

LEAK BEFORE BREAK PROCEDURE FOR SODIUM BOUNDARY COMPONENTS

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ABSTRACT

The aim of this paper is to present a Leak Before Break procedure to be used on components of Liquid Metal Fast Reactors (LMFR's).

This paper explains the background to the procedure and discusses the basic assumptions used in its development. A step by step description of the procedure is given for use by designers.

1 - INTRODUCTION

The Design and Construction Rules Committee (DCRC) whose members belong to engineering companies (ANSALDO, NNC, NOVATOME, SIEMENS-KWU) has been set up in order to evolve mutually agreed design and construction rules for the next LMFR (European Fast Reactor project). These rules are based on the work of activity groups AGT 9A and AGT 9B set up by R & D organisations (CEA, KFK, UKAEA).

Safety requirements for LMFR's aiming to prevent gross failure of the core support path and to minimize risks of sodium fires have led the DCRC to write a procedure on Leak Before Break (LBB) to be used on components such as the primary vessel and secondary piping. The procedure based on the work of AGT9B [1] is presently limited to structures fabricated in 316 L(N) not subjected to significant creep.

The paper presents the background to the procedure and a step by step description in a form for use by designers.

2 - GENERAL DESCRIPTION OF THE LBB APPROACH

Leak Before Break is a characteristic which may or may not be possessed by a given structure containing a fluid under a given set of loadings.

An LBB demonstration is largely based on fracture mechanics. The demonstration consists in showing that a through wall crack resulting from cyclic loading will be detected before reaching a critical length which would lead to the gross rupture of the component. The detection is linked to the crack opening area.

An LBB assessment depends on the structure (geometry and material properties) but also on the leak detection capabilities.

Such an approach supposes on the one hand to locate the most susceptible part of a component and on the other hand to be sure to have the appropriate leak detection system.

The LBB concept is particularly suitable for the design of LMFR's structures. This may be justified considering the following points :

- * the level of primary stresses is low,
- * the mechanisms of failure are relatively well known (except when ageing and corrosion effects are involved),
- * the materials used are defect tolerant and are likely to present large critical crack sizes,
- * the leak detection systems are efficient,
- * there is a good experience on operating conditions.

3 - BACKGROUND OF THE LBB APPROACH

Let us consider an initial semi elliptic surface crack with length $2 C_i$ and depth a_i .

Typical trajectories of crack shape development in 316 SS plates loaded by cyclic stresses are shown in figure 1. The curves on this figure indicate that all cracks irrespective of initial values a_i , c_i tend to converge towards a common curve the shape of which depends only on the ratio between the range of bending stress and the range of membrane stress $\frac{\Delta \sigma_b}{\Delta \sigma_m}$ and the exponent of the Paris Law :

$$\frac{da}{dN} = C (\Delta K)^n$$

Cracks which grow along the common curve reach a length at wall penetration $2 C_p = 2 C_s$ (see figure 4).

Cracks whose initial length $2 C_i$ is less than $2 C_s$ achieve penetration for $2 C_p = 2 C_s$. Cracks whose initial length $2 C_i$ is greater than $2 C_s$ grow essentially in the through thickness direction i.e. along straight lines passing through the origin of figure 1. $2 C_s$ is called the asymptotic crack length.

Figure 2 presents some common curves for different values of the ratio $\frac{\Delta \sigma_b}{\Delta \sigma_m}$ and for an exponent of the Paris Law which is equal to 4.

For $\Delta \sigma_b$	= 0	$\frac{t}{C_s}$	= 0.69
	$\Delta \sigma_b / \Delta \sigma_m = 1$	$\frac{t}{C_s}$	= 0.35
	$\Delta \sigma_b / \Delta \sigma_m = \infty$	$\frac{t}{C_s}$	= 0.105

Figure 3 shows the relation between $\frac{C_s}{t}$ and $\frac{\Delta \sigma_b}{\Delta \sigma_m}$.

Let us call $2 C_l$ the crack length at the penetrated surface which is required for a confident level of the leak detection and $2 C_G$ the critical crack length at global instability.

Two cases are to be considered (see figure 4) :

- * If $C_i < C_s$ the length at wall penetration is $2 C_p = 2 C_s$ and the LBB argument is : $2 C_s < 2 C_G - 2 C_L$.
- * If $C_i \geq C_s$ the length at wall penetration is $2 C_p = 2 C_i$ and the LBB argument is $2 C_i + 2 C_L < 2 C_G$.

For cracks for which $2 C_i < 2 C_G - 2 C_L$ and considering that $C_s \leq C_i$, the LBB argument becomes $2 C_s < 2 C_G - 2 C_L$.

In order to ensure a margin as regards global instability $2 C_G$ will be divided by a safety margin α :

$$2 C_G' = 2 C_G / \alpha$$

The LBB argument is eventually that, for all initial defect of length less than $2 (C_G' - C_L)$, it is to be demonstrated that :

$$C_s < C_G' - C_L$$

It is to be emphasized that the basic assumption of this LBB argument is that :

$$2 C_p = 2 C_i \quad \text{if} \quad C_i \geq C_s$$

This may be questionable in case of shallow cracks subjected to high bending stresses. However, some experiments are under way in the UK which seem to confirm that the above LBB argument is also valid for this type of cracks. This point has to be confirmed at a later stage.

4 - LBB PROCEDURE

The following procedure should be followed when carrying out an LBB assessment of a structure.

Step 1 : Elastic analysis of undefected structure

- * Define the geometry of the structure to be studied, the corresponding material data (the procedure is presently limited to the 316 L(N) SS) and the loadings from level A, C and D service conditions.
- * Perform elastic stress analyses of an undefected structure for all loadings.
- * Determine residual stress distributions due to manufacturing processes.

Step 2 : Identification of critical zones for LBB assessment

Critical zones as regards LBB assessment are chosen taking note of maximum stresses (under level C and D service conditions), maximum stress ranges (under level A service conditions), material property changes and the possible presence of flaws particularly with regard to weldments.

Step 3 : Definition of the plane of the crack

The procedure is based on the assumption that a plane crack exists and that only mode I for crack propagation is to be considered. The plane of the crack is defined taking note of crack growth considerations (under level A service conditions) and stability considerations (under level D service conditions).

Step 4 : Calculation of elastic stresses normal to the plane of a crack

For each of the locations selected in step 2 :

- * Calculate across the section defined in step 3 the normal membrane and bending stress components for each of the loading conditions defined in step 1.
- * Classify the stresses into primary and secondary parts and add the residual stress (if any) to the secondary stresses.
- * Determine the maximum variation of primary and secondary membrane and bending stresses for each of the different cycles operating under level A.

Step 5 : Determination of the critical through wall length $2 C_G$

For each of the locations selected in step 2 giving high stresses under level C and D service conditions calculate the length of the critical through wall defect $2 C_G$.

The critical crack length $2 C_G'$ including the margin is defined by $2 C_G/\alpha$.

The calculation of C_G is based on a failure assessment curve described in terms of a crack driving force as a function of crack length. The crack driving force curve for 316 L(N) steel is derived from an inversion of the option 1 failure curve of the R6 rule [2]. The critical crack length is then defined by the point of intersection of the materials fracture toughness value with the driving force curve.

Nota : The procedure described above is that of DCRC report 13. Other approaches presently not included in the report could be used for specific geometries. In particular, SIEMENS studies show that flow stress concept and plastic limit load concept for calculation of critical through wall crack length give conservative results for piping geometries [3].

The calculation is performed with and without the residual stresses, retaining the smaller value of $2 C_G$.

Step 6 : Determination of the asymptotic crack length $2 C_S$

For each of the level A cycles which provide a significant contribution to the total fatigue usage factor, calculate the ratio between the range of bending stress and the range of membrane stress $\frac{\Delta \sigma_b}{\Delta \sigma_m}$.

The highest value of the ratio is $\left[\frac{\Delta \sigma_b}{\Delta \sigma_m} \right]_{\max}$.

Determine from figure 3 the asymptotic crack length $2 C_S$ using $\left[\frac{\Delta \sigma_b}{\Delta \sigma_m} \right]_{\max}$:

- * If $2 C_S > 2 C_G'$ a more detailed analysis is required to demonstrate LBB.
- * If $2 C_S < 2 C_G'$ proceed to step 7.

Step 7 : Determination of the crack length required for detectable leakage, $2 C_L$

Using the membrane plus bending stress due to normal operating conditions (from level A loading) causing tension perpendicular to the crack, calculate the crack length $2 C_L$ for detectable leakage.

Analytical methods are provided for calculating $2 C_L$ in the laminar or in the turbulent regime.

Step 8 : Leak Before Break Argument

* If $C_s < C_G' - C_L$

leak before break has been demonstrated for all initial defects of length less than $2(C_G' - C_L)$.

For initial defects of length greater than $2(C_G' - C_L)$ a leak tightness calculation can be used to assess the integrity of the structure.

* If $C_s > C_G' - C_L$

leak before break has not been demonstrated by simplified analysis, but still may be possible by more detailed analysis.

5 - CONCLUSIONS

Safety and reliability considerations for LMFR's require LBB behaviour to be demonstrated for a range of structures and components.

An LBB procedure has been presented which contains simplifications and conservatisms. Its considerable advantage is its easy use by designers and the reduction of the amount of calculation required.

The method is still under development and needs in particular confirmation or definition of material data for 316 L(N) and mod 9Cr1Mo parent plate and weldments in the aged and unaged condition.

REFERENCES

- [1] - TOMKINS B., "A Leak Before Break procedure for application to EFR sodium boundary components". 2nd Milestone Report on Leak Before Break, AGT9B/SG4, March 1990
- [2] - MILNE, I et Al., "Assessment of the integrity of structures containing defects". CEGB report R/FH/R6 - Rev. 3.
- [3] - BARTHOLOME G., WELLEIN R., SENSKI G., 12th SMIRT (1993). LBB - analysis : verification of fracture mechanics approaches by components testing, p. GF 08/2.

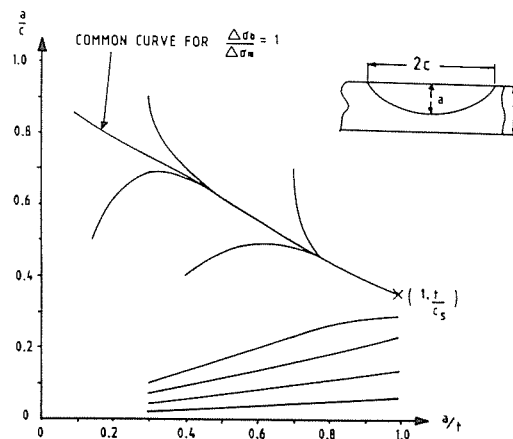


Figure 1 : TYPICAL TRAJECTORIES OF CRACK SHAPE DEVELOPMENT DURING CYCLIC LOADING

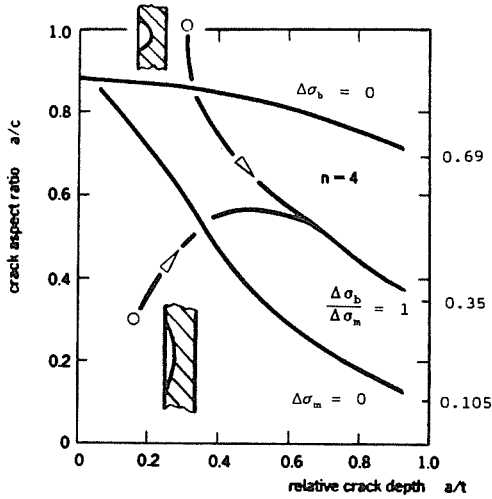


Figure 2 : SCHEMATIC REPRESENTATION OF SHAPE CRACK DEVELOPMENT

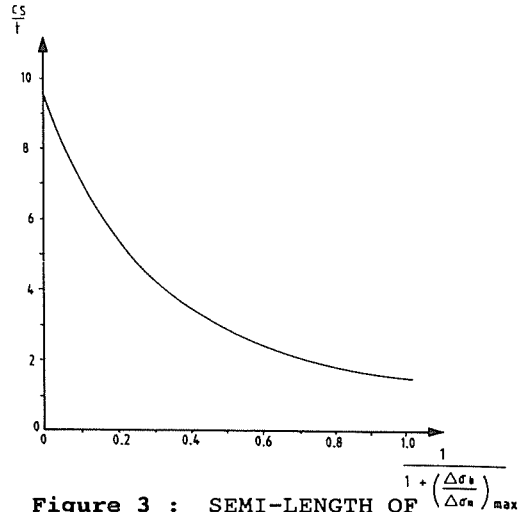


Figure 3 : SEMI-LENGTH OF ASYMPTOTIC CRACK SHAPE, C_s AS FUNCTION OF $\left(\frac{\Delta\sigma_b}{\Delta\sigma_m}\right)_{max}$ FOR STAINLESS STEEL

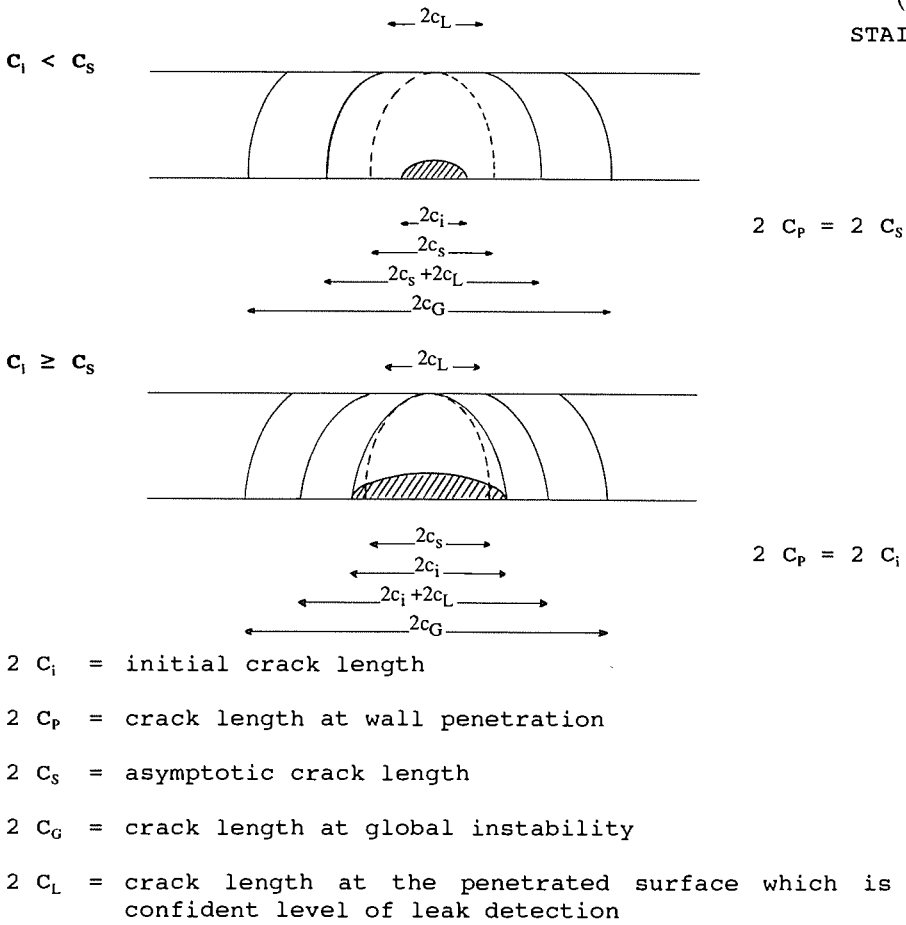


Figure 4 : CRACK FRONT PROFILE FOR LBB ARGUMENT