EVALUATION OF FAILURES PROBABILITY FOR HIGH FLUX RESEARCH REACTOR VESSEL AND RELATED METALLURGICAL PROBLEMS

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Increased interest in calculations of failures probability of the reactors equipment has recently arised concerning mainly to ensure the safe exploitation nuclear power stations [1, 2]. Nevertheless this problem may be also urgent for the same high flux research reactors as PIK (Gatchina, PNPI). Its vessel, manufactured from stainless steel (similar type 304), is a cylindrical pipe (diameter 400 mm, wall thickness 8 mm), water pressure 4.9 MPa. The density of a fast neutron flux ($E > 0.1$ MeV) on the surface of the vessel $\sim 10^{15}$ n/cm^2·s. A fast neutron fluence after two years of operation is $\sim 4 \cdot 10^{22}$ n/cm^2. A change of mechanical properties is considerable [3] (see Table).

Table

neutron fluence	ultimate tensile strength	yield strength	uniform elongation	narrowing
n/cm$^2 \cdot 10^{-22}$	MPa	MPa	%	%
0	500	275	41.5	78
5.3	720	675	26.0	59

Approximate number of loading cycles per year — 50. Stress state arises from pressure (membrane stress $\sigma^p = 122$ MPa) and from unevenness of temperature distribution (local thermal stress $\sigma^t = 450$ MPa).The sum of membrane stress and symbolic thermal stress becomes less than yield stress ($\sigma^{P+t} = 572$ MPa $< \sigma_Y = 675$ MPa) after one month of the reactor's work at a power. Initial safe defects receive possibility of increasing and may turn out to be dangerous as a centre of the following rapture. A fabrication ultrasonic control showed confidently absence of defects with dimensions $a = 0.5$ mm and $2c = 20$ mm , where a and $2c$ are axes of semi-elliptic shape (Fig.). Numerical calculations of dimensions increasing have been performedfor this initial defect in accordance with Paris equation [4] taking into account thermal stresses through the walls thickness (see curve 1 on the Fig.). Critical dimensions a and c for the crack of the same shape in accordancewith two alternative modes of failure: 1) plastic collapse and 2) unstable crack tearing failure [4, 5, 6] have been calculated. These calculations have been performed for membrane stress $\sigma^P = 122$ MPa and for sum $\sigma^P + \sigma^t = 572$ MPa. All these curves are shown in fig.1. The points of curve 1 intersection with corresponding curves 2,3,4 determine critical dimensions. The critical partthrough cracks reach the opposite side of the wall with high velocity and change into the through cracks with the same length $2c$. The following behaviour of the crack depends on the critical length for the same stress state. If the length of just now formed through crack is bigger than critical value, the large scale break takes place, otherwise we have only leak. It is evident that real critical dimensions are between above mentioned values for two types of failure and apparently will realize the situation "leak before break".

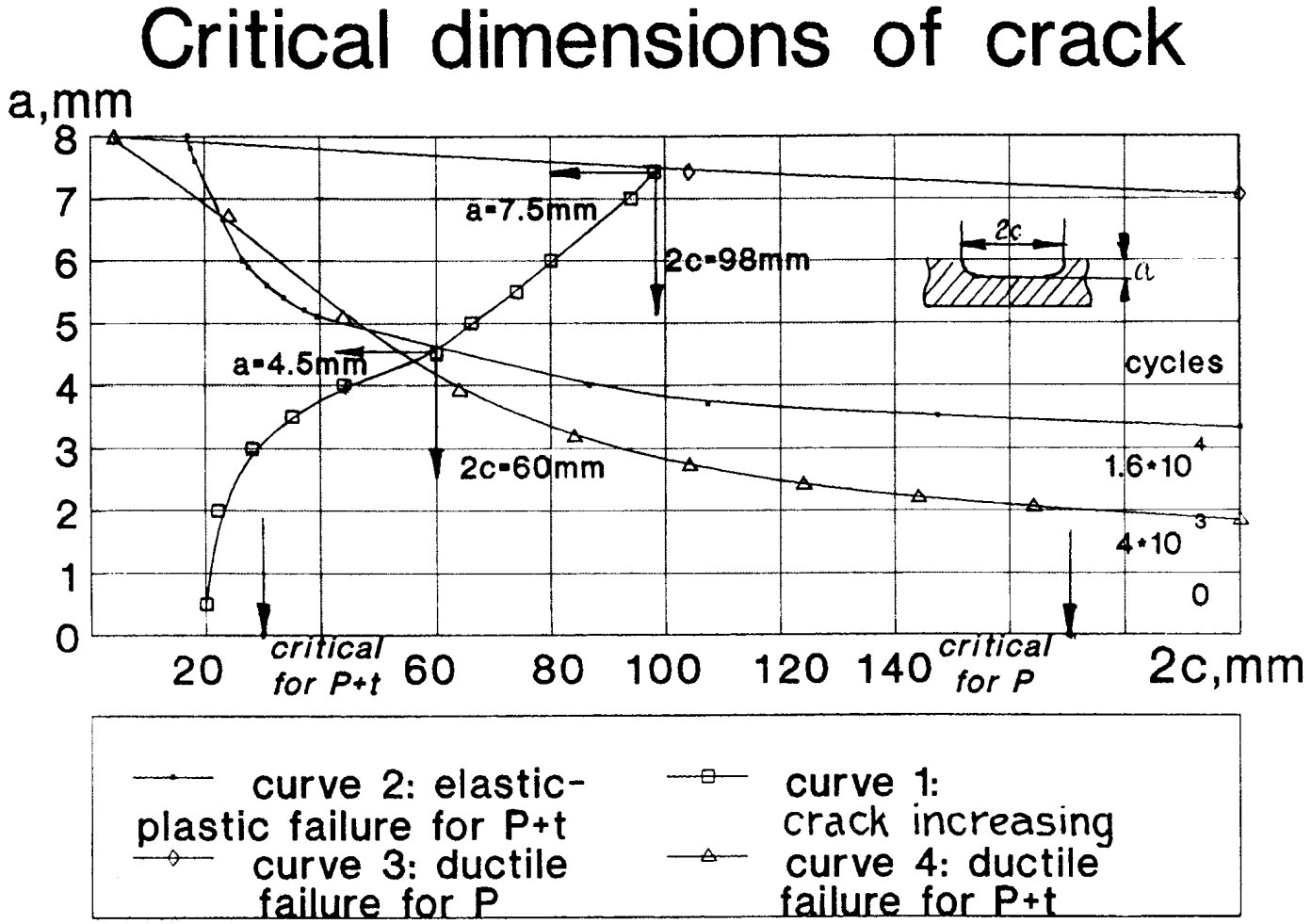
Critical dimensions of crack
a,mm
8
7
6
5
4
3
2
1
0
a=7.5mm
2c=98mm
a=4.5mm
2c=60mm
2c
a
cycles
1.6•10^4
4•10^3
0
20
critical for P+t
60
80
100
120
140
critical for P
2c,mm
curve 2: elastic-plastic failure for P+t
curve 1: crack increasing
curve 3: ductile failure for P
curve 4: ductile failure for P+t

Fig.

Conservative evaluation of failures probability have been calculated according to [1, 7] by means of overlap of probability density functions for actual and critical crack length. It was proved that there is a group of defects inside the vessels wall with depth 4,5 mm and length values are distributed in accordance with normal probability distribution $f(2c)$ with mean value $2c = 20$ mm and dispersion 4 mm. The second supposition is that critical length values are distributed in accordance with normal distribution $f(2c_{cr})$ with mean value $2c_{cr} = 60$ mm and dispersion 7 mm. According to [7] the probability of failure is identified by actual crack length equal to critical crack length and may be written as

$$P_f = \int_{-\infty}^{\infty} f(2c) \left(\int_{\infty}^{2c} f(2c_{cr}) dc_{cr} \right) dc.$$

The calculated value $P_f = 4 \cdot 10^{-7}$ per year is in conformity with atomic inspection standards It is necessary to perform experiments to confirm reality of the above mentioned values of critical and actual crack dimensions.

The necessery results of calculation carried out by institutes NIKIET(Moscow) and "Prometey"(St.Petersburg) were used in this report.

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