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Microstructures and damping properties in Ni-Al-based alloys

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Abstract: The binary Ni-rich $Ni_{64}Al_{36}$ (nominal compositions, all compositions are in atomic percent unless otherwise stated,) alloy and ternary Ni-21.2 Al-20 Fe alloy ingot were prepared by melting commercial pure Ni and pure Al in a vacuum arc furnace under an argon atmosphere. The ingots were then hot rolled into a rectangle with the length of 55 mm. The microstructures of Ni-Al-based alloys were investigated using optical microscope and X-ray diffraction. The damping capacity of oil-quenched ternary Ni-21.2 Al-20 Fe alloy from different temperature is investigated using a multifunctional internal friction apparatus.

Introduction

The Ni-rich part of the Ni-Al system has attracted much scientific interest. On one hand, it can potentially be used as shape memory material. On the other hand, the Ni-rich Ni-Al intermetallic compounds such as Ni_3Al and NiAl can also be used as high temperature structural material [1-2]. The microstructures of Ni-Al alloys exhibit relative complex since the alloys contains many intermetallic phases such as NiAl, Ni_3Al, Ni_2Al, N_5Al_3 and thermoelastic martensite. Therefore, a number of questions have not yet been unambiguously resolved, e.g. the martensitic structural features, the forming mechanisms and conditions of martensite and intermetallic phases.

In this study, optical microscope and XRD experiments are used to observe/detect the microstructures of oil-quenched $Ni_{64}Al_{36}$ alloy and internal friction technique has been used to detect structure changes of oil-quenched Ni-Al alloys during heating. The present study can therefore give a clear physical image of the microstructures for oil-quenched $Ni_{64}Al_{36}$ alloy, adding the understanding for forming mechanism of microstructures in the quenched Ni-Al alloys.

Experimental procedures

The binary Ni-rich $Ni_{64}Al_{36}$ (nominal compositions, all compositions are in atomic percent unless otherwise stated,) alloy and ternary Ni-21.2 Al-20 Fe alloy ingot were prepared by melting commercial pure Ni (3N5) and pure Al (5N5) in a vacuum arc furnace under an argon atmosphere. The ingot was then hot rolled into a rectangle with the length of 55 mm.

The specimens for the internal friction measurements (1.4×2×55 mm^3) and for optical observations (2×5×5 mm^3) were spark cut from the rectangle sample. They are homogenized at 1000°C for 1 hour in argon, and then oil-quenched or furnace-cooled. The internal friction (Q^{-1}) and the relative dynamic modulus (RDM) were measured using a multifunctional internal friction apparatus by forced-vibration methods from room temperature to 400°C. This apparatus consists of a pendulum, a programmable temperature controller and a photoelectron transformer. The whole measurement is controlled using a computer, and the data are processed in real time. The range of the maximum torsional strain amplitude is 10^{-6}–10^{-4}. The resolution of the internal friction is 1×10^{-4}.

The metallorgraphic specimens are usually prepared and etched by a solution of 1 part of ethanol and 1 part of saturated solution of $FeCl_3$ in HCl. In order to detect the microstructures of the specimens with different heat treatments, X-ray diffraction (XRD) experiments were also completed at room temperature.

Results and Discussion

Microstructures of $Ni_{64}Al_{36}$ Alloy. Fig. 1 shows the microstructure from metallorgraphic observation for the oil-quenched $Ni_{64}Al_{36}$ alloy from 1000 °C. Obviously, the specimen contains fine martensite structure. It is known that the Ni-rich Ni-Al with about 62-69 at. %Ni undergoes a diffusionless {110}<110> martensitic shear transformation on rapid-cooling resulting in a multiply twinned tetragonal $L1_0$ structure [3]. The present result is also in good agreement with the phase diagram [4], which can be seen in Fig. 2. However, the furnace-cooled $Ni_{64}Al_{36}$ alloy from 1000 °C

Fig.1 The microstructure of oil-quenched $Ni_{64}Al_{36}$ specimen at 1000°C (1000X)

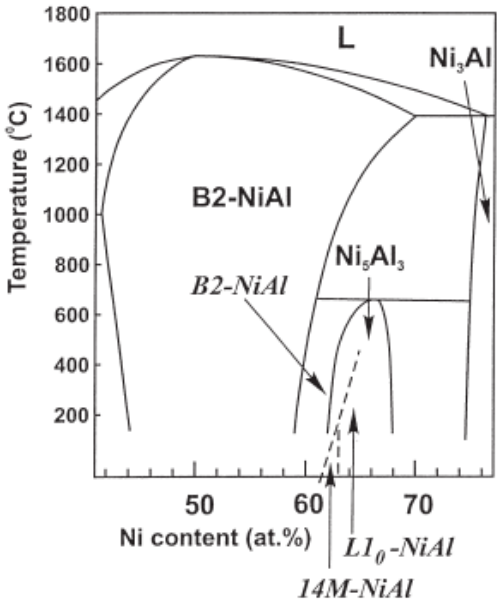

Fig. 2 Ni-rich part of the Ni–Al phase diagram. The $L1_0$ and14M structures form by a martensitic mechanism from the metastable Ni-rich B2 structure. The stable phases are typed in bold and the metastable phases are typed in italic. The dashed line indicates the start temperature Ms for the martensiticB2-$L1_0$ (14M) transformation.

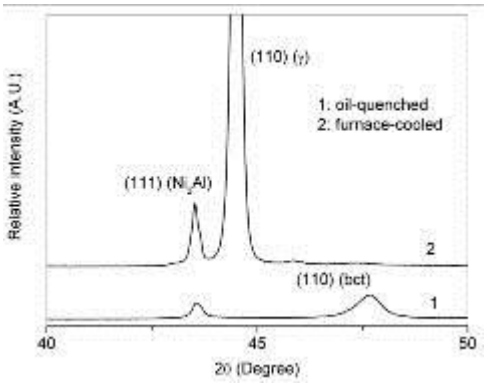

Fig. 3 The X-ray diffraction patterns for the oil-quenched and furnace-cooled $Ni_{64}Al_{36}$ specimens

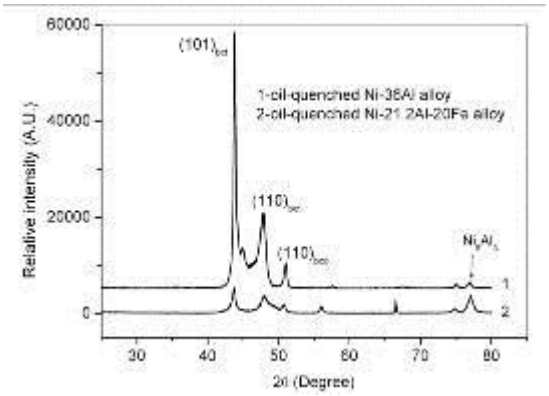

Fig. 4 The XRD results of oil-quenched and Ni-36Al and Ni-21.2Al-20Fe alloy

has different microstructures from oil-quenched alloy. As shown in Fig. 3, the furnace-cooled specimen possesses γ phase (110 peak on No.2 curve) as well as Ni_3A1 phase (111 peak on No.2 curve), and that the oil-quenched specimen possesses $L1_0$ (bct) phase (110 peak on No.1 curve) and a little Ni_3A1 phase. The XRD results are also in accordance with the observed microstructures by using optical microscope for the oil-quenched alloy.

It has been known that Fe can promote the formation of a ductile second phase with fcc structure and can improve bulk properties [2]. Adequate ductile can be obtained when Fe contents are over 14% for the alloys that have been conventionally cast. In fact, Fe addition introduces ductile phase such as γ or Ll_2 (Ni_3Al) into the microstructures of the Ni-Al based alloys [3], which can be confirmed by the results in Fig. 4. It can be seen that the oil-quenched Ni-21.2 Al-20 Fe alloy containing more Fe possesses less martensite compared with the oil-quenched Ni-36Al alloy.

Damping Capacity of Ni-21.2Al-20Fe Alloy. Fig. 5 shows the damping capacity of the oil-quenched Ni-21.2Al-20 Fe alloy from different temperature. It can be seen that the internal friction peak depends on the oil-quenching temperature. It has been reported that the internal friction peak is suggested to be resulted from reverse martensitic transformation of $L1_0 \rightarrow \gamma$ during heating [5-6]. When the oil-quenching temperature is low, the volume of formed $L1_0$ martensite is less and no apparent internal friction peak is produced during heating. Increasing oil-quenching temperature will elevate the $L1_0$ martensitic volume and thereby the internal friction peak is produced for the oil-quenched specimens from 1000°C and 1100°C. Nevertheless, when oil-quenching temperature is 1200 °C, the internal friction peak disappears, which is resulted from the pinning effect of more quenched-vacancies on the martensites [7]. In addition, the internal friction peak-temperature is also shifted to the higher temperature, which is also in agreement with the results in Ref. [7].

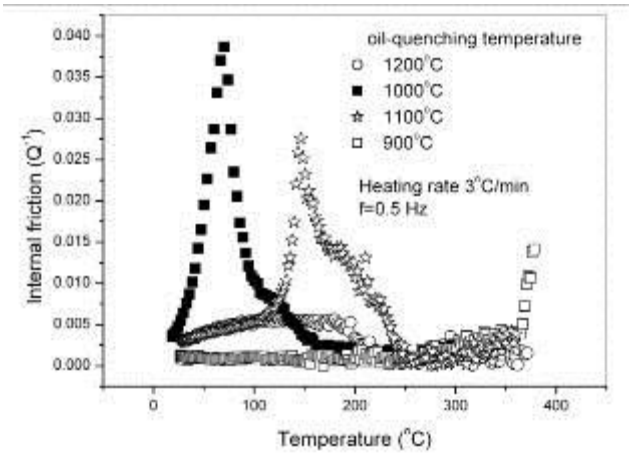

Fig. 5 The internal friction as a function of temperature for the oil-quenched Ni-21.2Al-20Fe alloy form different temperature at 0.5 Hz

Conclusions

Oil-quenched Ni-36Al and Ni-21.2Al-20Fe alloys can form the $L1_0$ martensitic structures. The adding of Fe results in the increase of γ and Ni_5Al_3 phases and the decrease of martensite. The $L1_0$ martensite can be transformted into γ phase during heating and produces an internal friction peak. The oil-quenched Ni-21.2Al-20Fe alloy at higher temperature cannot produce the internal friction peak due to the pinning effect of more quenched-vacancies on the martensites.

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