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Effect of minor Zr element on microstructure and properties of Fe-16Cr-2.5Mo damping alloys

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ABSTRACT

The Fe-16Cr-2.5Mo damping alloy was microalloyed with different amount of Zr element ranging from 0% to 0.5%. In this study, the effects of the different amount of Zr on the microstructure, mechanical properties and damping property of Fe-16Cr-2.5Mo alloys were investigated. The results suggested that the mean grain sizes of the Fe-16Cr-2.5Mo alloys with 0%, 0.1%, 0.3% and 0.5% Zr addition were 440 μm, 285 μm, 155 μm and 98 μm, respectively. The grain refinement strengthening was caused by Zener pinning and it leaded to improving the strength and elongation of the alloys. In addition, the Fe-16Cr-2.5Mo alloy with 0.1% Zr amount exhibited an impact toughness of 296J, which was much higher than those (<12J) of the alloys with more Zr element or without. On the other hand, Zr $(Fe, Cr)_2$ or Zr carbide precipitations (>0.5 μm) formed in the alloys notablely, based on the results of TEM and EDX. The large precipitations were apt to establish the cleavage initiation sites, thus damaging the impact toughness of the alloy. The maximum internal friction (Q^{-1}) of the alloys fluctuated within 0.016–0.014 with the increase of Zr content at a low strain amplitude (9×10^{-6}~3×10^{-4}). However, their damping properties are still marvelous.

1. Introduction

Fe-Cr based damping alloys possess both of excellent mechanical properties and high damping capacity [1]. It is regarded as a kind of excellent damping material to reduce the vibration and noise by material researchers.

The Fe-Cr based damping alloys are single phase ferrite at all temperatures [2] and they are known for their unmatched performance advantages [1,3,4], such as the high corrosion resistance, the high damping capacity with a wide range of temperatures, and the insensitiveness to vibration frequency. By far extensive researches mainly focus on improving the damping property of the alloys by adding alloying elements, such as Mo, Al etc., or changing the annealing temperatures and processes [4–6]. However, there are a few attentions on enhancing the low impact properties of the Fe-Cr based damping alloys.

The Fe-Cr based damping alloys compose by single-phase ferrite with body centered cubic (BCC) crystal structure at all temperature [2,7], which have fewer slip systems than the face centered cubic (FCC) and usually shows brittle fracture at low temperature. The final failure of the alloys is cleavage fracture along the low energy surface with a typical "river pattern" characteristic. As a structural material, the alloys need higher strength and toughness, as well as good damping capacity. The low toughness restricts the widespread use of the Fe-Cr based damping alloys. In order to better the damping property and the mechanical properties such as toughness, micro hardness and tension of the alloy, many researchers explored the effect of the stabilizing elements (Mo, Ti, Al, Nb, V) or homogenization on the microstructure to stabilize the ferrite phase [2,7–9]. Hu et al. [10] found that addition of 0.5%–1.0% Cu can acquire both high damping capacity and strength for Fe-Cr based damping alloys. And high-temperature annealing is used to acquire high damping capacity, simultaneity it results in the grain sizes coarsening, damaging the impact property.

In spite of a minor addition of the stabilizing elements considerably decrease the grain coarsening rate, the impact toughness of the alloy has no obvious change or even decrease. V.Kuzucu et al. [2] investigated that the toughness of the ferrite stainless steels

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which added stabilizing elements Mo, Ti, Nb respectively, are 11.14J, 10.57J, 11.14J. All of the results are lower than that (11.42J) of the control group.

Although stabilizing elements are effective approaches to stabilize the ferrite phase with a BCC structure and refine grain size, at the same time they can also promote the formation of precipitations. The crack initiation sites are apt to form at brittle phases and precipitates, hence they are detrimental to the impact toughness of the alloys.

This paper is devoted to get high impact toughness of the Fe-16Cr-2.5Mo based damping alloy and meanwhile keep its good damping property. Different amount of Zr elements (0%, 0.1 wt %, 0.3 wt % and 0.5 wt %) are added into the Fe-16Cr-2.5Mo alloys to investigate the effect of the minor Zr element on microstructures, damping property and mechanical properties such as impact toughness, tensile properties and elongation. And the relationship between the formation of Zr $(Fe, Cr)_2$ or Zr carbide precipitations and the evolution of the microstructure and mechanical properties of Fe-16Cr-2.5Mo based alloys are discussed in details. In addition, we envisage that the effect of Zr element may be applied into all of the Fe-Cr based damping alloys and ferrite stainless steels.

2. Materials and experimental procedures

2.1. Materials preparation

The main chemical compositions of the Fe-16Cr-2.5Mo alloys with different Zr contents in the present work are presented in Table 1 and the chemical compositions analyzed by optical emission spectrometry. The qualified alloys from raw materials of 99.9% pure iron, chromium and molybdenum are smelted in a vacuum high frequency induction furnace with high vacuum. Therefore, the element content of C, P, S (<0.030%) and impurity elements have been controlled within a relatively low extent levels. In order to reduce the loss of Zr elements, it is added into the metal liquid at the refining part under argon atmosphere. The as-cast ingots are hot forged to diameter 15 mm bars after a solution treatment. After that the samples in this experiment are cut by electrical discharge machining (W/EDM) from the forged bars. Before the performance testing, all of the samples are heat treated in vacuum furnace at 1100 °C holding for 1 h, followed by furnace cooling (FC).

2.2. Microstructural observation

The metallographic microstructures of the specimens (10 mm × 10 mm × 1 mm) are observed by the metallographic microscope (Olympus GX51). The samples are firstly mechanically fine grinded with a series of SiC sandpapers (# 800, # 1200, # 2000 and # 2500), and then they are polished on the diamond polishing pastes with 1.5 μm and 0.5 μm grit by standard techniques. Before the observation, the specimens are etched for 5 s in a solution containing 4 g chrysolepic acid, 20 mL hydrochloric acid and 100 mL absolute alcohol at room temperature. The microstructure characteristics of the etched surfaces and the fracture surfaces of Charpy U-notch impact specimens are observed by scanning electron microscope (SEM, S3400N) and which equips with the energy dispersive x-ray analysis (EDAX) using to identify the composition of the particles of the specimens. And the microstructures of precipitates are observed by a 200 kV transmission electron microscope (TEM, Tecnai G^2 F20 S-TWIN). The disk specimen of 3 mm in diameter and 50 μm in thickness is cut from the forged bar after heat treatment and the wafer electro-chemically polished using the twin-jet thining with 10% perchloric acid ($HClO_4$) + 90% ethanol (C_2H_5OH).

2.3. Mechanical and damping testing

Tensile and Charpy impact tests are carried out at room temperature and the results of the property tests acquire from the mean of three samples. The tensile tests are measured by the electronic universal testing machine (RGM-4300) with 20 KN load cell and a constant crosshead velocity of 1.0 mm/min. The tensile sample is flat plate with 10 mm × 2.5 mm cross section and an initial gauge length of 50 mm. Besides, the displacement extensometer is used to ensure the accuracy of the tensile test results. The impact toughness tests are performed by the standard [11] with Charpy U-notch impact testing machine. Furthermore, the instrumented charpy impact tests are carried out on the instrumented impact testing machine (RPK-450). The dimension of Charpy U-notch sample is 10 mm × 10 mm × 55 mm with U-shaped slot shown in Fig. 1.

The clamp dual cantilever model of the TA Q800 dynamical mechanic analyzer (DMA) is used to measure the lag phase δ, which is the lag phase between the responding strain and the applied stress, where the tangent δ value is used to describe the damping properties of these alloys, i.e. the internal friction Q^{-1} [1].The

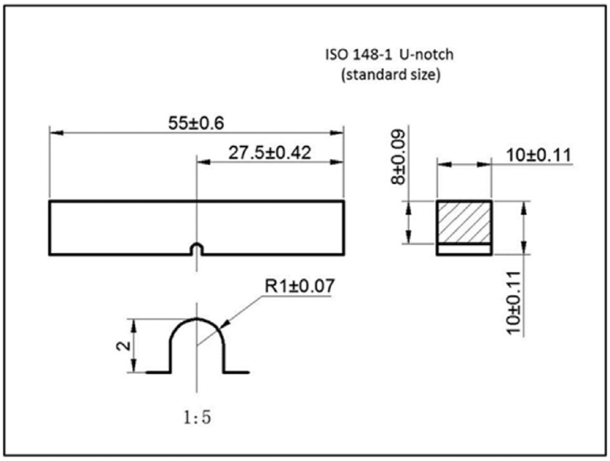

Fig. 1. Charpy U-notch sample for impact test.

Table 1
Chemical composition of the Fe-16Cr-2.5Mo alloys used in the present work.

Alloys	No.	Element (Wt%)							
		Zr		Cr	Mo	C	P	S	Fe
		Design	Actual						
Fe-16Cr-2.5Mo	1#	0	–	15.24	2.41	0.021	0.011	0.004	Bal.
Fe-16Cr-2.5Mo-xZr	2#	0.1	0.040	15.41	2.42	0.003	0.010	0.005	Bal.
	3#	0.3	0.166	15.25	2.45	0.003	0.011	0.004	Bal.
	4#	0.5	0.315	15.45	2.44	0.003	0.010	0.005	Bal.