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FAILURE OF STAINLESS STEELS BY CORROSION-FATIGUE

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INTRODUCTION

Corrosion-fatigue is often met in work pieces used in conditions which do not appear very aggressive: in this respect, corrosion-fatigue is analogous to, and as pernicious as, pitting corrosion or stress-corrosion.

One cannot help being struck by such close analogies, at least in appearance, which exist between corrosion-fatigue cracks and those of stress-corrosion, or again between corrosion-fatigue and pitting corrosion: these analogies have strongly attracted the attention of researchers who were interested in these various aspects [1], so that it seems impossible to study one of these three aspects in isolation, neglecting their analogies.

The aim of this study was to specify or determine the mechanisms leading to the failure of stainless steels by corrosion-fatigue in a chlorinated environment. In particular, it was proposed to define the respective roles of electrochemical corrosion phenomena and mechanical damage. This knowledge should allow a better choice of stainless steels to resist corrosion-fatigue to be made.

EXPERIMENTAL PROGRAMME

The tests were carried out to produce the S.N. curve in rotating-bending, and the rate of fatigue crack growth in air and in a corrosive medium.

The behaviour of the following stainless steels was studied:

- an austenitic stainless steel with molybdenum of the type AISI 316, quenched from 1100°C (steel A)
- a titanium stabilized austenitic steel of the type AISI 316, with titanium, quenched from 1100°C (steel B)
- an austeno-ferritic steel: C = 0,03, Ni = 6,2, Cr = 21,1, Mo = 2,4, Cu = 1,4, quenched from 1150°C (steel C)
- a ferritic steel with a high percentage of chromium: C = 0,001, Cr = 26,2, Mo = 1,0 quenched from 900°C (steel D).

It is well known that the nature of the corrosive medium can have a great effect on the kinetics of the corrosion-fatigue phenomena. It is also known that in the case of stainless steels, localized attacks on the

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stress-corrosion or pitting-corrosion type are characteristically produced in the presence of chloride ions. For simplicity, we have therefore chose to carry out these tests in a 3%, aerated solution, of sodium chloride.

In some cases, to demonstrate the influence of the electrochemical phenomena on the results, a fixed electric potential was imposed on the metal during the test.

The rotating-bending tests and the fatigue crack growth experiments were carried out in an immersion cell. All the metallic parts, other than the samples, were protected against the effects of galvanic coupling.

The rotating-bending tests were carried out with 15 samples to produce the Wohler curve and to determine the fatigue limit by means of the statistical method of the stair-case. The rotational speed of the samples was 3000 RPM.

The measurements of fatigue-crack growth were made on servo-hydraulic pulsating machines. For each of the steels, a curve was drawn given by the rate of fatigue crack growth as a function of the variation ΔK of the stress intensity factor K. The frequency of tests was, depending on the case, from 0,5 to 20 Hz.

RESULTS AND DISCUSSION OF THE TESTS

Rotating-Bending Tests

The results of the rotating-bending tests are given in Table 1. The value of endurance ratio σ_e/σ_{UTS} is shown beside each fatigue limit σ_e.

The results obtained in air show that the steels can be classified in increasing order of their endurance ratio : austenitic steels A and B : 0,54, austeno-ferritic steel C : 0,61, ferritic steel D : 0,62.

The results obtained in the corrosive medium show that the classification indicated above seems to be retained : austenitic steels A and B : 0,41, austeno-ferritic steel C : 0,45, ferritic steel D : 0,48.

Measurement of the Potential of the Specimens

During the corrosion-fatigue tests, the potential of the specimens was measured. For example, Figure 1 shows the types of curve obtained in the case of the austeno-ferritic steel C, for two samples tested under different stresses (420 and 340 N/mm^2). The recorded potential is a mixed potential (the results of the anodic and cathodic processes). The potential can be seen to decrease more quickly for the higher stresses. This rapid decrease of the potential under a high load confirms that the rate of anodic dissolution of the metal is augmented by the stress.

In the case of the lowest loads, oscillations in potential can be observed, which seems to be due to a cycle of depassivation and repassivation.

Effect of the Potential Imposed

The current-potential curves of the various steels studied have been determined by means of quasi-potentiostatic tests with samples turning at the same speed as that of the fatigue samples. Figure 2 shows, for example, the curve obtained in the case of the austeno-ferritic steel C. From the curve, it can be seen that the metal is passive below 100 mV, whereas the area in which pits are not repassivated lies above 100 mV.

Thus, tests carried out under a potential greater than 100 mV show there is a considerable deterioration in the steels resistance to corrosion-fatigue, as can be seen from Figure 3, which gives the results of tests made under a potential of 200 mV.

The results of tests carried out under a potential of 50 mV are somewhat confused with those made under an open circuit. This potential corresponds to an area where localized corrosion is still possible and can be accelerated by the stress because of the damage caused to the passive film.

This result can be explained by a shift of the quasi-potentiostatic curve under the effect of the applied stress, lowering the pitting potential

A significant rise of the fatigue limit can be seen, when tests are made under a potential of 0 mV. This potential corresponds to an area of greater passivity of the metal.

In the case of the ferritic steel D, the pitting potential is very high (greater than : 1200 mV) : the discharge of oxygen can be seen without pits appearing. We have therefore, only considered a low potential (0 mV). The fatigue limit obtained under this potential is equivalent to that observed in air: this time, the chosen potential corresponds to an extremely stable domain of passivity.

Fatigue Crack Growth Tests

The influence of the principal parameters studied can be assessed from the curves produced by the variation of fatigue crack growth rate da/dN as a function of the variation ΔK of the stress intensity factor.

The measurements made on the austenitic steels A and B show that, in this steel, at a frequency of 20 Hz, the corrosive solution has no influence on the crack growth rate. On the contrary, in the case of the austeno-ferritic steel C, for high values of ΔK, an overall increase in the rate of fatigue crack growth is observed (Figure 4), and the lower the frequency, the greater is this increase.

An analogous result is found in the case of the ferritic steel D.

The increase in rate of the fatigue crack growth can be explained by an acceleration of anodic dissolution under the effect of increasing stresses.

In the case of the austeno-ferritic steel C, some tests were made under an imposed potential. From the experience gained in the course of the rotating-bending tests, a potential of 0 mV was chosen. The results obtained show a decrease in the rate of fatigue crack growth, and for the higher values of ΔK, the curve tends to rejoin the curve obtained in air. These results confirm that this potential corresponds to a domain of passivity of the metal.

CONCLUSIONS

From the tests carried out, a study of the initiation and propagation stages of the fatigue cracks in four stainless steels was possible.

The rotating-bending tests and the rate of fatigue crack growth produced the following classification of the steels, in the order of increasing resistance to fatigue: austenitic steels, austeno-ferritic steel, ferritic steel.

From the measurements of potential and the tests made under an imposed potential, the effect of the applied load can be assessed. The region of passivity of the metal seems likely to depend on the stress.

In a corrosive medium with a sufficiently low potential, the values for the fatigue limit are found to be the same as those obtained in air, and the rate of the fatigue crack propagation is noticeably diminished for high values of ΔK.

The results overall show the importance of electrochemical phenomena in the mechanisms of corrosion-fatigue.

The capacity of the metal for dissolution and for passivation seems largely to be responsible for the behaviour of the metal is a corrosive medium. This capacity varies notably with the composition of the metal and the loading conditions of the samples. It appears, moreover, that the rate of dissolution can depend on the applied stress. A stable potential on an uncharged sample can correspond to a region where dissolution is still possible if the metal is under a high stress.

The result of these various findings is that, for stainless steels, the mechanisms of stress-corrosion and corrosion fatigue are similar. The damage of the passive film would be caused in the first instance by the formation of slip steps, and secondly by the phenomena of intrusions-extrusions.

Any accident in the microgeometry of the surface of the metal favours these phenomena. In this way, the cracks are preferentially initiated on inclusions (oxides - sulphides...) or on carbides and carbonitrides. This phenomenon explains the relations already shown by numerous researchers [2, 3], existing between resistance to corrosion fatigue and resistance to pits which are produced preferentially on inclusions.

The essential difference between mechanisms of corrosion-fatigue and stress-corrosion is the fact that the phenomena of intrusions-extrusions appear at lower levels of stress than are necessary to produce the slip bands which lead to the deterioration of the passive film in stress-corrosion.

REFERENCES

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Table 1 Results of the Rotating-Bending Tests

Steel	Air		Corrosive medium			
			Open circuit		Imposed potential	
	σ_e N/mm^2	$\frac{\sigma_e}{\sigma_{UTS}}$	σ_e N/mm^2	$\frac{\sigma_e}{\sigma_{UTS}}$	σ_e N/mm^2	$\frac{\sigma_e}{\sigma_{UTS}}$
A	320	0,56	235	0,41		
B	335	0,52	270	0,42		
C	400	0,61	290	0,45	$0mV_{335}$ $50mV_{278}$	0,51 0,43
D	292	0,62	227	0,48	$0mV_{280}$	0,59

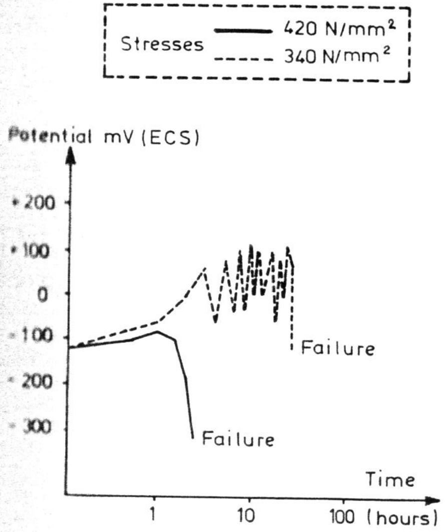

Figure 1 Evolution of Potential as a Function of the Life in Open Circuit

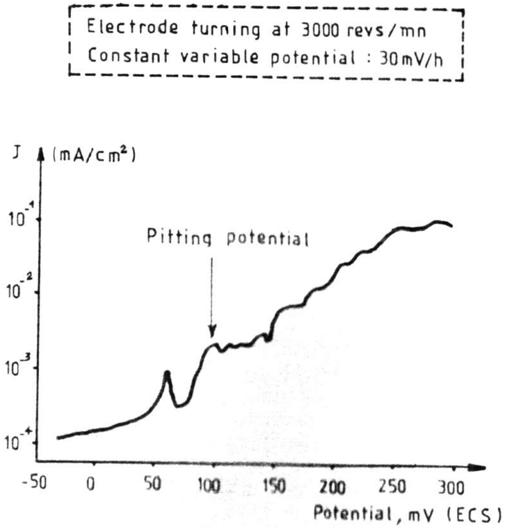

Figure 2 Results of Quasi Potentiostatic Tests

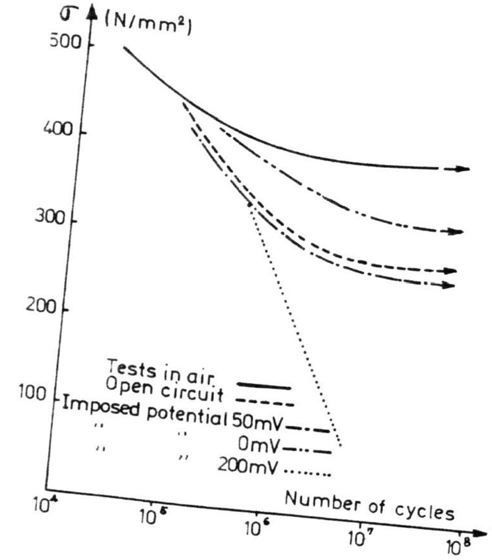

Figure 3 Results of Rotating Bending Tests

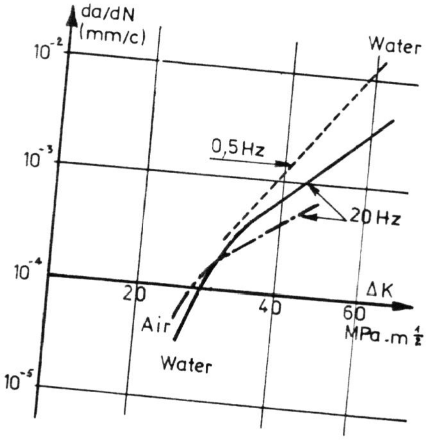

Figure 4 Influence of Corrosive Solution on the Rate of Fatigue Crack Growth

AUSTENO - FERRITIC STEEL C