IRRADIATION EMBRITTLEMENT OF REACTOR PRESSURE VESSELS OF WWER 440/V230

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The problem of irradiation induced shift in ductile/brittle transition temperature of weld metal of reactor vessel WWER 440 /V230 is discussed. Experimental date for chemical coefficient of irradiation embrittlement of reactor pressure vessel (RPV) in active power water reactor (PWR) are compared with the values obtained from different autor's relations. The correctness of these relations is estimated and conclusions about their applicability are made.

INTRODUCTION

The neutron irradiation embrittlement is the main ageing mechanism of the reactor pressure vessel (RPV) determining to a great extend the reliability and safety of nuclear power plants. Macrostructurally this appears as hardness and yield stress increase and fracture toughness decrease. Ductile/brittle transition temperature (Tk) determined by means of Charpy-V impact testing, has been used for the quantitative evaluation of steel embrittlement. Standards of different countries define this temperature at different levels of absorbed energy of fracture. The soviet standard (1) has been used in evaluating Tk of WWER440/V230 RPV. Unfortunately, no surveillance specimens have been provided.The aim of the present work is to compare the values of shift (ΔTF) of Tk calculated by different models. Basic parameters of 3rd unit in Kozloduj nuclear plant have been used.

RESULTS AND DISCUSSION

The irradiation embrittlement of RPV depends on the nature and purity of material used, the irradiation conditions and on the parameters of the neutron spectrum,Alekseenko et al (2). Maximum embrittlement occurs in

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the weld metal locate opposite the core zone where the effect of thermal and fatigue ageing is negligible,Havel (3). The values at 60 J/cm is recognized in (1) as the measure of critical temperature of embrittlement (Tk). In this case the Tk of irradiated material is presented by:

$$Tk = Tko + \Delta TF \quad (1)$$

$$\Delta TF = AF\ (F/Fo)^{0.33} \quad (2)$$

where Fo = 10^{22} n/m^2 , AF-chemical coefficient. For calculating the AF values, the literature suggests several equations:

ref.(1) AF(270°C) = 800(%P + 0.07 %Cu) (3)
ref.(4) AF(265°C) = 1200(%P + 0.1 %Cu) - 16 (4)
ref.(4) AF(285°C) = 600(%P + 0.1 %Cu) -1.5 (5)
ref.(5) AF(270°C) = 600(%P + 0.1 %Cu) (6)
ref.(6) AF(270°C) = 24 + 1537(%P - 0.008) + + 238(%Cu - 0.08)+ 191%Ni %Cu (7)

where %P, %Cu and %Ni are concentration of the impurity elements. Relation (2) is valid for all these equations with the exception of the last one (7),where the relation with fluence is expressed by (F/10Fo)in range 0.35. To assess the applicability of the various methods for calculating AF in table 1 the calculated AF values are compared with the little experimental data specified in the open literature. The relative difference between them is given in rel.%.

Table 1 - Comparison of calculated and experimental values of AF

ref.	T°C irrad.	F x10^{-22} n/m^2	AF exp.	AF eq.(3)	AF eq.(4)	AF eq.(6)
(4)	265	6	31.5	27.8 12%	30.8 3%	23.4 25%
(5,7)	270	45	40.5	35.5 12%	41.6 2%	28.8 29%
(7,8)	270	46.5	35.5	34.3 2%	41.6 17%	28.8 19%
(3)	250	25	55.4	40.5 19%	50.1 9%	33.0 40%

The results in table 1 show that neither of presented calculation techniques is universal. Also there is not sufficient repeatability in the experimental data themselves (4). Lowest deviation from the experimental data show the results from eq. (4). The AF values for RPV Kozloduj 3, calculated by means of different methods are compared in table 2 and trend curves of respective Tk values depending of years of operation are shown in figure 1. The fact that neutron fluence decreases with a coefficient of 0.855 at 1/4 wall depth is taken into account in Tk calculation.

TABLE 2 - The calculated values of AF for weldment 4 - Kozloduj 3

equation	(1)	(4)	(4)'	(6)	(7)	design
AF	40	51	46	34	97	13

It follows that the use of various AF calculation methods leads to different life times of pressure vessel which vary in a wide range. Interesting is the fact that eq.(7) which has been derived for other reactor PWR types, leads to results close to those obtained from eq.(4) interpolated towards 270°C -(4)'. It is possible to make only an approximate error estimation in determining ΔTF. Thus for the year 2005 ΔTF will be 113°C $\pm$ 19°C if the error in determining of P and Cu is 0,001 wt% and 0,01 wt% respectively, the error of method (1) is 10 rel.% and the error in fluence calculating is 15 rel.%.

On this basis it can be concluded that annealing of RPV of unit 3-Kozloduj carried out in 1989 has been imperative.It is necessary to get more experimental data about the materials of the operating nuclear plant reactors.For the safe and reliable operating of the reactor it is necessary to determine directly the chemical composition and mechanical properties of the metal of welding 4 by investigating templets taken from the pressure vessel material.

SYMBOLS USED

Tk = ductile/brittle transition temperature (°C)
Tko = ductile/brittle transition temperature before irradiaton (°C)
TKA = critical transition temperature calculated by design (°C)
ΔTF = irradiation induced shift of transition temperature (°C)
AF = chemical coefficient of embrittlement
ΔTKA= allowable shift of Tk by design
F = fluence (n/m^2)

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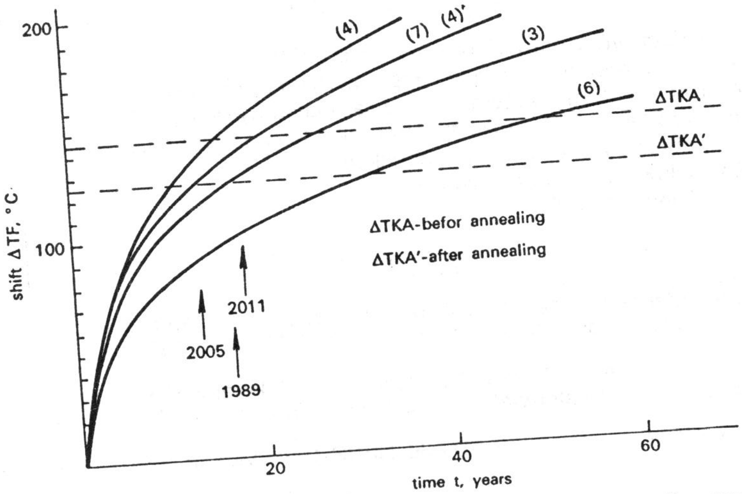

Fig.1. Tk (°C) of function of the operating time (years) calculated by means different equations.