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Effect of high strain amplitude and pre-deformation on damping property of Fe-Mn alloy

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ABSTRACT

In order to investigate the effect of high strain amplitude (maximum 1.6×10^{-3}) and large pre-deformation (maximum 15%) on the damping properties of Fe-Mn alloys, the damping properties of the alloys were measured by a computer controlled automatic inverted torsion pendulum, microstructures were observed by SEM and EBSD, and phases were identified by XRD. The results show that the damping performance decreases at first and then increases when the pre-deformation amount is higher than 10%, and the valley value is reached at about 12%. When the pre-deformation amount is more than 12%, the content of ε phase decreases, while the amount of γ austenite and α' martensite increases, the ε martensite phase of the alloy is divided and appears finer, ε martensitic phase and γ austenite have better parallelism, the phase interfaces of γ/ε significantly increase, and more damping sources with better slippage are provided, resulting in gradually increasing of damping properties of Fe-Mn binary alloy. When the strain amplitude is greater than 1×10^{-3}, the damping properties and strain amplitudes of the pre-deformation alloys do not always maintain an approximately linear relationship, which closely related to different characteristics of damping sources due to stress-induced phase transition and formation of different alloy microstructures.

1. Introduction

The mechanical components generate vibration and noise when activated by the external energy, which not only deteriorate the working conditions, endanger the physical and mental health of the staff, but also affect the accuracy and stability of the equipment and shorten the life of the mechanical components. Therefore, it is critical to control the vibration source whether for vibration reduction or noise reduction. The most effective method of controlling vibration and noise is to use a high damping alloy. Fe-Mn alloy is the damping alloy with the highest intensity and the lowest price [1], whose damping performance shows an approximately linear increase with the increase of strain amplitude. It can be used as large vibration and impact parts, such as brake discs, gears and cutting machines, and so on. Therefore, it is worth exploring the great research value and wide application prospect of Fe-Mn alloy.

Recent studies on Fe-Mn alloys have mainly focused on the effect of mechanical properties [2], the addition of the third element [1,3], grain size [4], etc. on the damping performance and the exploration of damping mechanism. In practical applications, Fe-Mn damping alloys often require cold rolling, cold drawing and other deformation processes. It is of critical significance to study the effect of deformation process on the damping properties of Fe-Mn alloys, and there have been a few studies in this area [5,6]. Some refences [7–9] pointed out that the trade-off between the damping capacity and hardness can be overcome by the thermomechanical training of Fe-Mn high damping alloy. It is an effective way to damping capacity and mechanical properties for Fe-Mn alloy. Pre-deformation that is easy to operate can change the microstructure of Fe-Mn alloy and then has great influence on damping performance. In recent years, some refences [10–13] showed that, in the range of pre-deformation less than 10%, the damping property of Fe-Mn alloy increased first and then declined with the increase of the pre-deformation amount and reached the maximum at 5% or 4%. However, it has not been known how the damping property of the Fe-Mn alloy will change as the deformation amount continues to increase. It is well known that Fe-Mn damping alloy has great

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advantages in the use of large vibration and strong impact parts. Exploring the damping properties of Fe-Mn alloy in high amplitude conditions provides a direct theoretical basis for practical engineering. At present, all research work test conditions and research contents of the Fe-Mn damping alloy are quite different from actual service conditions of the damping components (The strain amplitude is too low. The maximum is not more than 10^{-3} within the range of 10^{-6} to 10^{-5}) [14–17]. In order to accurately reflect the vibration and noise reduction ability of Fe-Mn alloy mechanical components in practical high amplitude conditions, it is necessary to conduct this research.

In regard to the two above-mentioned problems, this paper focuses on the effect of large pre-deformation (larger than 10%) and high strain amplitude (larger than 1.0×10^{-3}) on the damping property and microstructure of Fe-Mn alloy. It provides a theoretical basis for the damping property study of materials and components in high strain amplitude environment, and provides a guidance for the application of damping alloys under some severe working conditions. The effect of large deformation on the damping property of the material is clarified. A comprehensive understanding of the high-damping alloy and the theoretical support for the engineering application are provided.

2. Materials and methods

The alloy used in this paper is Fe-17 wt%Mn. The experimental alloy ingots were prepared by arc-melting industrial pure iron and electrolytic manganese in a ZG-25A vacuum induction furnace. After the ingots were homogenized at 1150 °C for 12 h, ingots were hot forged into 20-mm-thick sheets at 1100 °C (The thermal deformation was not less than 70%.), which were cut into a 60 mm × 30 mm × 10 mm thick sheets. After that, the sheets were subjected to high-temperature solution heat treatment (1000 °C/1h + water cooling) and the cold rolled pre-deformation was performed with the deformation amount of 3–15%, and finally stress relief annealing treatment was performed in the condition of 200 °C × 2 h. The damping property of Fe-17Mn alloy was measured by a computer controlled automatic inverted torsion pendulum (JN-1) with the force vibration mode, in which the vibration frequency was 1 Hz, the measurement temperature was 30 °C, and the strain amplitude was 2×10^{-5} to 1.6×10^{-3}. The sample size in the IF measurement was about 50 mm × 1.2 mm × 0.8 mm. X-ray diffractometer (XRD) was used to measure the damping alloy phase, the scanning electron microscopy (Oxford SEM: IE450XMax80) was used to observe the microstructure of the damping alloy, and the electron-backscatter diffraction (EBSD: Aztec NordlysMax3) was used to determine microstructure and crystal characteristics of the damping alloy.

3. Results and discussion

Fig. 1 shows the internal friction curves of Fe-17Mn alloy under different strain amplitudes and different cold rolling pre-deformation amount. It can be seen from Fig. 1(a) that when the strain amplitude is less than 1×10^{-3}, the damping performance of Fe-17Mn alloy increases linearly with the increase of strain amplitude. When the strain amplitude is larger than 1×10^{-3}, the damping property of the alloy with different deformation amounts does not continue to increase approximately linearly with increasing strain amplitude. When the pre-deformation is ranges from 6% to 12%, the damping performance of the alloy still increases linearly. When the pre-deformation amount is between 3% and 15%, the upward trend of the damping performance of the alloy goes slowly. When the pre-deformation amount is 9%, the damping performance tends to be stable within the strain amplitude of 1×10^{-3} to 1.1×10^{-3}, and the damping performance continues to grow as the strain amplitude increases. However, when the pre-deformation is 0%, the alloy damping performance tends to increase faster.

It can be seen from Fig. 1(b) that at different strain amplitudes (0.5×10^{-3}, 1×10^{-3}, 1.2×10^{-3}, 1.4×10^{-3}, 1.6×10^{-3}), with the increase of the pre-deformation damping performance of alloy with small pre-deformations (less than 10%) increases first and then decreases. It reaches the peak value when the pre-deformation amount is about 3%, and the curves of damping performance show "peak" shapes with the changes of pre-deformation amounts. This result is consistent with those reported in Refs. [10,17]. However, the changes of damping properties of Fe-Mn alloys with large pre-deformation (greater than 10%) are not clear. As can be seen from Fig. 1, when the pre-deformation is greater than 10%, the damping performance does not always decrease, but decreases first and then increases. When the pre-deformation amount reaches about 12%, the valley value reaches, and the curves of the damping performance with the changes of pre-deformation take on "Valley" shapes.

Fig. 2 shows the XRD pattern analysis of Fe-Mn alloy with different cold rolling pre-deformation amounts. It can be seen from Fig. 2(a) that the experimental alloy consists of three phases of γ austenite, ε martensite and α' martensite, within which ε martensite is the majority. With the increase of the pre-deformation, the contents of the three phases change significantly, which is because the $\gamma \rightarrow \alpha'$ and $\varepsilon \rightarrow \alpha'$ phase transitions also occur besides the stress-induced $\gamma \leftrightarrow \varepsilon$ martensite transformation. It has been confirmed by numerous studies [18,19]. Fig. 2(b) is a 40°–50° diffraction peak contour map filled with bright colors. Different colors represent different peak intensities. We can see from Fig. 2(b) that as the pre-deformation increases, the ε (100) peak strength increases first and then decreases, reaching a maximum and forming a "mountain peak" when the pre-deformation amount reaches around 12%. The ε (002) peak intensity also appears to have a similar pattern, but the ε (101) peak intensity decreases first, then rises and then decreases again. At a pre-deformation of about 3%, the ε (101) peak intensity reaches a minimum value, forming a "valley", and it reaches its maximum at about 12% pre-deformation, forming a "mountain peak". It can be taken from Fig. 2(a) and (b) that the ε martensite content is maximal after about 12% pre-deformation. In order to further accurately analyze three phase contents, phase analysis was performed by EBSD. Fig. 3 shows the EBSD morphology and corresponding phase distributions of Fe-17Mn alloys with different deformation amounts (0%, 3%, 12%, and 15%), in which blue is the ε phase, red is the γ phase, and yellow is the α' phase. The three phase contents are also provided in Fig. 3. It can be found from the comparison that the ε phase content of the alloy is high after 0% and 12% pre-deformation, and the γ austenite and α' martensite contents are low, while the alloys with 3% and 15% pre-deformation amount have low ε phase content and high γ austenite and α' martensite contents. It is inferred that:

(1) After less than 3% pre-deformation, $\varepsilon \rightarrow \gamma$ and $\varepsilon \rightarrow \alpha'$ phase transitions are in the majority, which reduce the content of ε phase and increase the content of γ austenite and α' martensite.
(2) After pre-deformation ranging from more than 3% to less than 12%, $\gamma \rightarrow \varepsilon$ and $\varepsilon \rightarrow \alpha'$ phase transitions are located in the majority. And $\gamma \rightarrow \varepsilon$ phase transition is larger than $\varepsilon \rightarrow \alpha'$ phase transition, and $\varepsilon \rightarrow \alpha'$ phase transformation is weakened, resulting in the increase of ε phase and the decrease of γ austenite and α' martensite content.
(3) After more than 12% pre-deformation, $\varepsilon \rightarrow \gamma$ and $\varepsilon \rightarrow \alpha'$ are the dominant phase transitions, resulting in the decrease of