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Assessment of σ_d approach for creep damage estimation of FBR components with crack like defects at welds

P. Chellapandi*, S.C. Chetal, Baldev Raj

Indira Gandhi Center for Atomic Research, Kalpakkam-603 102, India

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Abstract

The creep damage estimation procedure provided in RCC-MR: Appendix A16 which is based on the σ_d approach, is investigated by predicting the creep crack initiation life of two pre-cracked standard CT specimens machined from welded austenitic stainless steel plates, subjected to constant axial loading. The analysis indicates that the present version of A16 over-predicts the life. Hence, modifications are suggested for A16 including the effects of the hydrostatic stress component, after numerical investigation. The improved procedure predicts the experimental creep initiation life reasonable closely. Based on the investigations, RCC-MR: A16 may consider the revised procedure to estimate the creep damage of structures with geometrical singularity.

Keywords: Fast breeder reactor components; RCC-MR; A16; Crack like defects; Creep crack initiation life; σ_d Approach; CT specimen; Neuber's rule; Elastoplastic fracture mechanics

1. Introduction

Nuclear components which perform important safety functions such as reactor shutdown, decay heat removal, containment of radioactive materials, etc., are designed 'by analysis' to comply with the class-1 design rules of the Code ASME: Section III, Division 1 [1] and the French Code RCC-MR: Vol. RB [2]. These design codes specify stringent inspection requirements to ensure high quality of structural materials and manufacturing standards. In view of the fact that welds are weak links in a structure, the codes do not permit welds without adequate and reliable inspection methodologies. However, a few difficult locations for pre-service inspection, where crack-like defects, termed 'geometrical singular points' are unavoidable. Fig. 1 shows a few such locations, in the reactor assembly of a typical sodium cooled pool type Fast Breeder Reactor (FBR) made of austenitic stainless steels (ASS) type 316 LN or 304 LN. These geometrical singular points persist in the fuel pin-end plug welding, rolled and welded joint of the intermediate heat exchanger and plate shell weld junctions in the control plug. Considering the practical difficulties in completely excluding such singular points, RCC-MR: 2002 edition provides special design rules called the σ_d approach to ensure that singular points can be adequately addressed in class 1 components. With the σ_d approach, the state of stress and strain at the characteristic distance 'd' ahead of a crack tip is used to assess the basis of acceptance. In the current version of RCC-MR, i.e. the 2002 edition, this approach is recommended only for fatigue design. The robustness of the σ_d approach recommended in RCC-MR for the estimation of fatigue damage is reported in [3].

For a component operating at high temperature, creep damage at the critical weld locations could be a life limiting factor, depending upon the component and the service conditions. Specifically, for welded structures with crack like defects, the creep damage accumulated at the characteristic distance 'd' at the end of the design life should be less than unity to demonstrate the structural integrity as per design codes. The creep damage depends apart from operating temperature, on the state of stress at the specified location. Design procedures are not provided for the estimation of creep damage at welds with crack like defects in RCC-MR. However, in Appendix-A16 of

* Corresponding author. Fax: +91 4114 40268.
E-mail address: pcp@igcar.ernet.in (P. Chellapandi).

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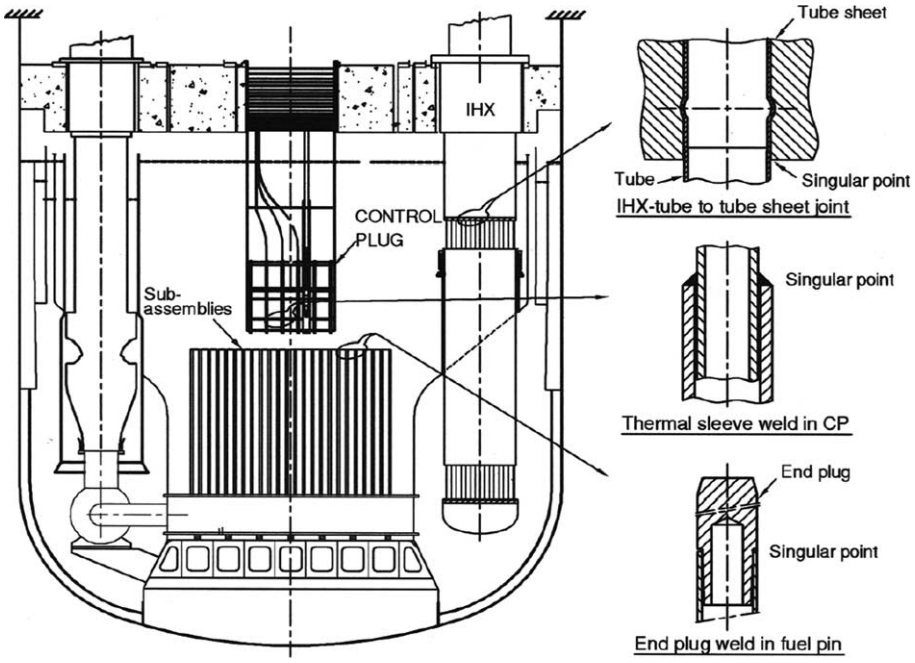

Fig. 1. Welds with singular points in fast breeder reactor assembly.

RCC-MR (A16) which is concerned with structures having a defect, a creep damage assessment procedure based on the σ_d approach is provided [4]. The σ_d approach has also been recommended in R5 for assessing creep damage [5].

The σ_d approach recommended in R5 has been assessed critically based on experimentally generated creep crack growth data from pre-cracked standard CT specimens machined from welded ASS plates [6]. However, similar application of the σ_d approach recommended in A16 is not reported to the best of the authors' knowledge. Hence, the validity of the A16 approach is assessed in this paper by predicting the creep crack initiation life of the pre-cracked standard compact tension (CT) specimens with welds. Based on the investigations, modifications are suggested for the procedure to improve the creep life prediction capability of A16 for welded structures with crack like defects based on the σ_d approach. Towards this, the elastoplastic fracture parameter J integral and elastoplastic stress fields in the CT specimen are determined by the computer code CASTEM-3M, issued by CEA, France.

2. Creep damage assessment by σ_d approach of RCC-MR:A16

A16 recommends a procedure to estimate the creep crack initiation life for a structure having a crack like defect. It is required to determine the equivalent stress, called σ_d based on Rankine theory, i.e. the maximum principal stress at the characteristic distance 'd' ahead the crack tip. The crack initiation life is the minimum time to rupture corresponding to σ_d at the specified temperature T. The recommended value for the characteristic distance (d) is equal to 50 μm for ASS in A16. However, the development of a visible crack (0.1–0.2 mm size) is generally considered as crack initiation. Using the distance of 50 μm for calculating σ_d may be considered a conservative value for the assessment. For the present investigation on experimental data, 0.2 mm is considered for defining crack initiation life.

The value of σ_d should be computed taking into account the effect of the singularity and plasticity. Using the simplified method recommended in A16, σ_d is derived from elastically computed stresses by applying Neuber's Rule to account for plasticity. The elastic stresses in turn are derived from associated stress intensity factors (K) using Creager's formula. K can be computed either using equations given in A16 for a few standard geometries or by numerical methods for complex geometries/loadings.

3. Benchmark problem definition

3.1. Geometrical details

The experimental benchmark problem which is concerned with creep crack propagation in the welded joint incorporated in two standard plane sided 19 mm thick CT specimens is extracted from [6]. It is worth mentioning that in [6], creep crack propagation results from six more tests are reported for side-grooved CT specimens, which are not analysed in the present paper. The plane CT specimens are manufactured from a single heat of welded plates made of Type 316 LN steel plates using a matching manual metal arc (MMA) weld combination. The interface between the parent