The Effect of Frozen Ultrasonic Shot Peening Treatment on Two Way Characteristic at Shape Memory Alloy

Y Watanabe, K Hattori, M Handa[1] and Y Yoshimi[2] and T Ikeda[3], E Fujii [4]

1.TOYO SEIKO CO., LTD., Umaganji, Yatomi City, AICHI, JAPAN
2 YOSHIMI Inc., Ohbu City, AICHI, JAPAN
3 Composite Engineering Research Center Graduate School of Engineering, NAGOYA University, AICHI, JAPAN
4 Headquarters for Industry, Academia, Government Cooperation, Nagoya University

Abstract
This paper shows the possibility whether shot peening treatment would be alternative method to bias spring. We conducted Ultrasonic Shot Peening (USP) at low temperature to induce compressive residual stress, which react as an outer force. Further to obtain the useful residual stress on SMA behavior, we developed the Frozen Ultrasonic Shot Peening (FUSP) treatment to meet the SMA function. As a result, the effective two way characteristic of SMA by frozen shot peening treatment was confirmed. And in order to confirm the durability of SMA, we conducted the fatigue test.

Keywords: Shape Memory Alloy, Frozen Ultrasonic Shot Peening, Coverage, Fatigue Test

Introduction

It could be possible that Shape Memory Alloy (SMA) memorize the shape at the stable Austenite phase in high temperature. On the other hand, it could not be possible that the shape at the stable Martensite phase in low temperature is memorized. So in case of using SMA as a kind of actuator by the change of temperature, the outer force should be required in low temperature. Normally spring is well known as a typical outer force though, the number of assembled part should be increased.
At this background, in order to confirm the possibility whether shot peening treatment would work as bias spring, we conducted USP to induce a compressive residual stress, which react as an outer force. Further we developed FUSP that SMA can put a characteristic in the condition, which was made a full martensite in the ultra low temperature.
As a result, it was confirmed that the effective two way characteristic of SMA by FUSP treatment. Further at fatigue test, the strain of two way was decreased by 10% at first 18 cycles, but shot peening treatment could keep the same strain until 10,000 cycles due to the effective compressive residual stress.

Experimental Methods

Ultrasonic Shot Peening

Shot peening was carried out by using Stressonic® [1] which is ultrasonically shot peening. Figure 1 shows the principle of this equipment and table 1 shows the shot peening conditions. In this study, we used polished bearing ball with a diameter of 0.8 mm and the hardness of HV800 for Stressonic® peening device. 100% coverage time would be 8 seconds at this study. Because after shot peening we had to conduct the heat treatment for shape memory at 480 degree C 40min keep then water quench, we selected much bigger coverage time in order to keep the effective residual stress distribution even after heat memory treatment. So, we conducted 120 seconds, which is equivalent to 1,500% coverage.
In order to induce the compressive residual stress at the proper material condition that is fully martensite crystal state, we developed the frozen ultrasonic equipment. Figure 2 shows the schematic illustration of device and the appearance of the device. We used the liquid nitrogen to keep the specimens a cold condition through heat exchanger during the treatment.

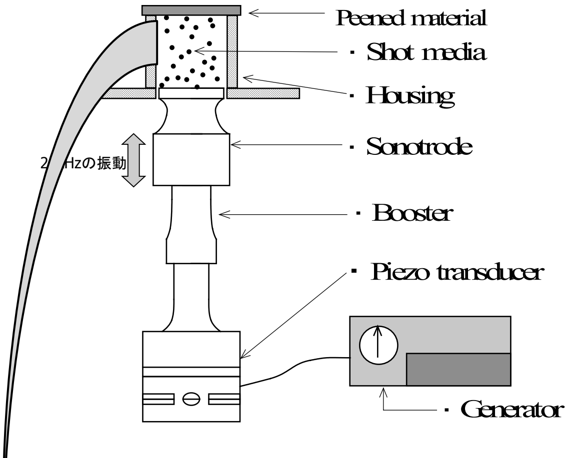


Fig. 1 The principle of ultrasonic shot peening

Table 1 Shot peening conditions

Sonotrode diameter	70mm dia.
Shot Material	SUJ2
Shot diameter	0.8mm
Shot hardness	800HV
Injection volume	4.83g(Posession rate 30%)
Amplitude	70μm
Injection distance	10mm
Injecting time	120 sec
Arc height	0.208mmA

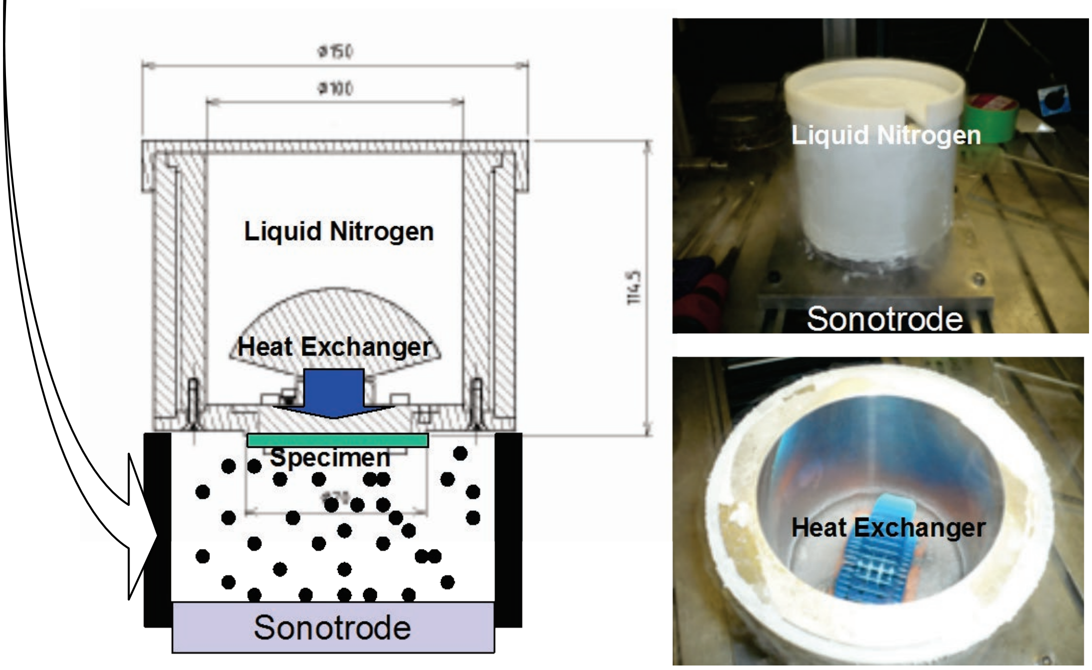


Fig. 2 The developed frozen Ultrasonic Shot Peening device

Shape Memory Specimens

Base ingot used in this study is Ti-Ni SHS (Self Propagating High Temperature Synthesis) material whose compositions are Ti-50.8at%Ni and Ti-50.0at%Ni [2]-[3]. Tensile tests specimens were made by centrifugal precision casting method. Here, three-phase 200V 40KVA casting machine with input current of approximate 115A and mold revolution speed of 1300 rpm that is available of melting and casting ingot-weighing 330g at one time was used. The geometry of specimen is 2mm(Width) X 50mm(Length) with the thickness of 1mm. Here, Figure 3 shows the principle of two-way characteristics by shot peening treatment. When shot peening treatment is conducted on one side as Figure 3(a), compressive residual stress could be induced at plastic deformation layer. According to the other study, it is difficult causing effect the phase transformation by heat changing at the plastic deformed region. Other saying, the peened surface could be considered to be changed amorphous condition from nominal shape memory alloy structure, which is not affected by heat treatment. In case of the specimen, which is peened as shown in figure 3(b), plastic deformed phase should behave as bias spring, as a result the deformation could be done even at the cooling stage.

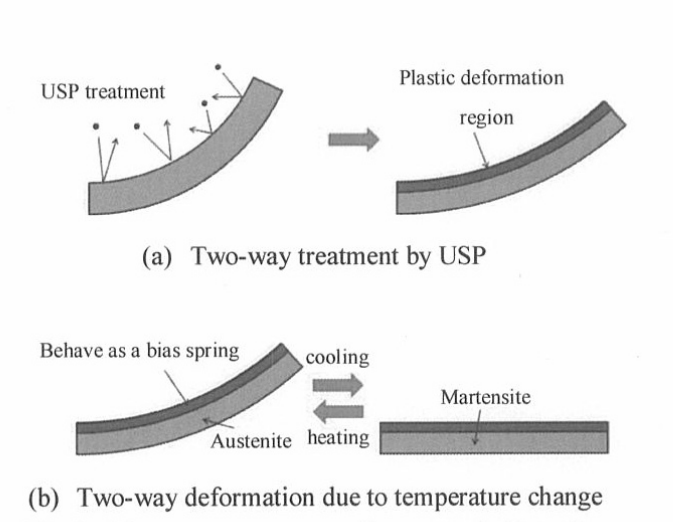


Fig.3 The principle of two-way characteristics

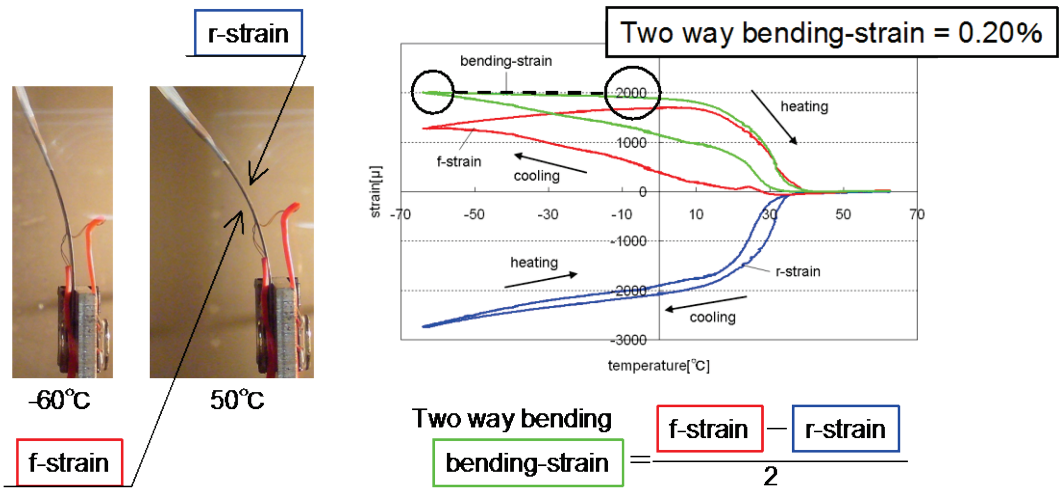


Fig.4 Experimental procedure at Temperature - Strain diagram

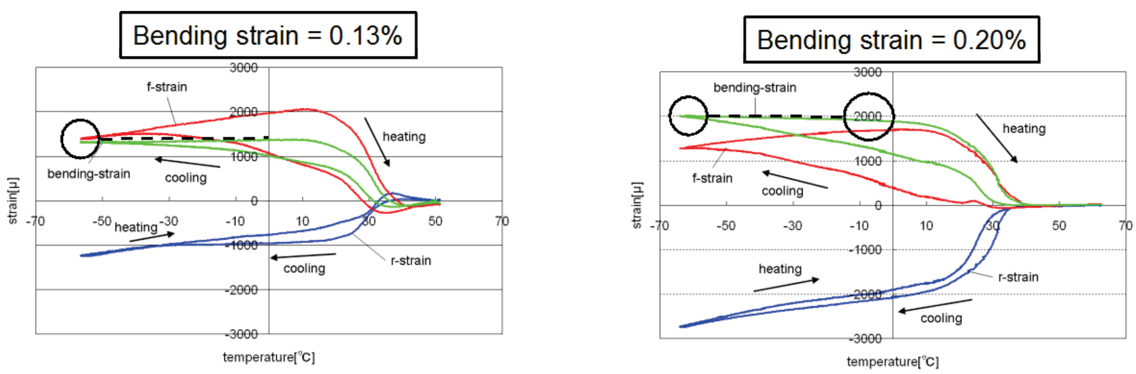


Fig.5 Comparison between room temperature USP (left) and Frozen USP (right)

Experimental Results

Two-way characteristics

In order to confirm this function, we prepared the specimen which is pasted the strain gauge on both side. After calibration at austenite phase that is 50 to 60 degree C, we measured the strain – temperature at from –60 to 60 degree C. Figure 4 shows experimental procedure.

Bending strain is determined from relationship between f-strain (peened surface) and r-strain(the opposite unpeened side) by using the above formula in Figure 4. Figure 5 shows the comparison between the effect of ultrasonic shot peening at room temperature and that at frozen temperature. As shown in this figure, we confirmed that the developed frozen shot peening shows the bigger strain with 0.2%, which is 1.5 times higher than the room temperature treatment. It is considered that the peening treatment at fully martensite phase causes the bigger compressive residual stress layer.

Fatigue characteristics of the specimens which is conducted by frozen treatment

Figure 6 shows the fatigue testing machine. As shown in this figure, the specimen is repeatedly dipped in to low temperature bath (-30 degree C) and high temperature bath at 60 degree C. Here, we used antifreeze liquid at low temperature bath. We measured the strain at each cycle, just before taking away from each bath after holding a several seconds. Traverse speed at each slider is 300mm/s and the dipping time is 30s at each bath. After several cyclic and 10,000 cyclic, we took away the specimen from the testing machine and measured the strain in order to obtain the hysteresis loop at a strain – temperature diagram by putting into the other thermostatic bath. In this thermostatic bath, the temperature is changed from –40 degree C to 60 degree C for the hysteresis loop.

Figure 7 shows the variation of strain during the fatigue test at peened side (f-strain at above definition). Here (C) means the value at cold bath with –30 degree C and H is hot bath with 60 degree C. It was confirmed that the specimens is well deformed repeatedly and the variation of strain is constantly 600 μ during entire fatigue testing(f-strain (H) at Figure 7).

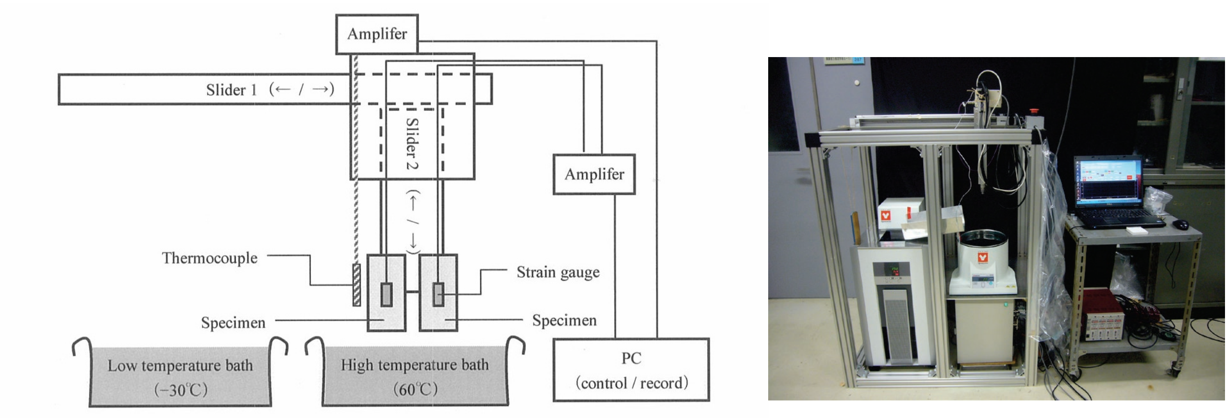


Fig.6 Schematic diagram of experimental apparatus

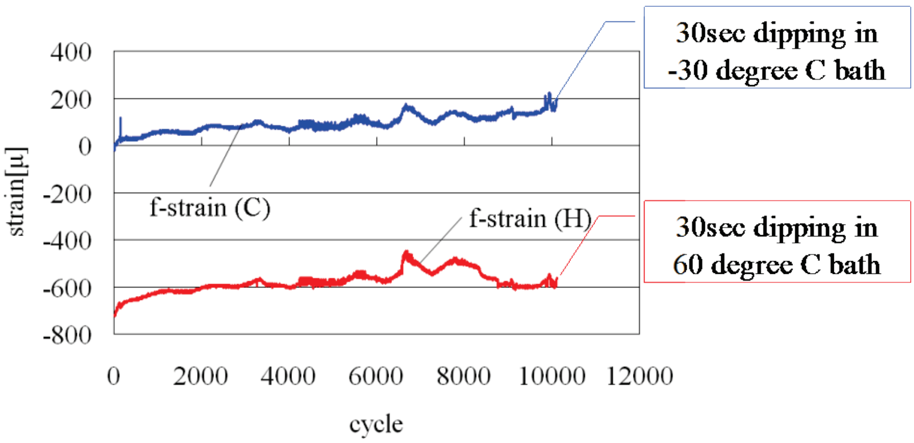
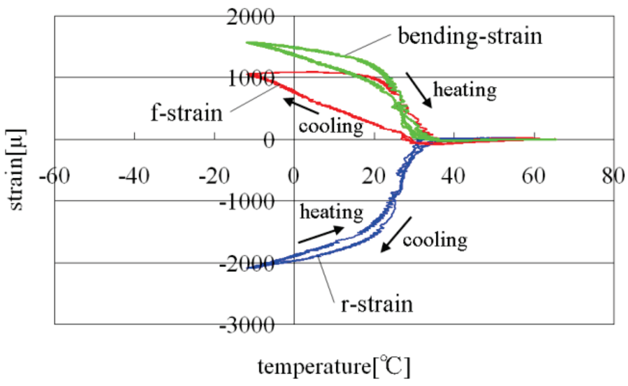
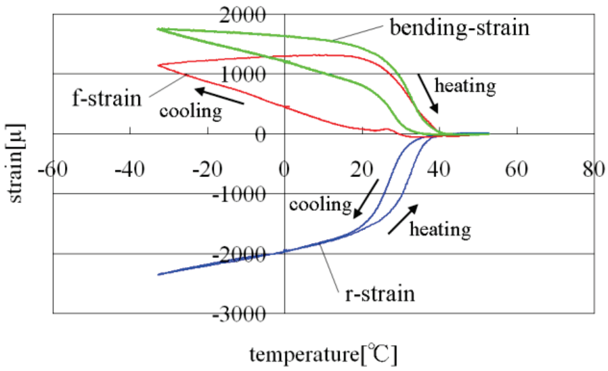


Fig.7 Strain on the ventral surface during the fatigue test

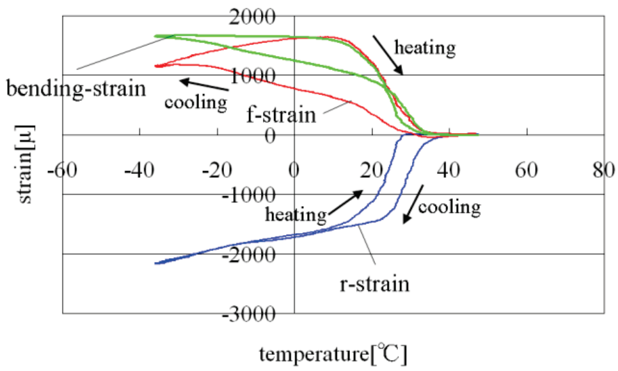
Figure 8 shows the temperature - strain diagram at each cycle, which is measured in thermostatic bath. Here, (a) is just before the fatigue test and (b) is also after a few cycles in advance to fatigue testing. (c) is just after fatigue testing. And f-strain and r-strain means the value at each side of specimen as mentioned before. And table 2 indicates the value of strain at -10 degree C and 0 degree C during the cooling process. The hysteresis loop was confirmed at each specimen at heating and cooling process. And also the shape of these loops at (b) and (c) were almost same.



(a) Before the fatigue test (1st cycle)



(b) Before the fatigue test (18th cycle)



(c) After the fatigue test (10,117th cycles)

Fig.8 Temperature and strain diagram

It was confirmed that two - way strain by shot peening treatment at 18th cycles was about 10% decreasing compared to the vale at 1st cycle. However, at comparison between 18th and 10,117th cycles, almost same strain was obtained. This results shows that the characteristic of deformation can be kept until first several cyclic deformation (like 18th cycle at this study). It is considered that shot peening treatment could improve the fatigue characteristic.

Table 2 Bending strain at each degree C

Cycle	- 10 degree C	0 degree C
1	1,567	1,366
18	1,373	1,206
10,117	1,373	1,250

Conclusions

In the present study, the frozen Ultrasonic Shot Peening treatment, Stressonic® on two – way characteristic was conducted to confirm the two-way characteristic. And the fatigue testing were conducted by bending from the deformation due to the temperature variation.
Following is a summary of the results obtained;
(1) We confirmed that the developed frozen Ultrasonic Shot Peening treatment shows the bigger strain with 0.2%, which is 1.5 times higher than the room temperature treatment. It is considered that the peening treatment at fully martensite phase causes the bigger compressive residual stress layer.
(2) Two - way strain by shot peening treatment at 18th cycles was about 10% decreasing compared to the value at 1st cycle. However, at comparison between 18th and 10,117th cycles, almost same strain was obtained. These results show that the characteristic of deformation can be kept after first several cyclic deformation. It is considered that shot peening treatment could improve the fatigue characteristic.

Acknowledgements

The authors sincerely acknowledge the encouragement and assistance given by Mr. Masaki Hayashi, Department of Aerospace Engineering, Graduate School of Engineering Nagoya University.

References

[1] Jean-Michel Duchazeaubeneix, SONATS, Proceedings of ICSP 7th, 1999, 444 – 452.
[2] Japanese Patent Application No.2009-060169
[3] Y Yoshimi, K Kitamura, Titanium Japan, Vol.54, No.4