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CRITICAL CRACK SIZE OF A PROTOTYPE PIPE BEND UNDER CYCLIC LOADING

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Abstract

The accurate assessment of critical crack size plays a vital role in demonstrating the Leak-Before-Break (LBB) criterion for the safety demonstration of a sodium-cooled Fast Breeder Reactor (FBR) piping system. The advancement of the crack size will increase the stress intensity factor and reduce the load-carrying capacity of the piping system. The prototype-sized pipe bend test revealed that even under a large-size crack growth situation, the ductile pipe bend fails by collapse rather than tearing instability. The critical crack size was realistically estimated based on a prototype-sized pipe bend cyclic test and compared with elastoplastic numerical analysis.

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1. Introduction

Leak-Before-Break (LBB) demonstration is an essential safety criterion to ensure the safe design of the sodium-cooled Fast Breeder Reactor (FBR) piping system. The critical crack size ($2C_G$) is a crucial parameter that must be estimated accurately for the LBB demonstration. '$2C_G$' corresponds to the crack length at which the structure becomes unstable due to either fracture or collapse. It depends on the pipe material and the overall stiffness of the component. The advancement of the crack size will reduce the stiffness of the geometry. If the crack tip at which the maximum stress intensity factor is close to the fracture toughness, then the component failure will be governed by fracture and lead to tearing instability. The advancement of the crack growth can also reduce the overall stiffness of the geometry, and then the component can also fail by collapse. Considering the co-existence of two different failure modes during the advancement of the crack size create, the computation of the CG becomes very complex. Hence experimental methods are essential for the accurate assessment of the CG.

A representative prototype-sized pipe bend belonging to a typical FBR piping system is used for the experimental estimate of CG. An initially cracked pipe bend of size 570 mm outer diameter and thickness of 15 mm is chosen for this purpose in this paper. The elastoplastic numerical analysis was also performed to simulate the test conditions.

2. Experimental Crack Growth Studies

The test pipe bend is made up of SS 316 LN material, and the test has been performed at room temperature. Pre-cracked pipe bend is used for the test. The cyclic in-plane bending moment is applied using a servo-hydraulic linear actuator that propagates the crack on the pipe bend. Top-end of the pipe bend is connected with the support structure, and the cyclic load is applied at the bottom free end through the up-and-down movement of the actuator.

The prototype pipe bend with a sufficiently long crack size on either side of the pipe bend is used for the experiment. The pipe bend is continued with the cyclic loading to propagate the crack. The stable crack growth behaviour is continued even after the crack size on either side of the pipe bend exceeds a crack size corresponding to the sum of asymptotic and detectable leak crack sizes. Thus it is confirmed that the given pipe bend qualifies the LBB criteria. The fatigue crack growth is further continued to understand the ultimate failure mechanism of the pipe bend.

Periodically the pipe stiffness and crack length are measured for this purpose. Overall load line stiffness of the pipe bend reduces during the advancement of crack length, as shown in Fig.1. The sudden drop in the pipe stiffness is considered the measure of collapse load. Due to the inbuilt safety features of the servo-hydraulic cyclic actuator, the cyclic operation will stop before collapsing the pipe bend. The sudden stoppage of the cyclic actuation followed by a considerable reduction in pipe stiffness indicates the collapse.

Subsequently, the actuator will continue to perform the cyclic loading only after reducing the applied range of cyclic load. These safety features in the actuator help to utilise the same specimen to continue for different load combinations to identify the critical crack size. Accordingly obtained critical crack length ($2C_G$) against different load combinations is presented in Fig.2

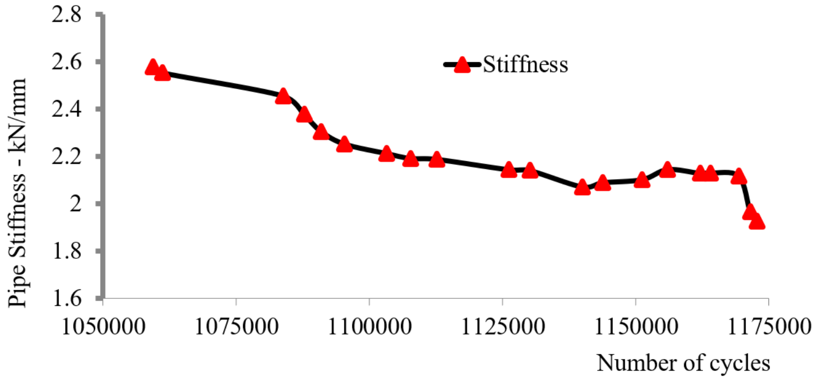

Fig.1 –Pipe bend stiffness variation during the advancement of crack length.

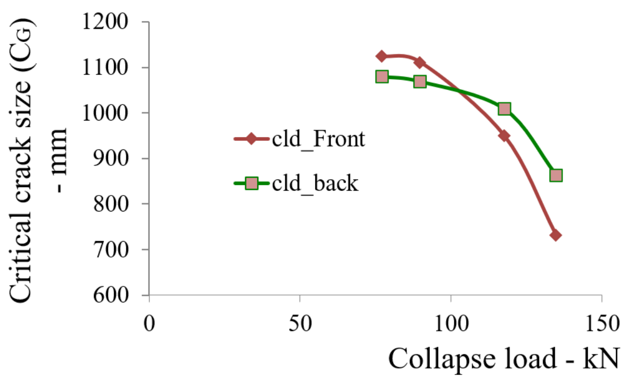

Fig.2 –Pipe bend stiffness variation during the advancement of crack length.

The following are the significant findings from the above investigations

- The ductile nature of the pipe bend resulted in collapse failure rather than tearing instability.
- It is observed that crack size corresponds to collapse increase with the decrease in the range of cyclic load. Subsequently, the variation becomes saturated to 1100 mm, independent of the applied cyclic load on either side of the pipe bend.

3. Conclusions

The current fatigue crack growth experiment demonstrated that the selected pipe bend met the LBB criteria. The prototype-sized pipe bend test revealed that even under a large-size crack growth situation, the ductile pipe bend fails by collapse rather than tearing instability. It is observed that crack size corresponds to collapse increase with the decrease in the range of cyclic load. Subsequently, the variation becomes saturated to 1100 mm for a 550 NB pipe bend and independent of the applied cyclic load on either side of the pipe bend.