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EVALUATION OF THE CREEP-FATIGUE BEHAVIOUR OF AUSTENITIC STAINLESS STEELS

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ABSTRACT

Creep-fatigue test results on austenitic stainless-steel grades 316 and 316L(N) have been collected and evaluated with respect to creep-fatigue interaction. For the assessment, the linear damage accumulation rule (time-based method) and the ductility exhaustion procedure (strain-based method) have been applied.

The two evaluation procedures gave different results. At low strain ranges lower creep damage values were calculated with the time-based method, whilst at high strain ranges higher values were obtained. From the present "best estimate" evaluation, no clear advantage for either method could be demonstrated unambiguously.

1 INTRODUCTION

Austenitic stainless steels are widely used in components for nuclear reactors, particularly the proposed European fast breeder reactor. For the latter the operating temperature is ≈ 550 °C and low cycle fatigue and creep-fatigue interaction are important phenomena which may determine the life of structures.

Within a Study Contract of the Working Group for Codes and Standards of the CEC (Commission of the European Community) creep-fatigue data for austenitic stainless steel have been evaluated using the entire data base generated for the European fast breeder reactor. Special emphasis has been given to experimental results at low strain ranges and long hold times. In addition to the assessment of the data with the linear damage method, as used in the ASME Code Case N47 (time-based creep damage calculation), the creep-fatigue data have also been evaluated with the ductility exhaustion method, as used in Britain (strain-based creep damage calculation).

2 MATERIALS AND DATA SOURCE

Results from fatigue tests with hold times for the austenitic stainless steel grades 316 and 316L(N) have been used for the present evaluation. 316L(N) is provided as a structural material for the European fast breeder reactor so that the behaviour of this material and its difference to the less narrowly specified 316 is of great interest. The chemical composition of the two grades is given in Table 1. The extent of data with respect to number of heats, test temperature, strain range and hold time is shown below:

Type	Heats	Test temperature [°C]	Strain range [%]	Max. hold time [min]	Total number of tests
316	3	550, 570, 600	0.35-3	2850	31
316L(N)	3	550, 600	0.40-1.64	4000	98

All data had been generated with strain controlled Low Cycle Fatigue (LCF) push-pull testing equipment on cylindrical shaped (parallel length) specimens with triangular or trapezoidal loading wave forms. The failure mode of the specimens was prevailingly defined as the number of cycles corresponding to 25 % drop of tensile stress from the stable cycle.

3 METHOD OF ANALYSIS

As already mentioned two methods have been applied in the present evaluation:

- Linear damage accumulation rule (time-based method)

- Creep ductility exhaustion method (strain-based method)

For both methods the total damage D is given by

$$D = D_f + D_c$$

with D_f the fatigue damage and D_c the creep damage. The most important difference between the two methods concerns the evaluation of creep damage. In the time-based method [1, 2], creep damage is related to creep rupture strength and calculated on a time fraction basis, whereas in the strain-based method [3], it is related to ductility and calculated on a strain fraction basis. The assessments in the present study are "best estimate" approaches, i. e. the evaluations are based on the average creep and fatigue behaviour of each cast of each steel grade at the relevant temperature and no safety margins are included.

Fatigue Damage

The fatigue damage was calculated by

$$D_f = N_{fc} \cdot \frac{1}{N_f}$$

with N_{fc} the number of cycles to fracture in the hold time test and

N_f the number of cycles to fracture in continuous cycling at the same strain range and test temperature. For N_f, cast specific data were used.

For the purpose of this study, the same N_f-values were used for both methods. It should be noted, however, that in the strain-based method (3), N_f is the number of cycles to grow a crack from an initial depth of 0.1 mm to a final depth of 0.5 mm. It is likely that the crack growth curve differs only slightly from the curve corresponding to the number of cycles to fracture.

Creep Damage

In the strain-based method the creep damage has the form

$$D_c = N_{fc} \cdot \sum_k \frac{\Delta\varepsilon_k}{(\varepsilon f)_k}$$

where N_{fc} is the number of cycles to fracture in the creep fatigue test, $\Delta\varepsilon_k$ is the creep strain interval at a constant strain rate k, and $(\varepsilon_f)_k$ is either strain or reduction of area at rupture for that strain rate. The values for $\Delta\varepsilon_k$ were determined from the stress relaxation curve and calculated from $\Delta\sigma_r/E$ where $\Delta\sigma_r$ is a stress relaxation interval and E is Young's modulus.

Ductility (reduction of area) data from creep and tensile tests were plotted against average strain rate (calculated as elongation at failure/time to failure) to determine the reference curves for each cast at the relevant temperature. Reduction of area rather than fracture elongation was used as ductility parameter since it gives a better representation.

In the time based method the creep damage is given by

$$D_c = N_{fc} \sum_j \frac{\Delta t_j}{(t_f)_j}$$

where Δt_j is the time interval under a constant stress j and $(t_f)_j$ is the rupture time at the same stress.For t_f, cast specific data have been used.

4 RESULTS

Typical examples of the results obtained are shown in Fig. 1 for 316 (cast 83 at 550 °C) and in Fig. 2 for 316L(N) (cast SP at 600 °C). It can be seen that at low strain ranges the time-based method yields lower creep damage values than the strain-based method. At higher strain ranges, generally the opposite is true.

The creep damage for both methods is plotted versus the length of hold time in Fig. 3. For the time-based method there is a tendency of an increase in creep damage with increasing hold time, whereas for the strain-based method creep damage is independent of hold time.

An example of creep damage versus total strain range is given in Fig. 4. Whereas for the strain-based method the creep damage increases with decreasing strain range, no clear trend can be established for the time-based method.

5 DISCUSSION AND CONCLUSIONS

The calculated creep versus fatigue damage values show a relatively large scatter. This is not unexpected and known from earlier evaluations. On the whole the scatter of data obtained with the time- and strain-based methods seems to be comparable. No systematic difference in creep-fatigue behaviour of 316 and 316L(N) is observed.

With respect to the influence of strain range on calculated creep damage different trends emerge for the two methods. Whereas for the strain-based method creep damage increases with decreasing strain range, there is no clear tendency for the time-based method. As a result, at low strain ranges creep damage values calculated with the strain-based method are higher than those determined with the time-based method.

This can also be seen from Fig. 5 in which the ratio of creep damage values calculated with the time-based method to those calculated with the strain-based method is plotted versus hold time.

The points with low strain ranges show a calculated creep damage ratio of less than 1, even when they are extrapolated to long hold times. This means that the two methods do not converge in the region of interest for design.

From experimental investigations [4] it is known that fracture at low strain ranges is predominantly intergranular (i. e. creep dominated) whereas at higher strain ranges a mixed mode fracture (i. e. fatigue dominated) is observed. Therefore, one could argue that the tendency shown by the strain-based method of high creep damage values at lower strain ranges is more appropriate. However, the strain-based method tends to overestimate the creep damage at low strain ranges.

From the present "best estimate" evaluation no clear advantage for either method can be established. Therefore, no change in current design practice is recommended.

Since the results for the two methods might be significantly different when using design data (including design margins) it would be worthwhile to carry out such an assessment, too.

6 REFERENCES

[1] RCC-MR Design and Construction Rules for Mechanical Components of FBR Nuclear Islands
Section I - Subsection Z,
Technical Appendix A3, June 1985

[2] ASME
Cases of ASME Boiler and Pressure Vessel Code
Case N-47-28, Class 1 Components in Elevated Temperature Service
Section III, Division 1, July 27, 1988

[3] Clayton A.M., 1988,
Creep Assessment Procedures for Fast Reactors in Recent Advances in Design Procedures for High Temperature Plant
I. Mech. E. Seminar, Risley, pp. 49

[4] Hales R., 1980,
A Quantitative Metallographic Assessment of Structural Degradation of Type 316 Stainless Steel during Creep-Fatigue
Fatigue of Engineering Materials and Structures
Vol. 3, No. 4, pp. 339

Table 1: Chemical composition of steels 316 and 316L(N)

Type		C	Cr	Ni	Mo	Mn	S	P	B(ppm)	N	Si	Co	Cu
316	min	0.04	16	12	2	1	-	-	-	-	-	-	-
	max	0.09	18	14	1.6	2	0.03	0.045	-	-	0.75	-	-
316 L(N)	min	0.015	17	12	2.3	1.6	0.005	-	15	0.06	-	-	-
	max	0.030	18	12.5	2.7	2	0.02	0.035	35	0.08	0.50	0.25	0.4

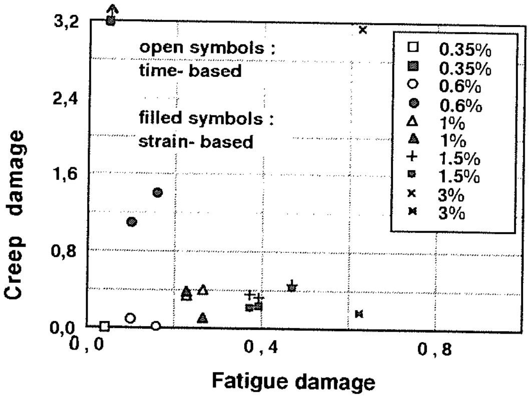

Fig. 1 Creep versus fatigue damage, 316, cast 83, 550 °C

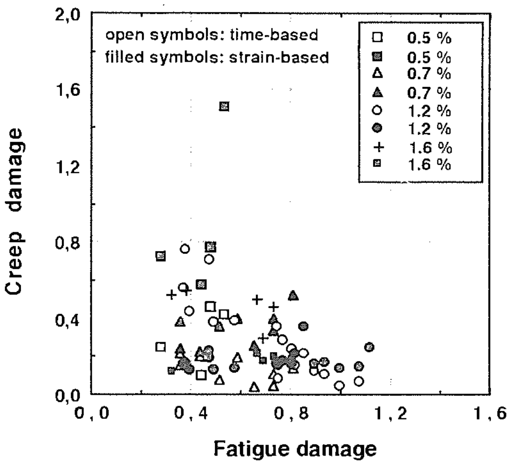

Fig. 2 Creep versus fatigue damage, 316 L(N), cast SP, 600 °C

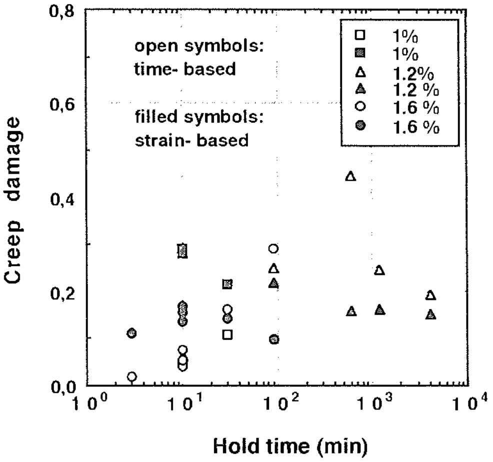

Fig. 3 Creep damage versus hold time, 316L(N), cast SP, 550 °C

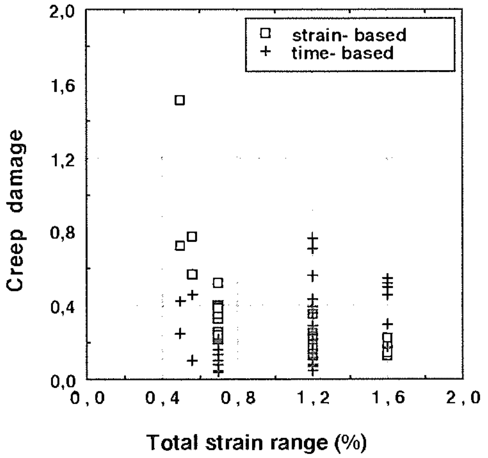

Fig. 4 Creep damage versus strain range 316 L(N), cast SP, 600 °C

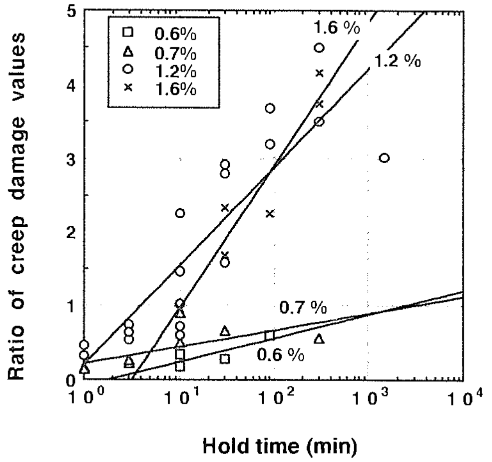

Fig. 5 Ratio of creep damage values of time- and strain-based method versus hold time, 316 L(N), cast SP, 600 °C