CREEP DUCTILITY AND FRACTURE IN AUSTENITIC STEELS

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ABSTRACT

Stress relief cracking is a well known phenomena in the heat affected zone of weld of temperature resistant low alloyed steel. Since similar effects on austenitic steels were reported in the literature several stabilized and non stabilized austenitic steels were studied by hot tensile tests at low strain rate of 4.10^{-4}/min and by creep tests up to 1000 hrs in the temperature region between 550 and 650°C. The type of fracture and the microstructure was investigated by optical and electron microscopy.
Samples with the structure of a heat affected zone of a weld in the austenitic steel were produced by direct current heating on a Gleebleapparatus of a short period of 5 sec. at 1300°C and quenching in water.

It was demonstrated that creep ductility was much lower than ductility of a tensile test at room temperature. The influence of the special heat treatment to simulate the heat affected zone had a minor influence on creep ductility and -strength. While the creep-ductility measured as elongation and reduction of an area at fracture was well above 10 % in all non stabilized austenitic steels, these ductility values were below 5 % for the Nb-stabilized steels. Yet, even for the specially annealed samples to simulate the matrix of a heat affected zone creep ductility never fell below 2 % as in those studies of low alloyed steels, which are susceptible to stress relief cracking.

From the present results was concluded, that stress relief cracking is very unlikely to occur in the austenitic steels investigated. It appeared however possible to produce cracks in Nb containing steels at temperatures around 650°C. The necessary conditions are stresses present as high as the 0,2 % yield strength at room temperature and presence of regions with stress concentrations.

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INTRODUCTION

It has been reported that heat affected zone cracking in welded austenitic steels can occur /1/2/3/. It is regarded as similar phenomenon to stress-relief-cracking in the heat affected zone of welded temperature resistant low alloyed steel /4/. Therefore it appeared necessary to study the mechanical properties of the materials structure present in the heat affected zone.

INVESTIGATION METHODS AND RESULTS

The list of austenitic steels investigated is given in Table 1. Those steels commercially manufactured into rolled bars then annealed at 1000 to 1100°C for 30 min and quenched in water were selected to study the influence of C and N content and of alloying elements such as Ti, Nb and Mo. In Table 2 the mechanical properties at room temperature of all the steels investigated in the as received condition are listed.

From these steels samples were prepared to simulate the structure of a heat affected zone in the neighborhood of a weldment. In a special apparatus called Gleeble-machine, the sample-rods were heated up to 1300°C by direct current, then held at 1300°C for 5 seconds and quenched in water. From those rods tensile specimens and creep specimens were machined. In Table 3 the ASTM grain size of the as-received structure is compared to the grain size after this heat treatment.

At temperatures between 550° and 650°C tensile tests were conducted at a very low constant straining rate of 4.10^{-4}/min. The results of the ultimate tensile strength Rm, total elongation A_5 and the reduction of area Z is shown in Fig. 1-3. Fig. 4 and 5 shows typical results of the temperature dependence of tensile strength and yield strength (Rp) and of A and Z between 550° and 650° of seven steels investigated.

In addition creep tests were conducted at 550°C and 650°C up to 1000 hrs on smooth bars and notched bars with a circumferential notch with a notch stress concentration factor K = 4. The time until fracture, the total elongation at fracture and the reduction of area at fracture were measured when a certain load was applied, which is expressed as tensile stress referring to the original cross section or net section of the notched bars e.g. typical results are shown in Fig. 6-9.

The microstructure of the samples investigated were studied by light and electron microscopy. Fig. 10 shows the grainstructure in the neighborhood of a fracture surface by light microscopy. Fig. 11 gives a micrograph of a scanning electron microscopy observation of the fracture surface. Fig. 12 and 13 shows the microstructure of steel (X6 Cr Ni 18 11) and of steel (X8 Cr Ni Nb 16 13) in the heat treated condition after a creep test observed by electron transmission microscopy.

DISCUSSION OF THE RESULTS

Fig. 1 and Fig. 2 show that all steels but steel 2 X 6 Cr Ni 18 11 with extreme low carbon content experience a considerable drop of ductility in a tensile test at 650° at such low strain rate compared to room temperature. This drop was most pronounced in both steels X8 Cr Ni Nb 16 13, in X3 Cr Ni Mn Mo 19 17, X8 Cr Ni Mo Nb 16 16 and X8 Cr Ni Mo V Nb 16 13. Fig. 4 and 5 confirm that ductility decreases with increasing temperature and has a minimum around 600 to 700°C, depending on the content in C and carbide forming elements. At those temperatures the difference in ductility between the as received state and the heat treated condition does not appear very pronounced, yet a lower ductility in the heat treated condition is noticable in all steels but X10 Cr Ni Ti 18 10. In both steels X8 Cr Ni Nb 16 13 values of reduction of area around 10 % were observed at 650°C in the heat treated condition.

Creep tests on smooth test bars also displayed, that low values of creep ductility were observed at 550°C in steel 1, 3, 6, 8, 11, 12.

A further lowering appeared possible at longer times to fracture. At 650°C extremely low values of creep ductility were observed in steels 6, 8 and 12. A further lowering of the values of creep elongation at longer times until fracture appears possible for steel 8 and 12. The steels 5 and 6 show a minimum of creep ductility around 200 or 300 hr at 650°C. Notch sensitivity during creep can be expected with steel 8 at 550°C and with steel 12 at 550° and 650°C. On steel 1, 3 and 11 notch sensitivity may occur at 550° at longer creep times above 1000 hr.

CONCLUSIONS

From these results the following conclusion can be drawn.

Of those temperatures investigated heat affected zone cracking as observed is not a similar phenomenon as stress relief cracking in the heat affected zone of welded temperature resistant low alloyed steel. The ductility at fracture is even at 550°C in all austenitic steels much larger than in the simulated structure of low alloyed steel, where creep elongation of a few tenth of a percent was to observe /4/. The minimum value of creep elongation of 2 % was observed in the steel 12 with Niob content at 650° after a creeptime of 800 hrs with a load of 180 N/mm^2 applied (Fig. 9). Furthermore this low value was observed in the as received condition, while the heat treated condition still showed creep elongation above 5 %. Therefore the total creep elongation appeared to be sufficient in order to relieve internal stress by creep. Furthermore the high temperature strength of austenitic steels will not allow, that stress relaxation by creep will occur at a sufficient degree at temperatures of 550 and 650°C. Therefore a temperature for stress relieving in austenitic steels as high as 800°C is normally prescribed.

On the other hand the results show that internal or external stresses below the values of 0,2 % yield stress at room temperature will lead to fracture in a short period within 1000 hrs at 650°C. In steel 1, 2, 3 and 5 fracture will occur after very short time of about 10 hrs, even when a stress of the order of the 0,2 % yield stress at room temperature is applied. At 550° fracture will occur only in steel 1 and 3 when stresses not higher than 0,2 % yield stress are applied. In all cases with Nb added low values of creep ductility are found indicating that stress concentration during creep will not be relieved by creep.

These regions with stress concentration will therefore act as crack initiators when the fracture time is approached.

Reckoning all the results reported on heat affected zone cracking in austenitic steels /1/2/3/ it was found, that stresses were present, which exceeded the creep strength at those periods and temperatures as tested. The stress concentration of those tests were located in areas of the heat affected zone. Therefore a special sensitivity of those structures can not be derived from those investigations either.

One can therefore conclude from the present results, stresses in the neighborhood of the yield strength at room temperature will lead to fracture around 600°C or higher. In the case of Nb containing austenitic steels, those stresses (around 200 N/mm^2) will lead to fracture with low ductility.

Internal stresses up to 0,2 % yield stress will normally not give rise to cracks, when the necessary precautions are kept to reduce stress and strain concentrations near to the weld, creep ductility would be sufficient to relieve the internal stresses. At 600 or 650°C those stresses however will not be relieved very much. In a geometry with inhomogeneous creep strain, crack formation can occur in regions with strain concentration, when stresses of the order of 0,2 % yield stress at room temperature are present. Yet, such crack formation does not depend on the special structure of the heat affected zone of a weld.

One can further conclude from the results, that corrosion sensitizing may occur in the heat affected zone. It was observed that grainboundary carbides were reduced by dissolving during the heattreatment to simulate the heat affected zone and that many new fine carbide particles are formed within the grains.

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Table 1 - List of austenitic steels investigated

No	Steel Description	Chemical Composition C	Cr	Ni	Mo	weight per cent other	Mn	N
1	X6 Cr Ni 18 11	0,049	18,0	11,1	0,08	-	1,24	0,029
2	X6 Cr Ni 18 11	0,025	17,5	10,0	0,39	-	1,07	0,005
3	X3 Cr Ni Mo N 17 13	0,020	17,4	13,1	2,30	-	1,07	0,117
4	X3 Cr Ni N 18 11	0,012	17,8	10,1	0,28	-	2,01	0,124
5	X8 Cr Ni Nb 16 13	0,052	16,2	12,9	0,41	0,78Nb	1,15	0,032
6	X3 Cr Ni Mn Mo 19 17	0,032	19,5	15,4	2,89	0,17Nb	4,58	0,226
7	X6 Cr Ni Mo 17 13	0,060	18,3	14,5	2,04	-	1,52	0,029
8	X8 Cr Ni Mo Nb 16 16	0,057	16,3	17,1	1,81	0,67Nb	1,14	0,022
9	X8 Cr Ni Mo V Nb 16 13	0,056	16,3	12,8	1,33	0,69Nb +0,65V	1,20	0,081
10	X10 Cr Ni Mo Ti 18 10	0,075	17,6	11,3	2,27	0,58Ti	1,25	0,004
11	X10 Cr Ni Ti 18 10	0,067	17,3	11,0	0,37	0,3 Ti	1,32	0,016
12	X8 Cr Ni Nb 16 13	0,074	16,2	12,6	0,29	0,89Nb	0,98	0,032

Table 2 - Mechanical Properties of austenitic steels investigated as received

No	Material	heat No	$R_{p0,2}$ N/mm^2	R_m N/mm^2	Z %	A %	a_k J	HV10
1	X6 Cr Ni 18 11	278669	232	529	67	62	174	113
2	X6 Cr Ni 18 11	272997	199	535	73	63	184	142
3	X3 Cr Ni Mo N 17 13	273495	301	625	65	48	137	144
4	X3 Cr Ni N 18 11	274755	275	597	73	56	254	144
5	X8 Cr Ni Nb 16 13	290610	253	562	53	48	101	138
6	X3 Cr Ni Mn Mo 19 17	232397	469	784	53	37	86	226
7	X6 Cr Ni Mo 17 13	232229	277	572	65	50	134	143
8	X8 Cr Ni Mo Nb 16 16	18677	259	575	72	48	> 103	139
9	X8 Xr Ni Mo V Nb 16 13	17955	314	622	68	47	> 69	212
10	X10 Cr Ni Mo Ti 18 10	92838	288	606	68	51	> 85	153
11	X10 Cr Ni Ti 18 10	275335	248	567	55	61	213	165
12	X8 Cr Ni Nb 16 13	20668	242	550	51	59	158	146

Table 3

Grainsize measurements (ASTM Size No)

Steel No	as received	after tensile test at 650 °C as received	heat treated
1	2	2.2	0/2
2	3	2.4	2.4
3	4	4.2	3.2
4	2/3	2.2	2/3
5	6/7	5	3/4
6	2/6	2,1/5,1	3,1/4,1
7	3/4	1/3,2	2
8	2/8	4/8	3.1
9	1/5	3,2/4.2	1.1/3.1
10	3/8	3/8	2/3
11	4	4/5	6
12	3/4/5	4/6	3

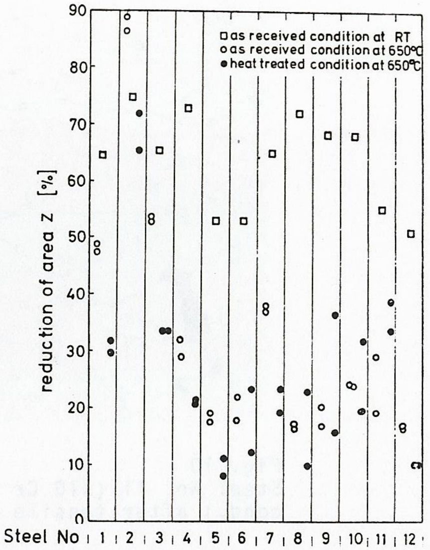

Fig 1 measured values of reduction of area Z

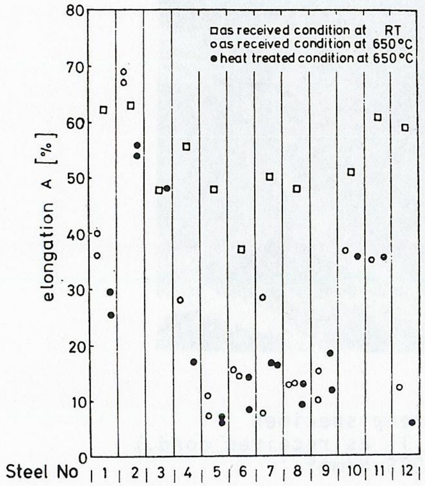

Fig 2 measured values of elongation A

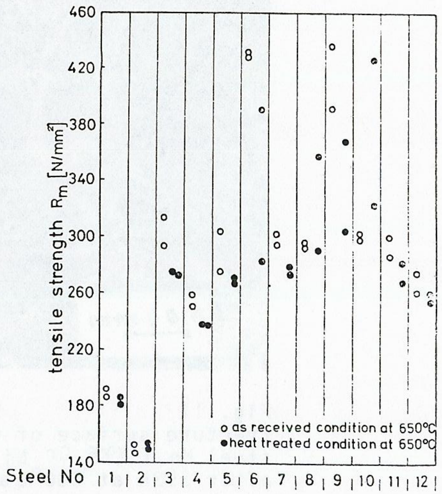

Fig 3 measured values of ultimate tensile strength R_m

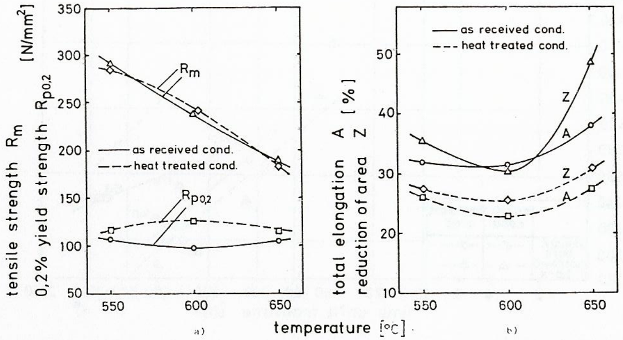

Fig 4 Steel 1 (X6 CrNi 18 11) temperature dependence of mechanical properties at elevated temperatures

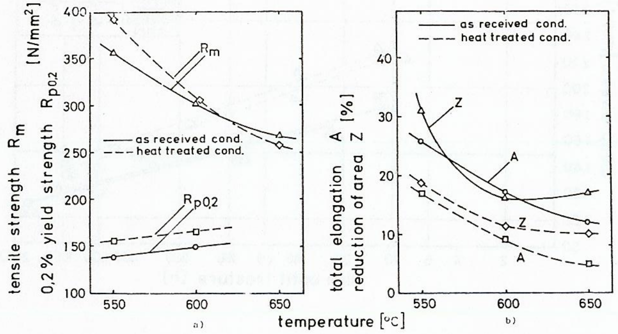

Fig 5 Steel 12 (X8 CrNiNb 16 13) temperature dependence of mechanical properties at elevated temperatures

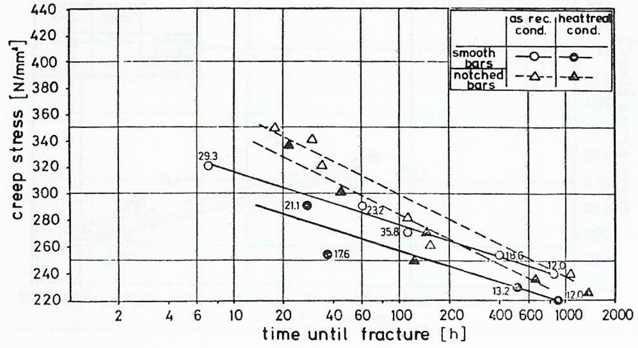

Fig 6 creep strength of steel 1 (X6 CrNi 18 11) at 550 °C
(written numbers are total elongation at fracture in percent)

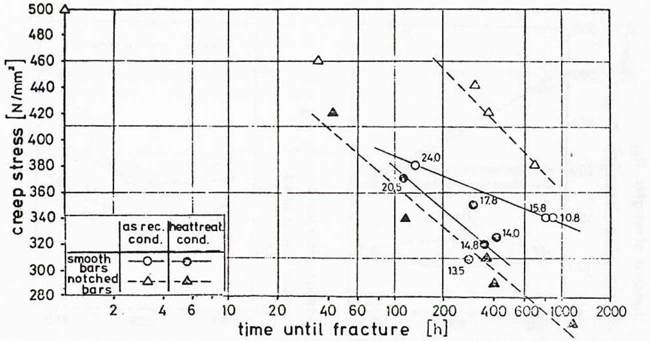

Fig 8 creep strength of steel 12 (X8 CrNi Nb16 13)at 550°C
(written numbers are total elongation at fracture in per cent)

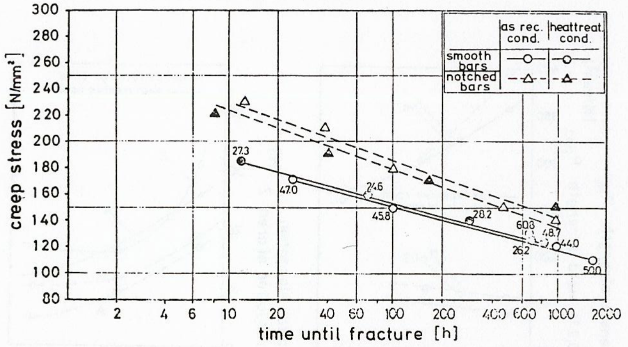

Fig 7 creep strength of steel 1 (X6 CrNi 18 11) at 650 °C
(written numbers are total elongation at fracture in per cent)

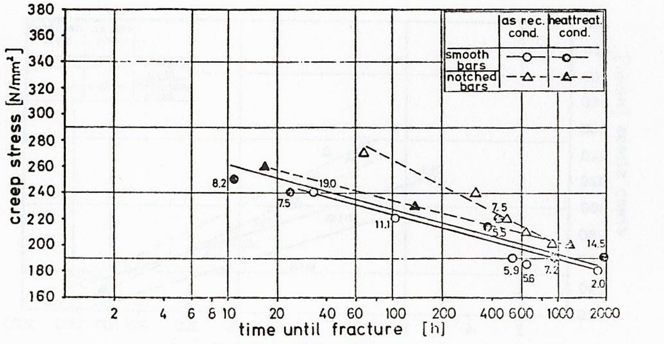

Fig 9 creep strength of steel 12 (X8 Cr Ni Nb 16 13) at 650°C
(written numbers are total elongation at fracture in per cent)

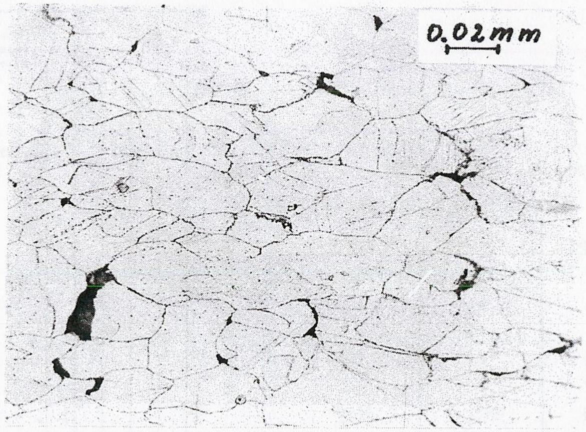

Fig. 10
Steel No. 11 (X10 Cr Ni Ti 18 10 heat treated cond.) after tensile test at 650°C

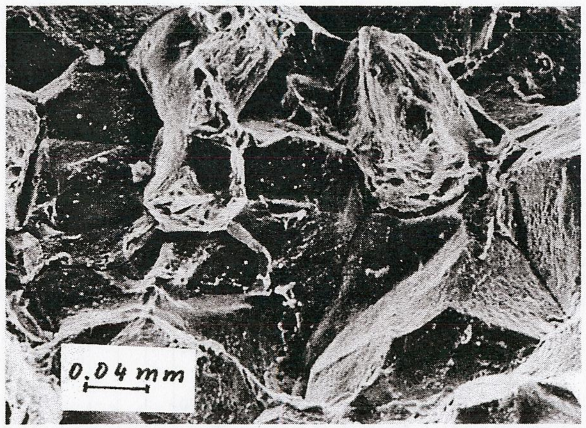

Fig. 11
fracture surface of a creep specimen steel No.1 (X6 Cr Ni 18 11 as received cond.) after 393h at 550°C and 255 N/mm²

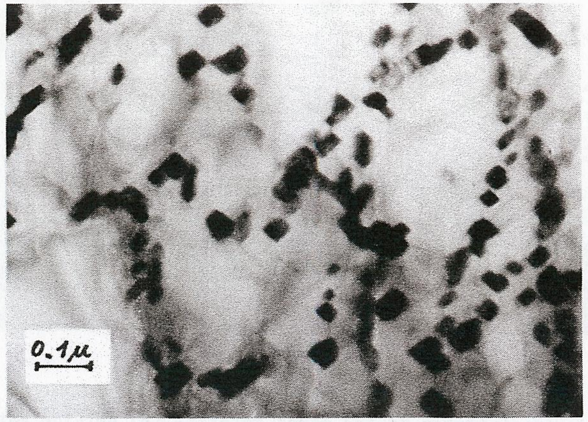

Fig. 12
Steel No 1 (X6 Cr Ni 18 11 heat treated cond.) after creep test 804 h at 650°C and 125 N/mm^2

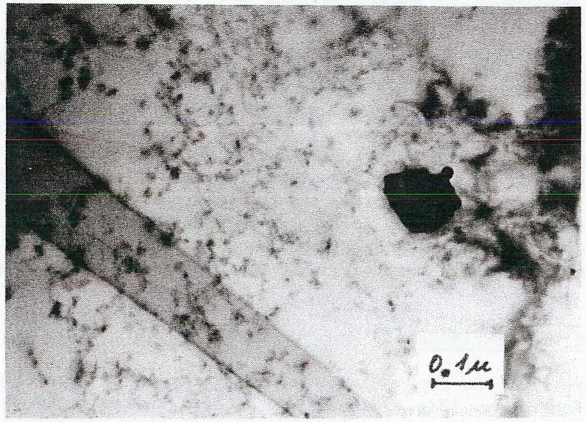

Fig. 13
Steel No. 12 (X8 Cr Ni Nb 16 13 heat treated cond.) after creep test 926 h at 650°C and 190 N/mm^2

EFFECTS OF MICROSTRUCTURAL DEGRADATION ON CREEP LIFE PREDICTION OF 2-1/4 Cr - 1 Mo STEEL

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ABSTRACT

Accelerated aging at 630°C has been performed on 2-1/4 Cr - 1 Mo steel in order to simulate microstructures observed in boiler tubing after long-time service. Results of microscopy, creep tests and tensile tests on the simulated microstructures are reported.

KEYWORDS

Creep; high temperature fracture; 2-1/4 Cr - 1 Mo steel; microstructural degradation; accelerated aging; boiler tubing; life prediction.

INTRODUCTION

Due to the importance of component integrity in long-time, high-temperature service, particularly in the power generation industry, considerable work has been carried out on residual creep life studies and damage accumulation with the object of predicting creep lives and avoiding premature failures of components (Hart, 1976; Sidey, et al., 1979; Williams and Wilshire, 1977; Williams and Cane, 1979; Woodford, 1973).

Many empirical relationships have been developed to predict long-term creep behaviour by extrapolating short-term laboratory creep data (Conway, 1969). These parametric approaches implicitly assume that the microstructure of the material remains unchanged during the creep life and also they do not accommodate the changes which may result from fluctuations in the operating stress and temperature. It is known that the microstructure of low alloy ferritic steels continues to change throughout the service life (Murphy and Branch, 1971; Toft and Marsden, 1961; Williams and Wilshire, 1977) which invalidates the basic assumption of most of the parametric approaches to creep life prediction. Also, the recent development of fracture mechanism maps emphasizes the fact that the mechanisms of failure can change from one mode to another through changes in temperature, strain rate and stress (Ashby, et al., 1979). Clearly, a predictive approach should consider the fracture mechanism and the changes in the microstructure of the material during service in order to achieve reliable estimates of creep life.