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# Fatigue crack growth of a metastable austenitic stainless steel

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ABSTRACT

The fatigue crack growth behavior of an austenitic metastable stainless steel AISI 301LN in the Paris region is investigated in this work. The fatigue crack growth rate curves are evaluated in terms of different parameters such as the range of stress intensity factor $\Delta K$, the effective stress intensity factor $\Delta K_{eff}$, and the two driving force parameter proposed by Kujawski $K^*$.

The finite element method is used to calculate the stress intensity factor of the specimens used in this investigation. The new stress intensity factor solution has been proved to be an alternative to explain contradictory results found in the literature.

Fatigue crack propagation tests have been carried out on thin sheets with two different microstructural conditions and different load ratios. The influence of microstructural and mechanical variables has been analyzed using different mechanisms proposed in the literature. The influence of the compressive residual stress induced by the martensitic transformation is determined by using a model based on the proposal of McMeeking et al. The analyses demonstrate the necessity of including $K_{max}$ as a true driving force for the fatigue crack growth. A combined parameter is proposed to explain the effects of different variables on the fatigue crack growth rate curves. It is found that along with residual stresses, the microcracks and microvoids are other factor affecting the fatigue crack growth rate in the steel studied.



## 1. Introduction

The new environmental standard for the automotive industry requires the fabrication of more efficient vehicles with less fuel consumption. This technological challenge demands the development of new light weight materials. The metastable austenitic stainless steels (MASS) are materials with good formability and high strength compared to other carbon steels or aluminum alloys used in the automotive industry [1]. This high strength of MASS can be used to reduce the components thickness without decreasing vehicle safety.

The fatigue crack growth rate (FCGR) of MASS has been related to the martensitic transformation that occurs in the crack tip of this kind of steels [2–5]. The first study of fatigue crack propagation in steel with martensitic transformation in the crack tip was published by Chanani et al. [6]. The results of this work shows a decrease in the fatigue crack growth rate for the same range of stress intensity factor $\Delta K$, when the austenitic structure was more unstable. Same result was obtained later by Pineau and Pelloux [2] in an austenitic metastable stainless steel AISI 301. The authors of both studies try to relate the decrease in the crack growth rate with the higher strain hardening coefficient of the more unstable alloy. To prove their hypothesis, the authors used a fatigue crack propagation model proposed by Head [7], and a fatigue crack propagation model proposed by Chanani et al. [6]. However, the crack propagation models used in both studies to establish a relationship between crack growth rate and $\Delta K$ exhibited an opposite tendency. Chanani's model predicts an increase in the FCGR with the increase in the work hardening, whereas Head's model predicts the opposite. Even in the case when the crack propagation in Head's model predicts a decrease in crack growth rate with the increase in work hardening coefficient, experimental results show differences with the prediction of the model.

Another mechanism used to explain the decrease in the FCGR associated to the martensitic transformation is the role of microstructure in the FCGR. To prove this hypothesis, Pineau and Pelloux [2] and Mei and Morris [3], in different studies, have compared the FCGR in the same alloy but under different conditions:

(a) Martensitic transformation induced by stress or strain during fatigue test *vs.* Martensite formed by quenching (1).

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(b) Martensitic transformation induced by stress or strain during fatigue test *vs.* Martensite formed by cold rolled (2).

In both cases the FCGR for the same $\Delta K$ was higher for the specimens in which the structure was transformed to martensite previous to the fatigue test. These results suggest that the decrease in the FCGR is associated to the martensitic transformation during crack propagation rather than to the existence of a martensitic structure in the crack path.

Though the studies on the subject show the importance of martensitic transformation in the FCGR, the role of the martensitic transformation in mechanical variables that influence the FCGR, like load ratio *R*, is not clear. It has been suggested that martensitic transformation can induce crack closure, and this phenomenon could be used to explain the effects of load ratio and martensitic transformation on FCGR of AMSS. However, there is a lack of appropriate and systematic research on the contribution of crack closure to the crack growth rate in MASS.

The analysis of previous studies on the fatigue crack growth (FCG) in thin sheet specimens of MASS show the influence of mean stress in the FCGR for the same *R* and the same $\Delta K$, in tests realized to constant *R* [4,8]. This is opposite to the behavior observed in thick specimens of MASS or to the common behavior reported for many alloys. This uncommon behavior will be discussed in this paper.

The present work will focus on the fatigue crack grow rate behavior of MASS in thin sheet specimens. The influence of martensitic transformation and mechanical variables on FCGR will be analyzed in the Paris region of FCG. In addition to the mechanism introduced above, another mechanism to explain the influence of the martensitic transformation in the FCGR is discussed.

## 2. Specimen, material, and testing

The material employed in the current study was an austenitic stainless steel AISI 301LN provided by OCAS NV, Arcelor-Mittal R&D Industry Gent (Belgium). The material was provided in thin sheet specimens of 1 mm and 1.5 mm thickness, in two different conditions: annealed and cold rolled (40% degree of cold rolling). The chemical composition of the material used is shown in Table 1. The mechanical properties with the transformation temperatures are shown in Table 2.

To reveal the microstructure, the material was grounded in the surface with SiC emery paper up to a roughness of 1200 grit and then polished. Since the mechanical grinding can induce martensitic transformation, the material was electro-polished with a solution consisting of 5 vol% perchloric acid and 95% ethanol at 45 V for 15 s. The austenite phase was revealed by electro-etching in a solution of 65% acid nitric at 1.2 V. Fig. 1a shows an homogeneous structure composed by equiaxial austenitic grains with an average grain size of 11.8 μm. Fig. 1b shows the austenitic grain oriented in the rolling direction. X-ray diffraction measurements showed that the cold rolled steel has a percentage of martensite that is approximately 38 ± 5%.

The same procedure used to reveal the microstructure was repeated for all specimens tested in order to observe the martensitic transformation around the crack tip. The martensite phase was revealed by chemical etching in a solution of 100 ml ethanol, 20 ml HCl, 1.5 g $K_2S_2O_5$ and 2 g $NH_4F{\cdot}HF$.

The FCG tests were carried out on single edge notch tension specimens (SENT). The width of the specimens was 35 mm and 40 mm, and the total length of most specimens was 25 cm.

**Table 1**
Chemical composition (wt.%).

| | Fe | Cr | Ni | Mo | C | Si | P | S | Mn | Cu | N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Annealed – 1 mm | Bal | 17.86 | 6.42 | 0.24 | 0.015 | 0.471 | 0.031 | 0.007 | 1.495 | 0.173 | 0.094–0.145 |
| Annealed – 1.5 mm | Bal | 17.98 | 6.78 | 0.23 | 0.012 | 0.548 | 0.031 | 0.004 | 1.562 | 0.057 | 0.094–0.145 |
| Cold-rolled – 1.5 mm | Bal | 17.94 | 6.30 | 0.18 | 0.016 | 0.513 | 0.032 | 0.005 | 1.481 | 0.135 | 0.094–0.145 |

**Table 2**
Mechanical properties with transformation temperatures.

| | $\sigma_{ys}$ (MPa) | $\sigma_{UTS}$ (MPa) | Total elongation (Pct) | Ms (°C) | $M_{d30}$ (°C) | $M_d$ (°C) |
|---|---|---|---|---|---|---|
| Annealed – 1 mm | 343 | 973 | 42.9[a] | −78.21[b] | 40.89[b] | 100[c] |
| Cold rolled – 1.5 mm | 1120 | 1207 | 20.5[a] | −76.62[b] | 42.57[b] | 100[c] |

[a] Tensile tests were carried out in subsize specimen (dimensions according to standard E 08-01).
[b] The Ms and the $M_d$ temperatures are calculated using equations taken from Ref. [9], to make the calculation, the average value of *N* was used.
[c] $M_d$ temperature for AISI 301 stainless steel [2].

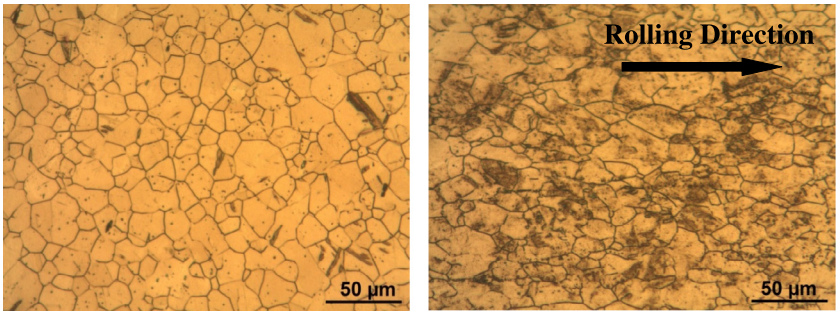


**Fig. 1.** Microstructure of an austenitic metastable stainless steel AISI 301LN: (a) annealed; (b) cold rolled. (In both pictures the thickness of the sheets is perpendicular to the micrographs.)