

# The internal friction peaks correlated to the relaxation of atomic defects in Fe<sub>47</sub>Al<sub>53</sub> alloy

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## Abstract

The internal friction behavior of a Fe<sub>47</sub>Al<sub>53</sub> alloy was examined to understand the evolution of the atomic defects. It is found that the internal friction peak observed at around 410 °C is in fact composed of two relaxational peaks (P1 and P2) that shifted toward high temperature with increasing frequencies. The P1 peak originates from the stress-induced migration of Al antisite atoms between the vacancies while the P2 peak originates from the dissociation of the interstitial carbon atoms from the C–V complexes and subsequent diffusion.

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## 1. Introduction

Iron aluminides with B2 structure have been recognized as a promising candidate in high-temperature environments due to their excellent oxidation and corrosion resistance, good high-temperature mechanical properties, light weight and low material cost. It is well known that the mechanical properties of Fe–Al alloys are closely related to the type and concentration of atomic defects and thus understanding the motion and evolution of the atomic defects is extremely important for engineering applications [1]. Several techniques have been used to study the atomic defects in Fe–Al alloys such as electrical resistivity, positron annihilation, internal friction (IF), etc., in which IF has been proved to be a particularly sensitive one to defects in atomic scale [2]. Five IF peaks have been observed and the operative mechanisms have been well documented [2]. They are as follows: (1) the dislocation-related relaxation IF peak with an average activation energy of about 0.5 eV appearing at a temperature range of –70 °C to –25 °C; (2) the Snoek peak due to the diffusion of interstitial carbon (C) atoms with the activation energy

ranging from 0.8 to 1.3 eV depending on the Al content; (3) the peak that is correlated to the vacancies and C atoms that only appear in alloys with an Al content (at%) of over 25; (4) the Zener peak caused by the stress-induced reorientation of Al atom pairs with the activation energy in the range of 2.2–2.9 eV and (5) the grain boundary relaxation peak. It has been found that the Al content significantly influences the IF behavior of Fe–Al alloys. With increasing Al content, the Snoek peak shifts to high temperatures and becomes broad as a result of C–Al long-range ‘elastic’ interaction [2,3], while the IF peak that is correlated to the vacancies and C atoms is elevated due to the increase in the vacancy concentration [3,4]. In the alloys with relatively high Al contents such as more than 25 at%, ordering significantly suppresses the Zener relaxation [2,5], and the Zener peak is impossible appearing in completely ordered structures [6]. Golovin et al. [7,8] have recently given the different activation energies for the Zener relaxation in A2, D0<sub>3</sub> and B2 phases of Fe–22Al and Fe–26Al alloys through isothermal mechanical spectroscopy technique, and the influence of Si additions on the Zener relaxation and ordering of Fe–20Al and Fe–5Al alloys, which will be helpful for characterizing the atomic defects in Fe–Al alloys.

Among the above IF peaks, the one correlated to the vacancies and C atoms may be the most attracting but frequently

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disputed. For example, Schaefer et al. [9,10] observed the peak with an activation energy of 1.8 eV at about 410 °C in Fe-rich B2 Fe–Al alloys. They attributed the presence of the IF peak to the reorientation of “Fe<sub>Al</sub>–V<sub>Fe</sub>” pairs [9], but later to the reorientation of divacancies composed of two neighboring V<sub>Fe</sub> [10], where Fe<sub>Al</sub> and V<sub>Fe</sub> represent Fe antisite atoms and vacancies on the Fe sublattices, respectively. However, Golovin et al. [11,12] found the peak in Fe<sub>3</sub>Al alloys and suggested that it resulted from the “diffusion under stress” of interstitial C atoms in the vicinity of the vacancies after a series of detailed tests.

Based on the importance of the atom defects in Fe–Al alloys and disputed results, the present study is aimed to give some evidence for better understanding the evolution of the atom defects in the Fe–Al alloys through IF measurements. The results and the analysis are expected to be useful for the development and applications of the Fe–Al alloys.

**2. Experimental procedure**

Fe–Al alloys with Al contents (at%) of 43 and 53 were prepared using commercially pure Fe (99.9 wt%) and Al (99.8 wt%) in a vacuum induction furnace, and the C contents (at%) of the resultant specimens were about 0.006 and 0.005, respectively. To ensure the identity in the chemical composition and the solidified structures, all the specimens used in the IF measurements were cut from the same ingot using an electric spark machine into a dimension of 70 × 1.7 × 0.7 mm<sup>3</sup>. In order to obtain varied microstructures and defect configurations, the specimens were heat treated at different temperatures ranging from 700 °C to 1000 °C for 1 h in an argon atmosphere, followed by either furnace-cooling with a cooling rate of 1 °C/min, air-cooling, or oil-cooling. Noting that the specimens will probably bend after water-cooling due to their very small dimension, the procedure of “water-cooling” was not applied in the present study. In addition, the partial specimens treated by air-cooling from 900 °C were aged at 400 °C from 2.5 h to 24 h to examine the effect of ageing on the behavior of the defects.

A computer-controlled automatic inverted torsion pendulum was used to measure the IF ( $Q^{-1}$ ) of the specimens by either free decay or by forced vibration with a strain amplitude of  $2 \times 10^{-5}$ . The effect of heating/cooling rate in the measurements on the IF behavior of the Fe–Al alloys was not discussed in the present study and to keep consistency of the IF results, the rate of 6 °C/min was chosen. The frequencies shown in the figures are resonance frequencies at temperatures corresponding to the presence of IF peaks in free decay measurements. The detailed description of the IF apparatus can be found in Ref. [13].

**3. Results and discussion**

*3.1. The typical IF behavior of the alloys*

Figs. 1–3 show the IF and the relative dynamic modulus (RDM) of the Fe<sub>47</sub>Al<sub>53</sub> alloy with different thermal histories

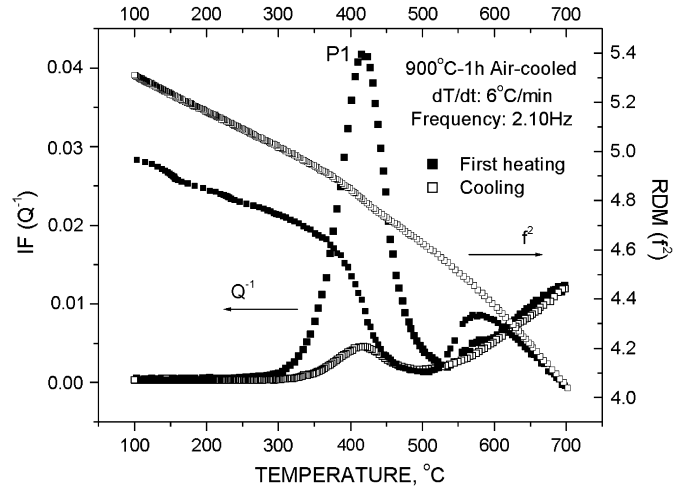


Fig. 1. IF and RDM as functions of temperature in a heating and cooling cycle for the air-cooled Fe<sub>47</sub>Al<sub>53</sub> alloy (by free decay).

as functions of temperature in a heating and cooling cycle, where the RDM is proportional to the second power of frequency. For the rapidly cooled specimens such as oil-cooled and air-cooled ones, there appeared an IF peak (termed as P1) in the heating processes at around 410 °C but it significantly decayed during the subsequent cooling measurements. Corresponding to the presence of the peak, the RDM showed a rapid drop with increasing temperatures and it became relatively smooth during the subsequent cooling measurements. It is noted that a minimum in the RDM can be seen at about 500 °C during heating, which is probably correlated to a process of increasing the degree of order since the exact degree of order decreases with increasing temperature in B2 Fe–Al alloys [14,15]. Moreover, the so-called Kronig–Kramers’ relation also contributes to the change in the RDM [16,17]. The similar effect of the RDM during the IF measurement has been discussed in Refs. [3,16] and it will not be discussed in the present study. In comparison to Figs. 1 and 2, it is seen that the two cooling modes do not show any obvious

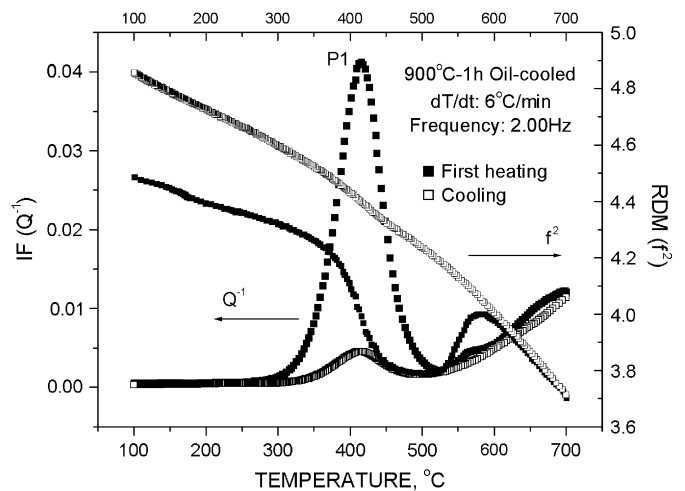


Fig. 2. IF and RDM as functions of temperature in a heating and cooling cycle for the oil-cooled Fe<sub>47</sub>Al<sub>53</sub> alloy (by free decay).

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