Development of a Prototypal Integrity Assessment Program for Flawed Tubes

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1. Introduction

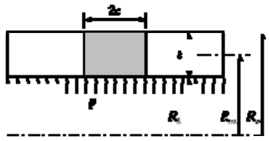
Steam generator (SG) tubes are one of pressure boundary components, which perform the role of heat transportation from primary system toward secondary system in a nuclear power plant. In general, a SG consists of thousands thin tubes with 10mm radius and 1mm thickness, approximately. Since it was reported that SG tubes in pressurized water reactors have experienced diverse types of degradation [1], to prevent rupture of them caused by unanticipated scenarios, lots of structural integrity evaluation and leak rate estimation models were proposed [2, 3]. Despite the efficiency of these methods, their application is not easy on the field because of complicated calculation schemes required. The purpose of the present paper is to introduce an activity to develop a program which is applicable to perform structural integrity assessment of SG tubes with various flaw types, rapidly and accurately, by employing promising models.

2. Integrity Assessment Methods

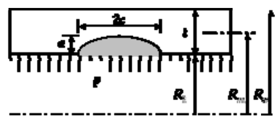
The activity of integrity assessment of flawed thin tubes can be classified into structural integrity evaluation part and leakage integrity evaluation part.

With regard to the former case, to predict load carrying capacity, most of previous researches have been focused on the well-known limit load method. It seems inherently reasonable to predict rupture pressure of thin SG tubes and easy to apply for the structural integrity evaluation of flawed tubes. However, as a shortcoming, it is conservative and lack of expandability for new analysis condition. Comparing with the limit load method, a relatively few data are needed for integrity evaluation based on Elastic Plastic Fracture Mechanics (EPFM) method. Also, it is appropriate to estimate Crack Opening Displacement (COD) and leak-rate. In this study, for the burst pressure estimation, total of seven limit load solutions [3, 4] were adopted for four types of planar cracks and three types of volumetric wear defects. The schematics of flawed thin tubes are shown in Figs. 1 and 2. On the other hand, to determine the *J*-integral and COD of thin tubes with four types of cracks shown in Fig. 1, engineering estimation equations based on parametric elastic-plastic finite element analyses by the authors and reference stress method were adopted.

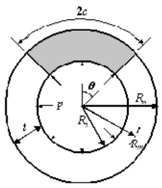
Meantime, with respect to the latter case, accurate estimation of leak rate of fluid through the flaw is also required. It is available by calculating Crack Opening Area (COA), as a function of COD, from engineering



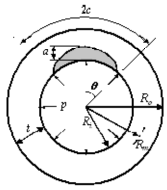
(a) Axial through-wall crack



(b) Axial surface crack

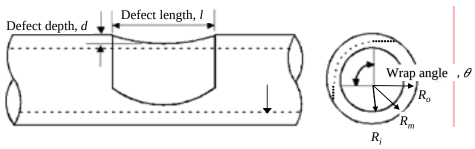


(c) Circumferential through-wall crack

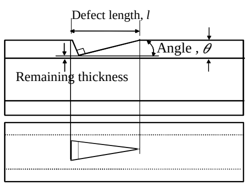


(c) Circumferential surface crack

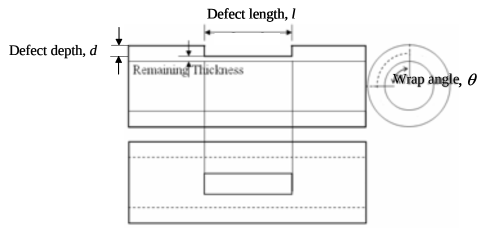
Fig. 1 Planar flaw types



(a) Elliptical wear defect



(a) Tapered wear defect



(c) Flat wear defect

Fig. 2 Volumetric flaw types

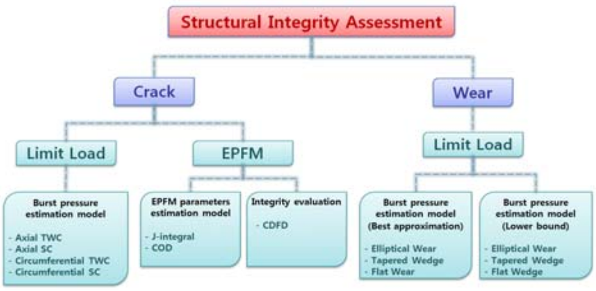
equations presented in fracture mechanics handbook [5] or detailed finite element analyses. Even though some useful complex models based on test data or analysis code to estimate leak rate such as PICEP and SQUIRT codes [6, 7] are exist, results obtained from these models showed large scatters. So, in this research, the leakage integrity of thin tubes is evaluated by a Bernoulli-like empirical equation based on domestic test data as well as overseas ones combined with the COA estimation equations [3].

3. Development of a Prototypal Program

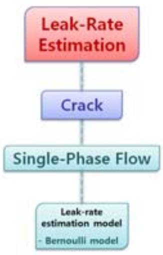
A prototypal integrity assessment program for flawed thin tubes is designed by Visual Basic. The aforementioned structural and leakage integrity evaluation methods are fully incorporated in the prototypal program, of which structure and available options are schematically shown in Fig. 3.

The structural integrity evaluation module possesses two methods according to flaw types; crack and wear type defects. In case of SG tubes with a crack, there are limit load and EPFM solutions to predict the unstable burst pressure. On the other hand, in case of tubes with wear type defects, there are just limit load solutions but as both best and lower bound approximations. The leakage integrity evaluation module can estimate leak rate by use of equivalent through-wall crack length and internal pressure applied to the SG tube.

For each evaluation, basic information on tube geometry with flaw type, length, depth and angle is required. Also, the loading condition as well as material properties such as yield strength, ultimate tensile strength and elastic modulus are necessary. Fig. 4 delineates typical input data required for the evaluation,



(a) Structural integrity evaluation



(b) Leakage integrity evaluation

Fig. 3 Structure of the prototypal program

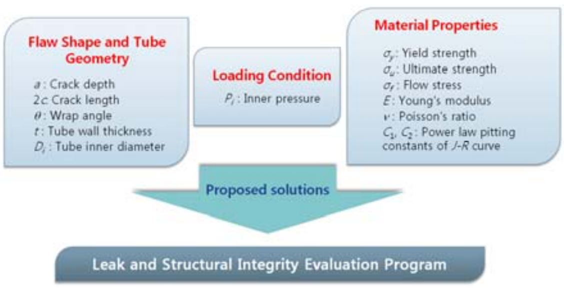


Fig. 4 Input data required for the prototypal program

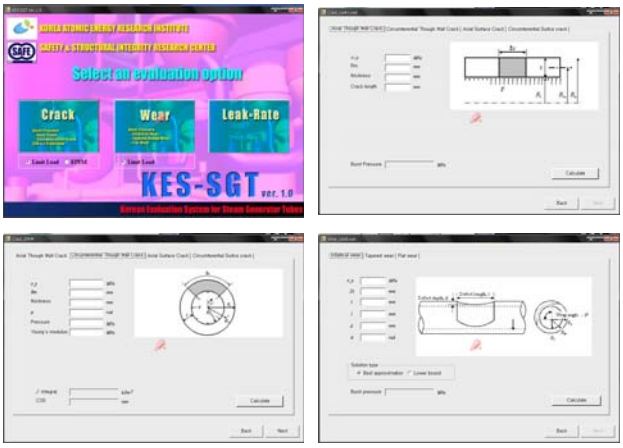


Fig.5 Main and evaluation screens of the prototypal program

which are put onto the edit-boxes throughout GUI interface. Fig. 5 shows main and representative evaluation screens of the prototypal program. Further options such as Crack Driving Force Diagram (CDFD) method and so on will be added by reflecting benchmarking test opinions.

4. Concluding Remarks

In this study, a prototypal program for integrity assessment of SG tubes is introduced, which consists of structural integrity and leakage integrity evaluation parts. In the structural integrity module, both limit load and EPFM solutions are included for typical planar and volumetric flaws. In the leakage integrity evaluation module a Bernoulli-like empirical equation based on test data combined with COA estimation equations. The prototypal program will be augmented by incorporating further available options, near future.

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