Probabilistic Model of PWSCC in Alloy 690 Steam Generator Tubing

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Background

◆ Primary water stress corrosion cracking (PWSCC) has been a threat for the safety of nuclear power plants (NPPs).

◆ PWSCC in Alloy 600 components

Some earliest Reported Occurrences of Alloy 600 PWSCC for Various PWR Component Items [1]

Component Item	Date PWSCC Initially Observed	Service Life (Calendar Years)
Steam Generator Hot Leg Tubes	1971	2
Steam Generator Cold Leg Tubes	1986	18
Pressurizer Heaters and Sleeves	1987	5
Steam Generator Channel Head Drain pipes	1988	1

And many others

[1] Materials Reliability Program (MRP), Resistance to Primary Water Stress Corrosion Cracking of Alloys 690, 52, and 152 in Pressurized Water Reactors (MRP-111), EPRI, Palo Alto, CA, U.S. Department of Energy, Washington, DC: 2004. 1009801.

◆ Replace Alloy 600 with Alloy 690

- Alloy 690 has been "immune" to PWSCC, but

◆ Predict PWSCC initiation time in Alloy 690 !!

- How?
- Deterministic or probabilistic modeling?

Mr. Deterministic : "PWSCC will definitely initiate after 2 years, no sooner or later than that"

Mrs. Probabilistic : "See the table.."

Method and Approach

◆ Base model: Weibull distribution

$$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right] \qquad F(t) = 1 - \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right]$$

$\eta>0$ is the scale parameter and $\beta>0$ is the shape parameter of the Weibull distribution

◆ Problem?

We have only *censored data* :

Testing time instead of time to PWSCC initiation is all we know about the "strong" Alloy 690 → zero-failure data.

◆ What can we do: Bayesian method

- Model parameters are treated as random variables with certain probabilistic dist.
- Formulation:

$$f(\theta|t) = \frac{g(t|\theta)\, h(\theta)}{\int g(t|\theta)\, h(\theta)\, \partial\theta}$$

- where $f(\theta|t)$ is the posterior distribution of parameter θ, $g(t|\theta)$ is the likelihood function of the observed data t given parameters θ, $h(\theta)$ is the prior distribution of θ.

- Likelihood:

$$g(t|\theta) = \prod_{i=1}^{r} f(t_i) \prod_{j=1}^{n-r} \{1 - F(t_j)\}$$

where r is number of failures, n is number of plants

- Prior distributions:

Alloy 600

$\eta \sim gamma(1/2, 0)$ → Jeffrey prior

$\beta \sim beta(0,0,0,5)$ → Uniform prior

Alloy 690

$t_{1st} \sim Normal(18.91, 5)$

$\beta \sim \text{posterior } \beta \text{ of Alloy 600}$

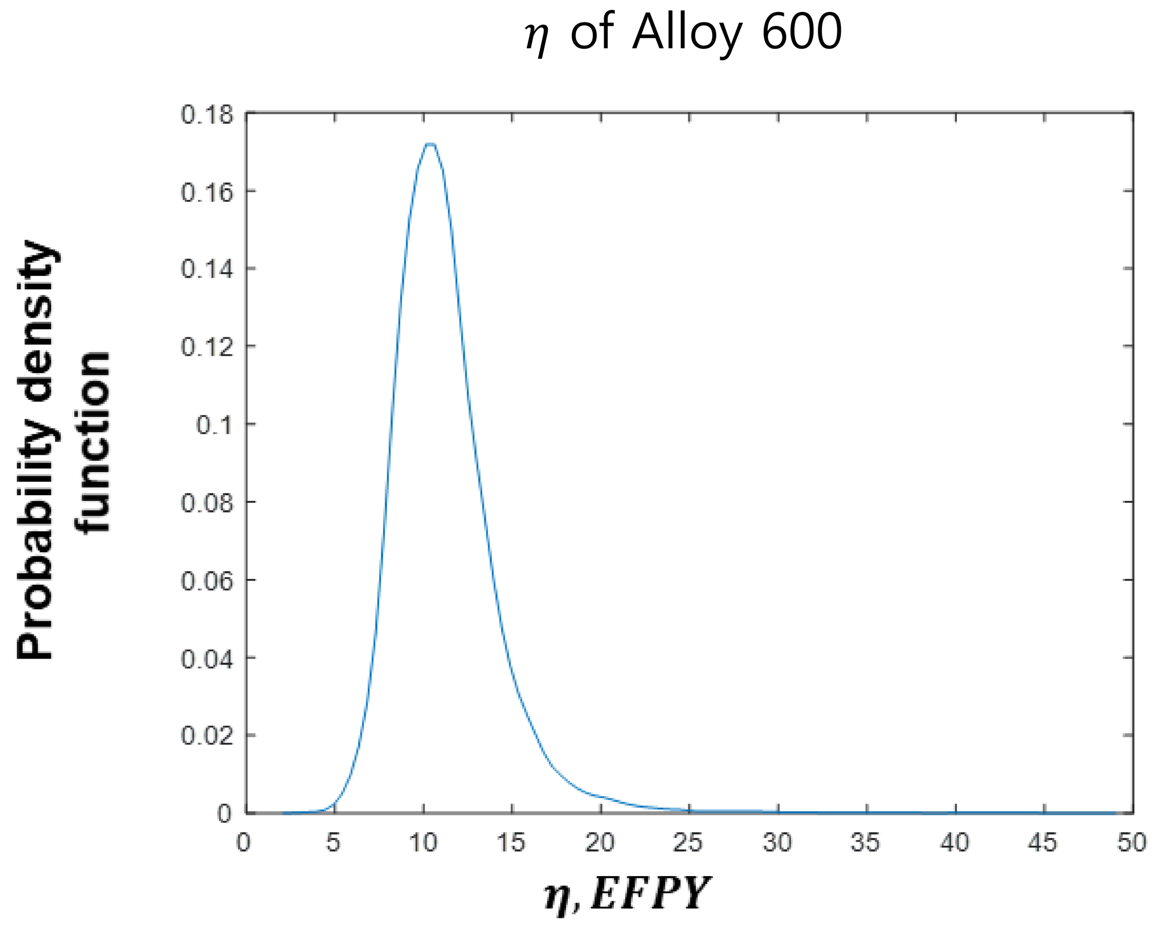
where t_{1st} is time to the earliest failure

Numerical Simulations and Results

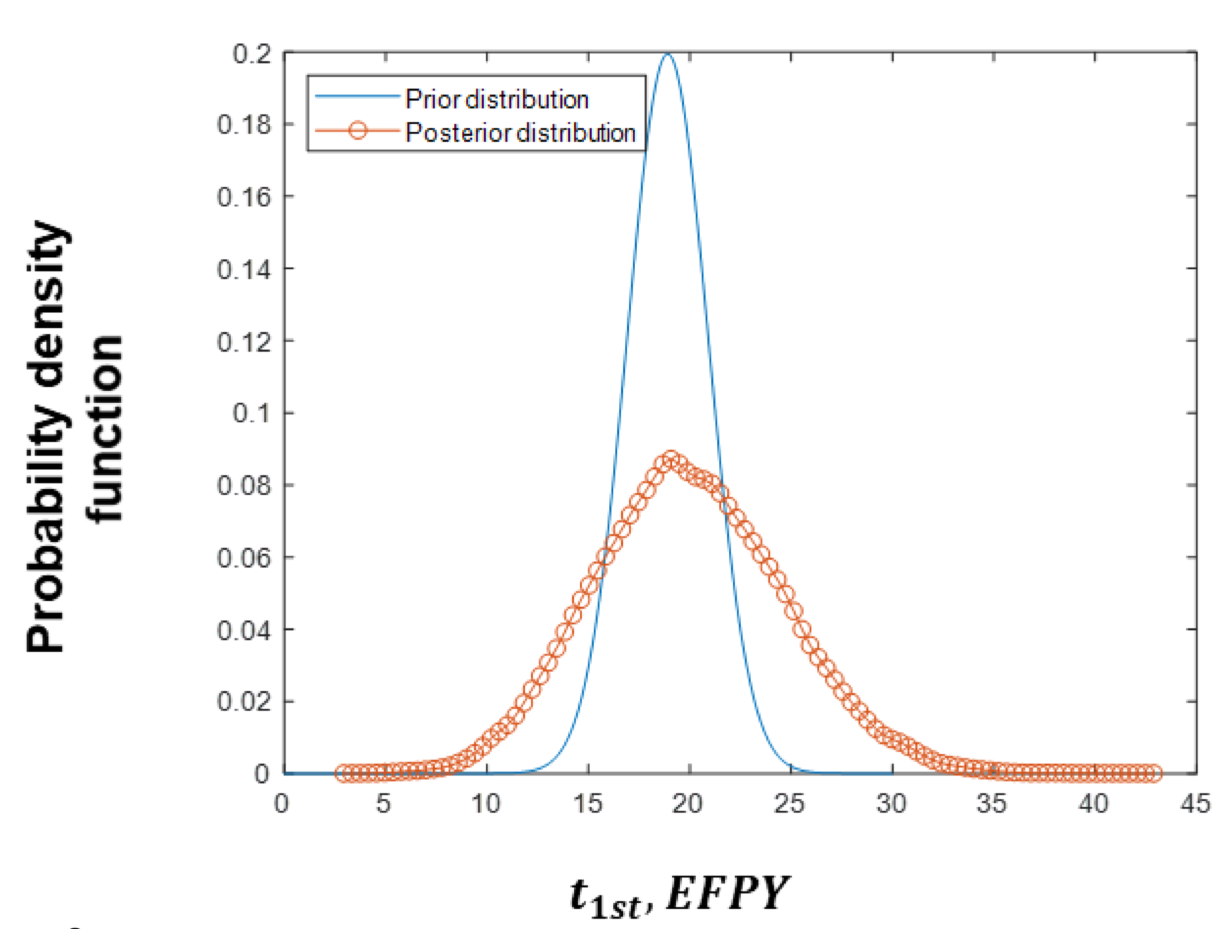
◆ Database on in-service experience of Alloy 600 MA and 690 TT steam generator tubing up to the year of 2008 summarized in [2]

◆ Results:

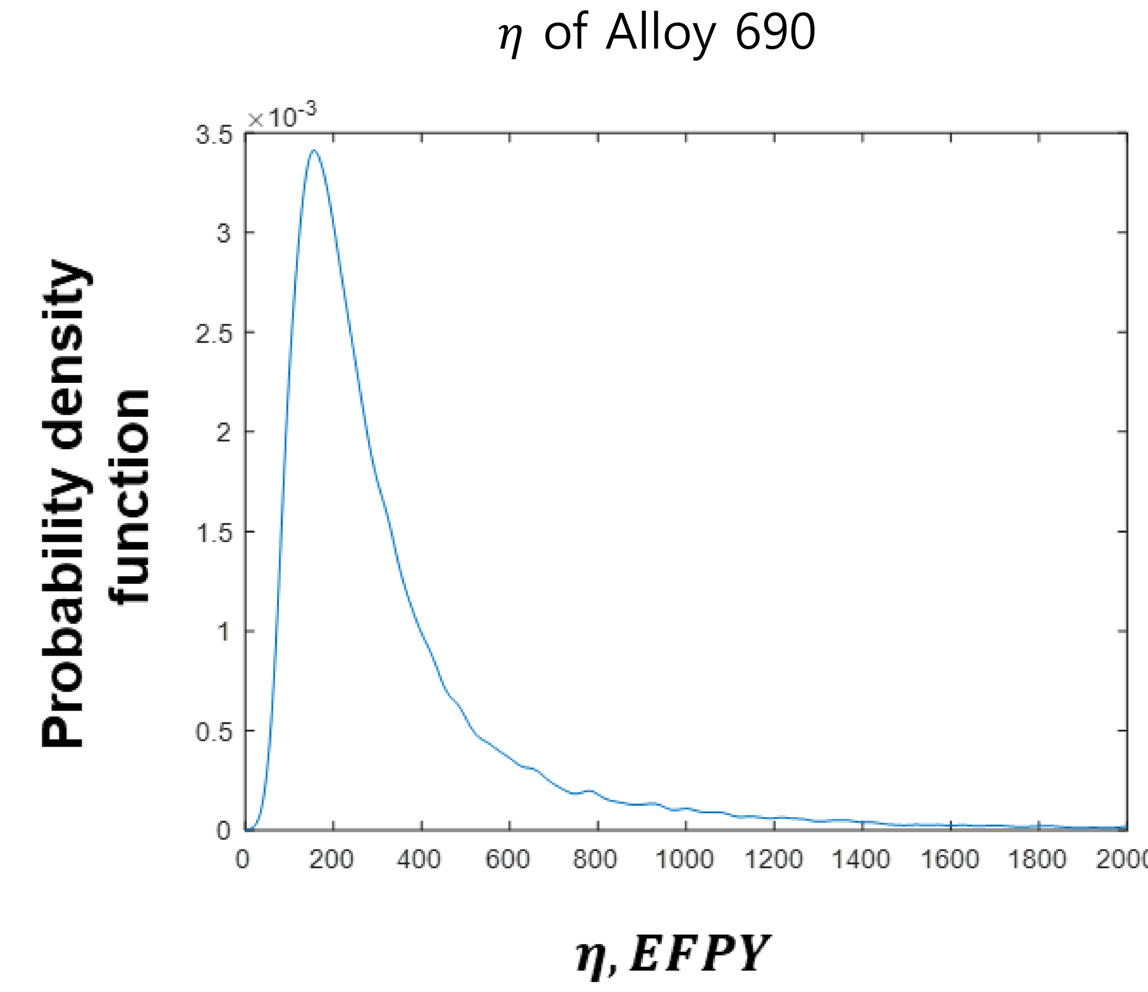
η of Alloy 600



t_{1st} of Alloy 690



η of Alloy 690



[2] Steam Generator Management Program: Improvement Factors for Pressurized Water Reactor Steam Generator Tube Materials. EPRI, Palo Alto, CA: 2009. 1019044.

Future works

◆ Using some different priors to see the sensitivity of the results to the choice of priors

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