INFLUENCE OF LOADING RATES ON THE DUCTILE CRACK GROWTH OF AUSTENITIC STAINLESS STEELS

C. Fenerol*, P. Balladon and J. Heritier****

**Framatome, Tour Fiat, 92084 Paris La Défense, France*
***Creusot-Loire, Centre de Recherches d'Unieux, B.P. 34, 42701 Firminy Cédex, France (now UNIREC, same address)*

ABSTRACT

A study of the influence of strain rate on fracture toughness of a 316 L type stainless has been made at 20°C and 350°C for displacement rates between 0,08 and 8mm/min. Using the J integral concept, J-R curves have been determined in each case and the influence of strain rate on initiation and propagation has been evaluated in terms of J_{1c} and dJ/da. In addition microfractographic examination has been carried out to establish a possible correlation between the mechanical properties (J, dJ/da) and the micromechanisms of fracture.

KEYWORDS

Ductile crack growth, strain rate, austenitic stainless steel, J-R curve.

INTRODUCTION

Austenitic stainless steel structural parts of pressurised water and liquid metal fast breeder reactors are submitted to large variations of temperature, stress, and strain.

In particular, they are used under conditions of either high or low strain rate : the influence of creep and relaxation on the behaviour of these structural parts may therefore be a main factor controlling their resistance to failures. For example such steels show creep and relaxation damage at room and elevated temperature (1,2). The potential danger of the defects to be found in those structures may be evaluated by using different élasto-plastic criteria : these criteria take account of both ductile crack growth (J, dJ/da) and creep crack growth resistance (C*) ; ....

The influence of temperature on ductile tearing of austenitic stainless steels is already known (3,4) for standard strain rates (ASTM E 813-81).

To determine stable crack growth resistance in the case of low strain rates, it is necessary to take into account the interaction of creep and relaxation with crack growth.

Some data are to be found for A 533 gr B showing the influence of dynamic strain aging phenomena on fracture toughness (5).

Strain rate variations should also influence ductile crack growth of austenitic stainless steels, since dynamic strain aging effects occur during tensile testing of these steels, (serrated curves), and also lower creep rates at temperatures near 350°C (1).

The first step of research for austenitic stainless steels is to study the variation of J - δa curves with strain rate at room and elevated temperatures.

EXPERIMENTAL PROGRAM

Materials

The material studied was an industrial austenitic stainless steel plate of 316 L grade with controlled nitrogen content. Table 1 gives the chemical analysis of the product.

TABLE 1 - Chemical analysis

C	Mn	Si	S	P	Ni	Cr	Mo	N2	B
.025	1.81	.49	.002	.027	12.22	17.22	2.38	.074	.0017

Such steels are used for nuclear plant construction and the compositions of the heats are balanced so that the amount of residual ferrite is 1 to 2 per cent after quenching from 1070°C.

specimens

The specimens used for determining J-R curves were compact tension type of 25mm thickness taken from a 40mm thick plate. These specimen were 20% side grooved after fatigue precracking according to ASTM E 813-81.

They were located in the plate at mid-thickness in the TL orientation; tensile and charpy properties of this plate are given in table 2.

TABLE 2 - Tensile and Charpy properties

	tensile properties (average values)				Charpy U notch at 20°C(J/cm2) (average values)
test tempe-rature (°C)	σ_{YS} (MPa)	σ_{UTS} (MPa)	total elongation (%)	RA (%)	
20°	254	584	66,7	81,5	270
350°	162	481	44	65	

Experimental methods

J-R curves were determined according to ASTM E 813-81 using the partial unloading compliance method. Due to the large opening of the specimens, compliance values were corrected to take account of the rotation.

Test program

J- δa tests were performed at two temperatures (room temperature and 350°C), with three different load line displacement rates (.08mm/min, .8mm/min, 8mm/min).

At the end of each test, specimens were broken either at low temperature after heat tinting or at room temperature by fatigue. Microfractographic and micrographic examinations were performed using a scanning electron microscope.

RESULTS

Loading curves (P - δ)

Load versus displacement curves are shown in figure 1 for room temperature and 350°C. The influence of the displacement rate on the loading curves can be seen in this figure.

At room temperature, lowering the displacement rate lowers the load at a given displacement. This behaviour is not so clear at 350°C.

Figure 2 shows that the maximum load does not depend on displacement rate at 0.8 and 8mm/min, but for a displacement rate of 0.08mm/min is slightly higheer at 350°C (~ 5%) and lower at room temperature (~ 8%).

J values for maximum load are shown as functions of strain rate in figure 3. The J values are independent of strain rate at room temperature but decrease by 12,5% when the strain rate is increased from 0.08 to 8mm/min at 350°C.

J - δ a curves

J - δ a curves at room and elevated temperatures appear on figure 4 and table 3 together with the J_{1C} and dJ/da values.

TABLE 3 - J_{1C} and dJ/da values

$\dot{\delta}$ mm/min	J_{1C} MJm^{-2}	dJ/da MPa	Temp. °C.
0.08 0.8 8	1.82 ± 0.12	622 ± 15	20
0.08	1.12	862	350
0.8	1.04	446	
8.	1.34	400	

At room temperature the experimental scatter bands of all the J - δa curves obtained by the compliance method have been represented. The optical measurements of ultimate crack propagation have also been plotted.

The following comments may be made :

- J levels obtained are very high (crack initiation higher than 1.5 MJm^{-2}) due to the low inclusion content of the material.
- good agreement is noted between optical measurements and crack growth calculated from the unloading compliance method using a rotation correction.
- no significant differences can be seen between the three different loading rates : for this 316 L steel in the range of strain rates studied all the curves obtained lie in the same scatter band.

The curves obtained at 350°C lead to the following comments :

- J and dJ/da values are lower (respectively 35% and 30%) than the room temperature values. The J - δa curve at a 0.08mm/min displacement rate may be separated from the other two curves (0.8 and 8mm/min) and gives higher J values for a given crack length.

TABLE 4 - J values for 2mm crack growth at 350°C

Strain rate mm/min	8	0.8	0.08
$J(MJm^{-2})$	1.8	1.56	2.1
δa (mm)	2	2	2

Micrographic examination

Fracture surfaces have been examined using a scanning election microscope. Microphotographs are shown on figure 5, for three strain rates at room temperature and 350°C. The rupture surfaces change with strain rate in the same way at 20°C and 350°C. Two families of dimples may be seen in each case : larger dimples initiated by inclusions (calcium silico aluminates) and smaller ones, which are initiated on a distribution of finer inclusions and are due to the final tearing, which occurs between the larger dimples when they have reached a critical size.

At room temperature and 350°C the number of small dimples decreases when the strain rate increases : this may be due to the shorter time of germination left for decohesion at higher strain rates leading to the growth of the smaller number of previously formed decohesions.

However the results obtained concerning the influence of strain rate on ductile crack growth resistance show that there is no obvious correlation between J, dJ/da and the micro-mechanisms (growth kinetics of decohesions) and form and size of dimples).

CONCLUSION

This study of the influence of strain rate on fracture toughness of a 316 L type stainless steel has been carried out at 20°C and 350°C for strain rates between 0.08 and 8mm/mn. In those conditions one cannot observe any significant influence of strain rate either on initiation (J_{1c}) or propagation (dJ/da) of ductile crack Nevertheless decreasing strain rate at 350°C seems to increase the ductile crack growth resistance. Microfractographic observation shows two different dimples families, larger ones initiated on inclusions and smaller ones which may be formed on defects during tearing. No direct correlation has been found between these micromechanisms and the variation of J and dJ/da with strain rate. These results suggest that a more marked influence could be expected in the ranges of strain rate where relaxation occurs, i.e. very low or very high strain rates : It is therefore necessary to go on to study the interaction between creep or relaxation and ductile crack growth, and also to determine resistance curves in dynamic loading (for $\dot{K}$ values near 10^{-5} MPa $m^{-1/2}s^{-1}$).

REFERENCES

1. HERITIER, J., and RABBE , P. - "Fluage àbasse température (de 20°C à 350°C) d'aciers inoxydables austénitiques". Ann. Chim. Fr., 1981, 6, p. 181.
2. NOMINE , A.M. , DUBOIS , D. , MIANNAY , D. , BALLADON , P. , and HERITIER , J. - "Creep and Cyclic Tension Behaviour of a Type 316 Stainless Steel at Room Temperature" - ASTM STP 770 , 1982 , pp. 45-68 .
3. BALLADON , P. , HERITIER , J. and RABBE , P. - "Influence of microstructure ont the Ductile Mechanisms of a 316 L Steel at Room and Elevated Temperatures" - ASTM STP 791 , 1983 , pp. II 496-513.

4. BALLADON , P. and HERITIER , J. - "Ductile crack growth in nuclear austenitic stainless steel plates : influence of crack orientation and steel microstructure" - Fracture Prevention in energy and Transport Systems, Rio de Janeiro 1983, I. Le May and S.N. Monteiro ed. pp. 70-79.
5. OSTENSSON , B. and Westin, R. - "The influence of temperature and strain rate on the fracture toughness, J_{1c} , of A 533 B pressure vesselsteel plate material" - Aktiebolaget Atomenergie Report S - 536 , Studsvik , Sweden 1976.

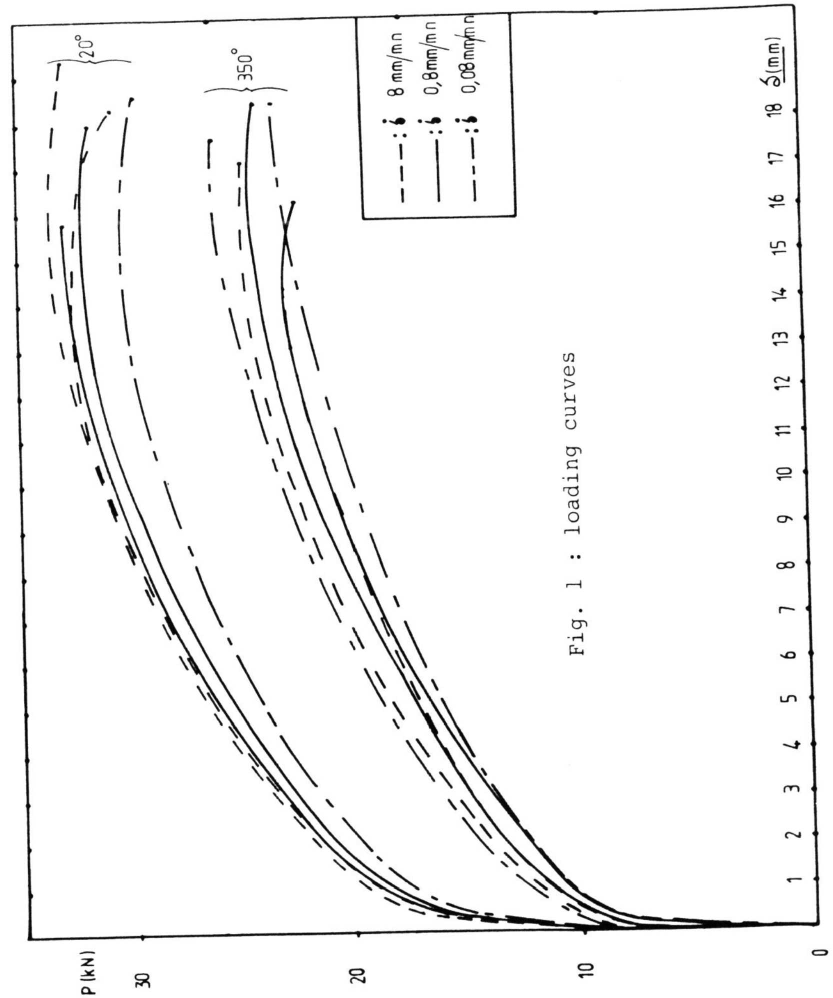


Fig. 1 : loading curves

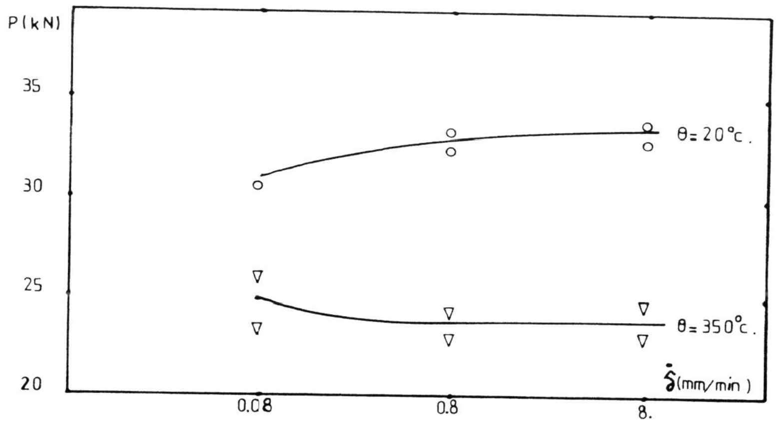


Fig. 2 : P values for maximum load

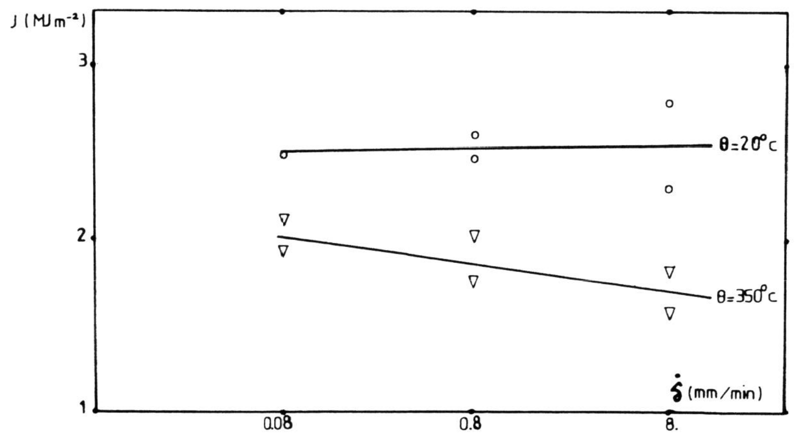


Fig. 3 : J values for maximum load

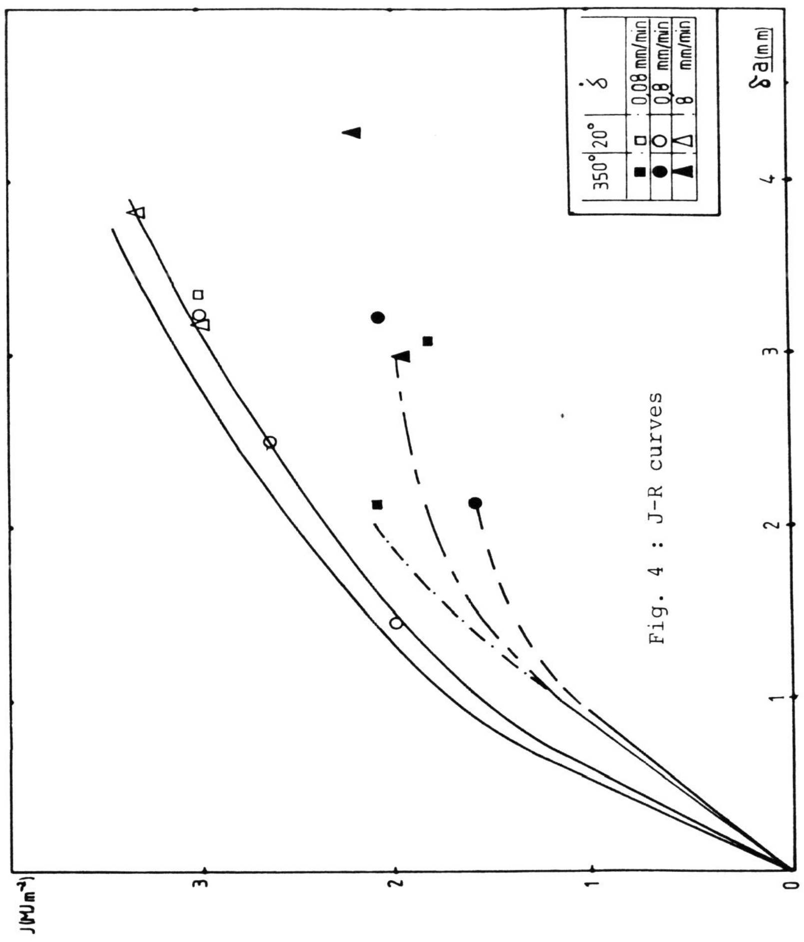
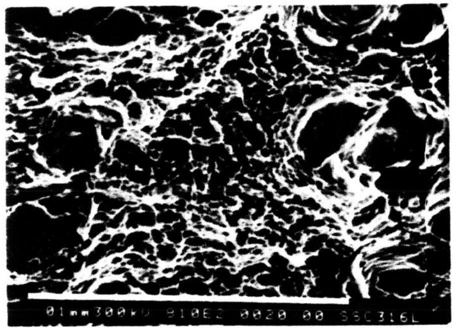


Fig. 4 : J-R curves

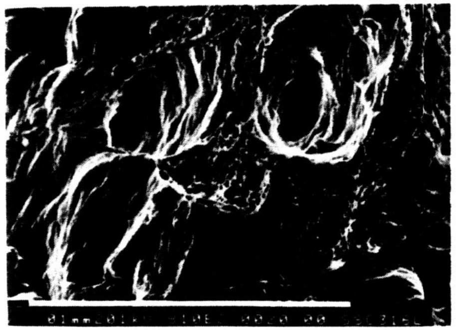
Temp. = 20°C

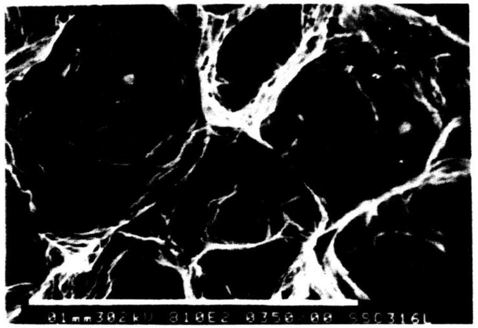
Temp. = 350°C



v = 0.08mm/min

v = 0.08mm/min





v = 0.8mm/min

v = 0.8mm/min

v = 8mm/min

v = 8mm/min

Fig. 5 : S E M Fractographies