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CHARACTERISTIC INTERNAL FRICTION SPECTRUM OF GREY CAST IRON

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Abstract.- The low temperature internal friction spectrum in grey cast iron is the same as in pure graphite. This fact tends to show that the graphite precipitates are responsible for the damping capacity of grey cast iron. As the hardening properties are due to the matrix, it is possible to obtain grey cast iron samples, which present together good mechanical properties and a good damping capacity.

The study of the internal friction spectrum shows that it is composed of two or three peaks and that its evolution is mainly due to a phase transformation of graphite between 200 and 270K.

1. Introduction.- Grey cast iron is often used in engineering because of its high damping capacity. Usually this advantage is associated with bad mechanical properties [1,2]. But, when the internal friction mechanisms are independent of the hardening phenomena, it is possible to search for a microstructure which presents together good mechanical properties and a high damping capacity.

The damping at room temperature is bound with the evolution of the low temperature internal friction spectrum. Therefore internal friction measurements have been performed from 80K to 350K on three types of grey cast iron defined by three different microstructural states: two types of lamellar graphite precipitates and one spheroidal type (fig.1).

Fig. 1: Characteristic microstructures (magn. 60x) of:
a) industrial lamellar 25 grey cast iron (perlitic matrix) 
b) industrial spheroidal 40 grey cast iron (ferritic matrix) 
c) experimental grey cast iron with a perlitic matrix containing orientated graphite precipitates.
Thus grey cast iron can be considered as a two-phase material: the matrix (perlitic or ferritic) and the graphite precipitates.

The purpose of the measurements is to put in evidence the contribution of each phase on the damping capacity of grey cast iron and to search for the origin of the internal friction mechanisms.

2. Experimental results.- Internal friction measurements have been performed in an inverted torsion pendulum [3]. The samples were machined wires of 2 mm in diameter and 100 mm in length.

The results obtained during heating at a 2K/mn rate and with a vibrational amplitude of 10^-5 are presented on figure 2 (a, b, c).

![Diagram A](image1)

**a)**

![Diagram B](image2)

**b)**

![Diagram C](image3)

**c)**

![Diagram D](image4)

**d)**

Fig. 2: Internal friction spectra (a, b, c) of the three different grey cast irons defined on figure 1 and their associated tensile test curves (d).

Let us consider the room temperature internal friction values and the tensile test curves (fig.2d) associated with the three microstructures defined on figure 1. Classical are the results presented by the lamellar 25 and the spheroidal 40 grey cast iron: high damping in lamellar 25 grey cast iron is bound with bad mechanical properties (fig.2d).
Remarkable is the behaviour of the grey cast iron with orientated lamellar graphite which presents together a higher damping capacity than the 25 grey cast iron, and mechanical properties which can be compared with the spheroidal cast iron ones.

Thus in grey cast iron, internal friction mechanisms are independent of hardening phenomena. It is then possible to obtain new microstructures which offer together a good mechanical resistance and a high damping capacity.

The damping capacity is related to a characteristic internal friction spectrum made of three peaks: $P_1, P_2$ and $P_3$ (fig.2). $P_1$ appears at $\approx 120K$, $P_2$ at $\approx 230K$ and $P_3$ at $\approx 300K$, only in the orientated structures (fig.2c).

Measurements have shown that the nature of the matrix (perlitic or ferritic) does not change this spectrum. Therefore the origins of the damping in grey cast iron have been searched in the graphite precipitates.

For this reason, internal friction has been measured in two types of graphite samples: pure nuclear graphite (99.999%) and extruded graphite (pencil) (fig.3).

The internal friction spectrum of nuclear graphite is the same as the 25 grey cast iron one, and the spectrum in extruded graphite is found identically in the orientated cast iron. This proves that the graphite precipitates are responsible for the damping in grey cast iron.

The peaks $P_1$ and $P_2$ can be due to intrinsic properties of graphite. $P_3$ peak appears only in particular cases like extruded graphite or orientated cast iron.

In order to analyse the characteristics of $P_1$ and $P_2$, measurements have been performed at different vibrational amplitudes, different frequencies and different heating rates.

The internal friction spectrum is not affected by vibrational amplitudes up to a value of $c = 5 \cdot 10^{-6}$.

Above this amplitude of deformation, the internal friction background increases and finally the peaks disappear. This behaviour confirms the results obtained in
graphite by other authors (4,5).

In the frequency range of the present measurements (1.5 to 3 Hz), the position of the peaks is weakly influenced (fig.4). In the case of P₁, it is difficult to determine the peak temperature because of its large broadening factor. After substraction of the background under P₂, it is possible to determine a shift of P₂ as a function of frequency. P₂ can be a relaxation peak. Its activation energy would be of ∼0.5 eV which gives a broadening factor of ∼1.8. The internal friction background under P₂ increases as a function of temperature till it reaches an equilibrium value at ∼270K.

In addition, internal friction is very sensitive to the heating rate (fig.5): it increases with the heating rate. The equilibrium values (T=0) for internal friction can be obtained by isotherm annealings at different temperatures (fig.6). When the heating has been stopped, internal friction decreases as a function of time. After about 30 minutes, the equilibrium seems to be reached. When the heating is set up again, internal friction increases till it reaches the precedent curve (T ≠ 0). Such a behaviour is the
same as this one observed in diffusionless phase transformations \(^{(6,7)}\).

On the other hand the electrical resistivity of graphite, which varies linearly in the logarithmic plot as a function of the inverted temperature, presents a change of slope at \(\sim 270K\) (fig.7). This fact argues for a phase transformation in graphite in the temperature range of \(P_2\) peak.

In another way, graphite can present two equilibrium structures: hexagonal and rhombohedral \(^{(4,8)}\). At room temperature, the rhombohedral phase could be induced by the applied stresses.

Now, the rhombohedral phase having a lower symmetry than the hexagonal one, it can be an equilibrium structure at low temperature. The internal friction gives an account for such a phase transformation by the evolution of the background from a low value at low temperatures to a high value at \(\sim 270K\), and by a relaxation peak \(P_2\) superimposed, which could be associated with the interfaces motions. Moreover, the higher value of internal friction in the high temperature phase can be due to an increase of the areas of relaxing interfaces or to an increase of the dislocations mobility in the graphite.

\(P_1\) peak can give an account for the dislocations mobility in the rhombohedral phase (Bordoni relaxation). It is bad defined while its broadening factor is great.

\(P_3\) peak seems to be connected with "coherency" parameters of the graphite precipitates. It seems to be associated with good mechanical properties of grey cast iron.

3. Conclusions.- The internal friction of grey cast iron has been measured. The results show that the low temperature spectrum is made of three peaks \(P_1, P_2, P_3\) which appear at \(\sim 120K, \sim 230K\) and \(\sim 300K\) respectively, and of an abrupt increase of the background between \(\sim 200K\) and \(\sim 270K\).

Pure graphite exhibits the same characteristic internal friction spectrum. Except \(P_3\), which could have to do with the precipitates morphology, this spectrum has to be related to intrinsic properties of graphite precipitates in cast iron. It is then concluded that the graphite precipitates are responsible for the high damping capacity of grey cast iron.

The abrupt increase of the background can be connected with a phase transformation of graphite (rhombohedral to hexagonal). Thus the high damping at room temperature would be due to a higher mobility of dislocations in hexagonal structure than in rhombohedral or to the increase of mobile interfaces in graphite.

Relaxation mechanisms at the rhombohedral-hexagonal interfaces could give rise to the relaxation peak \(P_2\), which appears during the phase transformation.

Finally \(P_1\) can be due to intrinsic properties of dislocations in the rhombohedral phase.
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