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SMA Bar Dampers using Bending Behavior Combined with Tension or Compression

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ABSTRACT: The Numerous studies have been conducted to prevent structural damage from external forces such as earthquakes, and viscous dampers and friction dampers have been developed and applied. In this study, the shape memory alloy is processed into a bar shape to function as a damper. By using a special material called shape memory alloy, it compensates for the disadvantages of existing dampers and has the function of self-centering, which restores itself after energy dissipation. Here, we show the result of finite element analysis through ANSYS program and bending test according to dynamic tension-compression of shape memory alloy bar. Experiments were carried out separately on shape memory alloy bars with superelasticity and shape memory effect properties and found unexpected results. The shape memory alloy bars behave differently when tensioning and compressing. Until the elastic range, it is the same as the analytical value, but the behavior was different as the displacement increased. Therefore, additional experiments were carried out to clarify the cause of the difference in behavior. At the same time, shape memory alloy bars with superelasticity and shape memory effect were applied to the one damper to confirm its performance.

1 INSTRUCTION

Shape memory alloys (SMA's) are unique materials for their superelasticity and shape memory effect. These properties are determined according to the phase of SMA's. As shown in the figure 1, if the phase has a superelastic property when it has an austenite arrangement and has a shape memory effect property when it has a martensite arrangement [1-3]. In addition, SMA's could be fabricated with each state at room temperature by using characteristics of stable martensite phase at low-temperature and high-stress as opposed to austenite phase which is stable at high-temperature and low-stress[4]. Due to their special properties in the phase, they are widely studied and used in the fields of machinery, civil engineering, and medical science. However, existing studies are mainly focused on simple tension or simple compression [5], and research on bending is hard to find. In this study, we investigate the bending behavior of the SMA bar for tension and compression, and try to understand its characteristics.

Furthermore, it is intended to improve the seismic performance of the structure by developing a damper using such behavior characteristics. At present, the number of earthquakes more than 5.0 on the scale is increasing more and more, and not only the physical damage but also the loss of human life is occurring a lot. Therefore, the importance of seismic design of structures is emphasized and it is necessary to prepare for existing structures. It is economical and effective to increase the resistance against external impact such as earthquakes by installing additional dampers on the structure rather than constructing new structures.

Damper is a device that dissipates external energy, and there are various kinds such as friction damper, viscous damper, and tuned mass damper. However, the damper, which is currently in the spotlight, is a smart damper that has restoration and self-centering ability to return to its original state after device operation. Therefore, the objective of this research is to develop and manufacture a damper that utilizes the nature of returning to the original state of SMA.

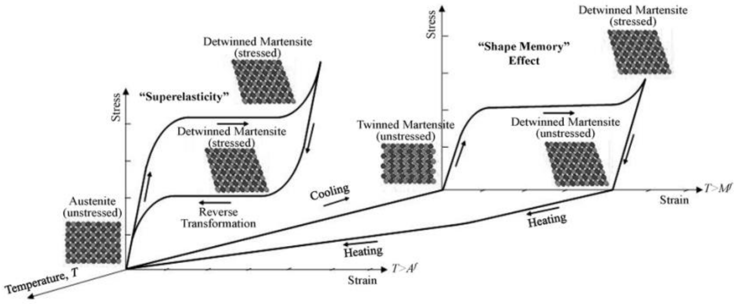


Figure 1. Characteristic of shape memory alloys

2 EXPERIMENT

2.1 Test apparatus

The test was conducted with universal testing machine (UTM) at the Advanced construction materials testing center at Keimyung university. After mounting the SMA bar as shown in the figure 2, snap both jigs to the UTM. In this case, it is important to balance the horizontal and vertical equilibrium. In order to reduce the visual error, we used a laser leveler to adjust the vertical direction between the damper and the experimental equipment.

Figure 2. Bending Test Setup

2.2 Fabrication of specimens

The SMA bars used in this test are the most commonly used nickel-titanium (NiTi) alloys. The bars are 270mm in length and 20mm in diameter. In order to give the stress concentration to the center of the bar, it was processed into dumbbell shape as shown in the figure 3.

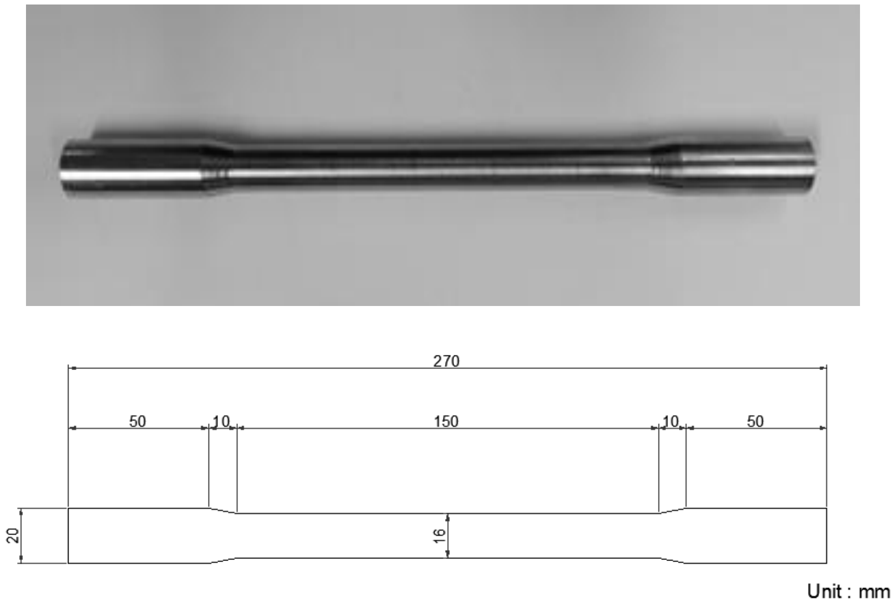


Figure 3. Specimen and plane drawing

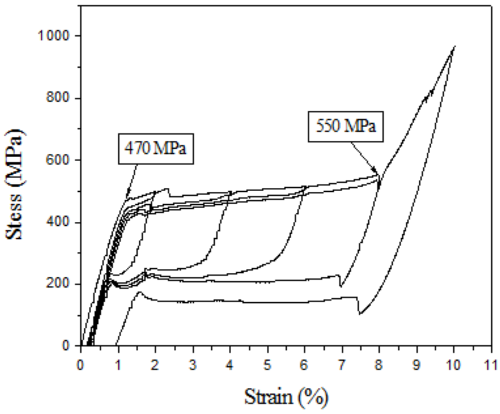
2.3 Material properties

2.3.1 Superelasticity

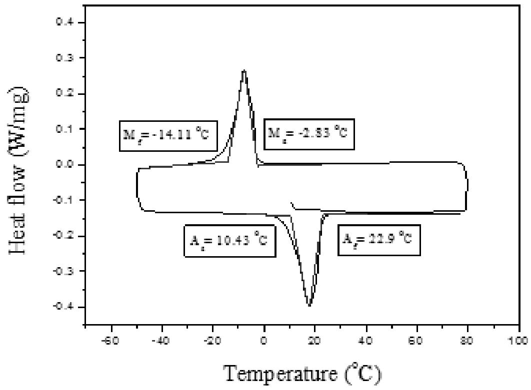
SMA wire with the same condition was also fabricated to investigate the properties of the superelastic SMA bar with the Austenite phase. Through the hysteretic curve of the wire, we could find not only the elastic modulus and the Poisson's ratio, but also the state transition range according to the stress for SMA property analysis. These allow you to plan the load and displacement range required for the test and program analysis. In the graph of figure 4 (a), it can be seen that the elastic section up to 470 MPa, the transition section between 470 ~ 550 MPa, and the plastic section after 550 MPa can be understood. It is also confirmed that residual strain occurs when the strain reaches 8%.

2.3.2 Shape memory effect

The properties of SMA bar with martensite phase were investigated by differential scanning calorimetry (DSC) test. In the case of SMA alloy with shape memory effect, it is necessary to catch the point of the phase change according to temperature. Through this test, martensite SMA bar used in this study is $M_s = -2.83℃$, $M_f = -14.11℃$, $A_s = 10.43℃$, $A_f = 22.9℃$



(a) Hysteretic stress-strain curve



(b) Differential scanning calorimetry test

Figure 4. Base test for understanding of properties with SMA wires

2.4 Design of jigs

As shown in the figure 5, the design of the jig is designed to be suitable for bracing the steel frame. The body of the jig is 60mm in width, 65mm in length, 130mm in height, and consists of a Y-shaped handle of 225mm in length that connects the body to the UMT. In addition, a 20mm hole is now drilled in the body of the jig to fit the SMA bar, and it is designed to be inserted up to 50mm. The lower bolts are used to fix the SMA bar.

The material property of the jig was steel called A193 Gr.2H at ASTM with a yield strength of 490MPa, a tensile strength of 686MPa and a hardness of 201 ~ 269MPa so that no deformation was caused by the bending stress of the SMA bars.

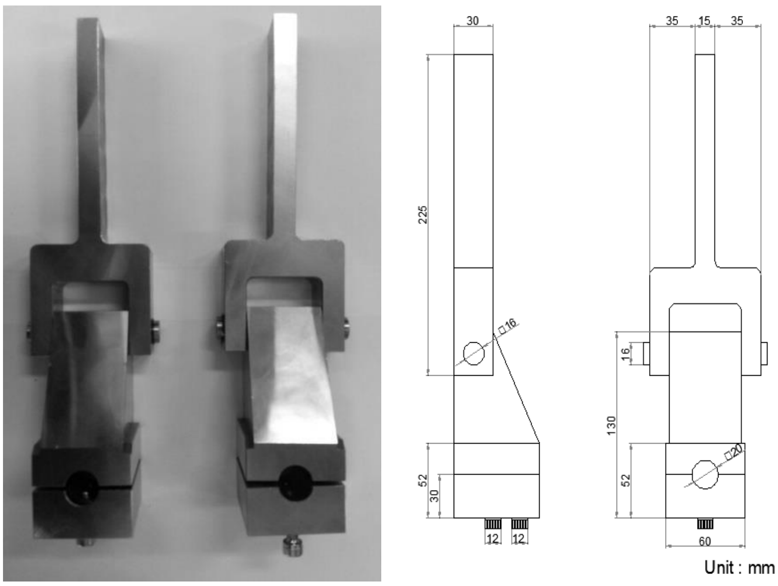


Figure 5. Experimental jig and its plane drawing

3 TEST METHOD

A total of three type tests were carried out. All the tests were carried out by repeating cycle loading and unloading, not monotonic. The displacement control was performed by calculating the strain on the entire length of the specimen, and repeatedly testing with 3 to 5 cycles for each displacement. The velocity of the load was adjusted to 1 mm/min for precise observation of the behavior, and the strain gage was attached to the bent portion at the center of the specimen and the portion perpendicular to the specimen to confirm the strain against the specimen bending.

The first test is a bending test through a simple tensile test of SMA bars with austenite phase and martensite phase at room temperature. Since the bending through simple tension and simple compression shows the same behavior characteristics and only the sign of load changes. So bending test through simple tension was performed.

The second test is the fatigue test of SMA bars with austenite phase. Fatigue tests were carried out for deflection at a displacement of 10 mm. The load velocities were measured at 1Hz and 1.2Hz, and the test was performed at the maximum velocity of the experimental apparatus according to the displacement.

The last test is the bending test of SMA bars with austenite phase and martensite phase under tension and compression. The conditions were adjusted as in the first test.

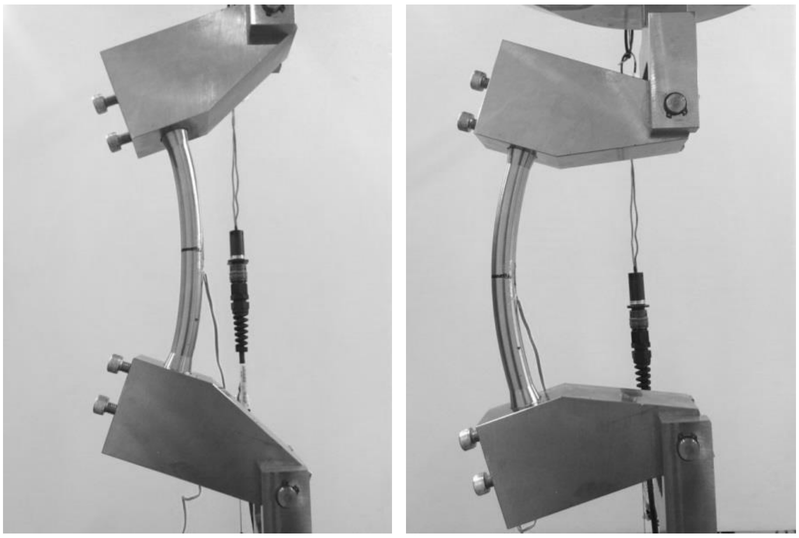


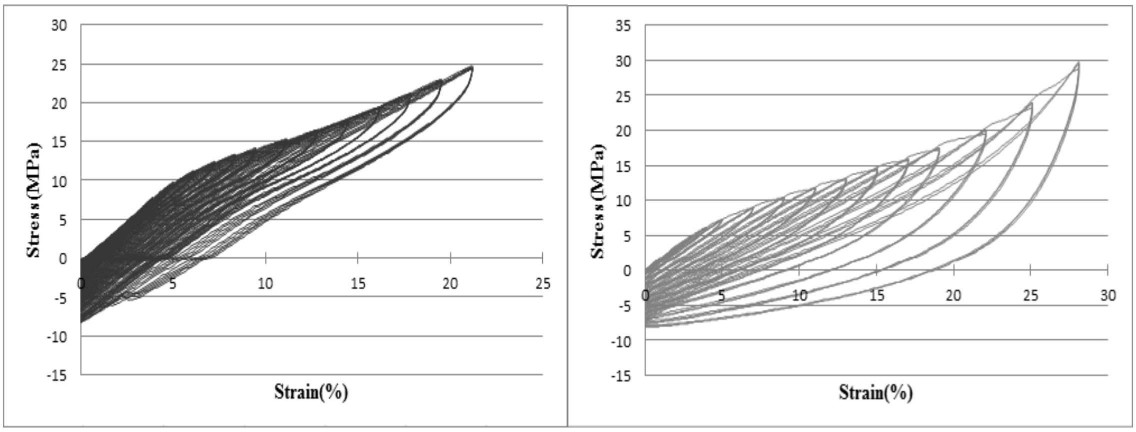
Figure 6. Bending of specimen in tension and compression

4 RESULTS

4.1 Bending tests through simple tension

First, the test was conducted to investigate the bending behavior of SMA bar for simple tension and simple compression. Figure 7 (a) is the superelastic SMA bar, and the displacement is measured up to 20% strain on the specimen length. The behavior of bending is similar to that of SMA, which is often expected. The test is carried out up to 20% of the strain and it is seen that residual strain is left because it passed the elastic section. The bending stress at 20% strain was measured to be 24.3 MPa. Figure 7 (b) is the SMA bar with shape memory effect, and the test is performed to the displacement corresponding to the strain of the specimen length of 28%.

Similar to steel, residual deformation remains, but when heated, it is restored to its original state. The bending stress at 28% strain was 29.7 MPa.



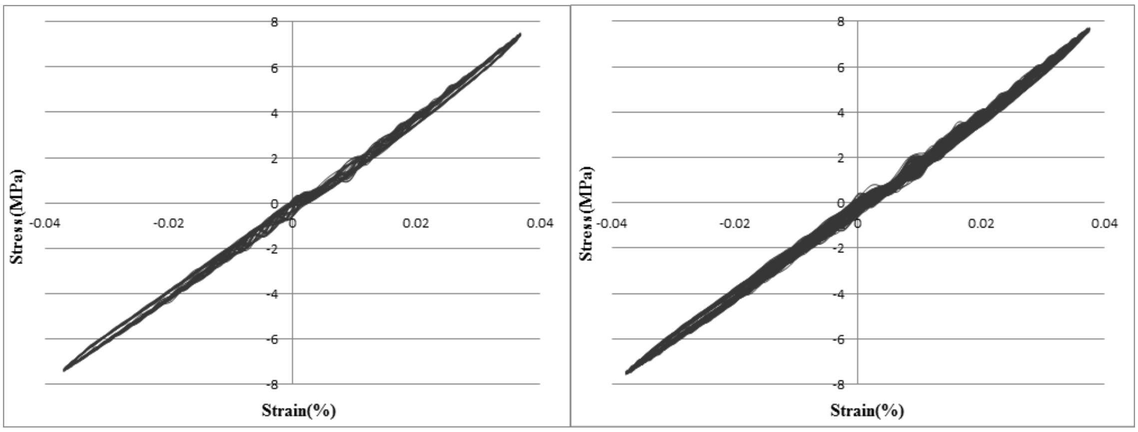
(a) Superelastic SMA bar (b) SMA bar of shape memory effect

Figure 7. Stress-strain curve about SMA bar of austenite phase (a) and martensite phase (b)

4.2 Fatigue tests of superelastic SMA bar

Secondly, fatigue test of superelastic sma bar was performed. The test was carried out with a displacement of ± 10 mm in 300 cycles at speeds of 1 Hz and 1.2 Hz. The fatigue test at a speed of 1 Hz can be seen in figure 8 (a), and it can be seen that the residual hardly occurs. Figure 8 (b) shows a slight increase in speed and a test at 1.2 Hz.

It was found that the SMA bar is suitable as a damper that should withstand frequent external loads.

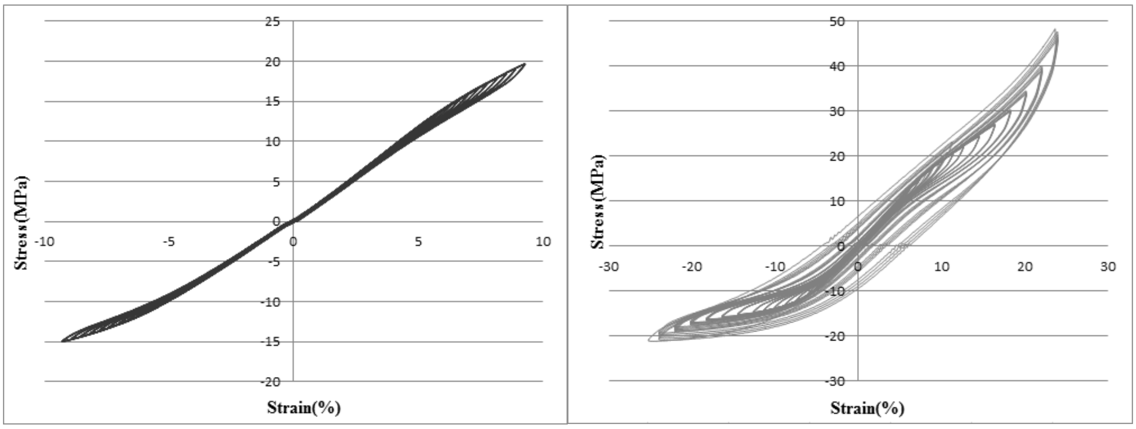


(a) Test of 1Hz (b) Test of 1.2Hz

Figure 8. Fatigue test of Superelastic SMA bar

4.3 Bending tests through tension and compression

The final test was a bending test with tension and compression. In the elastic section, it shows that the energy loss effect is small, but it is completely restored after the deformation In Figure 9 (a). In this time, the maximum bending stress was 19.6 MPa. On the other hand, Figure 9 (b) is the stress-strain curve that was tested until the superelastic SMA bar was broken. The energy loss effect is larger in comparison with the previous test, but the stress exceeding the elastic section is generated, and residual strain remains. Unusual is the difference about 27.4 MPa between the bending stress at tension and the bending stress at compression. In tension and compression, the graph shows symmetric, whereas the bending test is not symmetric. The martensite SMA bar shows a remarkable difference about 36.1MPa.



(a) Bending in the elastic section (b) Bending until plastic section

Figure 9. Stress-strain curve of the superelastic SMA bar

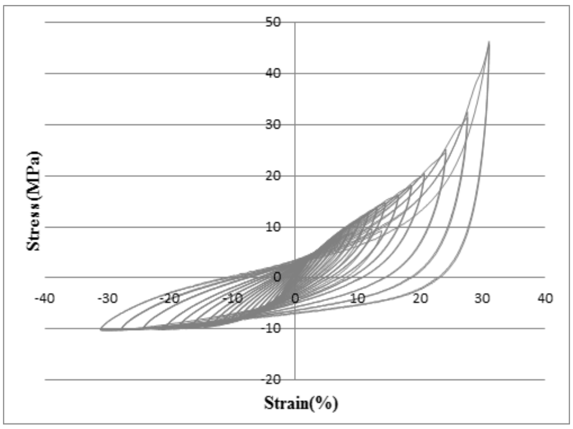
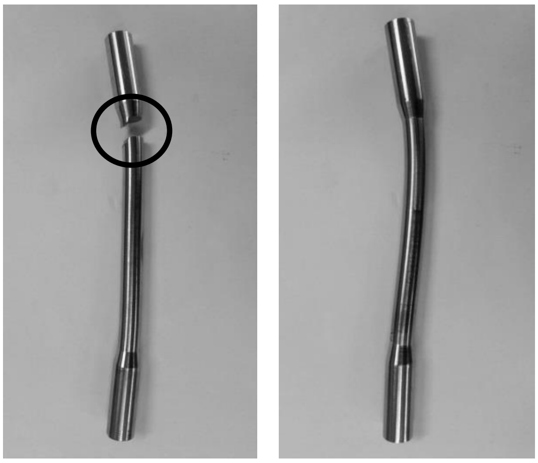


Figure 10. Stress-strain curve of the SMA bar with shape memory effect



(a) (b)

Figure 11. The specimens of the end of bending tests : (a) superelastic; (b) shape memory effect

5 CONCLUSIONS

What we found in this test is that the SMA bar is not symmetric in bending behavior under tension and compression. It was different from the expectation that it would behave in the same shape as the bending behavior when subjected to simple tensile and simple compression. When the tensile stress is applied first, the bending stress at the compression is 21.1 MPa, compared with 48.2 MPa at the tensile stress. This was the same not only in the austenite phase but also in the martensite phase. This should be considered by anyone using the SMA bar.

From the fatigue test, it can be seen that there is no problem even if the behavior of returning to the original state is repeated rapidly when the load is removed from the austenite phase. This means that when the SMA bar is applied to the structure as a damper, the damper will not be damaged even if the external load is continuously supplied.

In the future, further experiments will reveal the difference in bending behavior between tension and compression, and we will develop a damper using SMA bar by analyzing its properties.

6 REFERENCES

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