Exploring the Function Fatigue Behavior of Ferromagnetic Shape Memory Alloy

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Abstract. In the industrial applications of ferromagnetic shape memory alloy, the large magnetic field induced strain and long function fatigue life are the essential conditions for their application. In this cases, the ferromagnetic shape memory effect and the function fatigue of Ni2MnGa under applied magnetic field has been investigated. The magnetic field induced strain appear typical nonlinearity increasing trend apparently with the applied magnetic field rising. Meanwhile, the magnetic field induced strain keep decreasing tendency as the applied magnetic field cycles increasing and the magnetic field induced strain kept a small value in a long cycle ranges of 400 to 107. Furthermore, the sample appeared typical elastic deformation stage, twin martensite remigration stage and plastic deformation stage during compression test process.

1. Introduction
Since the first observation of the magnetic field induced strain in Ni2MnGa by Ullakko [1], the ferromagnetic shape memory alloys (FSMAs) have attracted a great attention as a kinds of intelligent material for actuator and sensor[2]. In past two decades, about 10% giant stains, biased on twin martensite variants remigration, were achieved in Ni2MnGa alloy [3]. However, the actuator and sensor made of Ni2MnGa has not getting a wide range of applications due to their function fatigue effect [4].

In industrial applications, the actuator and sensor must work a million times [5, 6]. In this case, the Ni2MnGa, as a drive material of actuator and sensor, should have a long function life (more than million cycles) [2, 7, 8]. Therefore, to clear the process of the magnetic field induced strain and to obtain a larger value of magnetic field induced strain is very significative. In this study, the ferromagnetic shape memory effect and the function fatigue of Ni2MnGa under applied magnetic field has been investigated.

2. Experimental
The alloy with a nominal composition of Ni2MnGa (at.%) was prepared by high purity nickel, manganese and gallium (>99.99 at.%) in melting furnace with argon atmosphere. In order to make sure the homogenous, the sample was melted four times, then annealed at 1473 K for 6 hour and quenched into ice water.
The magnetic field induced strain and the function fatigue life of the sample was tested by the homemade test system and the schematic was shown in Fig.1. Therein, the magnetic field induced strain was measured by HG-C1050 high precision laser rangefinder (Panasonic, Japan) in different applied magnetic field. Furthermore, the function fatigue life were tested by the rotating magnetic field, which created by the rotating magnet in Fig.1. The compression tests with the size 5[length]×3[width]×3[thickness] of sample was performed on CMT5105 electronic universal testing machine at the cross-head displacement speed of 0.05 mm/min.

![Figure 1. The schematic of homemade test system](image)

3. Results and Discussion

3.1. Ferromagnetic Shape Memory Effect

The ferromagnetic shape memory effect of FSMAs is the most basic function, which determines the area of their application. Therefore, to clear the process of the magnetic field induced strain and to obtain a larger value of magnetic field induced strain is very significative. Fig.2 shows the magnetic field induced strain value of sample changes in different applied magnetic field. One can see that the magnetic field induced strain of sample appear typical nonlinearity increasing trend apparently with the applied magnetic field rising. However, during applied magnetic field rising, the ascent rates of magnetic field induced strain demonstrate four different variations. The first step occurs at the beginning of applying magnetic field (about 0~350 Oe) and on obvious magnetic field induced strain observed in this stage when applied magnetic field increasing (step 1 in Fig.2). The second step occurs at a low applied magnetic field (about 350~1000 Oe), the magnetic field induced strain increase linearly when the applied magnetic field rising (step 2 in Fig.2). The third step occurs at moderate intensity applied magnetic field (about 1000~6400 Oe), the magnetic field induced strain increase very rapidly in this stage. The fourth step occurs at high applied magnetic field (more than 6400 Oe) and the increase trend of magnetic field induced strain become very gently. The largest magnetic field induced strain value (about 4.8%) was obtained near 1×104 Oe.
3.2. Function Fatigue

The other factor to determine the application of FSMAs is the function fatigue. So, to study the function fatigue process and find out a way to improve the function life of FSMAs is benefit for industrial application of alloys. The magnetic field induced strain of sample depend on different magnetic field induced strain cycles was shown in Fig. 3. As can be seen that the magnetic field induced strain value of the sample keep decreasing tendency as the applied magnetic field cycles increasing. The function fatigue curve in Fig. 3 can be divided into four steps due to the different slope of the function fatigue curve. The first step is less than 40 cycles. In this stage, the magnetic field induced strain of the sample kept a high value (about 4.8%) and no obviously decrease as cycle increases. The second step is between 40 and 400 cycles. The magnetic field induced strain value obvious decreases form 4.8% to 1.2% as the cycle increasing. The third step occurs from 400 to 107 cycles. In this part, the magnetic field induced strain stable at a low value (1.2%) in a long cycle time. The fourth step is more than 107 cycles. The magnetic field induced strain of the sample decrease rapidly and then disappeared.
3.3. Discussions on Ferromagnetic Shape Memory Effect and Function Fatigue

For FSMAs, the industrial applications of the alloy depend on their magnetic field induced strain and function fatigue life. In this study, the magnetic field induced strain value of sample was investigated and the result revealed that the strain appeared nonlinearity (4 step in curves) increasing with the applied magnetic field rising. At the first step, the applying magnetic field is too weak (about 0~350 Oe) to provide enough deformation driving force. So, the magnetic field induced strain of sample cannot be observed in this step. When the applied magnetic field strength become increase (about 350~1000 Oe), the strain of the sample appeared a linear increasing relation with applied magnetic field rising indicated that this strain is proportional to the magnetic force. Further increase the strength of applied magnetic field (about 1000~6400 Oe), the sample occurs an obvious strain due to a large magnetic force, which obtained by applied magnetic field, drove the twin martensite remigration and exhibits an obvious magnetic field induced strain in this stage. In the last step (more than 6400 Oe), the twin martensite remigration process finished and result in the magnetic field induced strain close to the maximum due to the magnetic force approaches the maximum value.

In order to demonstrate the analysis of the step of the magnetic field induced strain, the Stress-strain curve of the sample by compression test was shown in Fig.4. From Fig.4, the curve appeared three kinds stages due to their different slope. The first step is the typical elastic deformation region because of the linear relation between stress and strain. The second step appeared a large platform for strain increase. In this platform, the sample can be achieved a large strain with a small stress change as seen in Fig.4 (step 2). The reason for this platform can be ascribed into the twin martensite remigration by stress. The third step appeared nonlinear relation between stress and strain indicated that the sample become plastic deformation in this stage and then breakage as show in step 3. From Stress-strain curve analysis, the deformation stage, like elastic deformation, twin martensite remigration and plastic deformation, was consistent with the analysis of the step of the magnetic field induced strain.

![Figure 4. Stress-strain curve of the sample](image)

Another main factor for industrial applications of FSMAs is function fatigue life. From the result of the function fatigue life analysis in Fig.3, the magnetic field induced strain of the sample keep decreasing tendency as the applied magnetic field cycles increasing indicated that the function fatigue life is very sensitive to the applied magnetic field cycles. During the function fatigue process, the magnetic field induced strain has no obvious decrease in low cycles (less than 40 cycles) due to the defects does not occur in low cycles. When the applied magnetic field cycles rises to 400 cycles, the defect, which introducing by strain cycles, become accrue in the sample and result in the magnetic field induced strain begin to decrease. With the strain cycles continue to increase (400 to 107 cycles),
the magnetic field induced strain kept a small value in a long cycles range indicated that the number of defects curbed by the stain decrease. When the cycles reached a high value (more than 107 cycles), the magnetic field induced strain of sample disappeared due to the defects accumulation during long times cycles.

4. Conclusion
To improve the industrial applications of the Ni2MnGa shape memory alloy, the ferromagnetic shape memory effect and the function fatigue under applied magnetic field has been investigated. The main results were list as follows:
(1) The magnetic field induced strain of sample appear typical nonlinearity increasing trend apparently with the applied magnetic field rising.
(2) The magnetic field induced strain value of the sample keep decreasing tendency as the applied magnetic field cycles increasing and the magnetic field induced strain kept a small value in a long cycle’s range of 400 to 107 cycles.
(3) The sample appeared typical elastic deformation stage, twin martensite remigration stage and plastic deformation stage by compression test process.

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