Engineering Failure Analysis 33 (2013) 439–448

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

On a leak-before-break assessment methodology for piping systems of fast breeder reactor

Yeon-Sik Yoo [a], Nam-Su Huh [b,*]

[a] Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Daejeon 305-353, Republic of Korea
[b] Department of Mechanical System Design Engineering, Seoul National University of Science and Technology, 172 Gongreung 2-dong, Nowon-gu, Seoul 139-743, Republic of Korea

ARTICLE INFO

Article history:
Received 2 June 2013
Accepted 20 June 2013
Available online 30 June 2013

Keywords:
Buckling
Creep
Elbow
Fast breeder reactor
Leak-Before-Break

ABSTRACT

The Leak-Before-Break (LBB) concept has an effect on the safety design of Fast Breeder Reactors (FBRs), and thus its assessment has been one of the most significant issues. In the case of a commercial-scale FBR, since the main loads are the thermal expansion and thermal transient stresses, ferrite steel with a low thermal expansion rate has been a candidate material. Moreover, thin-walled and large-diametric pipes have been used to reduce the number of loops, which might also result in an economical advantage. A conventional LBB assessment method is insufficient to consider these characteristics, thus an advanced method is required. In this context, in the present paper, the following points were proposed to apply the LBB assessment method to ferrite steel pipes with thin walls and large diameters: (1) The surface resistance correction factor against a flow through penetrated cracks was improved for a reasonable leakage assessment under low-pressure. (2) The R6 method was applied to an unstable fracture assessment for postulated cracks. (3) A buckling assessment was introduced in determining the critical crack length for elbows. The applicability of this proposed method has been verified through an LBB assessment on typical ferrite steel pipes.

1. Introduction

Application of the Leak-Before-Break (LBB) concept has an important role in realizing a reasonable design of Fast Breeder Reactor (FBR) plants with the assurance of safety and economy. In the case of commercial-scale FBRs, a low-pressure conditions and the use of ductile materials have an advantage in the sense that the risk of unstable fracture in key structures can be virtually eliminated [1]. For example, double-ended guillotine breaks in pipes can be prevented by detecting a leakage that occurs at the through-wall stage of a crack opening under these conditions. A consideration of these LBB characteristics can enlarge the degree of design freedom with respect to the materials, piping layouts, and safety measures against a leakage, thus leading to improved plant reliability and economy.

To apply the LBB concept to FBR structures effectively, it is essential to notice their design characteristics. The representative influence factors of the FBR design characteristics on the LBB assessment are shown in Fig. 1. The FBR plants have realized a comparatively good generating efficiency under normal operating conditions of high temperature and low-pressure by virtue of coolant with a high boiling point [1]. Under high temperature, creep is not a negligible aspect for a defect assessment, and thus creep-fatigue crack growth evaluations considering the stress relaxation owing to creep and cyclic plant operating conditions were performed in this paper by reviewing the present defect assessment guidance [2]. Generally, a low-pressure condition makes leakage detection uneasy, and thus it may result in an unsafe leakage evaluation. For this

* Corresponding author. Tel.: +82 2 970 6317; fax: +82 2 974 8270.
E-mail address: nam-su.huh@seoultech.ac.kr (N.-S. Huh).

1350-6307/$ - see front matter
http://dx.doi.org/10.1016/j.engfailanal.2013.06.017

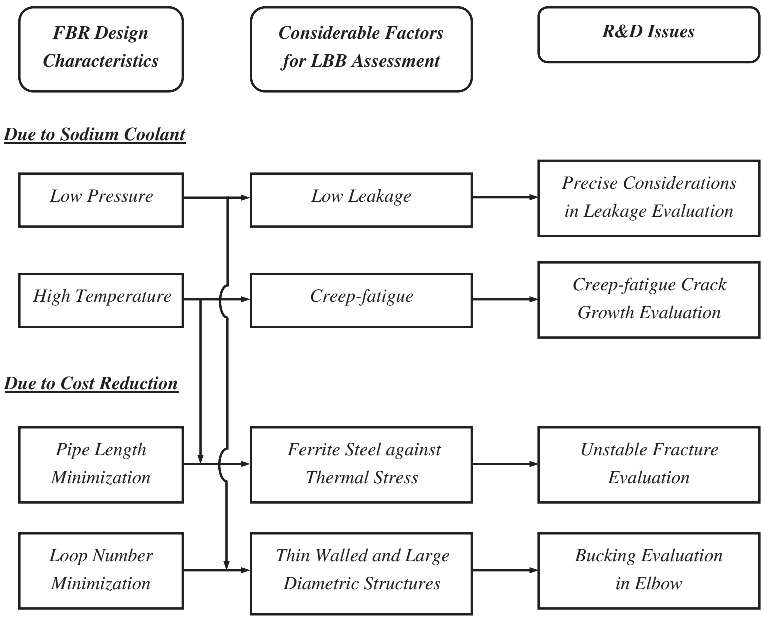

Fig. 1. Influence factors of FBR design characteristics on LBB assessment.

reason, careful considerations are required to determine the appropriate leakage evaluation techniques for an LBB assessment of FBR structures.

Meanwhile, an innovative FBR design is ongoing to minimize the piping length and number of loops for cost reduction. The minimized piping length is considered to increase the thermal expansion stress under high temperature. As a solution to the thermal stress problem, ferrite steel with a small thermal expansion has been recommended for FBR structures. Actually, thermal stress can be classified into the secondary stress of a displacement-controlled type, which is well known to reduce the risk of unstable fractures in the piping structures [3]. However, it is thought that the fracture assessment as a critical failure mode is necessary to confirm the LBB concept of FBR structures.

As shown in Fig. 1, a minimized number of loops and low internal pressure lead FBR structures for thin-walled and large-diametric piping systems. Another comprehended critical failure mode in these structures is considered to be buckling rather than an unstable fracture, and the representative object is an elbow with an axial crack. Based on these considerations, the present paper proposes a prospective LBB assessment methodology applicable to commercial-scale FBR piping structures with an emphasis on leakage evaluation under low-pressure condition, unstable fracture assessment taking into account material resistance to crack growth, and the possibility of buckling as a LBB assessment category in thin-walled and large-diametric elbow structures.

2. Proposed LBB assessment methodology for FBR piping structure

2.1. LBB assessment flow

The LBB assessment flow in a FBR structure with a postulated crack can be constructed as in Fig. 2 based on the LBB definition. Fig. 2 indicates that the LBB behavior arises and the fracture mode corresponds to a partial penetration when the detectable crack length due to leakage evaluation is smaller than the crack length at a critical state. The crack length caused by creep and fatigue at penetration is naturally deduced to be smaller than the detectable crack length, considering the crack growth under plant operating conditions. The critical crack length can be obtained from the fracture assessment considering the material and structural characteristics.

2.2. Creep-fatigue crack growth evaluation

Creep is a meaningful damage factor, together with fatigue, for crack growth in FBR structures subjected to high temperature. Generally, creep-fatigue crack growth may be evaluated from the following equations, which neglect the interaction between creep- and fatigue-induced damages:

$$\begin{aligned} da/dN &= (da/dN)_c + (da/dN)_f \\ (da/dN)_c &= C_c \cdot (\Delta J_c)^{m_c} \\ (da/dN)_f &= C_f \cdot (\Delta J_f)^{m_f} \end{aligned} \tag{1}$$