Internal friction measurements in iron-nickel-carbon alloys

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INTERNAL FRICTION MEASUREMENTS IN
IRON-NICKEL-CARBON ALLOYS

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Introduction

In b.c.c.iron with low carbon content, a "Snoek-peak" can be found by internal friction measurements as a result of stress-induced diffusion of interstitial carbon atoms in the octahedral sites(1).

Scheil et al.(2) and Jackson et al.(3) observed that the addition of nickel to the iron lowers this peak; and at a nickel content of ca. 15 wt.pct the peak has disappeared completely(3). At a temperature of ca. 200°C, however, another internal friction peak has been measured in this case by Scheil(2) and Förster(4).

Similar observations, i.e. the fading of the Snoek-peak and the occurrence of a 200°C-peak, are described for martensitic iron-carbon alloys (carbon content 0.5-1.0 wt.pct). A 200°C-peak has been measured also by Köster et al.(5) in low-carbon steels after plastic deformation.

It has been suggested(2,3) that the decrease of the Snoek-peak height with increasing nickel content may be due to:

1. The interactions of the carbon atoms with imperfections in the martensitic structure or
2. the ordering and stabilisation of the carbon atoms resulting in a tetragonal deformation of the lattice during the gamma-alpha transformation.

The 200°C-peak is suggested to arise from the interaction between the carbon atoms and the dislocations which are present in the martensitic structure(2) or are introduced by plastic deformation(5).

The above mentioned interaction between dislocations and carbon atoms could be the result of Cottrell- and/or Snoeklocking proposed by Cottrell(6) and Schoeck and Seeger(7) respectively.

Plastic deformation of FeNiC alloys would cause then an unlocking of dislocations from the Cottrell clouds increasing the amount of free interstitial carbon. This should result in a return of the Snoek-peak.

It is the object of the present investigation to study this phenomenon and the possible decrease with time of the Snoek-peak due to diffusion of the interstitial carbon toward the dislocations. Also the latter effect could give some information on the dislocation density of FeNiC martensite(8).

Experimental procedure

The composition of the FeNiC alloys used in this investigation are given in table I.

TABLE I
The composition of the used samples.

prep.	%Ni	%C	%Fe	in wt.pct.
1	16.1	0.05	balance	
2	25.0	0.05	balance	
3	28.9	0.05	balance	
4	31.5	0.05	balance	

The specimens were produced by argon arc melting of high purity iron(99.998 pct) and nickel(99.999 pct) with addition of eutectoidal iron carbon. The as cast samples were homogenised for 170 hr at 1150°C and subsequently drawn into wire of 0.61 mm diameter and 165 mm length.

The damping measurements were performed in a Kê-type(9) torsion pendulum described elsewhere(10). The damping was measured at a frequency

of 1 Hz. The maximum elastic strain at the surface of the specimen was 10^{-6} .

Results

The results of the damping measurements of the FeNiC-alloys with 16.1; 25; 28.9 and 31.5 wt.pct Ni resp. after heating at 900°C during 5 min. in purified Argon atmosphere and quenching in liquid N_2 are shown in fig. 1 (mean time of the measurements after quenching 1 hr).

FIG. 1

Internal friction v.s. temperature of various iron-nickel carbon alloys 1 hr after quenching from the gammaphase (900°C) in liquid N_2 (-196°C)

This figure indicates that the alloys with 16.1 and 25 wt.pct Ni do not exhibit a Snoek-peak, which agrees with previous investigations (2,3). The alloys with 29 and 31.5 wt.pct Ni, however, show a small damping peak at about 40°C .

It is also evident from figure 1 that there is a large difference in internal friction level between the alloys with 16 and 25 wt.pct Ni.

The Snoek-peak observed in the 29 and 31.5 pct Ni alloys decreases with time as shown in figure 2.

FIG. 2

The path of the internal friction peak height at 37°C measured v.s. time for Fe29Ni 0,05C and Fe31.5Ni 0,05C after quenching (finish quenching is $t = 0$)

After the disappearance of the Snoek-peak in these alloys, the wire was loaded "in situ" with a tensile stress of 30 kg/mm², resulting in a deformation of about 0.03 pct. Due to this deformation the Snoek-peak reappeared in both alloys, but disappeared again after some time, as illustrated in figure 3 for the 29 wt.pct Ni alloy.

FIG. 3

Internal friction v.s. temperature for Fe29Ni 0,05C after a tensile stress of 30 kg/mm² at different times after straining.

The decrease of the peak height with time after straining at 37°C is shown in fig. 4.

FIG. 4

Internal friction v.s. time at 37°C (maximum peak height) after a tensile stress of 30 kg/mm² at $t = 0$

The effect of tempering is shown in fig. 5 for the 25 wt.pct Ni alloy. In this alloy, which does not show a Snoek-peak after annealing and quenching, a damping peak is produced by tempering for $\frac{1}{2}$ hr at 400°C and quenching in liquid N₂. Similar to the peaks produced by deformation, also this peak disappears after some time.

FIG. 5

Internal friction v.s. temperature after annealing during $\frac{1}{2}$ hr at 400°C and quenching in liquid N₂ for different aging times (aging during Snoek-peak measurements.)

Discussion

The peaks observed at ca. 40°C after quenching and/or deformation in 29 and 31.5 wt.pct Ni alloys (figs. 1 and 3) and in 25 wt.pct Ni after tempering at 400°C (in fig. 5) strongly suggest Snoek-relaxation due to free interstitial carbon. The absence of such a peak in 16 and 25 wt.pct Ni alloys after quenching, could be the result of:

1. A high dislocation density in the massive martensite phase, locking practically all interstitials by Cottrell- and/or Snoek-locking. If this supposition is true then the 29 and 31.5 wt.pct Ni alloys should possess a lower dislocation density. This seems not unlikely because at 28-30 wt.pct Ni a transition occurs from massive to acicular martensite. This transition is accompanied by a change in the mode of the second shear from slip to twinning(11).
2. The other possible explanation given by Jackson et al(3) that the rapidly formed massive martensite is tetragonal due to transformation ordering of carbon atoms, is less likely, because according to Zener(12) the carbon will be randomly distributed at this low carbon content and the observed Ms-temperatures.
3. Finally the different radii of the iron and nickel atoms could cause differences in the sizes of the octahedral sites; consequently resulting in a stabilisation of the interstitial atoms, which also contributes to the observed decrease of the peak with increasing nickel content.

In our opinion the first explanation for lack of further evidences seems to be the most likely.

The decrease in peak height with time could then be caused by diffusion of carbon atoms towards dislocations. This decrease opens the possibility to estimate the dislocation density according to the theory of Harper(8). Harper showed that during strain aging of b.c.c. iron a migration of carbon atoms to dislocations may be detected by damping measurements. The decrease of the peak is given by:

$$Q_t / Q_o = \exp. \{ -2L(\frac{1}{2}\pi)^{1/3} \cdot (ADt/kT)^{2/3} \}$$

where Q_0 and Q_t are the values of the maximum of the internal friction peaks minus the background at the beginning of aging and after an aging time t respectively, L is the unknown dislocation density, A is the parameter in the relation: $U = Af(r, \phi)$ which describes the interaction energy between a dislocation and an interstitial atom as a function of the position of the atom, D is the diffusion coefficient at the absolute temperature T , K the Boltzmann's constant.

Using this equation and the above mentioned values (8) we have calculated from the curves in fig. 4 a dislocation density of about $7 \cdot 10^{11}$ and $4 \cdot 10^{11}$ lines cm^{-2} for the 29 and 31.5 pct Ni alloys respectively.

This value is somewhat higher than found in electrontransmission observations(13,14). It is however known that the dislocation density determined by thin film electronmicroscopy is lower than those measured by other methods (15,16).

A further investigation of this problem is being carried out. The results will be published in due course.

Conclusions

In martensite Fe-Ni-C alloys with 0.05 wt.pct C and 25; 29 and 31.5 wt.pct Ni a Snoek-peak has been found. The peak disappears with time but can be measured again after tempering (25 wt.pct) or deformation (29; 31.5 wt.pct).

The disappearance could be due to the diffusion of the interstitial C atoms toward dislocations by which they are locked.

The decrease of the peak height with time might provide a means to estimate the dislocation density.

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