A Probabilistic Life Prediction of PWSCC of Ni-base Alloy

Tae Hyun Lee[a*], Il Soon Hwang[a]
[a]*Nuclear Materials Lab., Seoul National Univ., Shinlim, Gwanak, Seoul, Rep. of Korea*
[*]*Corresponding author: ehfaks2@snu.ac.kr*

1. Introduction

Structural failures in metal components are frequently caused by the unchecked propagation of flaws or cracks in metal and welds until an intolerable crack size has been reached. A periodic inspection and flaw repair program is often used to help decrease this risk of failure by limiting the initial flaw sizes. In-service, non-destructive inspections are required at regular intervals and the results can be used for maintenance to mitigate failure risk. Moreover, the data obtained from the inspection can be combined with these models to update the reliability estimate during the remaining service life using Bayes' theorem. The foundations of Bayesian theory can be found for example in [1, 2], while its application to decision theory is treated by Raiffa and Schaifer [3]; Box and Tia [4] discuss its application in parameter estimation. The principle of the Bayesian analysis is to consider the parameters of the distribution functions as uncertain variables with prior distribution functions to be updated based on additional data, which defines posterior distribution function.

Some approaches have been developed for using information from non-destructive inspections to update fatigue reliability prediction based on Bayesian analysis as described in [5,6]. The purpose of this paper is to apply probabilistic fracture mechanics to the analysis of the influence of in-service inspection on structural reliability. Attention will be concentrated in this paper on the influence of in-service inspection on reliability. Hence, this paper is a direct extension of earlier work [5], but provides a considerable advance in that a general subcritical crack growth characteristic is considered (rather than just fatigue) and the results are presented in a more general form. Additionally, the procedures are expanded to consider more complex and realistic crack geometries that greatly complicates both the fracture mechanics and probabilistic consideration using Bayesian approach.

II. Description of General Model

In this paper, fatigue induced flaw growth behaviors was just considered to evaluate the effects of inspection uncertainties and random variables in flaw growth behavior as a case study. The major components of the physical life model incorporating deterministic and probabilistic fracture mechanics analysis of cracked metal structure is summarized in Figure 1. This schematic representation of the model shows the fundamental considerations in modeling and prediction of crack growth to instability in components of NPPs.

A probabilistic model was developed for fatigue crack growth based on the data generated in the experimentation that was used to develop the deterministic model. The uncertainties as well as the inability of the model to account for the stress intensity factor threshold below which crack growth will not occur is the primary reason for developing this probabilistic model. The evaluation of the sensitivity of the crack growth relation to the empirical constants is possible using the probabilistic model.

From the updated distribution of flaw size and density for a given length of weld which has been subjected to NDT inspection and repair, the probability that its largest flaw will exceed a certain critical size can be computed accordingly. Based on the current analysis technique of NDT data, if it is fortunate to find an NDT device whose threshold flaw size is less than the critical size, then the above probability would be 1.0. On the other hand, if such a device is not available, this probability cannot be reasonably estimated. Therefore, the proposed use of probability updating would lead to improvement over the current analysis technique.

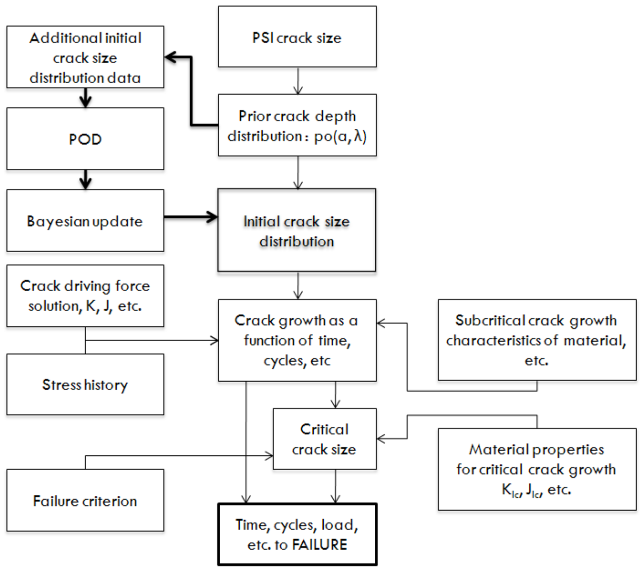

Fig. 1. Description of General Model

III. Monte Carlo Simulation on Flaw Growth Behaviour

A simple example is presented that demonstrates the use of varying topics, including fracture mechanics, probabilistic modelling of material properties, Monte Carlo simulation and Bayesian updating in a realistic fashion. As an example, we consider a center cracked panel of width 2h with a crack of length 2a subjected to a cyclic stress of $\Delta\sigma$ with a given R-ratio. The crack growth rate equation is following the Forman relation. Final failure occurs when K_{max} exceeds K_{Ic}. The underlying fracture mechanics calculations in the Monte Carlo simulation involve evaluating the critical crack size with a given increment step. The stress intensity factor and corresponding crack growth rate are evaluated at the midpoint of crack size interval. The growth rate is assumed constant during that interval, the cycle to failure is the sum of the number of cycles to grow in each increment.

Fig.2 presents a plot of the cumulative distribution of cycles to failure for the example problem with 10,000 trials and 100 crack growth steps. Fig. 2 is also the probability of failure within a given number of cycles. Three set of results are shown, both of which use of parameter of the initial crack size distribution that has been updated based on the results of an inspection, except one case of which use of no-updated initial λ value. One set of results considers no repairs of inspected cracks, and another considers the crack size distribution after inspection and perfect repair of detected cracks, and the other is for absolutely initial crack size distribution.

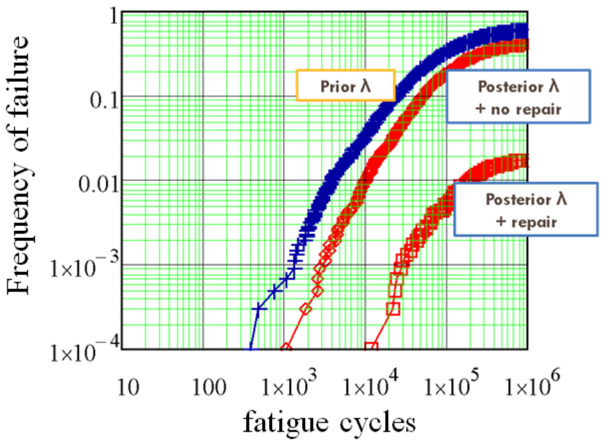

Fig. 2. Cumulative probability of failure as a function of fatigue cycles for the example

IV. Summary and Future Work

This paper summarized the effects of some important factors on concept of flaw growth rate, fracture mechanics and inspection. This framework has been prepared for Environmentally Assisted Cracking (EAC) growth and failure in primary piping and nozzles in PWR's and a simple example is also presented for demonstrating the use of the topics, including fracture mechanics, probabilistic modelling of material properties, Monte Carlo simulation and Bayesian updating in a realistic fashion.

It has been emphasized that uncertainty in crack size detected by non-destructive examination must be concepted to assess potential failure probability. An integrated probabilistic treatment of EAC phenomena is the future goal of this study.

Acknowledgments

This work was financially supported by the Korean Ministry of Commerce, Industry and Energy through the EIRC program of Electric Power Industry Technology Evaluation and Planning.

REFERENCES

[1] Lindley, D. V., Introduction to Probability and Statistics from a Bayesian Viewpoint, Cambridge University Press, Cambridge, 1976.
[2] Y. Garbatov.,et. al, Bayesian Updating in the Reliability Assessment of Maintained Floating Structures, Journal of Offshore Mechanics and Arctic Engineering, 2002.
[3] Box, G. E. P., and Tia, G. C., Bayesian Inference in Statistical Analysis, Addison-Wesley Publishing Co., 1973.
[4] Raiffa, H., and Schalifer, R., Applied Statistical Decision Theory, Harward University Press., 1961.
[5] Harris, D. O. and Lim, E, Y., "Applications of a Probabilistic Fractuie Mechanics Model to the Influence of In-Service Inspection on Structural Reliabllity", Probabilistic Fracture Mechanics and Fatigue Methods: Applications for Structural Design and Maintenance, ASTM STP 798, 1983
[6] Madsen, H. O., ''Model Updating in Reliability Theory,'' Proc. Of ICASP-5, Vancouver, 2, pp. 564–577., 1987.