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DEFECT ACCEPTANCE RULE FOR IN-SERVICE INSPECTIONS IN NUCLEAR POWER PLANT

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1. INTRODUCTION

Every ten years, French Nuclear Steam Supply systems must be subjected to in-service inspections and hydrotests.

Since these inspections are now frequent, the national french utility EDF has decided to set up rules for these inspections, the R.S.E.M. rules or rules for in-service surveillance of components.

Among the rules included in the R.S.E.M. are the rules concerning the in-service inspection methods allowing to detect defects and to measure their sizes. When a defect is discovered and characterized, its size is compared to acceptance standards which have been defined in a cooperation between EDF and FRAMATOME.

A first paper was presented on these standards at the 10th SMIRT Conference in 1989 [1].

During the last years, the methods have been extended and improved ; the set of data available for determining the standards has become larger and more accurate ; new standards have been defined and will be introduced in the R.S.E.M.

The new methods include :

- new method for surface crack propagation assessment,
- new methods for propagation and stability evaluation of embedded defects,
- new method for analyzing defect interaction,

The new data are concerned with :

- minimum material toughness (small changes),
- crack propagation laws for embedded defects,
- fatigue damage level.

This paper will cover :

1) the evolution of the methods,
2) the evolution of the data,
3) the evolution of the standards.

2. METHOD FOR PREDICTING THE CRACK PROPAGATION

2.1. definition of the propagation parameter P

The crack propagation is supposed to be predictable by the Paris Law on each axis of an elliptical crack :

$$\frac{da}{dN} = C\left(\frac{\Delta Ka}{f(R)}\right)^n \qquad \frac{dc}{dN} = C\left(\frac{\Delta Kc}{f(R)}\right)^n \qquad (1)$$

$$R = \frac{Kmin}{Kmax} \qquad \Delta K = F\left(\frac{a}{t}, \frac{a}{c}\right)\Delta\sigma\sqrt{\pi a} \qquad (2)$$

Where t is the thickness of the component.

We consider a small amount of crack propagation where the crack depth a grows from a_o to $a_o + \Delta a$ during a time duration ΔT. The parameter P is defined as :

$$P = \frac{1}{\Delta T.F^n}\left[\frac{1}{a_o^{\frac{n}{2}-1}} - \frac{1}{(a_o + \Delta a)^{\frac{n}{2}-1}}\right] \qquad (3)$$

2.2. P can be used to assess the maximum fatigue level in the component

It can be demonstrated that P is independent of the crack shape and of the time interval but depends on the loading conditions imposed on the component. In each component, a set of values of P can be determined from the set of available crack propagation analyses ; the largest value of P, Pmax, can often be considered as the maximum possible value of P for the component.

2.3. Assessment of the propagation of any crack

The equation (3) can be transformed into a differential equation giving $\frac{da}{dT}$ or $\frac{dc}{dT}$ as a function of $\frac{a}{t}$ and $\frac{a}{c}$. P is assumed to be equal to Pmax.

From the equation, can be derived the crack growth of any surface defect in the component.

The propagation of an embedded flaw can be calculated as the propagation of an appropriate equivalent surface flaw having an appropriate propagation parameter P.

3. METHOD FOR STABILITY ASSESSMENT OF EMBEDDED DEFECTS

The stability criterion is based on the crack driving force J. The requirement is $J < \alpha.J_{1C}$. In normal + upset conditions, the safety coefficient α is taken smaller than 1, so that crack initiation is surely prevented, and J is calculated from the primary plus secondary stress range (Pm + Pb + Q).

In faulted conditions, a small amount of crack initiation by ductile tearing is allowed and α may be greater than 1, J is calculated from Pm and Pb.

The method for assessing J integral for any semi-elliptical surface crack was presented in [1].

A new method has been developed for calculating J_e for any two dimensional embedded flaw subjected to a uniform stress. The J_e value can be compared to the J_s value for a two dimensional surface crack of the same depth in a component of thickness t_s. t_s can be determined such that the J_e value be equal or smaller than the J_s value.

The equivalence of internal and embedded defects is supposed to be valid also for semi-elliptical and elliptical defects with the same large axis c.

4. METHODS FOR DEFECT INTERACTIONS

The defect interaction plays a role in both crack propagation and in crack stability.

A method has been set up in order to take into account defect interaction in propagation assessment. It uses the P parameter defined by (3). The differential equation derived from (3) is used with a F shape factor taking into account conservatively the variable distance between the defects.

The stability of interacting defects is evaluated after crack propagation assessment in two steps. The first step consists in demonstrating that each crack supposed to be only one is acceptable. The second step consists in verifying that the effect of the interaction on the stress intensity factors in negligible.

5. EVOLUTION OF THE MATERIAL DATA

A very important evolution in the material data consisted in taking into account the effect of the vacuum environment in the crack propagation laws for embedded flaws.

6. EVOLUTION OF THE PROPAGATION PARAMETER P

The number of available crack propagation analyses has increased. This permitted to extend the set of P values and to define more accurately the Pmax values for all the components.

The new set is only slightly different from the first one.

7. EVOLUTION OF THE RSEM RULE

The work presented in this paper will allow to improve the present RS.E.M. acceptance rule.

7.1. The end of life acceptable surface crack will be slightly modified ; the crack propagation rate for c>> a defects will be more accurately calculated and largely reduced in the new approach.

7.2. Realistic rules for embedded defect will be defined. They will take into account properly both crack propagation and crack stability.

7.3. A new simplified rule for taking into account crack propagation in the crack interaction will be defined.

CONCLUSION

The R.S.E.M.standards have been defined from improved and sophisticated Fracture Mechnics methods and from a large data set : the defect stability assessment is based on the elastic-plastic J criterion ; a special method has been defined for calculating the maximum possible crack growth in any component ; it uses large propagation data set. Special rule for defect interaction analysis have been defined.

Though the R.S.E.M. standards are based on sophisticated Fracture Mechanics methods, they are not more difficult to use than current standards.

The consequence of the appropriateness of the methods is that the standards have been set up to take into account the main physical processes having influence on the defect behaviour ; they will be surely conservative and will tend to increase plant reliability and plant safety.

REFERENCE

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