JOURNAL DE PHYSIQUE

Colloque C9, supplément au n°12, Tome 44, décembre 1983 page C9-111

INTERNAL FRICTION AND ELASTIC MODULUS OF AN AMORPHOUS Fe-Ni-Si-B ALLOY

Xia Wurong, Wang Zixiao, Zhou Rusong and Shui Jiapeng*

Department of Physics, Wuhan University, Wuhan, China
**Institute of Metal Research, Academia Sinica, Shenyang, China*

Résumé - Cet artice présente les résultats obtenus dans la mesure du frottement interne en basse fréquence, et du module de cisaillement associés au processus de la relaxation de structure et au processus de cristallisation dans l'alliage amorphe (Fe0.6Ni0.4)82Si8B10. Un pic de frottement interne isothermique et un pic de frottement interne stable ont été observes pour la première fois dans un alliage métallique amorphe.

Abstract - The present work reports the results of low frequency internal friction and shear modulus measurements associated with the structural relaxation and crystallization process in amophous (Fe0.6Si0.4)82Si8B10 alloy. An isothermal internal friction peak and a stable internal friction peak are for the first time reported in amorphous metallic alloys.

I. INTRODUCTION

The internal friction of solids is known to be highly structure-sensitive. In the case of crystalline metals, the study of the internal friction has yielded a great many valuable informations, for example, the mobility of atoms and point defects, the grain boundary behaviours, the behaviour of dislocations, phase trandformations,etc.. But there have been only a few reports on the study of low-frequency internal friction in amorphous alloys. Soshiroda et al./1/, Hausch et al./2/ and Mo Chimei et al./3/ have studied the low-frequency interanl friction of amorphous alloys Fe80P13C7, Fe50Ni33P12C5 /1/, Fe32Ni36Cr14P12B6 /2/, Pd80Si20 /1.3/. Two (or one) internal friction peaks are observed. but the micrscopic mechanisms have not been understood. The present work reports the results of low-frequency internal friction and shear modulus ($\propto f^2$) measurements associated with the sturctural relaxation and crystallization process in amorphous (Fe0.6Ni0.4)82Si8B10 alloy. Two internal friction peaks, sensitive to the heating rate of the specimens and each having a corresponding sharp frequency minimum, are observed. An isothermal internal friction peak during the isothermal crystallization transition and a stable internal friction peak, independent of the heating rate, are also found. These two internal friction peaks are for the first time reported in amorphous alloys.

II. EXPERIMENTAL

The amorphous alloy (Fe0.6Ni0.4)82Si8B10 was obtained in the ribbon form of cross-section approximately 0.5 × 0.005 cm.. The size of the specimens is about 3×0.5×0.005 cm.. A conventional torsional pendulum, of which the total tension load on the specimen is about 0.8Kgf/mm , is used for the measurements of the internal friction and modulus ($\propto f^2$).

The frequency of measurement is in the range of 0.2-1.0 Hz.

III. RESULTS AND DISCUSSION

1) The temperature dependence of internal friction and shear modulus ($\propto f^2$) are measured as shown in Fig.1. The values of internal friction and frequency remain constant approximately from room temperature to a higher one which depends on the pre-annealing treatment, and then rise exponentially with temperature. This means that the microscopic structural relaxation occurs at temperatures well below the crystallization temperature, even though it can not be detected by X-ray diffraction techique,

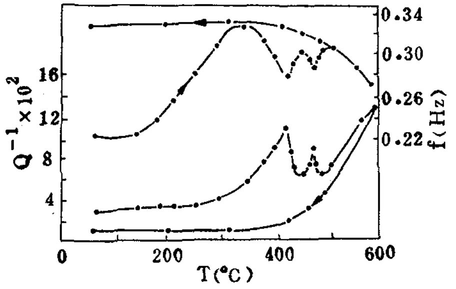

Fig.1 The internal frictiin and vibrational frequency (heating rate: 5°C/min.)

It is of interest to note that during the exponential rise of internal friction with temperature, the shear modulus increases with temperature too. This suggestes that there is an increase in the short range order of atomic arrangement or some kinds of micro-domain or cluster in the amorphous matrix may have been formed, which are supposed to be the pioneer of crystallization.

2) There exist two internal friction peaks, each associates with a corresponding sharp frequency minimum, one at~435°C, and the other at ~490°C, which are found to be almost independent of the frequency of measurement, but sensitive to the heating rate of the specimens. Two exothermic peaks in differential thermal analysis are also observed at temperatures close to that of the respective internal friction peak. By comparing with the result obtained from X-ray diffraction study, a conclusion may be drawn that these two internal friction peaks are associated with diffusion- controlled irreversible transitions from the amorphous phase to a metastable and a stable phase respectively. These transitions may be achieved through cooperative atomic displacement, hence a phonon mode softening accompanics the occurence of each of the intermal friction peaks.

3) As shown in Fig.2, an internal friction peak is also observed during

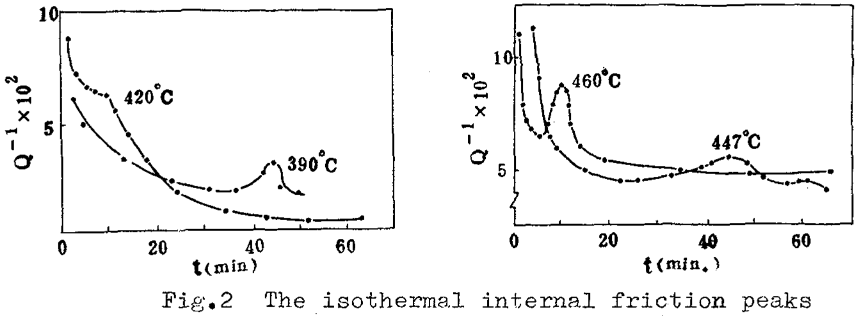

Fig.2 The isothermal internal friction peaks

the isothermal crystallization process in the temperature range lower than that of the internal friction peaks observed previously. After the completion of this isothermal internal friction peak, the original two peaks disappear during the subsequent measurements on reheating.

4) A linear variation of the height of the 435°C peak as a function of $\dot{T}/f$ is observed; for heating rate $\dot{T}=0$ (extrapolated), the peak height does not go to zero, but to a constant value (Fig.3). In order to verify this behaviour in a different way, the following experiment is done. At different temperatures during continuous heating, the temperature is kept constant for 30~120min. and the variation of internal friction and of modulus are measured during this isothermal annealing. Q^{-1} decreases and f increases until a constant value is approached. This means that Q^{-1} (f also) consists of two parts, one dependent on $\dot{T}$ and the other, independent on $\dot{T}$, of which we call the latter stable internal friction. The curve of the temperature dependence of the stable internal friction also exhibits a peak (Fig.4) which may be called the stable internal friction peak.

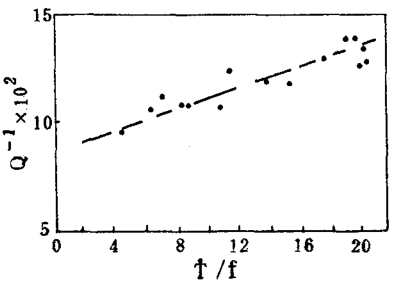

Fig.3 The heights of 435°C peak versus $\dot{T}/f$

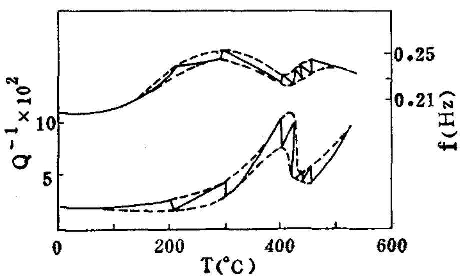

Fig.4 The stable internal friction

From the results mentioned above, it can be seen that both in the structural relaxation process and in the crystallization process, the internal friction may be divided into two parts, one is the stable internal friction, independent of $\dot{T}$ and the other, associated with temperature changes, dependent of $\dot{T}$. These two parts of internal friction should be attributed to different mechanisms, which are being studied.

5) There are some similiarities between the above experimental results and the behaviour of the low-frequency internal friction in martensitic phase transformation of crystalline NiTi and AuCd alloys /4,5/. It appears that the mechanism of internal friction peak may be explained by the De-Jonghe-Delorme's model /6/ in martensitic phase transformation tentatively. According to Delorme's Model

$$Q^{-1} \propto \frac{1}{\omega}\frac{dV}{dT}\frac{dT}{dt} \propto \frac{\dot{T}}{f}$$

where ω is the angular frequency and V is the amount of transformed material. The above approximation indicates that there is a linear relationship between the height of internal friction peak and $\dot{T}$. In addition to temperature the torsional stress σ as well can induce the transformation of amorphous phase to crystalline phase, that is

$$\frac{dV}{dt} = \frac{\partial V}{\partial T}\frac{\partial T}{\partial t} + \frac{\partial V}{\partial \sigma}\frac{\partial \sigma}{\partial t}$$

or

$$Q^{-1} \propto \frac{1}{\omega} \left(\frac{\partial V}{\partial T} \frac{\partial T}{\partial t} + \frac{\partial V}{\partial \sigma} \frac{\partial \sigma}{\partial t} \right)$$

It can explain not only the linear relationship between Q^{-1} and $\dot{T}/f$ in the measurement during temperature change, but also the fact that the stable internal friction exists and the damping should be proportional to the amount of material transformed per cycle. The mechanism of this internal friction peak is due to the motion of coherent boundary, hence, the magnitude of internal friction should be related to the amount of coherent boundary existing in the sample. According to the classic nucleation and growth mechanism or the spinodal decomposition mechanism of crystallization in amorphous alloys, such coherent boundaries must exist. Once the temperature rises to a much higher level, the elastic stress induced by the growth of crystalline phase will break the coherent boundary, the internal friction due to this mechanism must disappear duly, so that, after heating to ~550°C, the two original internal friction peak do not appear again.

6) As shown in Fig.5 and Fig.6, the structural relaxation and crystallization processes are both affected by the pre-annealing treatment. This shows that the internal friction in amorphous alloys is associated with the thermal history of the specimen.

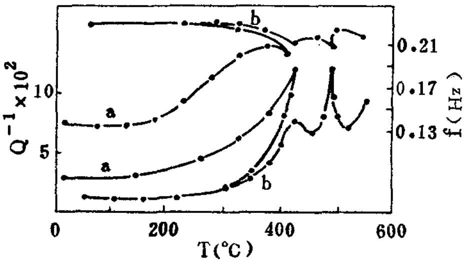

Fig.5 The effect of pre-annealing treatment upto 425°C on crystallization
a - as-quenched state
b - reheating

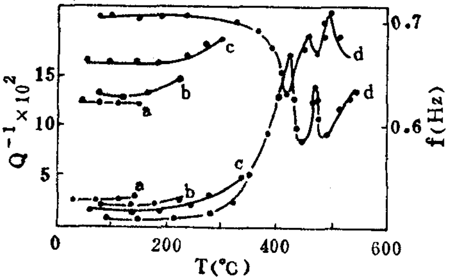

Fig.6 The effect of pre-annealing treatment on structural relaxation
a - as quenched state
b - after run a
c - after run b
d - after run c

References

1/ T. Sochiroda, M.Koiwa and T. Masumto, J.Non-Crystalline Solids 22 (1976)173

2/ G.Hausch and E. Torok, Internal Friction and Untrasonic Attenuation, Univ. Tokyo Press, P.269, 1977

3/ Mo Chimei, Shui Jiapeng and He Yizhen, ICIFUAS-7, J. de Physique 42 (1981) C5-523

4/ O.Mercier, K.V.Melton and Y.De Preville, Acta Met. 22(1979)1467

5/ Wang Yening, Chou Yifeng and Chang Zhifang, Acta Physica Sinica 29(1980) 1535

6/ W.De Jonghe, R.De Batist and L.Delaey, Scripta Metall. 10(1976) 1125