Fatigue-Creep Life Prediction for Notched Specimen of 2·1/4Cr-1Mo Steel at 600°C

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ABSTRACT

This paper presents the life prediction of 2·1/4Cr–1Mo notched specimens subjected to fast–fast, slow–slow and hold-time loadings at 600°C. Crack initiation lives of notched specimens were estimated based on the local stress/strain calculated by inelastic FEM analyses. For the life prediction, seven different constitutive models and five fatigue–creep damage laws were used. The applicability of the constitutive model and damage law was discussed.

1. INTRODUCTION

The Subcommittee of Inelastic Analysis and Life Prediction of High Temperature Analysis (members are listed in the footnote of the first paper [Inoue, et. al. 1991a]) has made benchmark projects on the life prediction of notched specimens under fatigue–creep condition. This paper consists of the forth part of the projects and discusses the life prediction of notched specimens under fatigue–creep loadings based on the local stress/strain calculated in the third project[Inoue et. al., 1991b].

Fatigue–creep tests were carried out for two types of the specimens and crack initiation and failure lives were obtained. The constitutive models used in the inelastic analysis were superposition model, modified superposition model, the models by Chaboche, Miller, Bodner, Ohno–Murakami and Endochronic model. The detailed description of the inelastic models is described in a different report of the benchmark project[Inoue, et. al., 1991b].

Damage laws applied were linear damage rule (LDR) [ASME, 1984], strain range partitioning method (SRP) [Halfold et. al., 1973], Lemaitre–Plumtree–Chaboche method (LPC) [Lemaitre, et. al., 1979], Majumdar method [Majumdar et. al., 1980] and Bui–Quoc method[Bui–Quoc, et. al., 1982]. Fatigue–creep lives were predicted based on the local stress/strain at the notch root, calculated by the FEM inelastic analyses using the seven constitutive models.

2. EXPERIMENTAL PROCEDURE

Nominal strain controlled fatigue–creep tests were carried out using 2·1/4Cr–1Mo circum–

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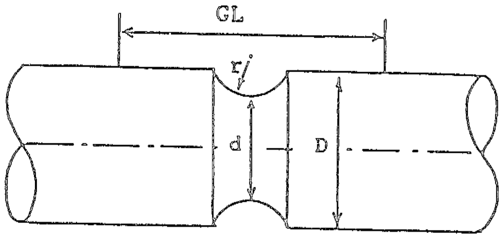

Fig. 1 Shape and dimensions of the notched part.

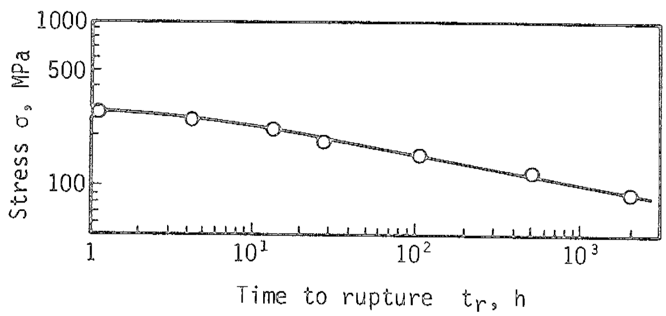

Fig. 2 Static creep rupture data used for the life prediction.

ferential notched specimens of which elastic stress concentration factors are 1.5 and 3.0. Nominal strain along 20–mm gage length including the notched part was controlled. Shape and dimensions of the test specimen are illustrated in Fig.1. Chemical composition and heat treatment of the material was presented elsewhere [Inoue et. al. 1989]. Fast–fast (pp), slow–slow (cc) and hold–time (t_H) tests were carried out at 600°C. Strain rate, strain amplitude and duration of hold–time are shown in Table 1. Crack initiation lives were detected by the direct current potential method following the recommendation of ISIJ[ISIJ, 1988].

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 FATIGUE–CREEP LIFE OF NOTCHED SPECIMEN

Table 2 shows the averaged value of fatigue–creep lives detected throughout this study. A small scatter of the data is found in the experimental results, so the averaged values of the tests of which number of cycles is shown in the table are employed as a representative value. In the table, the failure life is defined as the cycle of 25 percent tensile stress drop from saturation and crack initiation life as the cycle of rapid potential increase on d.c. potential versus number of cycles plot.

The base data used for the life prediction is the low cycle fatigue data in pp test and static creep rupture data. The low cycle fatigue data[Inoue, 1989] used is;

Table 1 Test condition.

Elastic stress concent. Kt	Strain rate $\dot{\varepsilon}_{GL}$ %/s	Nominal strain range $\Delta\varepsilon_{GL}$ %	Hold-time t_H min
1.5	0.025	0.20	0.0
	0.025	0.20	10.0
	0.001	0.20	0.0
3.0	0.025	0.20	0.0
	0.025	0.20	10.0
	0.001	0.20	0.0

Table 2 Average value of the crack initiation and failure lives.

Elastic stress concent. Kt	Strain wave shape	Crack initiation cycle N_c	Failure cycle N_f
1.5	pp	350	2983
	cc	250	1137
	t_H	405	1710
3.0	pp	155	1220
	cc	60	449
	t_H	63	606

$$\Delta\bar{\varepsilon}=1.273\,N_f^{-0.756}+8.170\times10^{-3}\,N_f^{-1.410}\quad,\ \Delta\bar{\varepsilon}\ ;\ mm/mm \qquad (1)$$

Figure 2 shows the creep rupture data used for the creep damage evaluation.

3.2 FATIGUE-CREEP LIFE PREDICTION

Figure 3 compares the predicted lives in cc and pp tests with the experimental lives (a) for Kt=1.5 and (b) for Kt=3.0, based on the linear damage rule. The predicted fatigue-creep lives were evaluated following the ASME Boiler and Pressure Vessel Code [ASME, 1984] using the stress/strain relation at the notch root which were analyzed in FEM by means of respective constitutive models. The value of the critical damage was assumed to be unity. In these figures, crack initiation life as well as failure life determined in experiments is shown by the lines. Since the notch has mainly an effect on crack initiation life, the predicted life must be compared with crack initiation life. Crack propagation period is included in the failure life so that the fracture mechanics approach should be taken for the failure life prediction.

From these figures, it is understood that the predicted life does not largely depend on the constitutive model. In cc tests, about a half of the constitutive models gives an unconservative estimation for Kt=1.5 but all the models give an exact or conservative estimation for Kt=3.0. In t_H tests, most of the models predicts conservatively for Kt=1.5 but appropriately for Kt=3.0.

Table 3 summarizes the predicted results in this study, where (a) is for Kt=1.5 and (b) for Kt=3.0. Values in the table are the ratio of the predicted life divided by the experimental crack initiation life. Thus, the life prediction becomes unconservative if the value is larger than unity, and the prediction is conservative if the value less than unity.

For the case of Kt=1.5 shown in Table 3 (a), as is understood from the row of average, all the constitutive models overestimate the crack initiation life for pp tests. The life ratio is ranged from 5.92 to 8.85. The life ratio in cc tests becomes smaller in comparison with pp tests. However, the value is still larger than 3.00. In t_H tests, the life prediction is quite satisfactory. All the constitutive models combined with the life prediction methods predict the experimental crack initiation life within a factor of two scatter. There exists no large

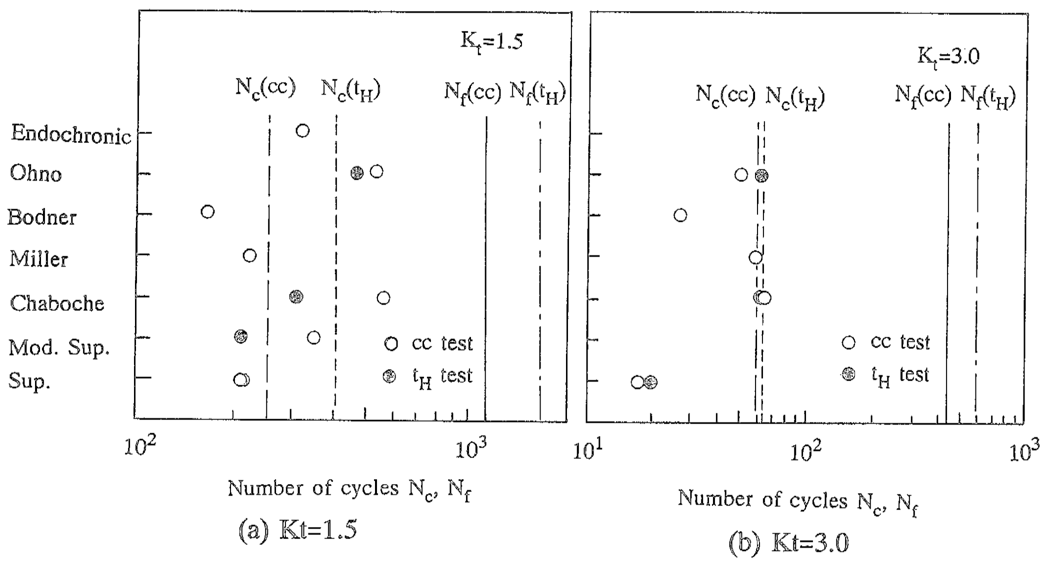

Fig. 3 Life prediction of the notched specimen by linear damage rule.

difference in the predicted result between the constitutive models.

Regarding the effect of damage law on the predicted results shown in the column of average, all the predictions overestimate the crack initiation life in pp tests for Kt=1.5. In cc tests, the value in the table becomes smaller in comparison with pp tests but still is larger than unity. In t_H tests, the value becomes much smaller and the prediction goes to the safety side in some damage laws. The characteristics of the predicted results are ; the Bui–Quoc method gives somewhat small values in t_H test and the Majumdar method estimates large crack initiation life.

For Kt=3.0 shown in Table 3 (b), it is hard to find any difference in the predicted results due to the constitutive model. It should be noted that the averaged values in all the constitutive models are within a factor of two scatter so that all the constitutive models appropriately estimate crack initiation lives. Also, there is no large difference in the predicted results due to the damage law. All the damage laws estimate properly crack initiation lives excepting the Majumdar's cc case. In this case, the prediction is unconservative in comparison with the other damage laws.

4. CONCLUSIONS

Fast–fast, slow–slow and hold–time tests were carried out and crack initiation and failure lives were determined by experiments. Crack initiation lives were estimated based on the local stress/strain relation by some combinations of seven constitutive models and five damage laws. The predicted results do not largely depend on the constitutive model and on the damage law. All the predictions overestimate the crack initiation life for Kt=1.5 and estimate properly for Kt=3.0. Only Majumdar's damage law predicts somewhat un–conservatively even for Kt=3.0.

Table 3 (a) Summary of the predicted results for Kt=1.5.

		Sup.	Mod.Sup.	Chaboche	Miller	Bodner	Ohno	Endo.	Average
LDR	pp	4.85	7.14	5.71	3.14	3.43	5.71	---	5.39
	cc	0.84	1.40	2.12	0.84	0.64	2.04	1.24	1.30
	t_H	0.51	0.51	0.74	---	---	1.14	---	0.75
SRP	pp	5.66	6.87	4.19	7.28	10.53	4.83	---	6.54
	cc	5.05	4.97	3.08	3.64	6.28	3.26	---	4.38
	t_H	2.44	3.17	1.80	---	---	2.10	---	2.38
LPC	pp	---	---	---	---	---	---	---	---
	cc	0.84*	0.95	1.94	0.83	0.66	1.98	1.05	1.18
	t_H	0.47*	0.60	0.64	---	---	0.96	---	0.65
Majumdar	pp	11.00	13.00	8.16	14.90	4.42	7.50	---	9.64
	cc	9.96	11.84	5.92	9.00	4.30	5.90	10.60	8.22
	t_H	3.24	4.03	2.38	---	---	2.26	---	3.05
Bui-Quoc	pp	7.14	8.41	5.60	5.55	8.76	6.21	---	6.75
	cc	5.30	6.13	3.34	3.17	5.84	4.03	5.43	4.93
	t_H	0.12	0.15	0.14	---	---	0.09	---	0.31
Average	pp	7.16	8.85	5.92	7.72	6.79	6.06	---	---
	cc	5.29	5.06	3.28	3.50	3.54	3.44	4.58	---
	t_H	1.56	1.69	1.04	---	---	1.31	---	---

* Somewhat different superposition rule

Table 3 (b) Summary of the predicted results for Kt=3.0.

		Sup.	Mod.Sup.	Chaboche	Miller	Bodner	Ohno	Endo.	Average
LDR	pp	0.84	---	1.10	1.10	0.90	0.71	---	0.97
	cc	0.27	---	1.02	0.90	0.41	0.83	---	0.69
	t_H	0.32	---	0.97	---	---	0.97	---	0.76
SRP	pp	0.77	---	0.55	0.51	1.22	0.77	---	0.76
	cc	0.67	---	0.23	0.18	0.35	0.27	---	0.34
	t_H	1.08	---	0.63	---	---	0.94	---	0.88
LPC	pp	---	---	---	---	---	---	---	---
	cc	1.07*	---	1.05	0.90	0.68	1.73	---	1.09
	t_H	0.87*	---	1.25	---	---	1.84	---	1.32
Majumdar	pp	2.50	---	2.16	2.33	2.79	1.30	---	2.15
	cc	4.43	---	3.15	3.48	4.80	2.13	---	3.60
	t_H	2.63	---	1.98	---	---	1.28	---	1.94
Bui-Quoc	pp	1.59	---	1.39	1.43	2.35	1.48	---	1.58
	cc	2.18	---	1.65	1.73	2.78	1.85	---	2.04
	t_H	0.48	---	0.40	---	---	0.40	---	0.51
Average	pp	1.42	---	1.30	1.34	1.82	1.07	---	---
	cc	1.89	---	1.42	1.44	1.80	1.36	---	---
	t_H	1.08	---	1.05	---	---	1.09	---	---

* Somewhat different superposition rule

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