J-INTEGRAL R-CURVES AND SZW-SZH RELATIONS IN DUPLEX STAINLESS STEELS AGED AT 475 °C

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The influence of ageing at 475 °C on the fracture resistance of two duplex stainless steels has been investigated by means of the evaluation of J-integral R-curves and fracture toughness K_{Ic}. The results are compared with those of a superferritic stainless steel.

In this evaluation the blunting phenomenon and the relation SZW-SZH (Strecht Zone Width-Strecht Zone Height) for different ageing conditions of the two duplex steels is also studied by means of SEM observations of the fracture surfaces.

INTRODUCTION

Duplex stainless steels are candidate materials for applications demanding high strength, toughness and corrosion resistance. One of the main problems with the use of duplex and ferritic stainless steels in the temperature range of 300-520 °C is the unstability of the Fe-Cr solid solution, which is spinodally decomposed in rich zones of Cr and Fe producing an increase in hardness and a decrease in fracture resistance. The reason of the strong influence of the spinodal decomposition on the embrittlement of the ferritic phase is still unknown(1).

The aim of this work is to study the loss of fracture resistance with ageing time and to determine the SZW-SZH evolution with the ageing time at 475 °C.

In this study two duplex stainless steels are evaluated and the results are compared with those of a superferritic stainless steel. The blunting phenomenon and the relation SZW-SZH for different ageing conditions are analyzed by means of SEM observations of the fracture surfaces. This allows an estimation of J_i, calculated based on those observations.

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EXPERIMENTAL PROCEDURE

The chemical composition of the steels is given in the Table 1.The steel AISI 329 was supplied in the form of square rods of 70 mm of side, while the steel UNS 31803 was provided in the form of cylindrical rods of 50 mm of diameter in the annealed state. The superferritic steel was supplied in the form of plate of 11 mm of thickness in the annealed state.

TABLE 1. Chemical composition in wt% of the steels.

Steel	C	N	Cr	Ni	Mo	Mn	Nb
AISI 329	0.036	0.07	24.65	5.4	1.4	1.73	-
UNS 31803	0.025	0.13	22	5.5	3	1.6	-
Superferritic	0.005	0.04	28.3	3.88	2.4	-	0.4

The single specimen unloading compliance technique was used according to the EGF P1-90 for the determination of the J-integral, while in the case of the superferritic stainless steels aged for long times the fracture toughness could be determinated by measuring K_{Ic} according to the ASTM E-399. SENB specimens were tested for the UNS 31803 steel (LR orientation) and the superferritic steel (LT orientation), having 15 and 10 mm in thickness respectively. WOL specimens of 24.5 mm of thickness were used for the AISI 329 steel (ST orientation).

In all specimens the notch was introduced before the ageing treatment and the fatigue precrack was nucleated after the ageing treatment with a load ratio of 0.5 in order to minimize the effects of crack closure. The expressions of K_I and normalized crack length in terms of the compliance were taken from the work of Saxena and Hudak(2). The steels were tested in the annealed condition and also after ageing at 475 °C for times up to 160 hours.

RESULTS AND DISCUSSION

The variation of the tensile properties with ageing time for the three steels is illustrated in Figs. 1 and 2, where the values of the yield strength and strain at fracture are displayed respectively. It can be seen that initially the yield strength increases with ageing and later it remains nearly constant. By contrast, the strain at fracture decreases for the duplex steels during the first 80 hours, after which it remains nearly constant. However, in the superferritic steel, a sharp drop in the strain to fracture after about 40 hours of ageing at 475 °C can be noted.

In the case of the UNS 31803 steel it was not possible to obtain a valid R-curve because of limitations in the specimen thickness (Fig. 3). Therefore, it has been tried to estimate J_i from a method based on the observation of the fracture surfaces by SEM. The SZW and SZH are measured from observations at 0° (Fig. 4) and by tilting the fracture surfaces 30-70° inclinations (Fig. 5) of the fracture surfaces, respectively. The 0° observations has been taken as the normal view to the fracture surfaces. In the first case the SZW can be directly measured while in the second case the SZH can be determined by the following expression:

$$SZH = \frac{l - SZW \cos\alpha}{\sin\alpha} \tag{1}$$

where l is the length of the stretch zone measured in the factography by tilting α degrees.

The ratio SZW/2SZH can then be obtained which usually is taken equal to 0.4 (3,6). In the present case, it changes with ageing time from 0.15 for the annealed steel to 0.42 for the steel aged 100 hours. The value of the J integral for initiation, J_i, can then be obtained from the following expression(3):

$$\Delta a_b = \frac{SZW}{2\,SZH}\, d_n^* \frac{J_i}{E} \tag{2}$$

This expression gives the blunting line according to the EGF P1-90 standard with SZW/2SZH equal to 0.4. In order to estimate J_i (where Δa_b=SZW) it can be obtained:

$$J_i = \frac{2\,SZH}{d_n^*} E \tag{3}$$

where d_n^* is a function of the strain hardening exponent n and σ_o/E, where σ_o is the flow stress. Therefore, this is a simple way of estimating J_i when the experimental points of the R-curve fall outside the limits suggested by the above standard(4,5) and when the SZW and SZH can be measured in the specimen. This method can also be used for obtaining a better estimation of the blunting line and J_i for stainless steels with a similar behaviour to the UNS 31803 studied in this work. The results for this material are given in Table 2.

In the case of AISI 329 steel the experimental values of J are inside the validity limits indicated by the standard (Fig. 6). The SZW-SZH was also used in order to get a better approximation to the blunting line. Since the ratio SZW/2SZH was very close to 0.4, the expression given in the standard was used for the annealed steel and for the steel aged 1 hour at 475 °C. For the steel aged 5, 25 and 100 hours, K_{Ic} was determined according to the ASTM E 399 standard. The results

TABLE 2. Values of SZW, SZH, SZW/2SZH and Ji* for the UNS 31803 steel

Ageing time (hours)	0	25	46	75	100
SZW (μm)	63	85	68	85	32
SZH (μm)	210	151	108	105	38
SZW/2SZH	0.15	0.28	0.31	0.4	0.42
J_i^* (KJ/m^2)	467.7	337.3	243	236	85

*Values obtained from equation (1)

This agrees with the expectations since the blunting line proposed in EGF P1-90 is best fitted by ferritic stainless steels. Then, it could be recommended that SZW-SZH relations be measured for a wide range of stainless steels in order to obtain better blunting lines.

TABLE 3. Values of fracture toughness for the AISI 329 steel

Ageing time (hours)	0	1	5	25	100
$J_{i\,SZW\text{-}SZH}$ (KJ/m^2)	113	74	-	-	-
J_i (KJ/m^2)	110*	70*	-	-	-
$J_{0.2/BL}$ (KJ/m^2)	246*	200*	-	-	-
K_{Ic} (MPam$^{-1/2}$)	-	-	82*	48*	49*

*This values are according with premises of EGF P1-90 and ASTM E-399

In the case of the superferritic stainless steel aged for 1 to 7 hours, the values of J obtained were outside the validity box proposed in the standard EGF P1-90. From SEM observations it was not possible to measure the stretch zone, and the value of J estimated was that of $J_{0.2}$. K_{Ic} was determinated for ageing times longer than 8 hours, the values are shown in Table 4.

It is worthwhile to notice that ageing at 475 °C produces a strong decrease of fracture toughness but this is more pronounced in the superferritic steel. In addition, the fracture toughness changes slowly in the duplex stainless steels in the time interval between 25 and 100 hours of ageing, while it continues decreasing in the superferritic stainless steel.

TABLE 4. Values of fracture toughness for the superferritic steel

Ageing time (hours)	0	0.25	0.5	2	2.5	3.5	5.5	7	8	100	160
$J_{0.2}$ (KJ/m^2)	520	260	100	80	60	50	40	20	-	-	-
K_{Ic} MPa $m^{-1/2}$	-	-	-	-	-	-	-	-	49*	36*	30*

*Values according with the ASTM E-399

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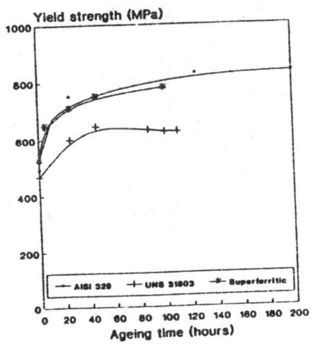

Fig. 1. Evolution of yield strength with ageing time

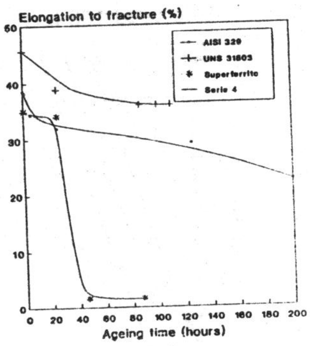

Fig. 2. Evolution of strain to fracture with ageing time

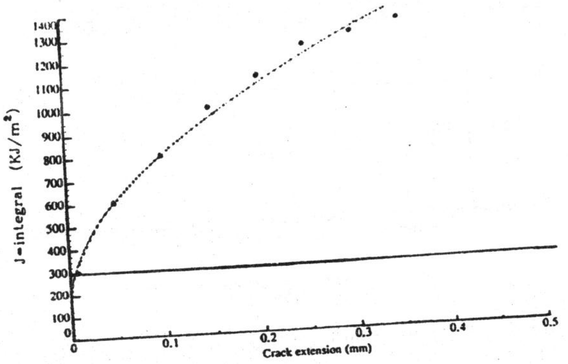

Fig. 3. J-integral R-curve for UNS 31803 steel in the annealed state

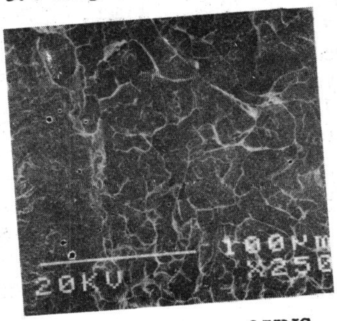

Fig. 4. Fracture surfaces of UNS 31803 aged 100 hours (α=0°)

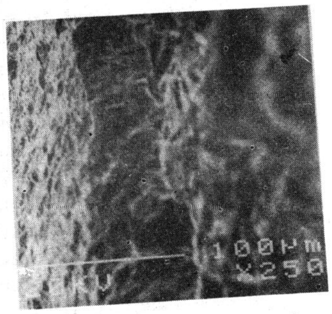

Fig. 5. Fracture surfaces of UNS 31803 aged 100 hours (α=70°)

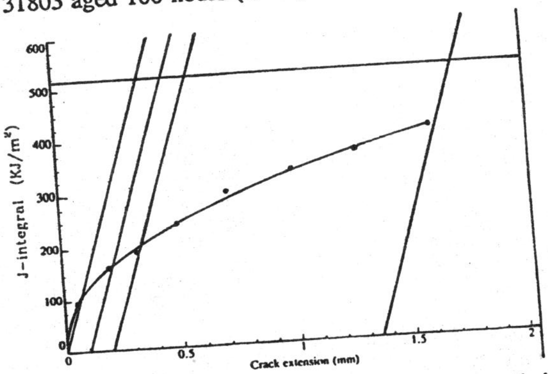

Fig. 6. J-integral R-curve for AISI 329 steel in the annealed state