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Abstract : Some experimental conditions which generate the dislocation-enhanced Snoek peak in Fe-C alloys are presented. The results indicate that the movement of non-screw dislocation segments is involved in the relaxation mechanism. The results are consistent with the movement of non-screw dislocations in a medium with a viscosity proportional to the Snoek relaxation time, or alternatively, to a limiting case of the generation of kink-pairs on non-screw dislocation, i.e. a carbon Snoek-Köster relaxation.

I - INTRODUCTION

Recent development of a specific model of the Snoek-Köster (S-K) relaxation (1,3) has led to renewed interest in the internal friction (IF) relaxations attributed to the interactions between impurity interstitial atoms (IIA's) and dislocations in the bcc metals (3). According to Seeger and coworkers (4,5), the dislocation-enhanced Snoek peak (DESP) can also be explained by a generalized theory of the interactions of IIA's with dislocation kinks. In the case of the Fe-C alloys studied here, this theory implies that the DESP is due to the stress induced movement of non-screw dislocations in an atmosphere of interstitial C atoms whose effective viscosity is proportional to the relaxation time τ_o^S of the normal Snoek peak.

The defining feature of a DESP is that a normal Snoek peak is substantially magnified in height by room temperature cold work (CW), while to a first approximation the limiting relaxation time τ_o^S and the relaxation enthalpy H^S remain unchanged. This behaviour could be explained if room temperature CW produced relaxation centers with an increased contribution to the relaxation strength per center e.g. IIA pairs /6/. However, it is difficult to imagine that the increase in relaxation strength per pair outweighs the smaller number of relaxation centers formed in determining the relaxation strength. Estimates of the relaxation parameters of the C-C relaxation from magnetic aftereffect studies /7/ lead to the expectation that this phenomenon would produce extremately small satellite IF peak, slightly to the high temperature side of the normal Snoek peak.

II - MATERIALS AND TECHNIQUE

Wire samples (0.6 mm in diameter and 100 mm long) of CEN-G pure Fe (8) pre-doped with 1000 appm or 25 appm of C were annealed for 5h at 823K in pure He. These alloys are referred to as Fe-1000 and Fe-25, respectively. In each case, a saturated solid solution of carbon was produced by fast cooling (∿400K s^{-1}) from 823K in a flow of He. The samples were immediately transferred to a liquid nitrogen Dewar and stored at 77K until required for experimentation.

III - EXPERIMENTAL RESULTS

3.1. The DESP in Fe-1000

The normal Snoek peak in Fe-1000 is shown in Fig. 1 (curve 1). It corresponds to 120 appm of C in solid solution. The same curve was also obtained after annealing at 400K. Following torsional CW of 2.5% at 300K, the Snoek peak is transformed into a DESP (curve 2). Similar results have been reported recently in Fe-N (10), Nb-O and Ta-O alloys (5).

Peak heights of DESP's following torsional CW at 77K and 300K are compared in Fig. 2. Similar results for tensile deformations were also obtained (10). These results show that deformation at 300K is more efficient at enhancing the Snoek peak than deformation at 77K.

The activation parameters of the DESP in Fe-1000 are $H^{DESP} = 0.84 \pm 0.03$ eV and $\tau_o^{DESP} = 10^{-14.2 \pm 0.1}$ s which should be compared with the parameters of the normal Snoek peak of $H^S = 0.80$ eV and $\tau_o^S = 10^{-13.7}$ s as reported by Diehl et al (11).

3.2. The DESP in Fe-25

The DESP and normal S-K peak obtained after 13% CW at 300K in Fe-25 are shown in Fig. 3, curve 1. In contrast, on cooling the same sample, the S-K peak is stabilized (10,12,13) while the DESP is suppressed (curve 1'). A 5h strain ageing treatment of a similarly pre-deformed sample also suppressed the DESP on heating. From these results it is concluded that the dislocations contributing to the DESP are not fully pinned. Further evidence of this for the Fe-1000 alloy is given in section 3.3.

The DESP in Fe-25 does not exhibit any appreciable amplitude dependence in the strain amplitude range investigated and is not generated or is negligibly small after CW at 77K.

3.3. New Experimental Conditions that Generate the DESP

The IF spectra of Fe-1000 samples subjected to different deformation treatments at 300K are illustrated in Fig. 4. Curve 0 shows the normal Snoek peak which is suppressed after heating to 673K and cooling. Subsequent deformation of 1.5% in torsion at 300K generated the DESP on warm-up, curve 1 and it was suppressed on cool-down, curve 1'. This cyclic procedure was continued with increasing torsional deformation up to 13%. Only the runs for 1.5%, 2.5% and 3.5% are shown in Fig. 5. On each successive run the DESP was generated with increasing height on warm-up and suppressed again on cool-down. In addition, it should be noted that the dynamic shear modulus (inset, Fig. 5) began to increase on the high temperature side of the DESP on warm-up.

From these results it is concluded that "fresh" dislocations are required to generate the DESP. By fresh dislocations we mean those dislocations that are surrounded by metastable atmosphere following deformation, or those that have been pulled from a stable fully-pinned configuration and have come to rest in a metastable atmosphere during redeformation.

IV - DISCUSSION

Because of the direct evidence in the above results that the relaxation strength of the DESP increaseswith increasing amount of deformation /and, therefore, increasing dislocation density, Λ/, we assume that dislocation movement is involved in the mechanism and confine our discussion to such mechanisms. In particular, we consider the type of dislocations involved and the activation parameters of the relaxation.

Seeger and co-workers (4,5) attribute the DESP's to dislocation lines with small or negligible Peierls barriers (in the case of Fe this means non-screw dislocations) moving in an atmosphere of IIA's with low symmetry strain fields (in our case C interstitials). Under these circunstances it is shown that the effective viscosity of the atmosphere is proportional to τ^S and therefore, the activation enthalpy of the process is H^S as observed experimentally (4). Although the limiting relaxation time τ_o^{DESP} is proportional to C_d, the concentration of IIA's at the dislocation line, the full expression has not been determined to date (5).

It is well known that in relativity pure samples of Fe deformation at 77K produces a preponderance of long, straight screw dislocations, whereas deformation at 300K produces a tangle of both screw and non-screw components (14). Consequently, comparison of the effect of deformation temperatures of 77K and 300K on the height of the DESP (Fig. 2) represents strong evidence that non-screw dislocations are involved. More importantly, our inability to generate a DESP by deformation at 77K in the pure Fe-25 alloy strengthens this evidence. Thus, the experimental evidence of the dislocations involved and the available data on the activation parameters of the DESP in Fe-C alloys are in agreement with Seeger's model for the DESP's in bcc metals.

It is interesting to note that the experimental conditions which generate the DESP in Fe-C alloys also fulfill the requirements for one of the limiting conditions for the S-K relaxation on non-screw dislocations. These requirements are that long range migration of the IIA's can be disregarded, i.e. C_d can be treated as a constant, and $\rho_k^{eq} L >> 1$ (ρ_k^{eq} is the one dimensional density of kinks of one sign in thermal equilibrium and L is the separation of obstacles insurmountable to the kinks) (4). Under these conditions, Seeger's (3) expression for the relaxation time may be rewritten as

$$\tau^{S-K} = \gamma kTC_d \exp[(1/2\, H^{\alpha} + H^{s})/kT] \qquad (1)$$

where H^{α} is the relaxation enthalpy of peak α (attributed to kink-pair generation on non-screw dislocations (15)). For Fe $H^{\alpha} = 0.06$ eV (15) and $H^{s} = 0.80$ eV (11). Thus, eqn [1] predicts a relaxation enthalpy of 0.83 eV in excellent agreement with the experimental value of 0.84 ± 0.03 eV.

Although the parameter γ in eqn. [1] has not been determined rigorously, Seeger (1) argues on general grounds that it is almost independent of T and C_d but proportional to L^2. Consequently, τ_o^{S-K} (= γkTC_d) should show a structure dependence. However most reported experimental studies of the S-K peaks have given $\tau_o^{S-K} \cong 10^{-14}$s (5,16). Thus, our result of $\tau_o^{DESP} = 10^{-14.2 \pm 0.1}$s is not inconsistent with the interpretation of the DESP as the S-K for non-screw dislocations.
As is the case with most relaxations associated with the movement of dislocations, the relaxation strenghts for both of the mechanisms discussed above are controlled by the product ΛL^2. Again, the increase in the peak height of the experimentally measured DESP with the amoun of plastic deformation (Figs. 2,4) is consistent with a dependence on ΛL^2. (Λ is the dislocation density).

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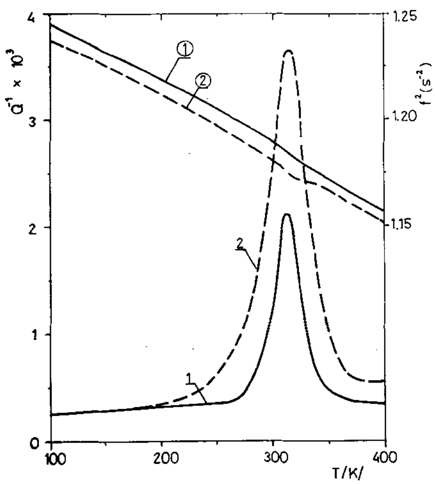

Fig. 1 - Curve 1 is the normal Snoek peak in Fe-1000. Curve 2 is the DESP after 2.5% CW in torsion at 300 K. Curves (1) and (2) are the corresponding changes in the elastic shear modulus.

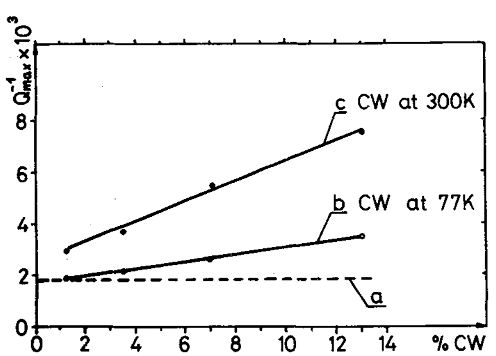

Fig. 2 - The influence of CW in torsion at 77K curve b, at 300K curve c, on the peak heigh of the DESP in Fe-1000. The level of the original Snoek peak height is indicated by a.

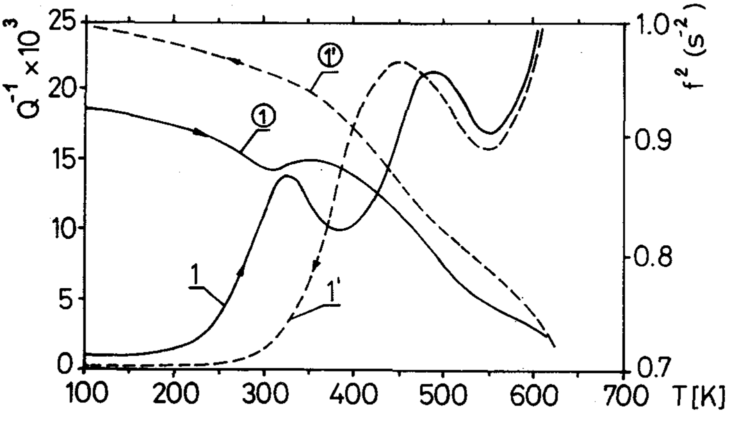

Fig. 3 - IF spectra after 13% CW at 300K in Fe-25. Curves 1, are the IF and dynamic modulus changes, respectively, during warm-up. Curves 1, (1') the results on cool-down.

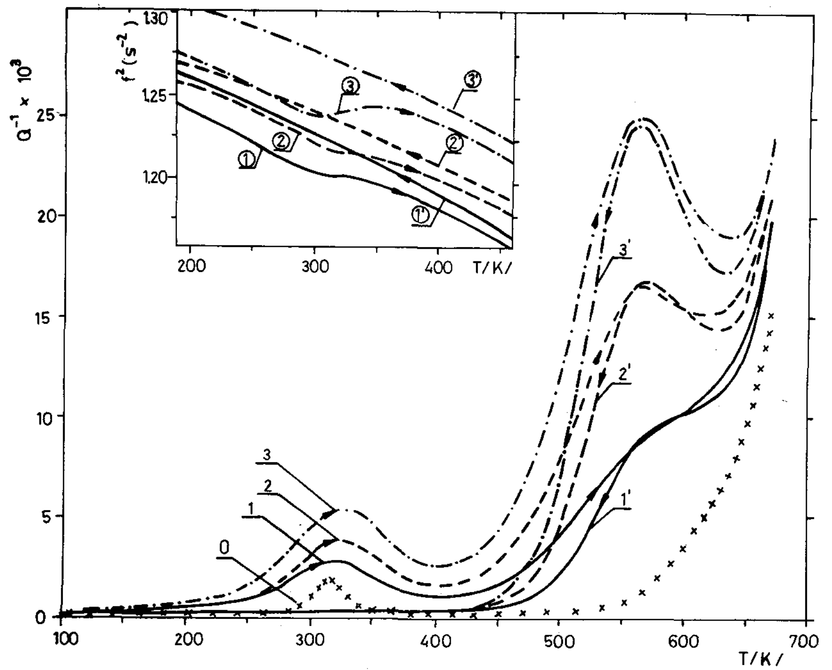

Fig. 4 - The DESP and S-K peaks in Fe-1000 after torsional deformation at 300K. Curve 0 - the initial Snoek peak. Curves 1, (1) ; 2, (2) ; 3, (3) are the IF and dynamic modulus changes during warm-up after CW of 1.5%, 2.5% and 3.5%, respectively. Curves 1', (1') ; 2', (2') ; 3', (3') are the corresponding results on cool-down.