The Study on the Effects of the PWSCC Mitigation Methods on Degradation Behavior of Steam Generator Tubes Using the Weibull Approach

One Yoo[a*], J. S. Kim[a], K. H. Nam[a], K. S. Yoon[a], S. H. Jung[a], J. S. Choi[b], H. Y. Yang[b]
[a]*KEPCO E&C NSSS Division, 989 Gil, Deaduckdaero, Yueson-gu, Daejeon, 305-353, Korea*
[b]*KHNP, Central Research Institute, 1312 Gil,70,Yuseongdaero, Yueson-gu, Daejeon, 305-600, Korea*
[*]*Corresponding author: oyoo@kepco-enc.com*

1. Introduction

Many cracked steam generator tubes had been found at kiss roll region of the top of tubesheet (TTS) in Ulchin unit 1 steam generators, where Alloy 600TT was used as tube material. The PWSCC is a mechanism responsible for tube degradation. Shot peening was performed at 5th planned maintenance in Feb. 1994 and Zn addition at 17th fuel cycle in April 2010 for reduction of the PWSCC occurrence[1]. For Zn addition, 4 ~ 35grams of Zn were injected to the RCS system everyday for 4 months. Maximum measurement of Zn in the RCS coolant was 8.8 ppb.

In this study, the effect of shot peening and Zn addition on the PWSCC occurrence is discussed.

2. Methods

In this section, Weibull approach which is used to model the tube degradation behavior is described.

2.1 2-parameter Weibull approach for PWSCC evaluation

EPRI suggests a 2- parameter Weibull distribution as a suitable method to evaluate the steam generator tube degradation analysis [2]. The Weibull distribution is shown below:

$$F(t) = 1 - \exp[-(t/\theta)^b] \quad \text{------------------------} \quad 1)$$

where F(t) is cumulative fraction of tubes failed, t is operation time, θ is characteristic time (equal to the time to 63.2% failed), and b is slope or shape parameter.

2.2 The meaning of the variation of Weibull parameters

The analysis of the tube degradation using the Weibull distribution is performed based on assumption that the data should be obtained under the same condition[2]. Therefore, plant operating condition change such as Zn addition and tube property change such as kiss rolling lead to the change of the Weibull parameters. Fig. 1 shows the transition of Weibull slope parameter b due to the Zn addition. Reversely, the change of Weibull parameters may indicate the change of steam generator operation and/or tube condition.

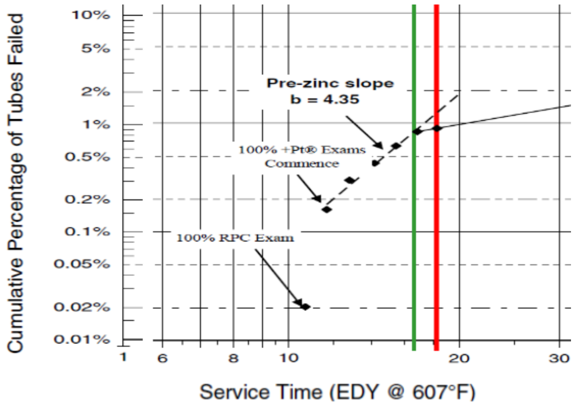

Fig. 1. Weibull plot of the degraded tubes of Sequoyah 2 steam generators (PWSCC): Ref. [3]

3. Results

3.1 The behavior of Ulchin 1 steam generator cracked tubes

Fig. 2 represents the Weibull plot showing the Ulchin 1 plant data. The tubes were operated at temperature of 323℃. There are three clear regions on Weibull plot which show the different trend of the cumulative tubes failed. Region 1 covers from 4th to 10th planned maintenance, Region 2, from 10th to 16th, and Region 3, from the time Zn is added to 17th.

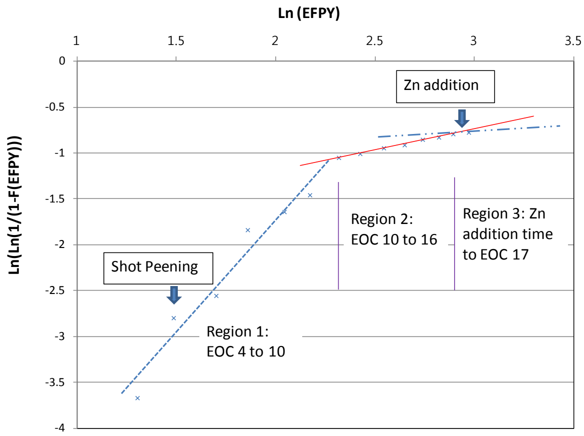

Fig. 2. Weibull plot of PWSCC affected tubes at top of tubesheet of Ulchin 1.

3.2 The analysis of Weibull parameters of Ulchin 1 tubes

Weibull distributions, fitted per region, are also identified in Fig. 2. The fitted equations are as below:

Region 1: ln(ln(1/(1-F(EFPY)))
= 2.421 x ln(EFPY) – 6.584 ---------------- 2)
Region 2: ln(ln(1/(1-F(EFPY)))
= 0.451 x ln(EFPY) – 2.095 ---------------- 3)
Region 3: ln(ln(1/(1-F(EFPY)))
= 0.165 x ln(EFPY) – 1.254 -------------- 4)

The review of steam generator maintenance and operation history says that the shot peening of TTS area was performed at 5th planned maintenance which is belonged to Region 1 and Zn was added at 17th fuel cycle in Region 3. However, there are not any specific plant condition or tube condition changes the fuel cycles in Region 2.

From eq. 2), Weibull slope of Region 1 is 2.421. This is a little smaller than the slope value of 3 that alloy 600 tubes generally show. Therefore, it seems that the shot peening performance does not give any credit on the PWSCC mitigation in Region 1. In Region 2, plant data show a good linearity with small standard deviation. This linearity usually occurs after certain degradation mechanism is found and a few number of fuel cycles has passed[3]. Interesting point is that the slope parameter in Region 2 is 0.451 (see eq. 3), which is two to four times less than the values obtained from some shot peened U.S plants.

Fig. 3 shows the Weibull plot on the plant data of Region 2 and Region 3. Detailed equations are eq. 3) and 4) above. To develop eq. 4), Weibull fit line of eq. 3) is extrapolated to determine the hypothetical data point for Zn addition starting point. It should be noted that the Weibull slope of eq. 4) is conservative because the maximum error range which is obtained for the Range 2 is added to the 17th ECT inspection data (See Fig. 3). A 63% reduction in Weibull slope after Zn addition is obtained. Therefore the effect of Zn addition is clear for Ulchin 1.

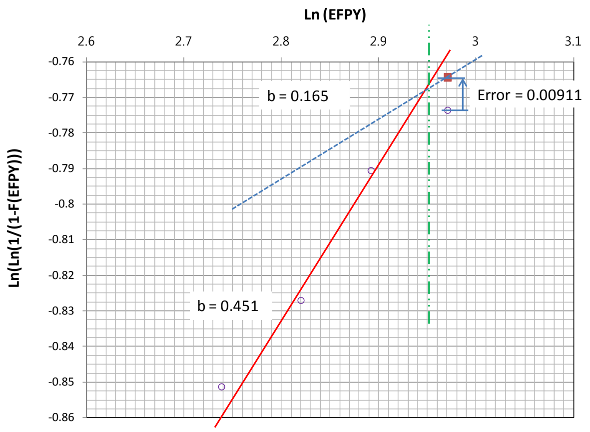

Fig. 3. The effect of Zn addition on Weibull slope parameter. Red solid line: Weibull fit of Region 2 plant data. Blue dotted line: Weibull fit of the data after Zn addition. Two point chain line (green): starting point of Zn addition.

3.3 The improvement by Zn addition at the end of plant life

Since the capacity factor of Ulchin 1 is approximately 90%, its design life is 36 EFPY. Using equations 3) and 4), cumulative percentages of failed tubes at the end of plant life are calculated. The effect of Zn addition starting from 17th fuel cycle is 5.7% based on the reduced number of failed tubes.

3. Conclusions

The results of this study are summarized as follows:

1) Shot peening effects were not identified in the first 7 fuel cycles after shot peening.
2) After 10th planned maintenance, Weibull slope becomes abruptly smaller compared with the values from shot peened plants in US.
3) The effect of Zn addition is clear for Ulchin 1. A 63% reduction in Weibull slope after Zn addition is obtained.
4) At the end of plant operation, at least 5.7% reduction in failed tubes when Zn addition starts from 17th fuel cycle.

REFERENCES

1] Esposito, J.N., et al., "The Addition of Zinc to Primary Reactor Coolant for Enhanced PWSCC Resistance", Proceedings, 5th International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, Monterey, CA, Aug. 1991

[2] EPRI, “Statistical Analysis of Steam Generator Tube Degradation”, EPRI NP-7493, 1991

[3] EPRI, “Evaluation of Plant Data to Determine Effects of Zinc on PWSCC”, 1016558, 2008