Journal of Alloys and Compounds 650 (2015) 92–96

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Investigation of constant prestress in effecting damping capacity of Fe–15Cr–2.5Mo–1.0Ni casting ferromagnetic alloy

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ARTICLE INFO

Article history:
Received 3 June 2015
Received in revised form
27 July 2015
Accepted 29 July 2015
Available online 1 August 2015

Keywords:
Ferromagnetic alloy
Constant prestress
Damping capacity
Domain structure

ABSTRACT

The present study focuses on the effect of constant prestress on damping capacity of Fe–15Cr–2.5Mo–1.0Ni casting ferromagnetic alloy by using dynamic mechanical analyzer (DMA). The stable magnetic fluid was used to observe the magnetic domain structure, a self-regulating apparatus was adopted to obtain the domain structure change under constant prestress. The result shows that the constant prestress exhibits significant effect on damping capacity of the alloy, the internal friction decreases as the prestress increases. It is ascribed to the magnetic domain walls movement of 90° or angled domains caused by domain walls redistribution in responding to the applied constant prestress. Under the constant prestress, the domain structure shows apparent modification. The angle between the domain wall sides dwindles and the domain walls tend to assemble themselves towards the prestress direction. As a result, new 180° domains generate with the domain walls paralleling to the prestress direction and they contribute zero to energy dissipation under following periodic vibration stress, thus causing damping capacity decrease. However, the damping capacity does not decrease when the prestress is small as it is not enough to provide the fluctuating energy of domain wall movement, and the magnetic domain structure remains the initial condition. With the amounts of 90° or angled domain walls and tangle-like sub-domains which devote to a relatively high magnetostriction coefficient λ_s, the alloy obtains high damping behavior.

1. Introduction

The continuous improvement of industry has generated severe vibration and noise, which increasingly deteriorate our civil environment. High damping Fe–Cr alloys, combining good mechanical properties with fairly damping capacity, are the material workers' answer to the unwanted noise and reduced vibration. Damping mechanism of this kind of damping material is mainly derived from three aspects: macro eddy current damping, micro eddy current damping and magnetomechanical hysteresis damping [1], all of which are phenomenologically contributed to dissipate mechanic energy and can operate simultaneously [2]. Experimental study [3] showed that magnetomechanical damping is much more effective than the sum of macro and micro eddy current damping which makes it be the main damping mechanism of ferromagnetic alloy in the low measured frequency. Due to its specific magnetic domain structure form in the alloy, under the influence of external periodic stress such as vibration, this kind of ferromagnetic alloy can bring about magnetic domain structure irreversible movement, and thus produce internal friction.

The effect of stress regardless of its concrete forms (internal stress or external stress) processing on damping capacity of Fe–Cr based alloy has gained much attention of the researchers and extensive studies have been investigated [4–6]. Internal stress caused by dislocations, alloying atoms, grain boundaries, secondary phase particles and other defects, acts as obstacle to the movement of domain walls will dramatically decrease damping properties. An optimum heat treatment can diminish the indications and recovery damping properties [7]. Hu [8] studied the influence of static stress when the preload was conducted on the sample with a fixed percentage of the oscillation driving force on damping behavior in Fe–15Cr alloy with DMA, and found that with the increase of preload, damping capacity decreases correspondingly. Researchers [8,9] in the past gravitated towards analyzing the decreasing damping capacity phenomenon under stress with the revised S–B model [10], nevertheless the relation between the damping capacity variation under stress and the

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http://dx.doi.org/10.1016/j.jallcom.2015.07.273
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domain structure modification caused by domain walls movement is lack of investigation. In this paper we pay our attention to the effect of constant prestress which is more relevant in engineering work on damping capacity of Fe–15Cr–2.5Mo–1.0Ni casting alloy. We tentatively put forward a stress-induced movement manner of domain walls via metallographic magnetic domain structure in-situ observation with our self-regulating apparatus, and try to demonstrate the domain walls movement under prestress in effecting the damping capacity of the alloy.

2. Experimental procedure

2.1. Sample preparation and treatment

The nominal composition of the alloy investigated in this paper is Fe–15Cr–2.5Mo–1.0Ni (wt.%), in order to improve castability of the alloy, little silicon and manganese (0.5 wt.% of each) were added. The alloy was melted and cast in a vacuum high-frequency induction furnace under high vacuum so that the content of C, N element and interstitial impurity atoms could be controlled within a relatively low extent. Samples with dimension of 35 mm × 0.8 mm × 0.7 mm were cut by wire electrical discharge machining (WEDM) from the cast ingot. The heat treatment of the samples was carried out in vacuum furnace at 1000 °C for 1 h followed by furnace cooling (FC). Microstructure of the alloy (Fig. 1) shows that heat treatment does not appreciably change the grain size, the grain keeps the coarse casting grain and no secondary phase is precipitated.

2.2. Damping capacity test

The damping capacity of the alloy was measured on a TA Q800 dynamic mechanical analyzer (DMA), three point bending deformation model was adopted to measure the lag phase δ between the applied cyclic stress and the responding strain. The damping capacity of the experimental alloy is characterized by internal friction Q^{-1} ($Q^{-1} = \tan\delta$ [11]). In contrast with superimposing a preload which was always proportional upon the oscillation driving force on the specimen in literature [8], we conducted the preload under a constant value in consideration of its more engineering relevance. The damping capacity under preload of 0.5, 1, 2, 2.5, 3.5, 5 and 8 N was measured respectively of the annealed alloy varying with strain–amplitude ($4 \times 10^{-6} \sim 1 \times 10^{-4}$) at frequency 1 Hz at ambient temperature. According to the elastic mechanics analysis, the preload was calculated into constant prestress: 4, 8, 16, 20, 28, 40 and 64 MPa, respectively.

Fig. 1. Microstructure of Fe–15Cr–2.5Mo–1.0Ni alloy annealed at 1000 °C for 1 h followed by furnace cooling (FC).

2.3. Magnetic domain structure

Specimens for domain structure observation were polished mechanically followed by electro polishing to eliminate surface stress. The electrolysis was carried out in a solution composed of 100 mL perchloric acid and 900 mL glacial acetic acid. A kind of qualified water-based magnetic fluid was used to obtain clear domain structure, the magnetic nano Fe_3O_4 particles in which can move freely and gather along the domain boundaries due to the leaked magnetic field along the boundaries [5]. The colloidal fluid was prepared by co-precipitation method with Fe^{2+}, Fe^{3+} and OH^- along with sodium oleate coated in order to prevent the nanoparticles from agglomeration to gain stable fluid. For investigating domain structure change under constant prestress, we designed a simply equipped apparatus (Fig. 2). The specimen for in-situ observation is totally alike with the DMA sample, the driving bar on the upper surface of the specimen provides prestress and it is loaded on the sample to simulate the loading condition of DMA test.

3. Results and discussion

The strain sweeping of DMA was used to obtain the damping curves under different prestress varying from 4 MPa to 64 MPa. The result (Fig. 3) shows that the internal friction Q^{-1} not only shows an evident linear correlation with low strain amplitude (below 1.0×10^{-4}), which has been extensive reported in literature [6,9,12], but also is intensely characterized by prestress-changing influence. It can be seen that the damping capacity decreases with the increasing constant prestress. Q^{-1} is 0.037 (strain amplitude = 4.0×10^{-5}) for prestress of 8 MPa while only 0.0028 (strain amplitude = 4.0×10^{-5}) for that of 64 MPa, which is less than one over ten of the former. It is in agreement with the previous reports demonstrating the damping decrease under preload [8,9]. As a phenomenological description, the S–B model with the influence of applied stress has been successfully adopted to fit the ferromagnetic phenomenon [10]. Another noteworthy result can be seen from the figure is that the damping capacity does not decrease too much with small prestress, the Q^{-1} curve under prestress of 4 MPa almost coincides with that of 8 MPa. Only when the prestress exceeds some extent of value does the damping capacity decrease drastically. We must sincerely point out the shortage that we measure the damping capacity under different prestress, as can been seen in Fig. 3. Due to the test mechanism of DMA three point

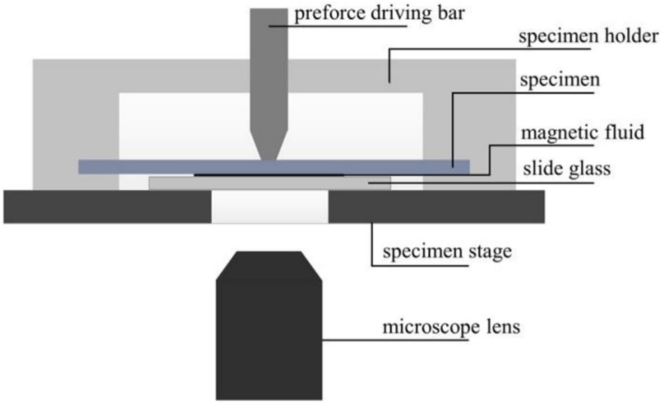

Fig. 2. Schematic diagram of apparatus for domain structure in-situ observation.