The Study on Environmental Fatigue Behavior of Low Alloy Steel and Stainless Steel Pipes Using the Simplified Plant Transients

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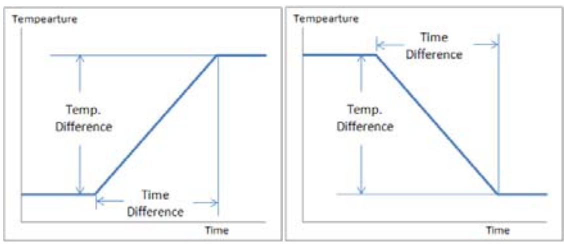
1. Introduction

Nuclear components categorized as ASME Code [1] Class 1 shall be evaluated for the fatigue and satisfy the fatigue acceptance criteria, CUF(cumulative usage factor) < 1 in accordance with ASME Code. However, recent studies have shown the fatigue evaluation procedure may not give conservative results when the components operate in the water environment. NRC issued Regulatory Guide 1.207 [2] which enforces the new fatigue evaluation method or F_{en}(environmental fatigue correction factor) method to nuclear plants to be newly constructed. This paper describes the characteristics of the behavior of low alloy and austenitic stainless steel straight pipe related to environmental fatigue, which are obtained by using the method suggested by Regulatory Guide 1.207 and simplified plant transients.

2. Methods and Results

2.1 Methods

Fig. 1 shows simplified heat-up and cool-down transients used in this study. Variables related to the curves are identified in Table 1. 2D axisymmetric FEM model is prepared to simulate 1 inch thick and 10 inch diameter straight pipes. Input variables are applied on the inner surface of the pipe and it is assumed that outer surface of the pipe is perfectly insulated. F_{en}s and maximum strain values are calculated.



Heat-up Transient　　Cool-down Transient

Fig. 1. Simplified heat-up and cool-down curves

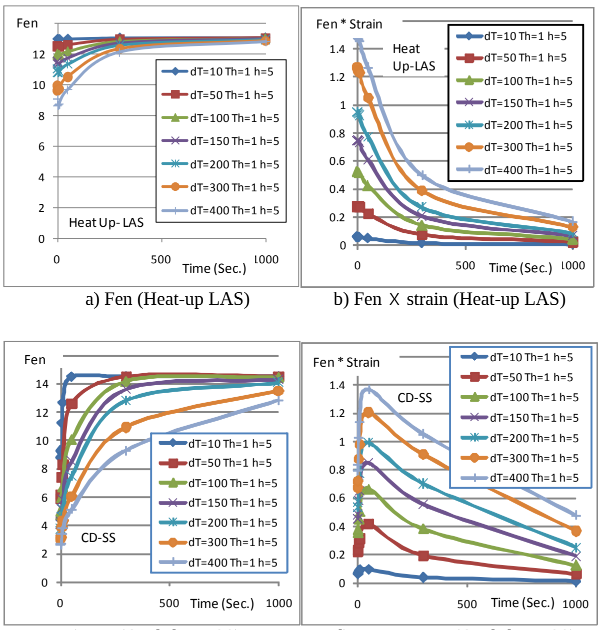
Table 1. Input variables of FEM analysis

Variables	Values
Temperature Differences, dT (°F)	10, 50, 100, 150, 200, 300, 400
Time Differences (sec.)	0, 0.0036, 0.5, 5, 10, 50, 300, 1000
Heat Transfer Coefficients, h (Btu/hr-in^2°F)	0.1, 1, 5, 10, 20, 30
Material Types	A508 Cl. 3 Gr. 1 (low alloy steel (LAS), Type 316 stainless steel (SS)

2.2 Results

A new parameter defined as (F_{en}×strain) is introduced to clarify effects of the transients and other input variables on environmental fatigue.

From Fig. 2, it is expected that (Fen×strain) parameter can realize the overall environmental effects on fatigue damage more directly than Fen parameter only. The environmental effect increases as the temperature difference become larger for both heat-up and cool-down cases. For heat-up transients, (F_{en}×strain) parameter decreases monotonically as the time difference increases. Meanwhile, for cool-down transients, the effect has a peak around 50 seconds of the time difference and then decreases.



a) Fen (Heat-up LAS)　b) Fen X strain (Heat-up LAS)

c) Fen (Cool-down SS)　d) Fen X strain (Cool-down SS)

Fig. 2. F_{en} and (F_{en}×strain) behaviors per time difference, which are calculated corresponding to transient curves (heat-up and cool-down) and material types (low alloy steel and stainless steel). Hereafter, Th in the figure means thickness.

Fig. 3 shows the relation of the time difference and the ratio of (F_{en}×strain) parameters between stainless steel and low alloy steel pipes when they are in the same environmental condition. The ratio is 1.5 ~ 3.5 times larger in stainless steel than in low alloy steel for the heat-up condition and 1 ~ 3 times for the cool-down condition. It increases as the time difference increases, but tends to converge to about 3 if h > 1.

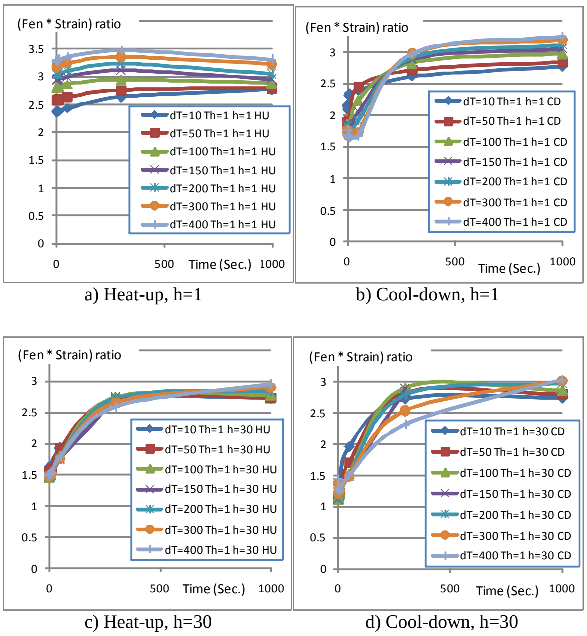


Fig. 3. Time differences vs. $[(F_{en}\times strain)_{stainless\ steel} / (F_{en}\times strain)_{low\ alloy\ steel}]$ (h=1 and 30 cases are shown in this figure).

Fig. 4 shows the relation of the time difference and the ratio of $(F_{en}\times strain)$ parameters between heat-up and cool-down cases for low alloy steel and stainless steel.

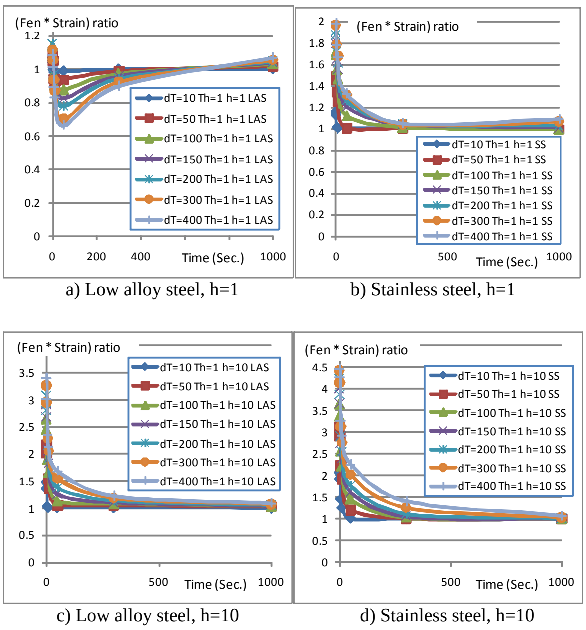


Fig. 4. Time differences vs. $[(F_{en}\times strain)_{heat\text{-}up} / (F_{en}\times strain)_{cool\text{-}down}]$ (h=1 and 10 cases are shown for each of low alloy steel and stainless steel.)

The ratio of $(F_{en}\times strain)$ parameters would be smaller in the heat-up condition than in the cool-down condition by 0.5 ~ 1.2 times if h is small, for example, h = 1. However, the ratio is reversed as h increases. If h is large enough, for example, h = 5, the ratio shows the highest value of about 5 at the time difference = 0 (that is, step change cases) and then decreases monotonically and finally converges into 1.

3. Conclusions

A new parameter, $(F_{en}\times strain)$ is introduced to clarify the environmental fatigue effects among input variables, including simplified transients and material types. Based on the parameter, main findings of this study are as follows.

1. The environmental fatigue effects become larger as the temperature difference increases and the time difference decreases.
2. The environmental fatigue effect is 1.5 ~ 3 times larger in stainless steel than in low alloy steel for the heat-up condition and 1 ~ 3 times for the cool-down condition. The effect increases logarithmically for most h values as the time difference increases.
3. The environmental fatigue effect due to transients is the highest at the time difference = 0 and decreases exponentially and finally converges into 1 as the time difference increases (not for small h). Therefore, the effect of heat-up and cool-down transients on environmental fatigue will be equal if the time difference is sufficiently large.

REFERENCES

[1] ASME Code Section III, Subsection NB, Rules for Construction of Nuclear Power Plant Components, Class 1 Components
[2] NRC, Regulatory Guide 1.207, Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light Water Reactor Environmental for New Reactor, March 2007.