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SNOEK LIKE RELAXATION IN Fe-Ni-C VIRGIN MARTENSITE

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Résumé - Nous proposons d'interpréter par la théorie de SCHOECK et SEEGER le spectre de frottement intérieur, relevé dans la martensite récemment trempée d'alliages Fe-Ni-C. Le mécanisme de relaxation envisagé consiste en des sauts réversibles des atomes de carbone, d'un site octaédrique à un autre, dans le champ de contrainte des dislocations gliss. Pour les températures supérieures à 150K, ce processus présente un caractère irréversible de plus en plus marqué, conduisant ainsi à l'ancrage des dislocations par le carbone.

Abstract - The internal friction plot reported in virgin Fe-Ni-C martensite is interpreted in terms of SCHOECK-SEEGER theory. The relaxation phenomenon considered here results from reversible carbon redistribution in the screw dislocation stress field. For temperatures higher than 150K this process becomes more and more irreversible, thus inducing dislocation pinning by carbon.

I - INTRODUCTION

In a recent overview on tempering of virgin martensite [1] three stages were considered, as proposed earlier by WINCHELL et al. [2]. The first one, named "relaxation stage", occurs at low temperatures (<220K). The second one called "aging" takes place in the (220-300)K temperature range. Finally, "tempering" refers to clustering and precipitation phenomena occurring above room temperature.

We have demonstrated [3] that an isothermal martensitic transformation exhibiting C curve behavior develops in the temperature range of the "relaxation" stage. Furthermore, we have shown [4] that, except for the isothermal martensitic component, the internal friction plot is nearly reversible in the (77-190)K temperature range, whereas irreversible behavior is observed for higher temperatures, where aging occurs.

The purpose of this paper is to present a new approach of anelastic behavior in the so-called "relaxation" and "aging" stages. Our results are shown to be consistent with SCHOECK-SEEGER'S theory [5].

II - EXPERIMENTAL PROCEDURE

The internal friction experiments were performed on an automatic inverted torsion pendulum [6]. Unless otherwise stated the test frequency was 1.5 Hz. Three Fe-Ni-C alloys having similar Ms temperature (≈ 225K) were tested : A (Fe-30 Ni-0.02 C), B (Fe-27Ni-0.18C) and C (Fe-19Ni-0.51C). After in situ quenching at 77K (1.5K/min.) and a 100 minute holding at 77K, measurements where realized during reheating to room temperature.
We have reported in Figure 1 the internal friction evolutions, for alloys A, B and C, during reheating (1.5K/min) virgin martensite from 77K up to room temperature. Three maxima labelled respectively A, M and B are observed. The first one (A), associated to the isothermal martensitic transformation [5] is discussed in another contribution [7]. Although increasing carbon content increases the maxima A and B, the temperature of maximum M remains constant (218K).

The influence of the heating rate on M and B (Fig.2) has been studied for alloy B, after having suppressed anomaly A by thermal cycling the sample in the (77-170)K temperature range (see insert in Fig.2). We can observe that increasing heating rates raise maximum B without any change in its temperature, whereas maximum M is shifted towards higher temperatures and tends to become only a shoulder of the main peak B (Fig.2 - curve 4). Furthermore, relative frequency evolutions (curves 1', 2', 3', 4') indicate that the increase of the modulus is greater the lower the heating rate. No influence of the heating rate is observed below 170K.

Figure 3, which presents the influence of the test frequency on the internal friction plot for alloy B, shows that frequency does not affect the maximum M temperature whereas B is strongly frequency dependent: decreasing frequency shifts maximum B towards lower temperature and increases its intensity. Furthermore, the low temperature part of the internal friction plot is also shifted towards lower temperature and this temperature shift is identical to that
Fig. 3 - Influence of the test frequency on the internal friction (1,2...) and relative frequency (1',2') evolutions (alloy B).

Relative frequency evolutions (curves 1', 2', 3', 4') indicate that increasing the test frequency tends to increase the modulus in the (150-300)K temperature range. Using results reported in Fig.3 we calculated the activation energy $E = (0.78 \pm 0.05)$ eV. associated to the peak $\beta$. Assuming that $\omega \tau = 1$ for the maximum of the relaxation phenomenon, we can deduce the value of the pre-exponential factor: $\tau_0 = 5 \times 10^{-17}$ s.

IV - DISCUSSION

As observed in Fig.1, the maxima M and B are related to the presence of carbon in the martensitic structure. Since we have shown previously [4] that increasing dislocation density in virgin martensite increases the intensity of M and B, the interpretation of these maxima must account for the influence of these two parameters.

Furthermore, the influence of heating rate (Fig. 2) and test frequency (Fig.3) strongly suggest that maximum B can be associated to the development of a relaxation phenomenon occurring in the (100-300)K temperature range, with a maximum of the relaxation strength at 253K for 1.5Hz experiments. Nevertheless, if the heating rate is low enough (Fig.2 curves 1, 2, 3) the main maximum B is considerably weakened, due to irreversible processes, occurring for temperatures higher than 150K, which tend to decrease the internal friction and to increase the modulus.
According to these experimental observations the internal friction plot would result from two contributions:

1) a relaxation phenomenon developing in the (100-300)°K temperature range, with a maximum of the relaxation strength at 253K (for 1.5Hz experiments).
2) an irreversible process which should be significant in the (150-300)°K temperature range, thus interfering with the relaxation phenomenon by increasing the modulus and lowering the internal friction.

We have presented in Fig.4 a schematic plot of this phenomenological interpretation of the internal friction evolution, assuming a pure relaxation peak. The difference between the theoretical behavior and the real plot reveals the negative contribution of the irreversible component (labelled "pinning"). This model is consistent with the influence of frequency and heating rate.

We believe that, among existing models of relaxation phenomenon involving carbon and dislocations, SCHOECK and SEEGER theory [5] can give a convenient description of our experiments. They pointed out that carbon can respond to a screw dislocation stress field, just as it can respond to an applied stress, by diffusing among its octaedral lattice sites. This process is expected to give rise to a SNOEK-like relaxation peak, never mentioned before because reversible behavior is only observed for very low frequency experiments performed in the low temperature range. For increasing temperatures (T>150K) the carbon atoms can be progressively trapped on defects (dislocations, twins, interfaces), thus inducing an irreversible pinning of the dislocations, which is revealed by the increase of the modulus and the decrease of the internal friction. The kinetics of this short range distance rearrangement is extremely high. This pinning process decreases the internal friction (thus inducing the maximum (\(\@\)) and lowers the maximum\(\@\) so that for high frequency experiments (>10Hz) this peak (which should appear at 280K) is not observed.

Such an irreversible SNOEK pinning has been proposed to interpret the first stage of strain ageing in iron [8-11] and in iron nickel carbon alloys [12,13].

Our interpretation is supported by the activation energy (E=0.78 eV.) calculated for the relaxation process. The very low pre-exponential factor could be attributed to the extremely high internal stresses existing in the martensitic plates.

References.