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Vibration Damping of High-Chromium Ferromagnetic Steel

Satish BM, Girish BM , Mahesh K

***Abstract*—**The aim of the present work is to study the effect of annealing on the vibration damping capacity of high-chromium (16%) ferromagnetic steel. The alloys were prepared from raw materials of 99.9% purity melted in a high frequency induction furnace under high vacuum. The samples were heat-treated in vacuum at various temperatures (800 to 1200ºC) for 1 hour followed by slow cooling (120ºC/h). The inverted torsional pendulum method was used to evaluate the vibration damping capacity. The results indicated that the vibration damping capacity of the alloys is influenced by annealing and there exists a critical annealing temperature after 1000ºC. The damping capacity increases quickly below the critical temperature since the magnetic domains move more easily.

***Keywords*—**Vibration, Damping, Ferromagnetic, Steel.

I. Introduction

ENGINEERING components like turbines, compressors, propeller blades, shafts, transmission cables, and so on commonly encounter vibrational stresses. The damping capacity of materials may prove to be of utmost importance in such applications. The significance of the damping capacity as an engineering property of materials has received widespread recognition in recent years. Though the importance of damping capacity as a criterion for the selection of materials for engineering components is being acknowledged, relatively little work has been reported so far on the damping behavior of engineering alloys [1,2].

The intrinsic mechanical damping or internal friction of a material has long been used by researchers interested in defects in materials and their effects on mechanical properties. It is well known that many viscoelastic materials like rubber, polymers, and plastics have the ability to damp out noise and vibration. However in applications where elevated damping levels must be accompanied by good mechanical properties at temperatures much above ambient temperatures, only High-Damping Metals (HIDAMETS) and certain high-damping ceramics are available for passive damping [3].

Smart materials have been playing an important role in applications on active and passive control of vibration and noise. Ferromagnetic damping alloys as a group of smart materials have attracted much attention of researchers for being able to absorb the vibration and noise energy. Their applications have been widely found in several fields like automobiles, warships, household appliances, and so on [4].

Research and Development, Department of Mechanical Engineering, East Point College of Engineering and Technology, Virgonagar Post, Bidarahalli, Bangalore-560049, Karnataka, India.

Chromium-rich ferromagnetic steels have been reported to exhibit good damping capacity along with high mechanical strength and corrosion resistance. These properties make them candidate materials to be used in a variety of engineering applications for the purpose of noise and vibration damping [5]. Such alloys have been drawing a great deal of interest of the scientists and engineers across the world as new type of structural and functional materials for depressing noise and vibrations.

The ferromagnetic damping alloys which possess high damping capacity at both ambient and elevated temperatures are composed of magnetic domains [6]. Each domain is separated from its neighbor by a domain wall. These walls can move under external magnetic fields or stresses. When this movement is irreversible, a fraction of energy provided to the material is dissipated as internal friction. This mechanism is responsible for the intrinsic damping of the material and is known as magneto-mechanical damping. Thus the damping level in ferromagnetic alloys depends on the magnetic domains, the structure of which in turn is dependent on the microstructure of the material [7].

The purpose of this paper is to evaluate the effect of annealing treatment on the vibration damping of high-chromium ferromagnetic steels.

II. Experimental Procedure

The vibration damping analysis was conducted using annealed ferromagnetic steel of composition Fe-16%Cr-2%Al-1%Mg-1%Mo and 2%Si by weight. The alloys were prepared from raw materials of 99.9% purity melted in a high frequency induction furnace under high vacuum. The samples 150 mm length and 1.5 mm diameter were cut from the cast ingots by electroerosion and then polished to obtain metallographic surfaces. The samples were heat-treated in vacuum at various temperatures (800 to 1200ºC) for 1 hour followed by slow cooling (120ºC/h).

The vibration damping capacity was evaluated using a reversal torsion technique at room temperature. The specimens were made to vibrate at the resonant frequency with a constant drive force. An optical sensor was used to measure the vibration attenuation process. The vibration amplitude of the samples change with time, from which process is obtained from the damping curve. The damping is shown by the logarithmic decrement (δ), the details of which is available elsewhere [8].

III. RESULTS

The figure1 (a-c) shows the microstructure of the specimens annealed at different temperatures. It follows from the micrograph that as the annealing temperature increases, so does the enlargement of the grain size. This is the major microstructural change that is observed in the process. The difference in the grain size is the major reason for the variation in mechanical properties of the annealed alloys as is depicted by the result shown in Table 1. It follows from the results that as the annealing temperature increases from 800 to 1200°C, the tensile strength and the rupture elongation of the alloy decreases considerably. The major transformations are recovery and recrystallisation since there is no phase transformation that occurs during the annealing process.

The figure 2 is the graph of annealing temperature (°C) plotted against the logarithmic decrement (δ). It follows from the graph that the damping capacity is maximum at annealing temperature of around 1000°C, which can be called the critical temperature. Several researchers have reported that the damping capacity of ferromagnetic alloys increases due to annealing treatment [9,10]. Hence it follows that the annealing treatment can significantly improve the vibration capacity of the alloy. This is due to the fact that the crystal defects like dislocations, crystal lattice strain, etc., which are introduced into the material during the cold-working process get reduced or even eliminated by the annealing process. It is to be noted that the residual stress also decreases during the process. It follows from the graph that the damping capacity of the material decreases significantly above the critical temperature which is consistent with the results reported by others [11, 12].

IV. DISCUSSION

According to the experimental results, it can be concluded that after the annealing treatment, the damping capacity of the alloy increases. This increase is attributed by many researchers [13] to the mobility of magnetic domain walls. The mobility of the domain walls generally may be affected by the residual stress and defects such as dislocations, alloying atoms and grain boundaries [14].

According to the experimental results, as referred to Fe-Al alloys, there exists a critical annealing temperature between 800 and 1200°C (fig.2) at which the damping capacity can get its maximum. A similar phenomena is also confirmed in literature related to study of Fe-Cr based damping alloys [13, 14]. In consideration of the fall of damping capacity at 'over-annealing' temperatures, it can be proposed that the damping capacity be the combined result of domain wall mobility and domain size, both of which depend on the annealing treatment. In the annealing process, the main transformation mechanisms that occur are recovery and recrystallisation. In the cold-working state, the residual stress and the defects are significant in this alloy. These factors cause higher energy barriers, which restrict the movement of the domain walls. During the annealing treatment, the defect density and the residual stress decrease sharply. Hence at about 1000°C, the damping capacity reaches a maximum. However, above this critical temperature, which is 1200°C in this case, even though the microstructural defects from cold work disappear significantly, the domain size grows to a large extent that the increase of domain size plays a much more important role in the change of damping capacity compared with the domain wall mobility. The domain wall area decrease makes the amount of the exhausted energy less during the domain wall movement, and as a result, the damping capacity decreases.

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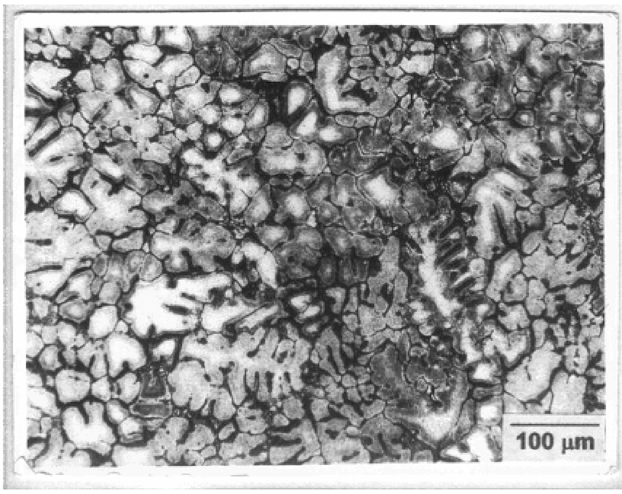

Fig. 1a. Microstructure of the alloy annealed at 800°C

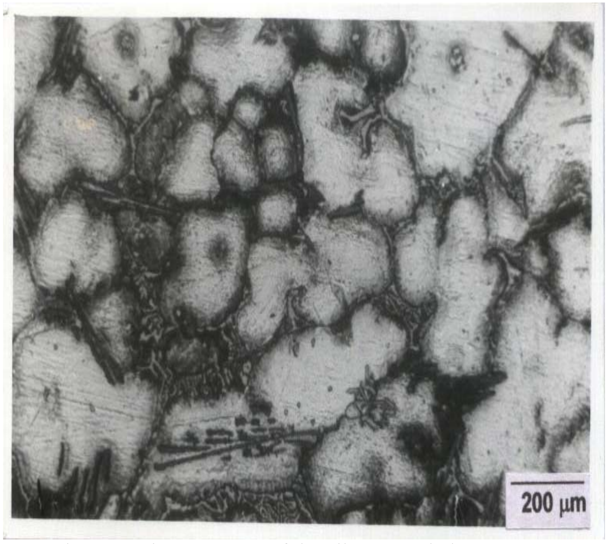

Fig. 1c. Microstructure of the alloy annealed at 1200 °C

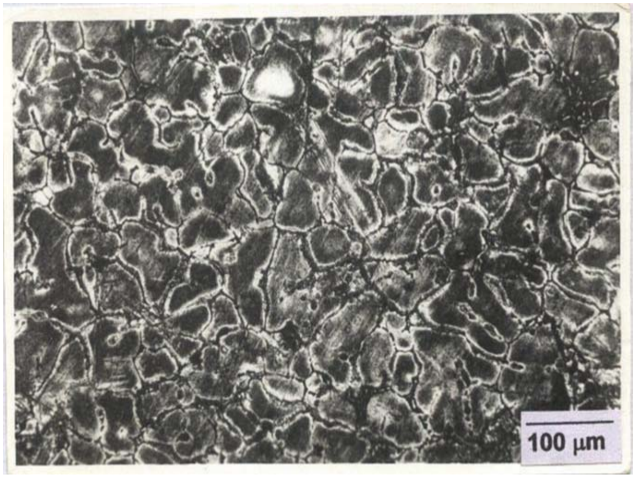

Fig. 1b. Microstructure of the alloy annealed at 1000°C.

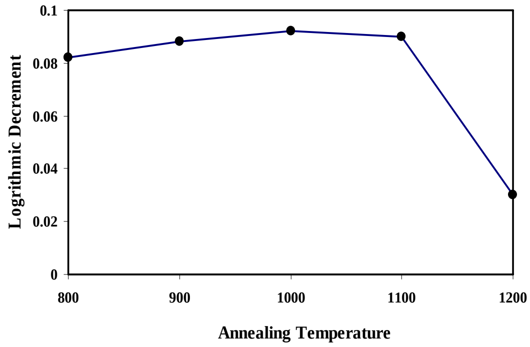

Fig. 2: Graph of Annealing Temperature (°C) v/s Logarithmic Decrement (δ)