HIGH DAMPING IN GREY CAST IRON

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HIGH DAMPING IN GREY CAST IRON

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Résumé : Le frottement intérieur des fontes grises est dû au mouvement des dislocations dans la phase graphite et aux interactions de celles-ci avec les impuretés intercalaires. Le développement de fontes grises à forte capacité d'amortissement requiert alors des structures à graphite lamellaire éventuellement dopé en impuretés intercalaires.

Abstract : Internal friction in grey cast iron is due to the movement of the dislocations in the graphite phase and to their interactions with the intercalated impurities. The development of grey cast iron which exhibits a high damping capacity, requires then lamellar graphite phase possibly doped with intercalated impurities.

I. INTRODUCTION

Grey cast iron can be considered as a two phase material composed of a matrix containing graphite precipitates. In order to put in evidence the contribution of each phase to the damping capacity and to the mechanical properties, internal friction measurements had been performed on numerous specimen of grey cast iron differing from one another in the morphology of the graphite precipitates [1, 2, 3].

The obtained results have shown that grey cast iron exhibits a typical internal friction spectrum (fig. 1) and that this spectrum presents the same characteristics as the one observed in pure graphite. It has been then concluded that the damping capacity of grey cast iron is due to internal friction mechanisms which take place in the graphite precipitates.

In addition, the nature of the matrix (perlitic or ferritic) doesn't alter the internal friction but has a sensitive influence on the value of the elastic modulus [4]. It is then possible to optimize the morphology of the two phases in order to develop new types of grey cast iron, which present simultaneously a high damping capacity and good mechanical properties [2].

The fundamental parameters which must be taken into account for this optimization, can be obtained from internal friction measurements in graphite. The aim of the present paper is to present these mechanisms.

II. INTERNAL FRICTION SPECTRUM

The main characteristic of the internal friction spectrum of grey cast iron (or of graphite) is a rapid increase of the internal friction between 180 K and 250 K (fig. 1). At higher temperatures the internal friction is nearly constant. In addition one can observe an anomalous change of slope (at ~ 180 K) in the decrease of the vibrational frequency.

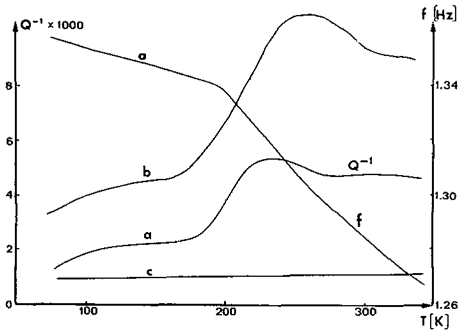

Fig. 1: Internal friction spectrum of:
a) grey cast iron
b) graphite
c) white iron

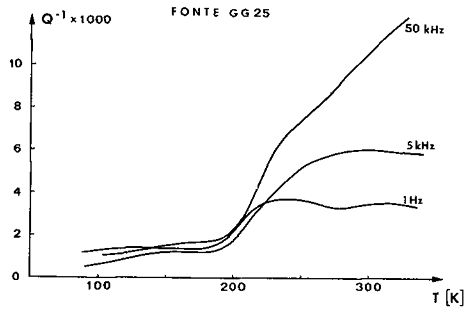

Fig. 2: Internal friction of grey cast iron measured in three frequency ranges: 1 Hz, 5 kHz, 50 kHz.

Measurements have been performed at different frequencies (1 Hz, 5 kHz, 50 kHz) (fig. 2). As no shift in temperature of the curves is observed, the internal friction increase is not due to an anelastic relaxation mechanism, but is rather bound to a transformation of graphite at ~ 200 K. Moreover, it has been shown [3] that, in the low frequency range, internal friction of grey cast iron is very sensitive to the heating or cooling rates. This behaviour is similar to the one observed in the case of the phase transitions [5].

But, on the other hand, electrical restistivity, calorimetry and X-rays measurements have not revealed any phase transformation of graphite in this temperature range [6].

Graphite presents long dislocations loops on the basal planes of the hexagonal structure [7]. By means of tensile tests performed in a transmission electron microscope, it has been possible to put in evidence that these dislocations are mobile at room temperature and immobile at ~ 100 K. This behaviour can give an account for the increase of the internal friction between 180 and 250 K. At these temperatures, a modification of graphite could act on the mobility of the dislocations.

III. MODEL

Internal friction of grey cast iron is assumed to be due to the movements of the dislocations on the basal planes of the graphite precipitates. In the low frequency range, the internal friction doesn't depend on the frequency giving an account for movements of hysteretic type [6].

For this reason, a supplementary force Fr, due to a solid friction, is introduced in the classical equation of the motion of the dislocation:

$$B\dot{u} + Fr\frac{\dot{u}}{|\dot{u}|} + Ku = \sigma b \qquad (1)$$

where the other terms are classical: u = mean displacement of the dislocation, $B\dot{u}$ = viscous force, Ku = restoring force, σb = applied force.

Equation (1), which presents a discontinuity at $\dot{u} = 0$, can be solved approximately by using the complex formulation.

The following expressions are derived for the internal friction Q^{-1} and the modulus defect $\Delta E/E$:

$$Q^{-1} = \frac{\Lambda\, b^2}{K^2 J_u}\,(H + \omega B)$$

$$\frac{\Delta E}{E} = \frac{\Lambda\, b^2}{K\, J_u} \qquad (2)$$

with Λ = dislocations density, b = Burgers vector, J_u = unrelaxed compliance, H = Fr/u_0 (u_0 = vibration amplitude of the dislocation).

Expressions (2) can give an account for the results obtained at 300 K at different frequencies (fig. 3). In the low frequency range, $\omega B \ll H$, the internal friction is frequency independent. At high frequency, $\omega B \gg H$, an increase of the internal friction with the frequency is observed.

Using equations (2), the simultaneous evolution of Q^{-1} and $\Delta E/E$ at ~ 180 K (fig. 1) can only be explained by a drop of the restoring force Ku. In the string model, the diminution of K can be due either to a decrease of the dislocation line tension γ or to an increase of the mean dislocations loops length l ($K = 12\ \gamma/l^2$).

In this latter case, it can be assumed that the dislocations are pinned by impurities at low temperature and l is consequently small. The increase of the internal friction and the decrease of the elastic modulus at ~ 180 K are due to the breakaway of the dislocations from their pinning points giving rise to an increase of l.

In order to check this model, some specimen of graphite have been doped with intercalated impurities, as for example H_2SO_4 molecules.

The obtained results are conclusive (fig. 4, curves 1 and 2): the intercalation of impurities in graphite increases the amplitude of the variation of the internal friction between 180 and 250 K.

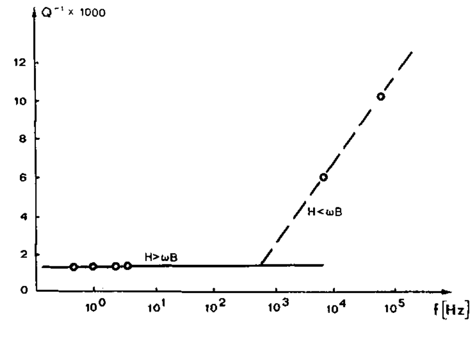

Fig. 3: Internal friction of grey cast iron as a function of the frequency.

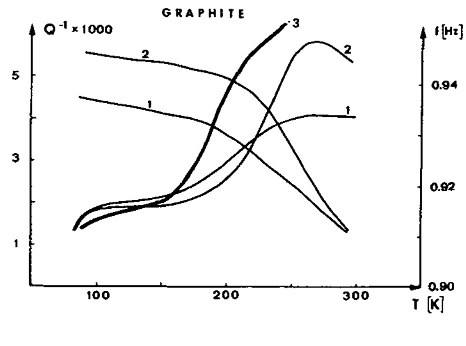

Fig. 4: Modifications of the internal friction of graphite (1) by intercalation of H_2SO_4 (2) and NHO_3 (3) molecules.

At low temperature, the elastic modulus is increased by the intercalated impurities; which, on the other hand, certainly pin the dislocations.

As a function of temperature, the distance c between the basal planes of graphite increases. At ~ 180 K, this distance is great enough to allow the breakaway of the dislocations from the intercalated impurities. At room temperature, the dislocations can move but they feel the effects of the impurities as a solid friction force. In expression (2), H is then certainly a function of the concentration of these impurities.

The critical temperature of breakaway depends on the size of the intercalated molecules. Effectively, same specimens have been doped with HNO_3 molecules, the size of which is smaller than that of H_2SO_4 molecules [8]. In accordance with our interpretation, the critical temperature of breakaway is lower (fig. 4, curve 3).

IV. CONCLUSIONS

Internal friction of grey cast iron is due to the movements of the dislocations in the graphite phase. Two parameters play an important role for the damping capacity: the length l of the dislocations loops and the friction coefficient H.

Long dislocations loops are favoured by great lamellar graphite precipitates. Naturally, the size of these lamellae must be optimized so that the increase of damping doesn't give rise to a great decrease of the mechanical resistance.

The friction coefficient H depends certainly on the nature and concentration of the intercalated impurities in graphite. Graphite of high purity exhibits a low level internal friction.

Finally, it can be shown that depending on the orientation of the lamellae of graphite, the damping capacity of grey cast iron can be included between 5 to 70 % of the internal friction level of graphite.

ACKNOWLEDGMENTS

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