FATIGUE BEHAVIOUR OF WELDED JOINTS BETWEEN DISSIMILAR METALS (AUSTENITIC STAINLESS STEELS AND LOW ALLOY STEELS)

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ABSTRACT

To evaluate the cyclic behaviour of the junction between austenitic stainless steel pipes and low alloy steel nozzles, fatigue tests have been performed on a simulated welded joint. The low cycle fatigue and crack growth behaviours of the junction were evaluated. The number of cycles to initiate a fatigue crack and the relationship between propagation paths and the metallurgical structure were determined. The results obtained showed the influence of the microstructure on the initiation and propagation of fatigue cracks in this heterogeneous joint.

KEYWORDS

Fatigue ; Heterogeneous welded joint ; Crack initiation ; Crack propagation ; Crack growth rate ; Microstructure.

INTRODUCTION

Austenitic stainless steel welds deposited on low alloy base metal are currently found in large components of the nuclear and chemical industries. Indeed, the complexity and the dimensions of these components imply joining of different elements, which must combine resistance against mechanical and thermal loadings, and resistance against corrosion.

The main cases encountered are (Castro, 1968) :
- structures where it is necessary to join two different kinds of steel ; the deposited metal is then different from at least one of the base metals.
- cladding of low alloy steels with stainless steels for protecting the surface against corrosion.
- joining of identical alloys with a filler metal of a different nature for pratical reasons.

Heterogeneous welds show a complex metallurgical structure which results from phenemena of dilution, solidification and diffusion. In order to evaluate the fatigue behaviour of such junctions, it is necessary to study in details the role of the microstructure on fatigue crack initiation and propagation.

Within this framework, we have studied the simulation of a heterogenous welded joint which belongs to the first category mentionned above,i.e. a junction between an austenitic stainless steel piping and a low alloy steel nozzle.

METALLURGICAL STRUCTURE OF THE WELDED JOINT STUDIED

Such welded joints have been the subject of metallurgical studies for several years (Castro,1968 ; Thielsh, 1952). This weldment shows a complex metallurgical structure resulting from dilution during welding, and from diffusion of carbon from the base metal toward the deposited metal, during heat treatments. Figure 1 gives a schematic of the microstructure of the dilution zone.

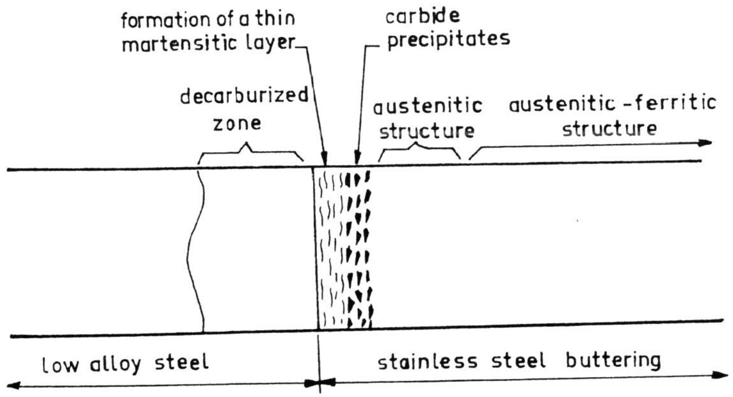

Fig. 1 - Schematic of the microstructure of the dilution zone between low alloy steel 25MN4 and 309L-308L austenitic-ferritic steels

Depending upon the amount of dilution, controlled by welding parameters, and the intensity of the carbon diffusion, controlled by heat treatments, a more or less extended decarburized zone develops in the base metal. For the same reasons, a thin martensitic layer develops in the weld metal, containing carbide precipitates. An austenitic zone also forms with some carbide precipitated at grain boundaries.

In the welded joint studied here, one finds the following elements :

- a cast low alloy steel of 25 MN4 type.
- two layer of buttering in austenitic-ferritic steels 309L (24Cr-12Ni) and 308 L(20Cr-10Ni-Mo).
- a weld in 308L deposited metal
- a forged stainless steel of 316 type.

A 610°C post weld heat treatment was applied to this weld.

The heterogeneous junction, between the stainless steel deposited metal and the cast low alloy steel was investigated.

LOW CYCLE FATIGUE TESTS UNDER STRAIN CONTROL

Experimental conditions

The tests have been carried out on composite specimens ; the zone investigated was located at the center of the gage length. Similar tests have been performed by Brinkman, Korth and Beeston (1973) for studying the junction between forged stainless steel of 304 type and stainless steel deposited metal of 308 L type. The majority of the tests were performed with the junction (fig. 1) perpendicular to the specimen axis. Same tests were also performed with the junction making an angle of 45° with respect to the specimen axis, in order to load this junction in shear and in tension. The tests have been carried out, at room temperature, in tension compression, under strain control, with a strain rate $\dot{\varepsilon}_t = 4 \cdot 10^{-3}$/s. The gage length was 10 mm.

Due to the difference in the mechanical characteristics of the base and deposited metals,the strain imposed to the composite specimen was not homogeneous along the gage length. A mixed zone (stainless and ferritic steels), having a length of 10 mm, and containing the junction, was thus loaded.

Results

The majority of the specimens broke in the low alloy base metal far from the junction and out of the HAZ. Figure 2 shows for some specimens the location of the fracture with respect to the junction.

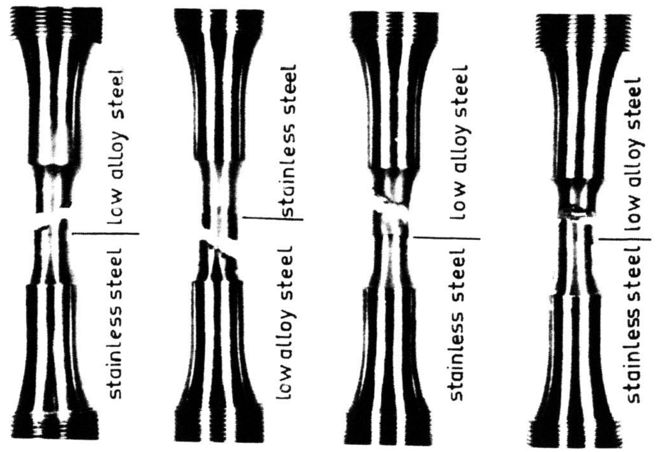

Fig. 2 Location of the fracture in composite L.C.F. specimens

The fatigue curve obtained with the composite specimens is given on Figure 3. The curve relative to the low alloy steel is also given on this figure, as a reference.

The fatigue lives are similar for intermediate and low strain. A slight difference appears, for the highest strains, it can be attributed to the inhomogeneous deformations in the composite specimens.

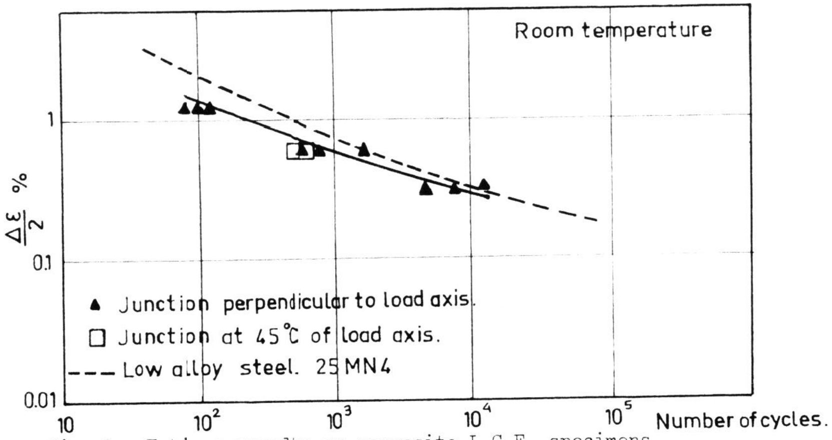

Fig. 3 - Fatigue results on composite L.C.F. specimens

Micrographic examinations

Fig. 4 - Initiation sites in low cycle Fatigue (low alloy steel 25 MN 4)

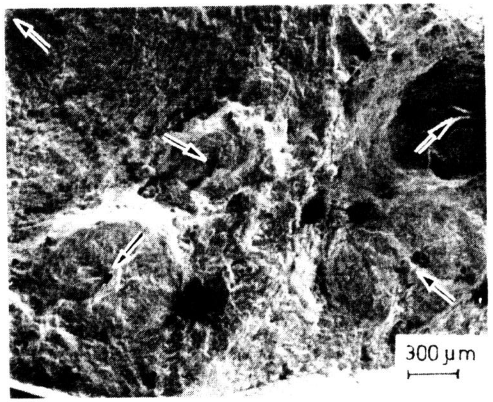

Fig. 5 - Initiation and propagation sites in low cycle Fatigue (Low alloy steel 25 MN 4)

As mentioned above, the majority of fractures occured in the cast base metal, far fromthe junction.S.E.M. examinations showed that the initiation sites are,in general, multiple. They consist of little discontinuities of microshrinkage type, i.e. spaces between several dentritic branches which were solidified before joining together (Fig. 4)
Some inclusions were also noticed at the surface of these microshrinkages ; grain boundaries can also be seen. The crack propagates from these discontinuities uniformely in all directions, in a plane perpendicular to the load axis (Fig. 5). The crack front has therefore a circular pattern centered on the initial defect (Fig.5). Since the initiation sites are in general multiple and not planar,

coalescence of cracks is observed and give a final microscopie steplike aspect. Some cracks initiated from inclusions present in the cast base material.

FATIGUE CRACK INITIATION AND PROPAGATION TEST

Crack initiation and propagation tests were performed on 20 mm thick compact-tension specimens. The root of the notch was located between the low alloy and the stainless steel. The notch root radius (r = 0.4 mm) was choosen in order to locate crack initiation on the fusion line.

Crack initiation tests were performed at 320°C, at a frequency of 1 Hz, with a

stress ratio $R = \frac{\sigma\ min}{\sigma\ max} = .05$

Fatigue crack initiation was studied by measuring the number of cycles necessary to yield a detectable variation of the specimen compliance. Test procedure is detailed by Rabbe and Amzallag (1974).

Results are presented in terms of maximal stress variation at the root of the notch $\Delta\sigma max$ vs. the number of cycles of initiation Na. In this formulation, according to Wilson (1974) $\Delta\sigma_{max} \simeq 2\ \Delta K/\sqrt{\pi r}$ with ΔK calculated pretending the notch to be a crack (r = o)

Fatigue crack growth tests were performed in air at 320°C, a frequency of 10 Hz, with R = .05, on specimens previously used for fatigue crack initiation tests.

Results of fatigue crack initiation tests.

The aim was to locate the root of the notch at the junction between the low alloy and stainless steels. However, due to the geometry of the weld passes, this appeared to be very difficult. In the specimens tested, the root of the notch was located for a large part in the base metal and sometimes in the stainless steel deposited metal; crack initiation occured in both materials, but preferentially in the decarburized zone of the ferritic base metal.

Figure 6 shows a section of a specimen, perpendicular to the mechanical notch in the crack initiation zone : one notices that crack initiation occured preferentially in the decarburized zone.

Figure 7 shows the variation of Δσ max vs. the number of cycles for initiations. On this figure results previously obtained by Rabbe and Amzallag (1974) on a forged stainless steel of 316 L type (0.03 C - 17 Cr - 12 Ni), with controlled nitrogen, are also recalled. For the highest stresses, the results obtained on composite C.T. specimens are in the scatterband of the results obtained on the forged 316 L steel, for the low stresses, the composite specimens show a better resistance against crack initiation than the 316 L steel.

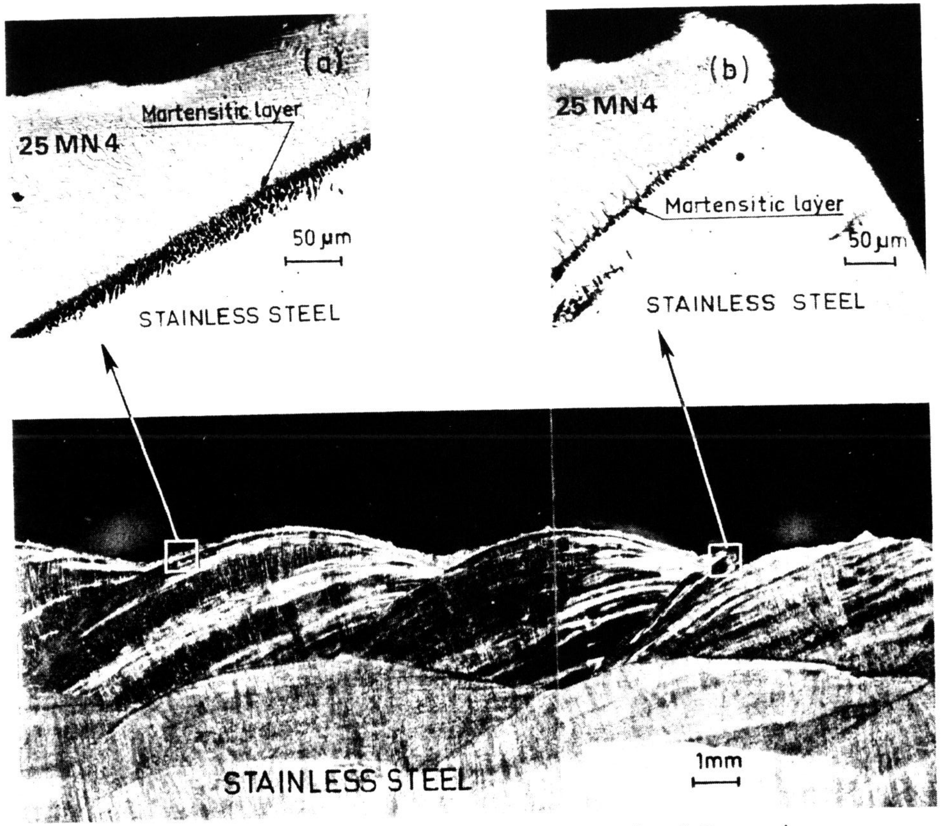

Fig. 6 - Initiation sites in notched composite C.T. specimens.
(Initiation occurs in both materials : Ferritic materials (a), stainless steel (b)).

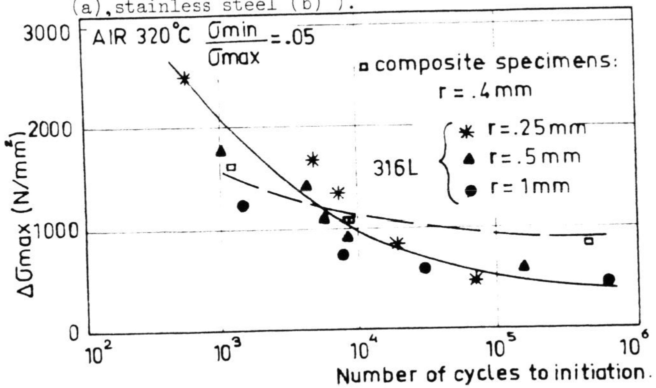

Fig.7 - Initiation data obtained on composite notched C.T. specimen- Comparison with data obtained on 316 L stainless steel.

Results of the crack propagation test

Crack initiated mostly in the decarburized zone, as mentioned before. Subsequently it propagated in this zone, having the lowest hardness, and sometimes went through stainless steel. Figure 8 shows the propagation path of a crack in the decarburized zone, near the thin martensitic layer.

In cases where the fatigue crack propagates occasionally in the stainless steel (Fig. 9) it propagates preferentially in the " softest " metal, avoiding in particular, the martensitic thin layer and martensitic bands due to the trapping of some undiluted base metal in the molten pool during the first pass of welding.

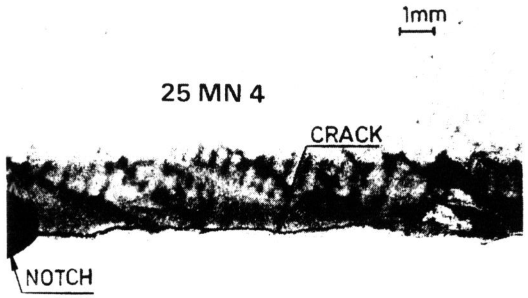

Fig. 8 - Propagation path of a crack in the decarburized zone

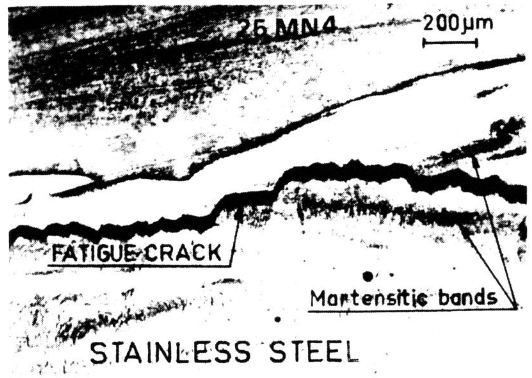

Fig. 9 - Crack propagation in stainless steel Crack deviations due to martensitic bands.

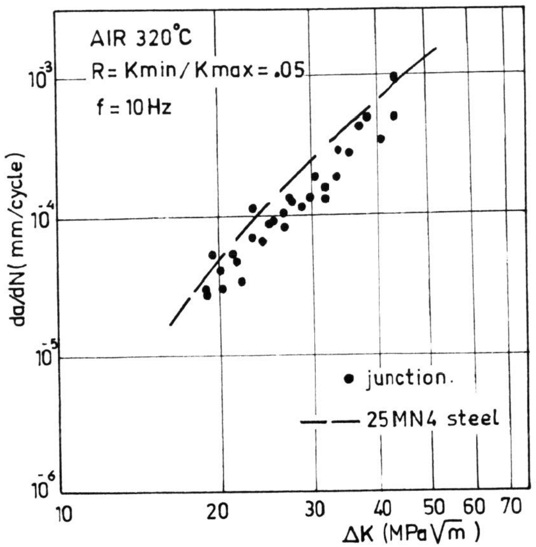

Fig. 10 - Fatigue crack growth rate in the junction between low alloy steel 25 MN 4 and stainless steel deposited metal.

The fatigue crack growth rate curve : da/dN = f (ΔK) obtained is shown on figure 10.

This curve is close to that obtained in a previous study (Bernard, Houssin and Slama, 1978) on the cast steel 25 MN 4 (fig. 10).

We can conclude that, in the decarburized zone of the junction a crack loaded in mode I does not propagate faster than in the cast base metal 25 MN 4.

CONCLUSIONS

The results obtained in this study showed the influence of microstructure on fatigue crack initiation and propagation in welded joints between dissimilar metals (austenitic stainless steel and low alloy steel). In particular a crack initiated in the decarburized zone tends to remain in it during the most part of the propagation. However, the crack growth rate in this zone is very close to that in the base metal itself. In cases where the fatigue crack propagates in the stainless steel, it propagates preferentially in the softest metal, avoiding in particular the thin martensitic layer and martensitic bands. The overall results showed that the junction studied is not a weak zone of the structure.

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