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Experimental Investigation of Strain Concentration Evaluation Based on the Stress Redistribution Locus Method

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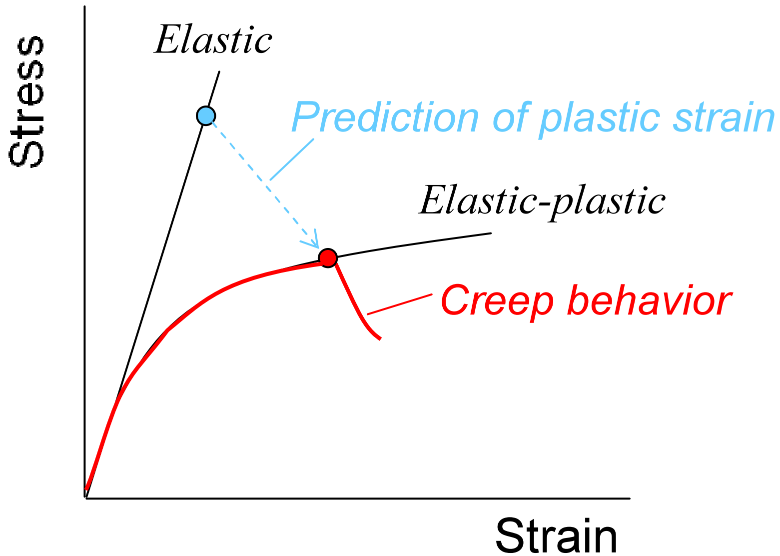
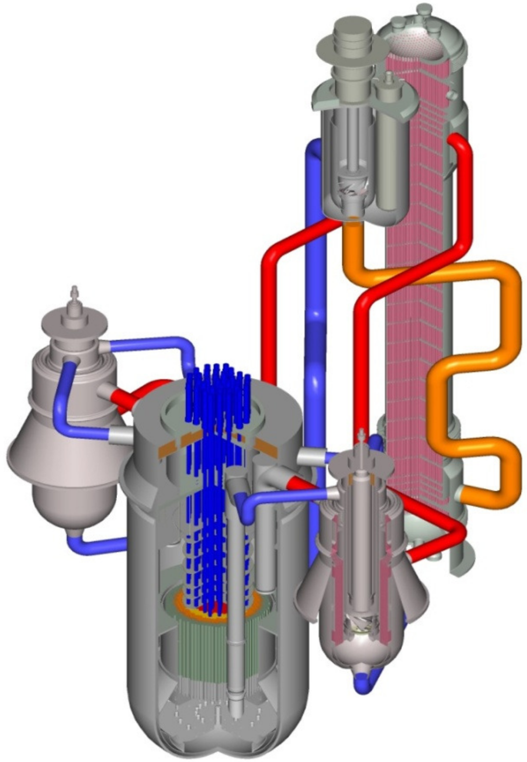
1. Background

Inelastic strain should be considered in the design of fast reactors because of high temperature operation.

Evaluation methods based on elastic analysis are used in the current codes and they include relatively large conservatisms.

To improve and rationalize high temperature design rule of fast reactors.





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Neuber's rule

$$K_\sigma \cdot K_\varepsilon = K_t^2$$

the locus of stress redistribution from elastic to plastic state is a hyperbolic curve

Elastic follow-up

Inelastic strain concentration by the difference of stiffness between components is considered.
The locus is obtained by using the factor q as follows;

$$q = \frac{(\varepsilon - \varepsilon^e)E}{\sigma^e - \sigma} + 1$$

In the Japanese code, DDS;
Neuber's rule - local strain, Elastic follow-up - nominal strain

2-2. Stress redistribution Locus (SRL) concept

The locus of stress redistribution for a structure can be obtained from elastic-creep analysis.
The effect of creep law and loading magnitude on loci is small and the locus mainly depends on the structure.

A master curve for this method has been proposed;

$$\tilde{\varepsilon} = \frac{1}{\kappa}\left(\frac{1}{\tilde{\sigma}} + (\kappa - 1)\tilde{\sigma}\right) \qquad \tilde{\varepsilon} = \frac{K_\varepsilon}{K_t} \qquad \tilde{\sigma} = \frac{K_\sigma}{K_t}$$

The master curve coincide with the Neuber's rule when κ=1.
κ is usually 1.4-1.6.

2-3. Comparison of methods

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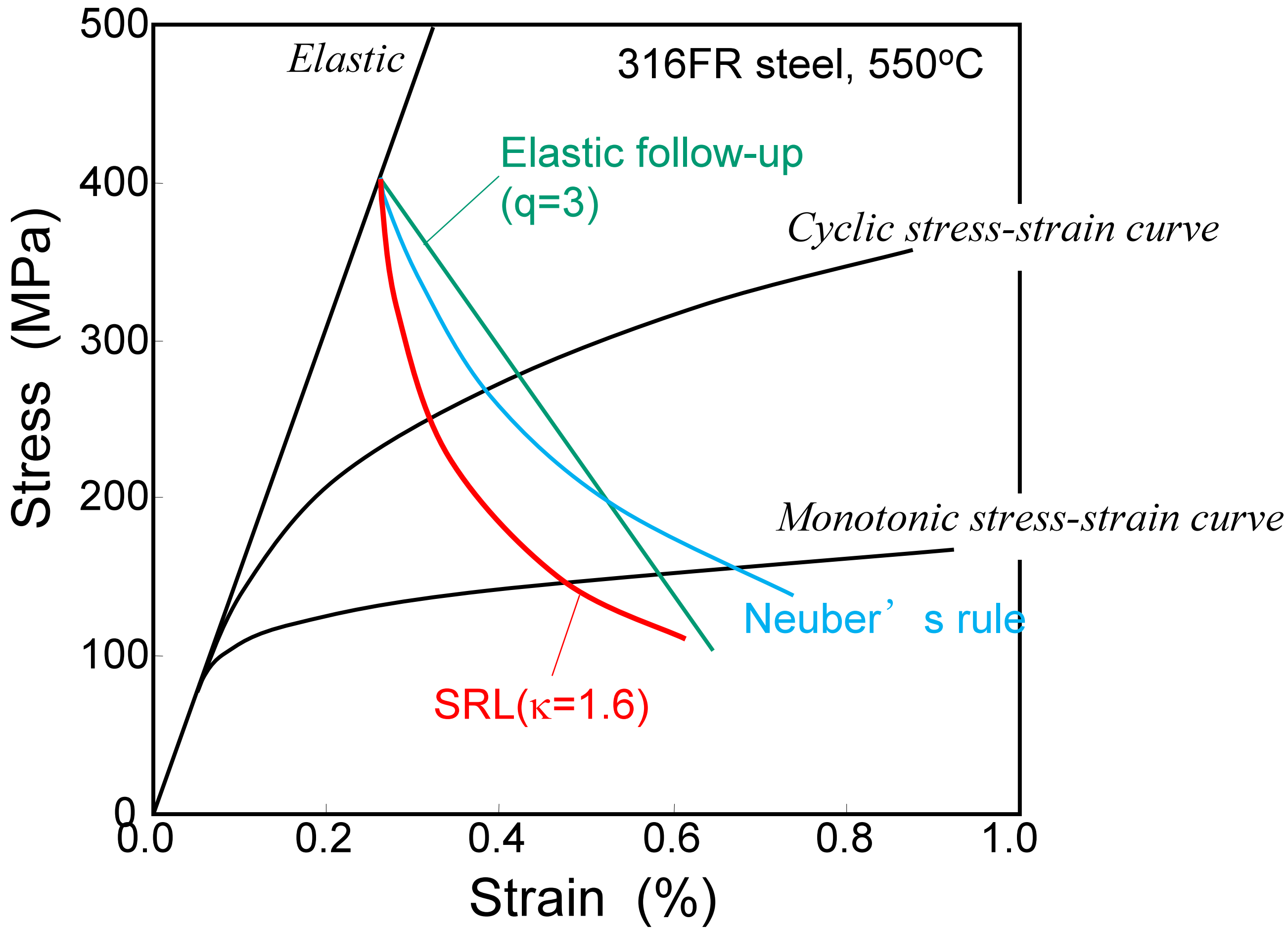
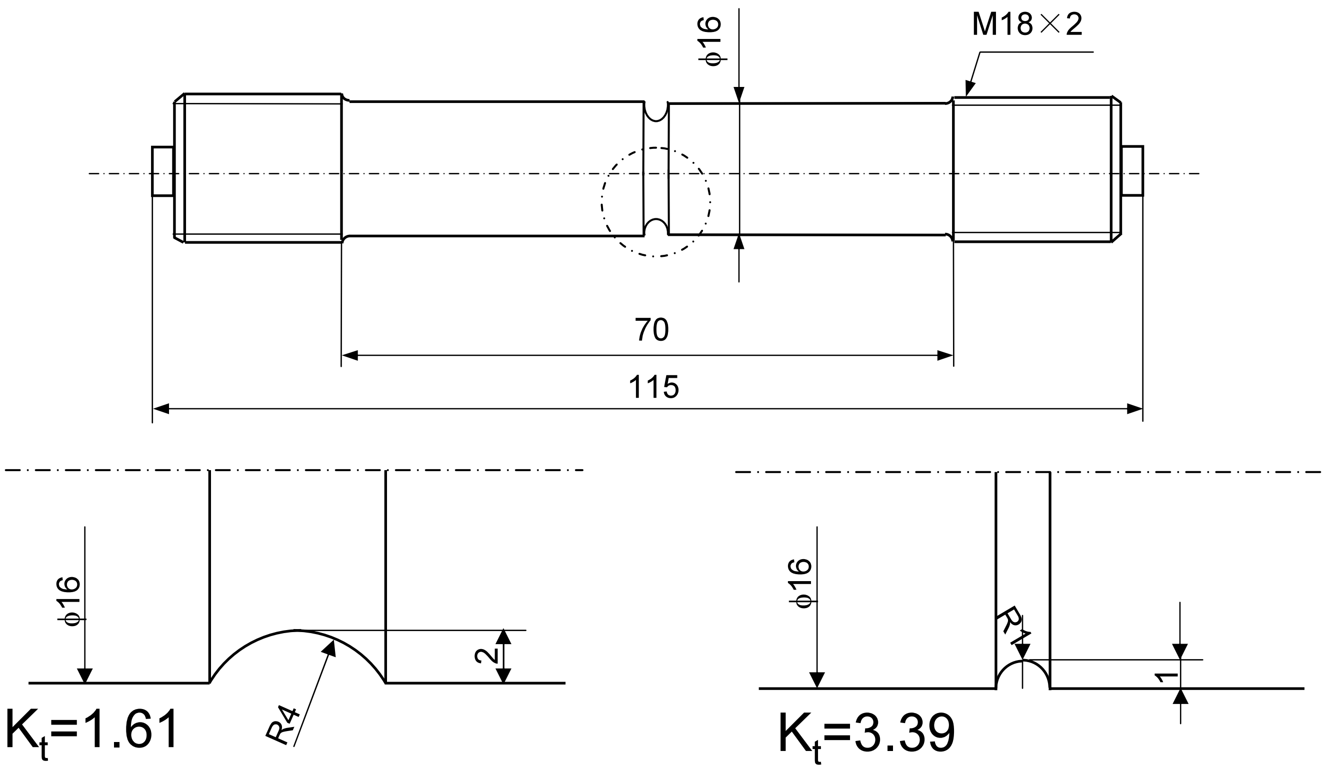


- The SRL method gives smaller strain than conventional methods.
- The SRL method improves high temperature design methods if its validity has been verified.

3-1. Fatigue tests

Material : 316FR steel

C	Si	Mn	P	S	Ni	Cr	Mo	N
0.009	0.55	0.84	0.024	0.007	11.25	17.00	2.11	0.0751



Circumferentially notched specimen

3-2. Experimental conditions

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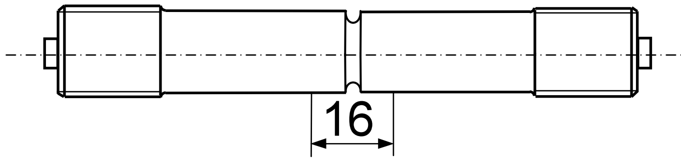
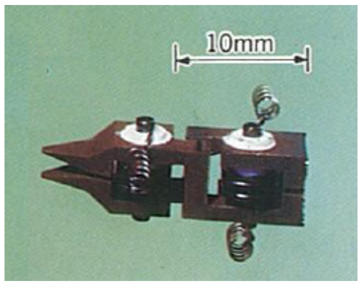
Fatigue test condition

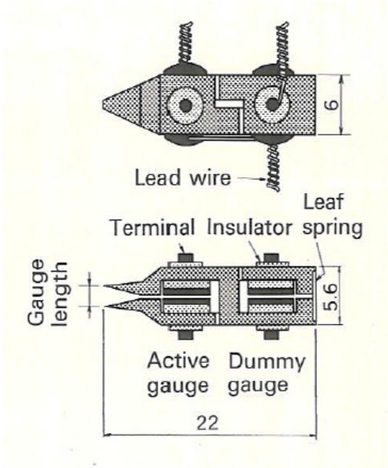
Temp.（℃）	Kt	Nominal strain range（%）
Room temp.	1.61	0.4%
	3.39	0.3%
550	1.61	0.4%
	3.39	0.26%

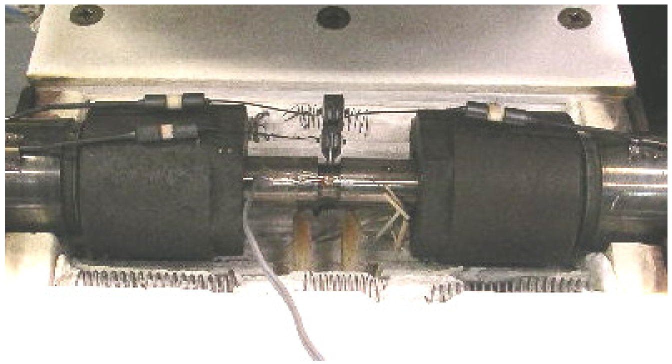


Gauge length
of nominal strain

Local strain measurement

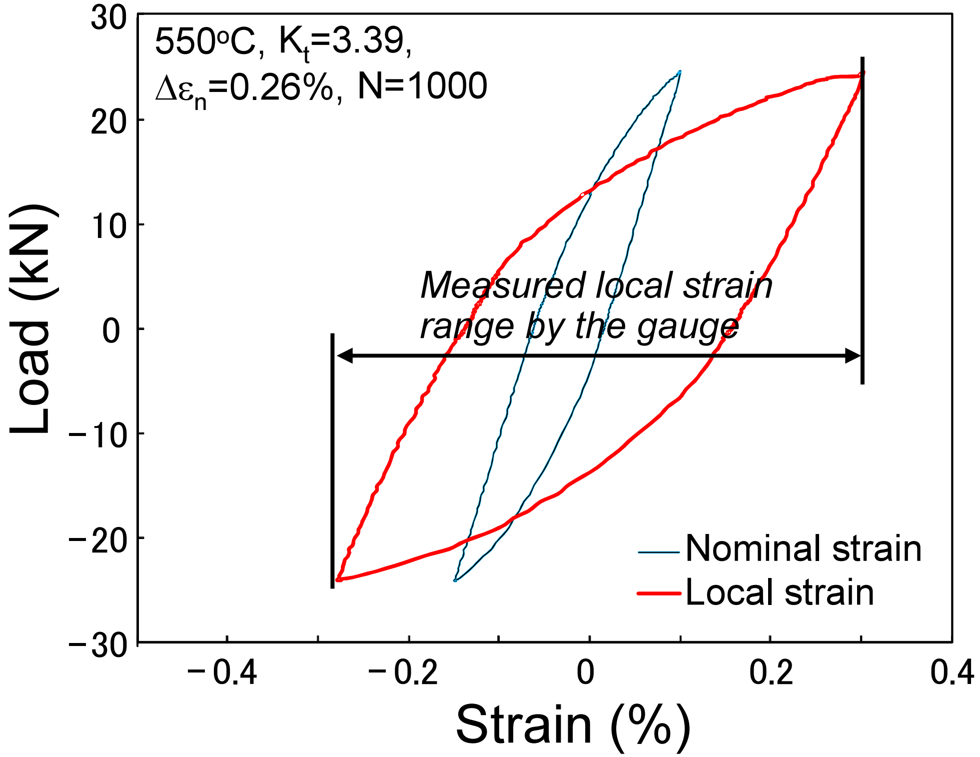


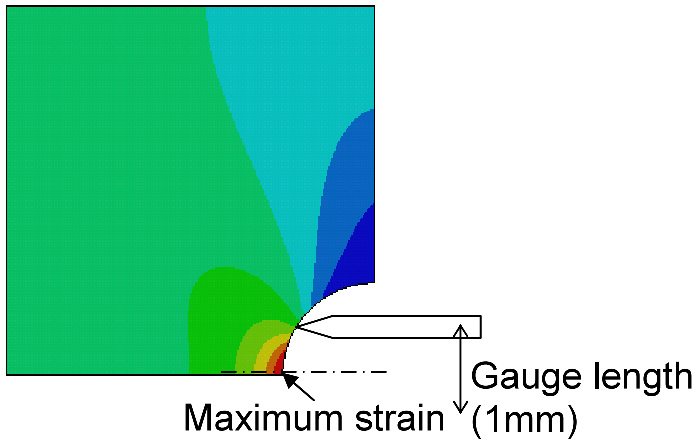




Capacitance type high temperature gage: Strain Pecker

3-1. Experimental results



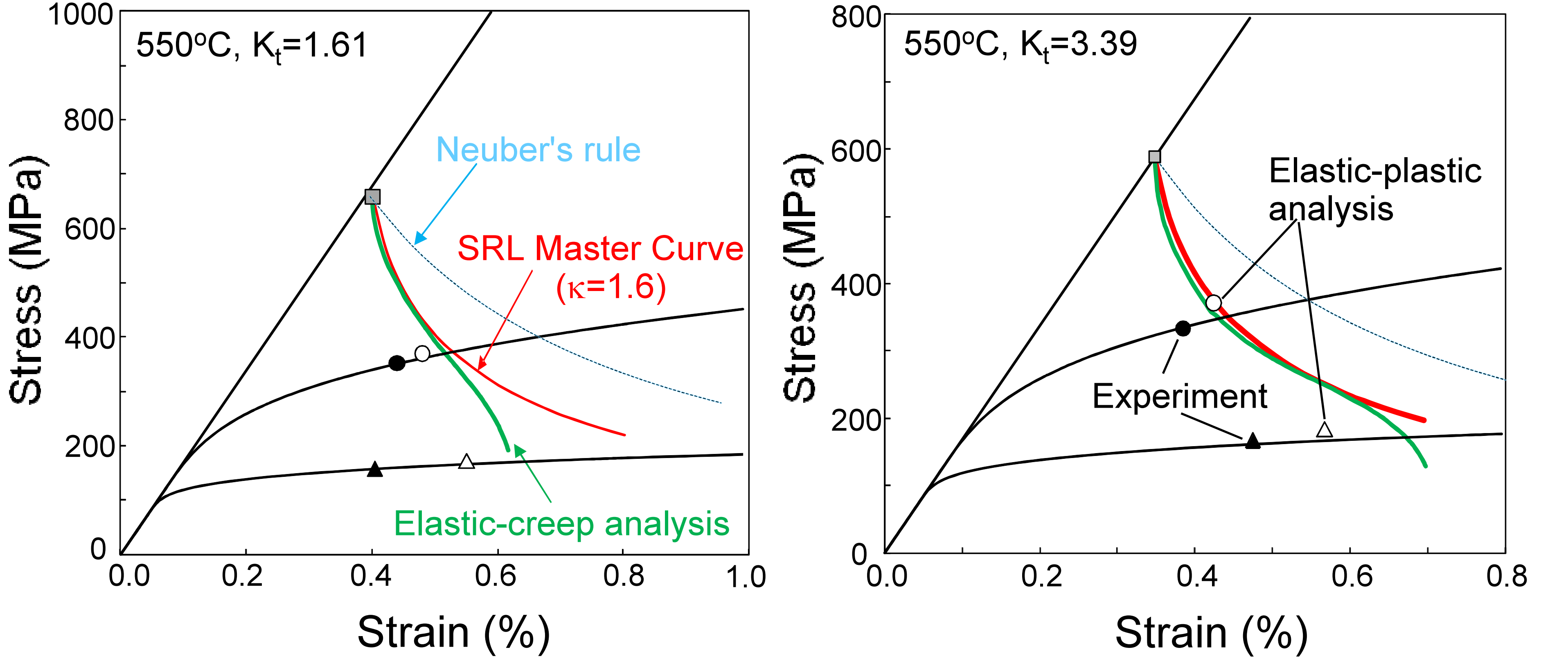


The maximum strain at the notch root is larger than the gauge output:
K_t =1.61 → ×1.02, K_t =3.39 → ×1.32

Measured local strains were compared with prediction. The following methods are discussed;

1. The SRL master curve,
2. Stress redistribution locus by elastic-creep analysis,
3. Elastic-plastic analysis,
4. The Neuber's rule,
5. Strain range corresponding to failure life of each specimen.

3-2. Evaluation results of strain concentration



- All the methods discussed in this study gives conservative prediction.
- The SRL master curve, elastic-creep and elastic-plastic analysis give similar estimations except for the condition that a large plastic strain arises.

3-3. Evaluation results of strain concentration

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Prediction method	Stress-strain curve	Strain range (%)			
		RT, K_t=1.61	RT, K_t=3.39	550°C, K_t=1.61	550°C, K_t=3.39
SRL(k=1.6)	Monotonic	1.56	1.70	> 2	1.60
	Cyclic			1.12	0.94
Elastic-creep analysis	Monotonic	1.24	1.58	1.24	1.36
	Cyclic			1.08	0.90
Elastic-plastic analysis	Monotonic	1.14	1.46	1.10	1.12
	Cyclic			0.96	0.85
Neuber's rule	Monotonic	> 2	> 2	> 2	> 2
	Cyclic			1.33	1.08
Estimation from fatigue curve		0.80	1.40	0.87	0.78
Measured value	1st cycle	0.73	1.14	0.81	0.72
	Middle life	0.81	1.31	0.88	0.58

- Strain range corresponding to failure life is closed to measured strain range.
- Method based on the SRL concept and inelastic analysis gives 30-50 percent smaller strain than the Neuber's rule.

3-4. Comparison of predicted failure lives

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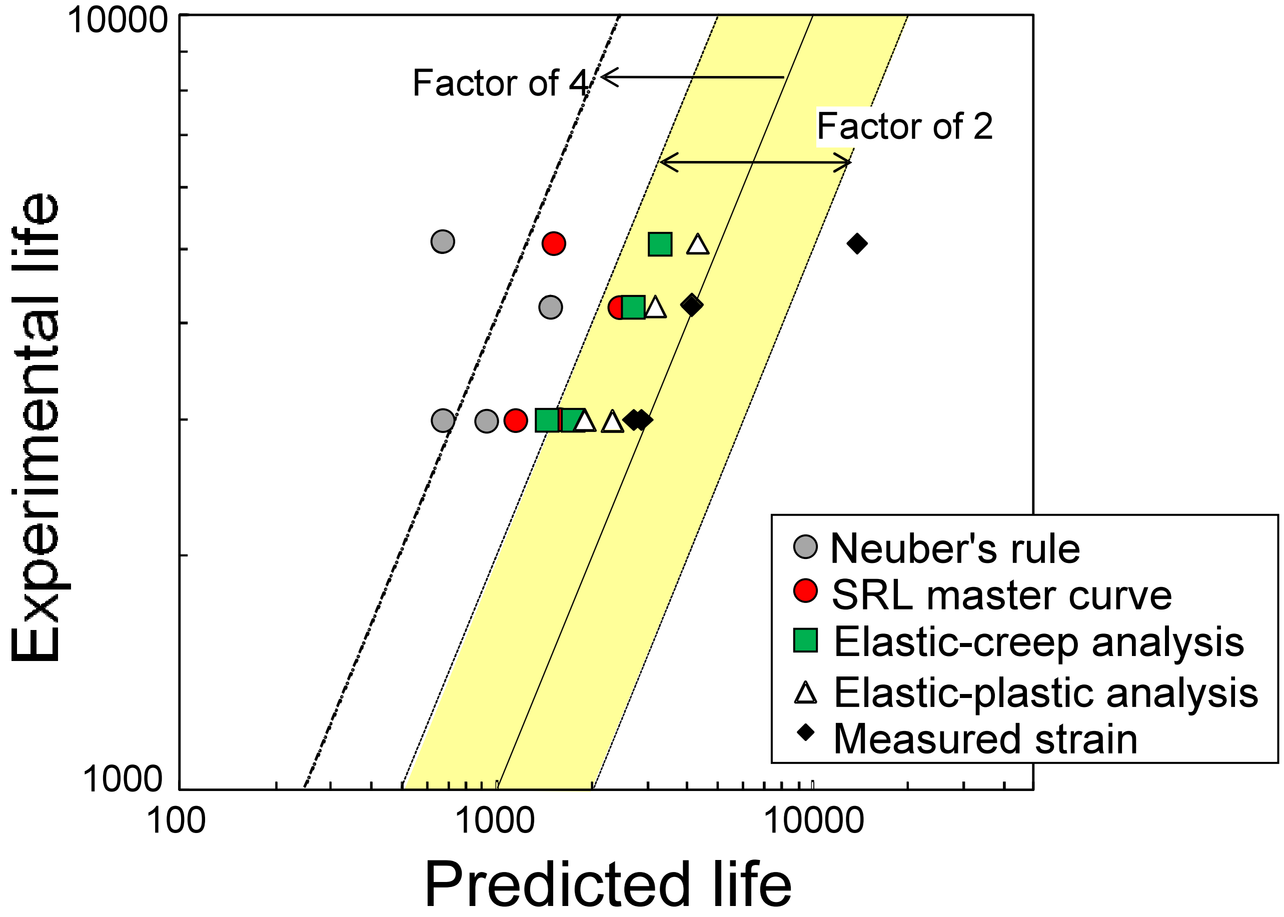


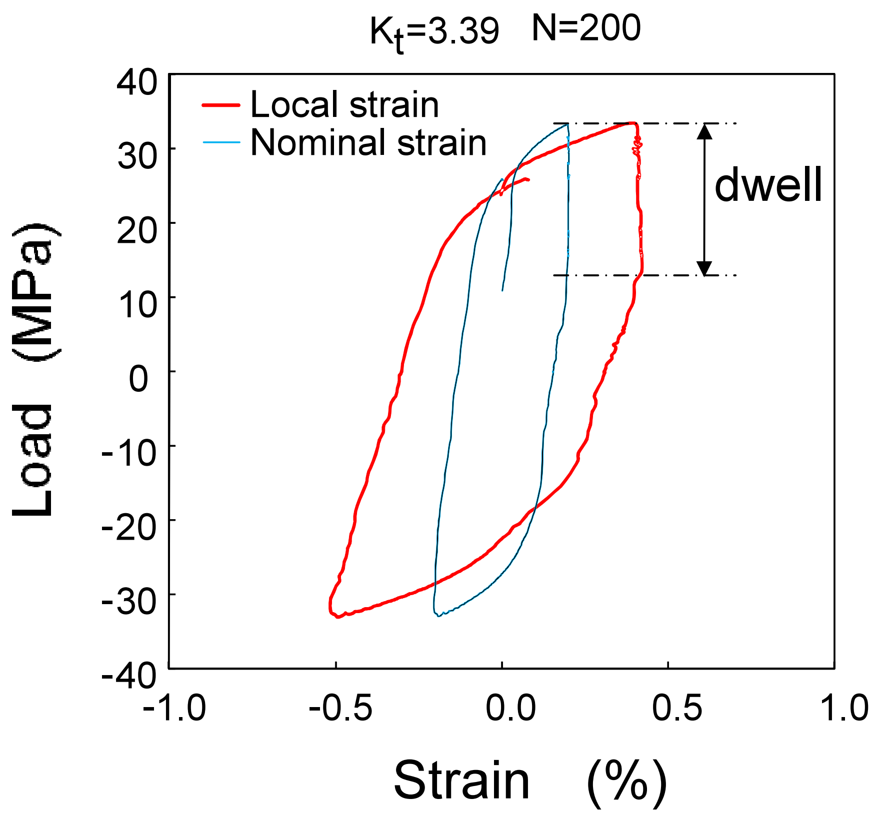
The SRL method has a reasonable conservatisms about fatigue life.

Creep-fatigue tests had been carried out to discuss local strain behaviors during dwell.

Test condition

Temp. (℃)	Kt	$\Delta\varepsilon_n$ (%)
650	1.61	0.4%
	3.39	0.4%

Strain hold inserted at 1-5, 10, 20, 50, 100, 200, 500 cycles
- not every cycle.



3-6. Comparison of relaxation behaviors

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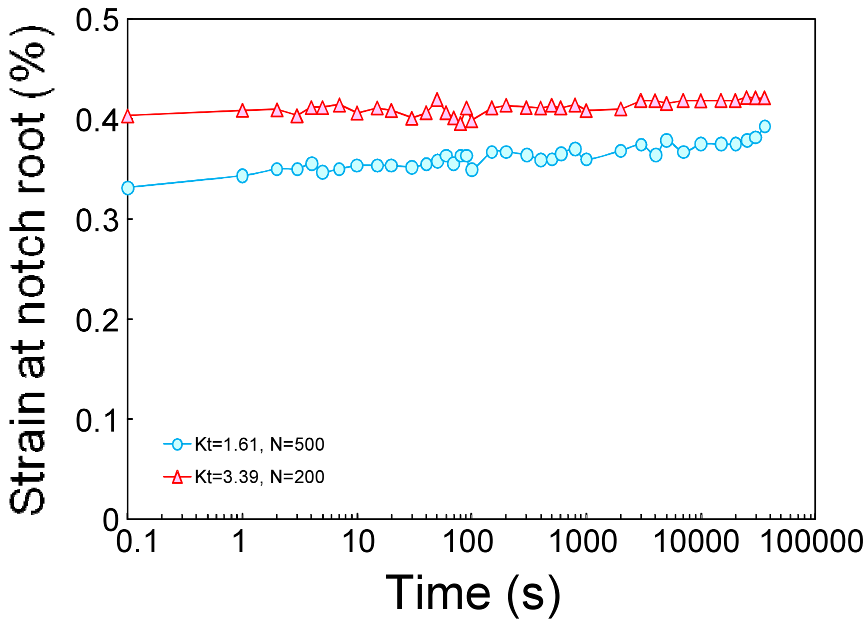
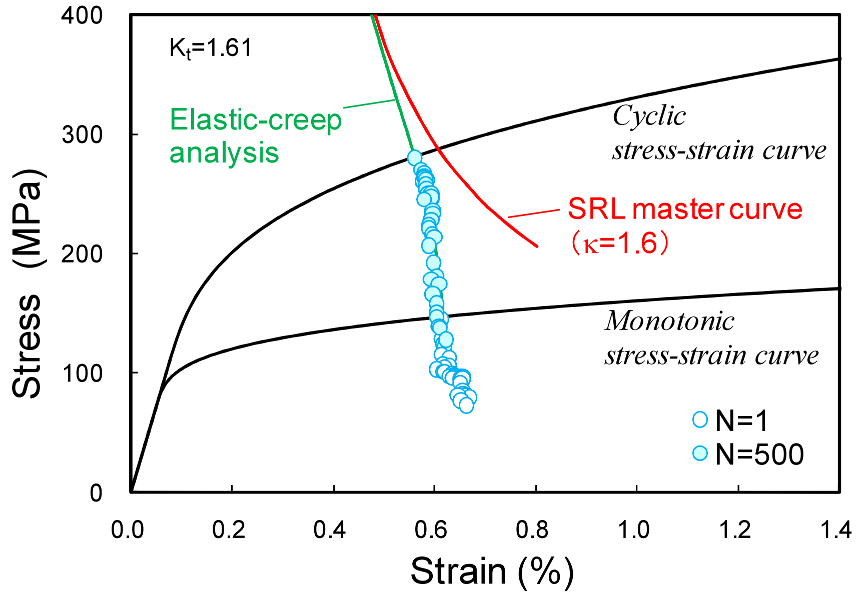
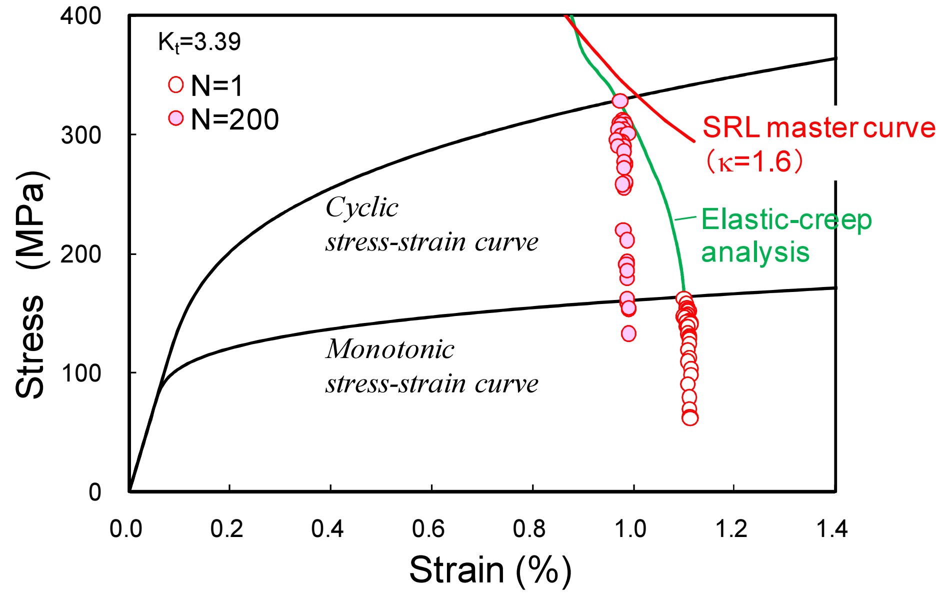


Straining behaviors during dwell





- The experimental locus is almost coincide with the locus by elastic-creep analysis.
- The SRL method improves the accuracy of inelastic strain concentration in comparison with current.

4. Summary

The stress redistribution locus (SRL) method was investigated experimentally in order to improve and rationalize creep-fatigue damage evaluation methods in the high temperature design rule of fast reactors.

(1) High temperature fatigue tests of circumferential notched specimens were conducted accompanying with local strain measurement.

The SRL method is able to rationalize the evaluation of inelastic strain concentration with keeping a reasonable conservatisms.

(2) Creep-fatigue tests are also conducted and local strain behaviors at the notch root during dwell is observed.

Stress-strain loci estimated from experimental results shows a good agreement with prediction by the SRL concept.

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