2006 춘계 한국신뢰성학회

원전 배관용 스테인리스강의 2축 저주기 피로수명 평가

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Introduction

- Continuous construction and plan of nuclear power plant for electric power security
- Increase of accident and breakdown at equipment of nuclear power plant (IAEA '99)

↓

Pipes of the primary coolant system in the nuclear power plant
[Duplex cast stainless steels (CF8M)]
Occurrence of embrittlement phenomenon at operating temperature range

↓

Prevention of failure | Extension of life

↓

Evaluation of degradation and life prediction for pipes

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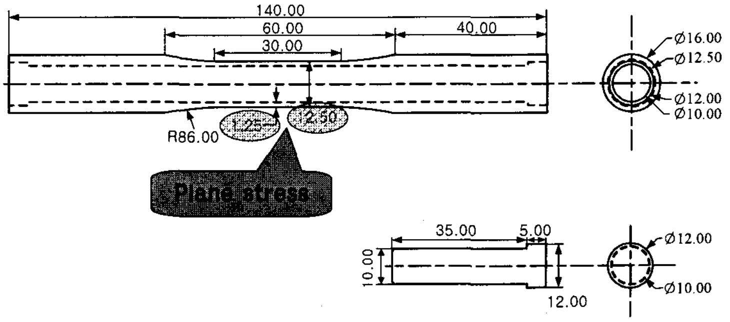
Specimen

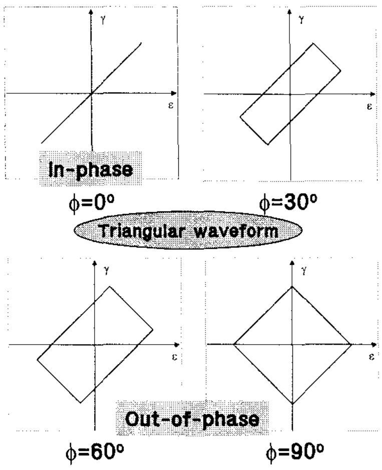
- Virgin Material (As received)
- Degraded material (Thermal aging for 3600 hrs at 430°C)
- Thin-walled tubular specimen
- Electrolytic polishing (To inhibit fatigue crack initiation from the inner surface)



Mechanical Properties & Fatigue Data

	Virgin material		3600 hrs degraded	
	Axial property	Shear property	Axial property	Shear property
Transition fatigue life ($2N_t$)	125,111	115,924	76,186	47,224
Fatigue strength coefficient (σ_f , τ_f), [MPa]	822	570	840	692
Elastic modulus (E, G), [MPa]	198	77	199	78
Elastic Poisson's ratio (ν_e)	0.28			
Plastic Poisson's ratio (ν_p)	0.50			
σ'_f / E , τ'_f / G	0.00414	0.00736	0.00423	0.00890
Fatigue ductility coefficient (ε'_f , γ'_f)	0.175	0.5701	0.1007	0.8175
Fatigue strength exponent (b, c)	0.111	0.125	0.116	0.137
Fatigue ductility exponent (b_t , c_t)	0.430	0.498	0.398	0.557

Multiaxial Fatigue Test Condition



Strain paths

#	ε_a(%)	γ_a(%)	$\lambda(\gamma_a/\varepsilon_a)$	ϕ
1	0.20	0.30	1.50	0°
2	0.30	0.50	1.67	0°
3	0.80	0.90	1.13	0°
4	0.45	1.10	2.44	0°
5	0.40	0.45	1.13	30°
6	0.50	0.65	1.30	60°
7	0.45	0.75	1.67	90°
8	0.25	0.55	2.20	90°
9	0.20	0.40	2.00	90°
10	0.30	1.20	4.00	90°

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Results

Obtained from the hysteresis loops at ½ point of the fatigue life

#	λ	ϕ [deg.]	σ_{max} [MPa]	τ_{max} [MPa]	N_f
1	1.50	0°	168	112	12,453
2	1.67	0°	197	132	5,284
3	1.13	0°	307	126	1,102
4	2.44	0°	173	187	1,528
5	1.13	30°	268	143	2,931
6	1.30	60°	360	231	1,341
7	1.67	90°	367	270	663
8	2.20	90°	273	203	3,738
9	2.00	90°	179	148	8,341
10	4.00	90°	264	279	612

Virgin materials

#	λ	ϕ [deg.]	σ_{max} [MPa]	τ_{max} [MPa]	N_f
1	1.50	0°	170	116	11,032
2	1.67	0°	202	152	3,174
3	1.13	0°	319	144	457
4	2.44	0°	180	196	887
5	1.13	30°	277	158	2,755
6	1.30	60°	363	236	1,263
7	1.67	90°	463	306	571
8	2.20	90°	292	215	2,896
9	2.00	90°	187	156	6,564
10	4.00	90°	274	285	411

Degraded materials

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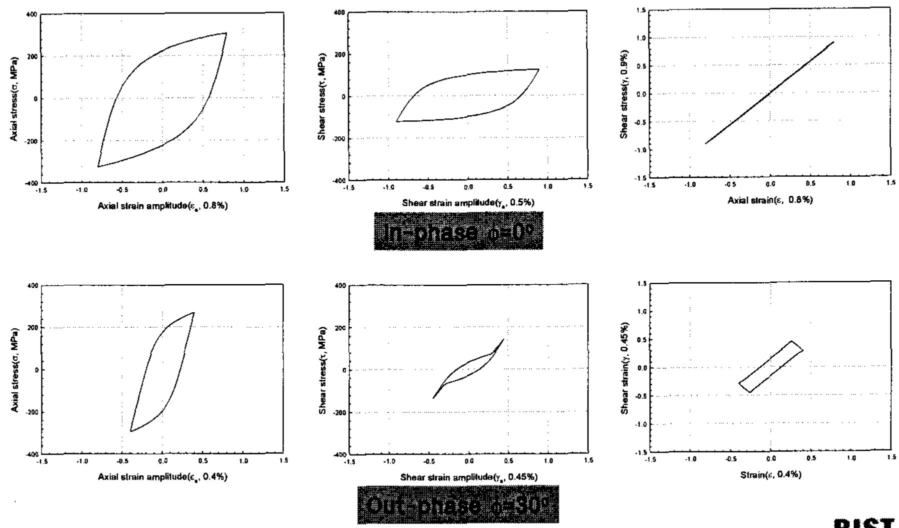
Results : Hysteresis loops of virgin material



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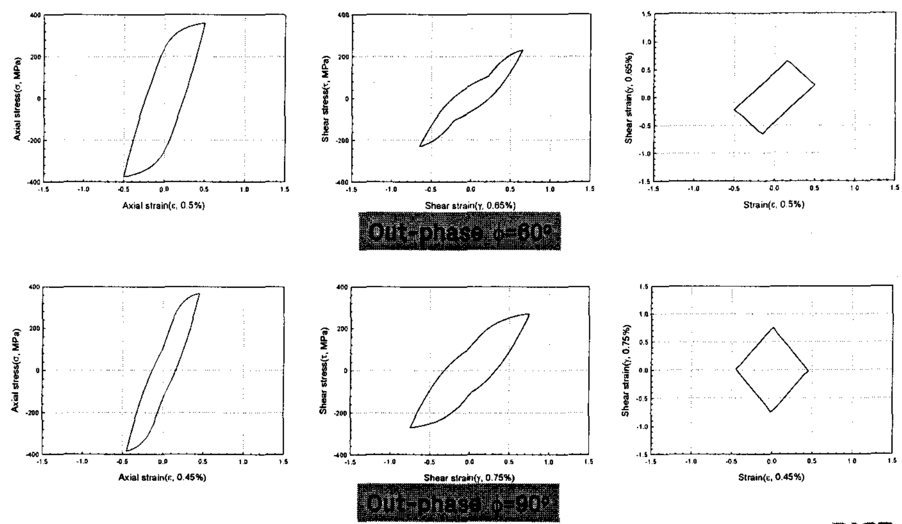
Results : Hysteresis loops of virgin material



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The von Mises Equivalent Strain

$$\varepsilon_{eq} = \left[\frac{(\varepsilon_{xx}-\varepsilon_{yy})^2 + (\varepsilon_{yy}-\varepsilon_{zz})^2 + (\varepsilon_{zz}-\varepsilon_{xx})^2 + \frac{3}{2}(\gamma_{xy}^2+\gamma_{yz}^2+\gamma_{zx}^2)}{2(1+\nu_{eff})^2} \right]^{1/2}$$

$$\nu_{eff} = \left[\frac{\varepsilon_e \nu_e + \varepsilon_p \nu_p}{\varepsilon_a} \right]$$

$$\varepsilon_{xx} \neq 0 \qquad \gamma_{xy} \neq 0$$

$$\varepsilon_{yy} = \varepsilon_{zz} = -\nu_{eff}\varepsilon_{xx} \qquad \gamma_{yz} = \varepsilon_{zx} = 0$$

Thin walled tubular specimen

$$\varepsilon_{eq} = \left[\varepsilon_{xx}^2 + \frac{3}{4(1+\nu_{eff})^2}\gamma_{xy}^2 \right]^{1/2}$$

$$\frac{1}{2}\Delta\varepsilon^t_{eq} = \frac{1}{2}\Delta\varepsilon^e_{eq} + \frac{1}{2}\Delta\varepsilon^p_{eq} = \frac{\sigma_f'}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c$$

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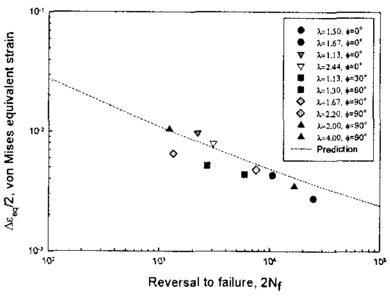
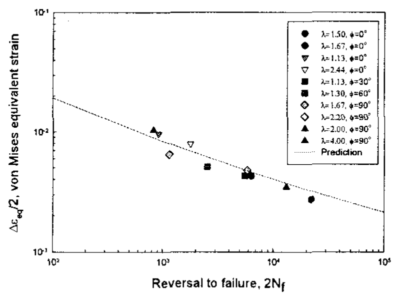
The von Mises Equivalent Strain



Virgin materials



Degraded materials

$$\frac{1}{2}\Delta\varepsilon^t_{eq} = \frac{\sigma_f'}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c$$

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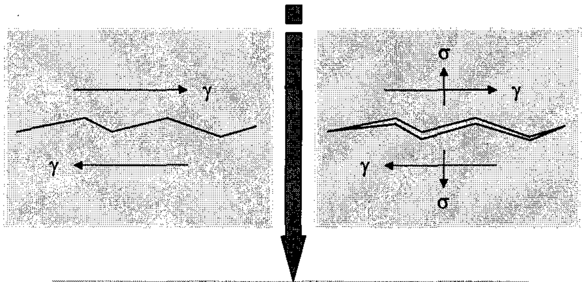
Fatemi-Socie (FS) Parameter

$$\frac{\Delta\gamma_{max}}{2}(1+\bullet\frac{\sigma_n^{max}}{\sigma_y}) = C$$



- k : material constant
- $\Delta\gamma_{max}/2$: maximum shear strain amplitude
- σ_n^{max} : maximum normal stress
- σ_y : yield strength

$$\frac{\Delta\gamma_{max}}{2}(1+\bullet\frac{\sigma_n^{max}}{\sigma_y}) = \frac{\tau_f'}{G}(2N_f)^{b_f} + \gamma_f'(2N_f)^{c_f}$$

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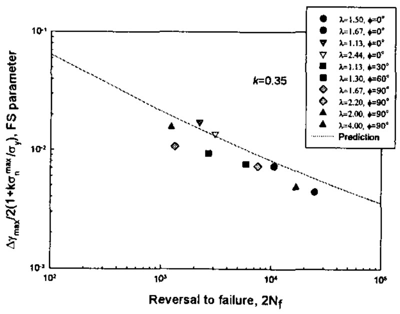
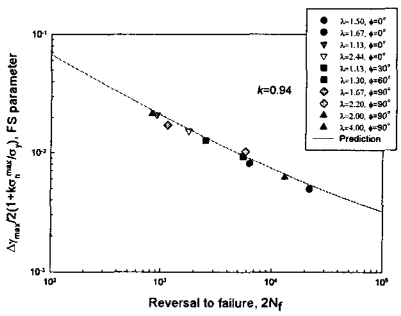
Fatemi-Socie (FS) Parameter



Virgin materials



Degraded materials

$$\frac{\Delta\gamma_{max}}{2}(1+k\frac{\sigma_n^{max}}{\sigma_y}) = \frac{\tau_f'}{G}(2N_f)^{b_f} + \gamma_f'(2N_f)^{c_f}$$

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Smith-Watson-Topper (SWT) Parameter

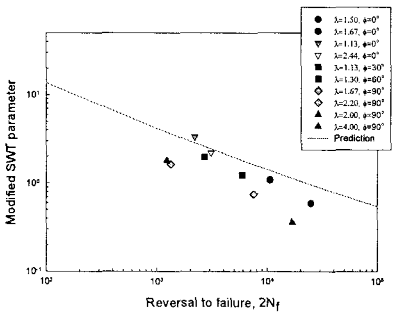
$$\sigma_1^{max} = \sigma_f'(2N_f)^b \quad \times \quad \frac{\Delta\varepsilon_1}{2} = \frac{\sigma_f'}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c$$

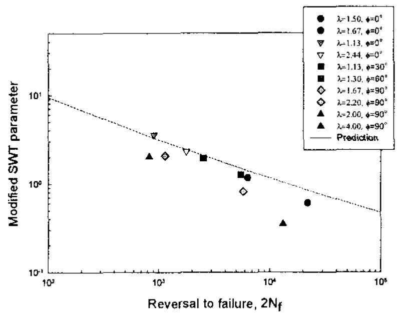
σ_1^{max} : maximum normal stress

$\Delta\varepsilon_1/2$: maximum principal strain

$$\frac{\Delta\varepsilon_1}{2}\sigma_1^{max} = \frac{\sigma_f'^2}{E}(2N_f)^{2b} + \sigma_f'\varepsilon_f'(2N_f)^{b+c}$$

Smith-Watson-Topper (SWT) Parameter

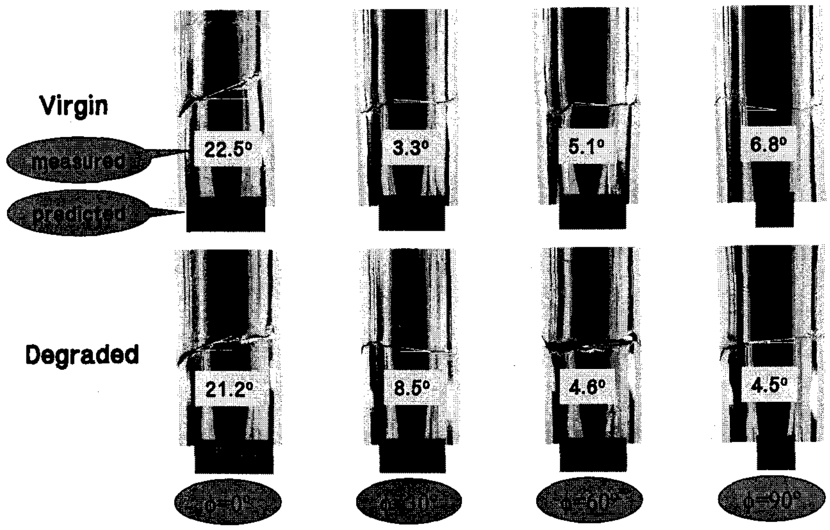




Virgin materials **Degraded materials**

$$\frac{\Delta\varepsilon_1}{2}\sigma_1^{max} = \frac{\sigma_f'^2}{E}(2N_f)^{2b} + \sigma_f'\varepsilon_f'(2N_f)^{b+c}$$

Prediction of Crack Orientation



Conclusions

Multiaxial fatigue tests were conducted on virgin and 3600 hrs degraded materials for CF8M under axial-torsional load.
The following conclusions were obtained:

(1) The material properties and the change of the fatigue life
- Acquisition data for multiaxial fatigue life prediction
- Fatigue life decreased by material degradation

(2) The prediction of the fatigue life under the combined axial-torsional loading
- Multiaxial fatigue life decreased by material degradation
- FS parameter showed the best results
- Non of three models showed any prediction of the fatigue life in the conservative aspect.