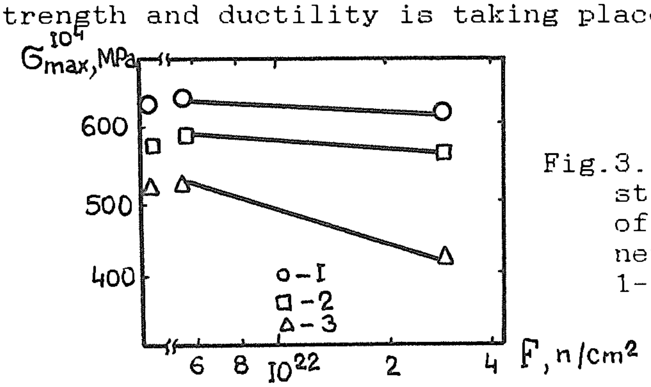

Fig.3. The dependence of fracture stress amplitude, on the base of 10^4 cycles to failure on neutron fluence:
1-3 - T_{Na}= 20, 350 and 500°C, respectively.

6. CALCULATED AND EXPERIMENTAL ESTIMATION OF THREADED JOINT SERVICEABILITY WITH VARIOUS FASTENER METAL DAMAGE,INDUCED BY IRRADIATION

In view with the absence of data about the XH35BT alloy behaviour with regard for its damage as the result of various thermo-radiation attack by operation, the definition of stress and strain concentration factors was performed on approximate formulas.

The stress concentration factor in elastic-plastic field defined from the expression:

$$K_\sigma = YS \, / \, (\sigma_a)_{np} ,$$

where $(\sigma_a)_{np}$ - amplitude of reduced stresses.

The strain concentration factor was defined from the correlation

$$K_\sigma = \alpha_H \, / \, K_\varepsilon ,$$

where K_ε - strain concentration factor or its value with regard for loading redistribution on thread screws by elastic-plastic loading.

The amplitude of local strains in the thread by a low frequency tensile cycle was defined with the expression

$$\bar{e}_{aM} = \bar{e}_{anp} \cdot K_\varepsilon ,$$

where $\bar{e}_{anp}$ – amplitude of nominal strains was defined from the correlation

$$\bar{e}_{anp} = \sigma_{nom}/2E,$$

where $\sigma_{nom} = \sigma_{max}$ for cyclic "mild" loading,
E – modulus of normal elasticity.

The calculaions of local strain amplitudes in the hollow of the first screw of threads were conducted with the consideration of loading redistribution on thread screws of a stud/nut joint by the introduction of the correction – the coefficient of non-uniform distribution of loading.The obtained results are given in Figure 4. It is shown, that in the case of as-produced metal condition and stud metal,simulating XH35BT alloy strengthening after 5,7x10^{21} n/cm^2 fluence attack, the calculated-experimental amplitude values correspond to experimental data, obtained for smooth specimens from the experiments Lava and Koistra (Forrest 1968).

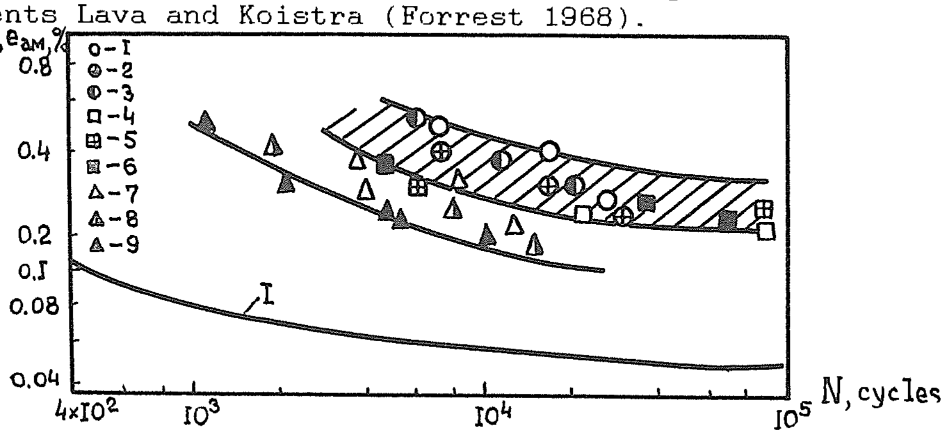

Fig.4. The dependence of local strain amplitude in the stud thread on the number of loading cycles of threaded joint in the temperature range of 20-500°C:
I – calculated curve for XH35BT alloy with the consideration and carburizing sodium effect.
(1, 4, 7) – T = 20°C; (2, 5, 8) – T =350°C; (3, 6, 9) – T = 500°C; (1-3) – F= 0; (4-6) – F = 5.7x10^{21} n/cm^2 ; (7-9) – F = 3x10^{22} n/cm^2 .

The amplitude values for XH35BT alloy, simulating embrittlement by 3,0x10^{22}n/cm^2 fluence attack at 500°C are lower by 50-60%, than experimental values for smooth specimens, as related to the low boundary of scatter band for lifetime 10^3- 5x10^4 cycles.

The calculated-experimental estimation analysis of threaded joint lifetime and calculation fatigue curves for XH35BT alloy by a symmetrical cycle (Norms of calculation on strength, 1989) showed, that threaded joint serviceability by low-frequency cyclic tension by T=500 °C (stud metal,simulating embrittlement after the irradiation by 3x10^{22}n/cm^2 fluence) was provided. Safety factors on local strains were equal to 3,75 and 2,50 for 10^4 and 5x10^{4}cycles to fracture, respectively.

Conclusion.

1. The effect of irradiated fastener metal on the threaded joint stud-nut, made from the model alloy XH35BT was experimentally studied in the temperature range of 20-500°C. It was shown, that the minium joint serviceability took place by luence $3x10^{22}$ n/cm^2 effect simulation at 500°C.

2. A simple calculated-experimental procedure to estimate strain concentration in the hollow of the thread of studs with regard for loading redistribution on the screws of the joint thread was suggested.

3. It was established that reactor equipment threaded joints in the case of the maximumally embrittled metal (fluence - $3x10^{22}$ n/cm^2) has a sufficient residual service life.

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