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ScienceDirect
Trans. Nonferrous Met. Soc. China 19(2009) 1470−1473
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Influence of aging on damping behavior of TiNi/TiNi alloys synthesized by explosive welding

XING Ting-yong(邢廷勇)[1], ZHENG Yan-jun(郑雁军)[2], CUI Li-shan(崔立山)[2], MI Xu-jun(米绪军)[1]

1. State Key Laboratory for Fabrication and Processing of Non-ferrous Metals, General Research Institute for Nonferrous Metals, Beijing 100088, China;
2. Department of Materials Science and Engineering, University of Petroleum, Beijing 102249, China

Received 10 August 2009; accepted 15 September 2009

Abstract: The influence of aging time, measuring frequency and strain amplitude on the internal friction of $TiNi_{51}/TiNi_{50.2}$ sandwich composite was investigated. The DSC and internal friction measurements were employed to characterize the sample. The two internal friction peaks of the specimen were confirmed corresponding to the reverse transformation of $TiNi_{51}$ and $TiNi_{50.2}$ component, respectively. The internal friction as a function of the temperature at different measuring frequencies was presented and it was found that the height of both internal friction peaks increased with decreasing frequency; however, the increase corresponding to $TiNi_{50.2}$ component was larger than that of $TiNi_{51}$ component. Furthermore, the internal friction of the TiNi/TiNi composite alloy decreased with increasing the measuring strain amplitude. The height of internal friction peak of $TiNi_{51}$ component increased with increasing the aging time, whereas that of the $TiNi_{50.2}$ component did not change significantly. The increase in internal friction of $TiNi_{51}$ appeared to be associated with the formation and growth of precipitate during the aging process.

Key words: shape memory alloy; aging; internal friction; explosive welding

1 Introduction

The problem of harmful vibration becomes more and more serious in modern industrial society. Correspondingly, the needs for high damping materials are increasing dramatically. Shape memory alloys have attracted increasing interest as they can be used for passive as well as active damping materials for years. Among shape memory alloys, TiNi-based alloys are confirmed to be the best due to their superior functional properties such as shape memory effect, excellent corrosion resistance and pseudoelasticity. So far, many factors that can influence internal friction and relative modulus have been investigated, such as thermal cycle [1−4], heat treatment[5−7], external parameter and the third element[8−10].

From the application point of view, the broader the internal friction temperature range is, the more promising the industrial application will be. However, the high internal friction of TiNi-based alloys only appears during the forward/reverse martensite transformation, where the massive parent phase/martensite interfaces exist. Thus, the range is so narrow that the application of TiNi-based alloys is strictly limited. To resolve this problem, TiNi/TiNi composite alloy was fabricated with two different composition components by explosive welding. Due to the compositional heterogeneity, the temperature range of internal friction is confirmed to broaden significantly. In this work, the effects of aging time, measuring frequency and strain amplitude on internal friction of TiNi/TiNi composite alloy were investigated by low frequency mechanical relaxation spectrum analyzer.

2 Experimental

$TiNi_{51}$ (TiNi-1) and $TiNi_{50.2}$ (TiNi-2) alloy sheets of 0.7 mm in thickness were obtained from the Generous Research Institute for Nonferrous Metals, China. Fig.1 shows the schematic diagram of the explosive welding process. The parameters of the explosive welding used in this work can be seen in Table 1. After the explosive welding, the sheets were hot rolled at 800 ℃. Specimens

Foundation item: Projects(50871121; 50671120) supported by the National Natural Science Foundation of China
Corresponding author: XING Ting-yong; Tel: +86-10-62055407; E-mail: xingtingyong@gmail.com
DOI: 10.1016/S1003-6326(09)60053-4

Table 1 Parameters of explosive welding process

Sample	Dimension	Explosive density/ ($g\cdot cm^{-3}$)	Unit dosage/ ($g\cdot cm^{-2}$)	Correction factor	Explosive thickness/cm
TiNi-1(Flyer plate)	130 mm×110 mm×0.85 mm	0.62	1.44	0.85	2.35
TiNi-2(Base plate)	120 mm×100 mm×0.85 mm	0.62	1.35	0.8	2.2
Q235 steel(Buffer plate)	200 mm×140 mm×3.00 mm	0.62	1.28	0.75	2.08

of 0.8 mm thick, 2 mm wide and 100 mm long were spark cut from the hot-rolled tandems. In succession, specimens were aged in vacuum at 400 and 500 ℃, respectively. The aging times were 20, 40 and 60 min for each temperature, respectively. All aged specimens were cooled in ice water. The damping behavior testing was conducted on a LMR−1 low frequency mechanical relaxation spectrum analyzer. This apparatus consists of an inverted torsion pendulum, a temperature controller, a photoelectron transformer and an industrial computer 610 which controls all measurements and the data can be processed in real time. The internal friction measurements of the specimens were carried out as a function of temperature at a heating rate of 1 ℃/min and frequencies of 0.5, 1 and 2 Hz. All measurements of the internal friction were conducted on the specimens by forced oscillation. Small samples with length of 4 mm were cut from the specimens using a low speed diamond saw. DSC experiments were conducted by using a Netzsch DSC 2004 Phoenix. All specimens were cooled to −20 ℃ prior to DSC and damping test running.

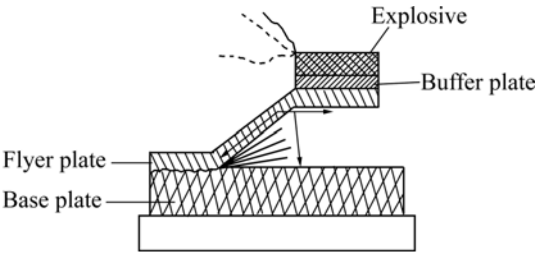

Fig.1 Schematic diagram of explosive welding process

3 Results and discussion

Fig.2 shows the DSC results of the two TiNi alloys before and after the explosive welding without any heat treatment. It can be seen that two perfect endothermic peaks took place during the heating process, which corresponded to the two TiNi components respectively. This indicates that the reverse martensitic transformation of the components was retained very well in the composite alloy after the explosive welding. It is worth noticing that the reverse martensite transformation temperature of TiNi/TiNi composite alloy is about 100 ℃, which is higher than each of the two TiNi components. This feature will surely increase the potential of engineering application in future.

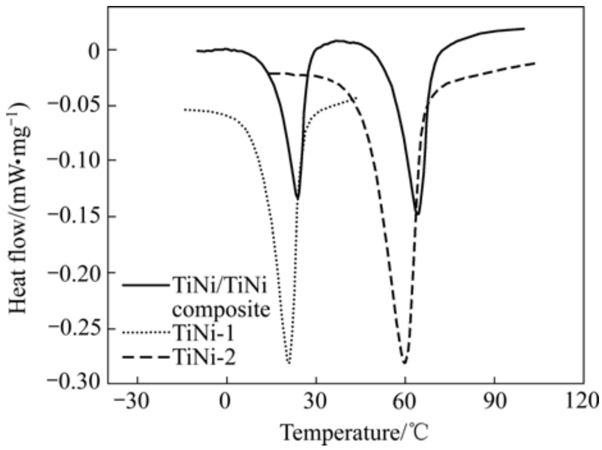

Fig.2 DSC curves of two TiNi alloys before and after explosive welding

Fig.3 exhibits the internal friction of TiNi/TiNi composite alloy aged at 400 ℃ for 20 min as a function of temperature at different measuring frequencies during the heating process. The two internal friction peaks at 15 ℃ and 49 ℃ corresponded to the reverse martensite transformation of TiNi-1 and TiNi-2 alloy, respectively [11]. One can see that the temperatures of the internal friction peaks are independent on the measuring frequency. The height of both internal friction peaks increases with decreasing the measuring frequency. Furthermore, the increase of the internal friction peak of $TiNi_{50.2}$ component was more significant than that of $TiNi_{51}$.

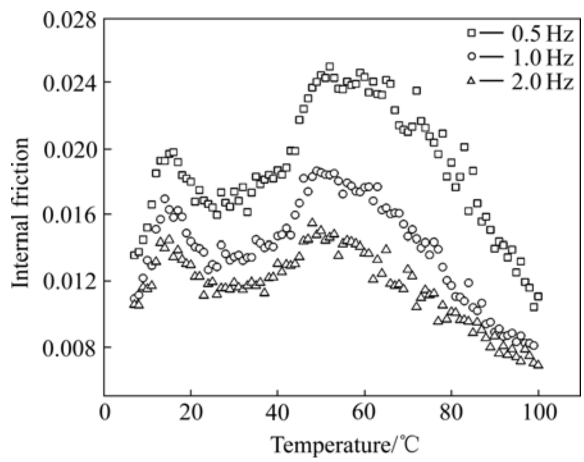

Fig.3 Internal friction curves of TiNi/TiNi composite alloy aged at 400 ℃ for 20 min at different measuring frequencies during heating process

It is known that transformation of internal friction is due to the moving of austenite/martensite coherent interfaces, twin boundaries between martensite variants and mutual merging of martensite variants[12]. As well known, when the measuring frequency decreases, the measuring period will increase. So, the measuring frequency is inversely proportional to the amount of reverse martensite transformation. The further the reverse martensite transformation is, the larger the corresponding internal friction would be.

Fig.4 shows the relative modulus curves of TiNi/TiNi composite alloy aged at 400 ℃ for 20 min at the different measuring frequencies during the heating process. There are two independent peaks in each curve, which corresponded as well to the reverse martensite transformation of TiNi-1 and TiNi-2 alloy, respectively. Contrary to internal friction of composite alloy, the value of relative modulus peaks decreases with decreasing the measuring frequency.

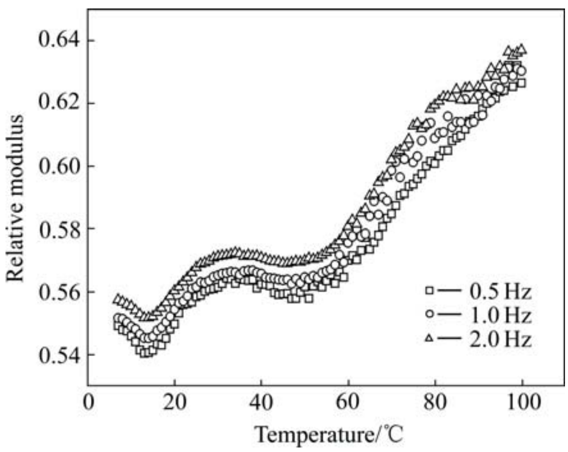

Fig.4 Relative modulus curves of TiNi/TiNi composite alloy aged at 400 ℃ for 20 min at different frequencies during heating process

Fig.5 gives the internal friction curves of TiNi/TiNi composite alloy subjected to different time aging at 400 ℃. It can be seen that the height of the low-temperature internal friction peak (PL) increases with increasing aging time, but that of the high-temperature internal friction peak (HP) is almost unchanged. The same phenomena appeared for the specimens aged at 500 ℃. The results are summarized in Fig.6.

It is well known when Ni content (atomic ratio) of TiNi alloy is more than 50.5%, Ni-rich phase will precipitate during aging treatment. According to some recent studies[13−15], lots of fine and dispersed precipitates in TiNi-1 alloy appear at the beginning of aging treatment. The precipitate keeps coherent with the matrix and forms a quite strong coherent stress field. Combined action of coherent stress field and applied stress field makes the transformation of some local

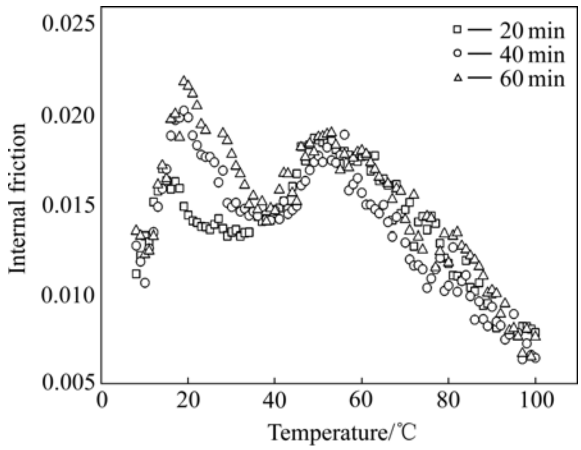

Fig.5 Internal friction curves of TiNi/TiNi composite alloy aged for different time at 400 ℃ during heating process

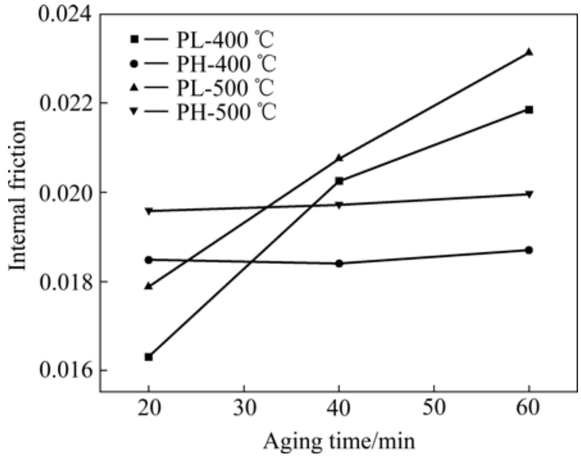

Fig.6 Value of internal friction peaks of TiNi/TiNi composite alloy as function of aging time at different aging temperatures

region easier. So, the low-temperature internal friction peaks, which correspond to TiNi-1 with precipitate, increase with increasing aging time. However, the high-temperature internal friction peaks correspond to TiNi-2 alloy with a Ni content of 50.2%. Thus, no precipitate appears during aging treatment, which results in the absence of coherent stress field. That is why the high-temperature internal friction peak has no obvious change. Furthermore, the location of the low-temperature internal friction peaks shifts towards high temperature with increasing the aging time, as also shown in Fig.5. It is associated with the decrease of Ni content in TiNi-1 alloy due to the precipitation of Ni-rich phase[16].

Fig.7 shows the internal friction vs. strain amplitude curves of the TiNi/TiNi composite alloy aged at different temperatures for 20 min. It can be seen that the internal friction of composite alloy decreases with the increase of strain amplitude. A similar phenomenon was observed in the study of internal friction of TiNi/Ni composite as well[17]. From the point of view of energy, the SDC (specific damping capability) can be expressed as

SDC=$\Delta W/W$, where ΔW is the dissipated energy and W is the total energy during one vibration period. With increasing strain amplitude, the number of stress-introduced martensite as well as the moving distance of interfaces increases. Therefore, ΔW and W will both increase. The SDC variation is dependent upon both ΔW and W. For the martensitic TiNi alloy, the major damping mechanism is the slipping of thermal martensite twin boundaries under the applied stress. So, the mechanical energy is dissipated by the nonelastic strain, which results in the relaxation of the applied stress. The lager the strain amplitude is, the more difficult the twin boundaries slipping will be. So, the internal friction of TiNi/TiNi composite alloy decreases with increasing strain amplitude.

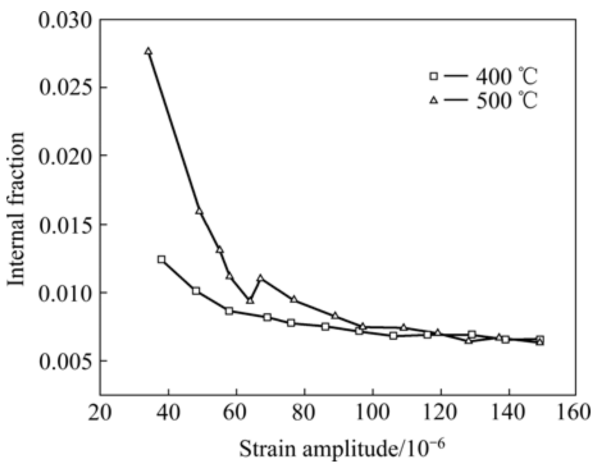

Fig.7 Internal friction of TiNi/TiNi composite alloy aged at different temperatures for 20 min vs strain amplitude at frequency of 1 Hz and room temperature

4 Conclusions

1) Two TiNi shape memory alloys with different chemical compositions and transformation temperatures are perfectly integrated together by explosive welding.

2) The high damping temperature range of TiNi-based alloy is broadened successfully. It must be very useful in the future engineering application.

3) The aging treatment has different effects upon the two components. The height of low-temperature internal friction peak increases with increasing the aging time, while the high-temperature internal friction peak has no obvious change.

4) At the room temperature, the internal friction of TiNi/TiNi composite alloy decreases with increasing the strain amplitude.

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(Edited by YANG Hua)