Damping device having self-centering capacity using SMA rings

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ABSTRACT: This study introduces the use of SMA rings as self-centering and damping devices. Cyclic tests on single and dual rings systems have been conducted. Both superelasticity (SE) and martensitic (MA) SMA have been used to manufacture SMA rings. Based on the use of SMA and number of rings, five specimens have been named as follow: single superelasticity ring (SE), single martensitic SMA ring (MA), two superelastic SMA rings (SE-SE), two martensitic SMA rings (MA-MA), and martensitic-superelastic SMA rings (MA-SE). Experimental results show that the dual rings systems show perfect symmetrical behaviors. The damping capacity has been investigated through a damping ratio. Experimental results show that it is recommended to use MA in SMA rings system if the damping capacity is a priority. On the basis of a displacement recovery ratio (DRR), the self-centering capacity of SMA ring systems has been investigated. It is believed that the use of SE in SMA rings systems could provide higher self-centering capacity in comparing to MA SMA. In order to provide a symmetrical behavior, it is supposed to use dual SMA rings systems or 2 rings at symmetrical structures.

1 INTRODUCTION

Shape memory alloys (SMAs) have been utilized as promising materials to enhance the seismic performance of civil structures due to their unique characteristics, such as the ability to recover from high applied strain. Recently, SMA bars and rings have been utilized as a self-centering devices and dampers. Although the device using SMA bars was simple, it could not be used in compression due to the buckling problem. The SMA bar was under pure bending without any existing of compression or tension, showed symmetric behavior. In the case, the SMA bars showed non-symmetric behavior when they were exposed to compression because of p-delta effect. With the use of SMA rings, self-centering device or damper could be used for both pushing and pulling actions without any concern regarding buckling. The use of SMA rings in civil structures has been investigated in various studies. For example, SMA rings used to enhance seismic performance of concrete columns and connect ultrahigh-vacuum pipes. Also SMA ring system for a bracing system of steel frame to control its side sway and provide self-centering capacity. This study aimed to investigate the behavior of single and dual SMA rings under the combination of bending and tension or compression and to examine their symmetrical behaviors, damping, and self-centering capacity.

2 EXPERIMENT

2.1 *Properties of SMA rings*

The martensitic SMA (MA) showed the shape memory effect, which is recovering its strain during heating. Because of the thermoelastic characteristic, martensitic SMA can change its shape depending on temperature. Another specific characteristic of SMA is superelasticity (SE). With SE SMA, recovery from deformation occurs during unloading process.

The SMA ring has a thickness of 10 mm, and outer and inner diameters are 80 mm and 60 mm. Seven specimens were manufactured and the detail of them were showed in Table 1. Two types of SMA ring systems, namely, single and dual rings systems, were investigated. The specimens were named based on the use of superelastic or martensitic SMA, and combinations of them.

Table 1. Test specimens

ID	Outer diameters (mm)	Thickness (mm)	Types of SMA	Single or Dual	No. of specimens
SE	80	10	Superelastic	Single	2
MA	80	10	Martensite	Single	1
SE-SE	80	10	Superelastic	Dual	2
MA-MA	80	10	Martensite	Dual	1
MA-SE	80	10	Martensite, Superelastic	Dual	1

2.2 *Test set up procedure*

Experiments were conducted with quasi-static displacement control at a speed of 1 mm/sec. One cycle load was completed when the pulling and pushing actions were completed and all of the load was released. The rings first were tested under a pulling action, which was outward from the ring. The loading displacement was 1.6 mm, which was 2% of the outer diameter of the ring. Then, the displacement was reversed in pushing action until 2% displacement was reached. Then, the displacement was increased for each cycle until the rings were failed.
After completing the tests, the martensitic SMA rings still remained with deformed shapes since they did not recover the deformation without heating.
However, the superelastic SMA rings recovered partially the deformation.

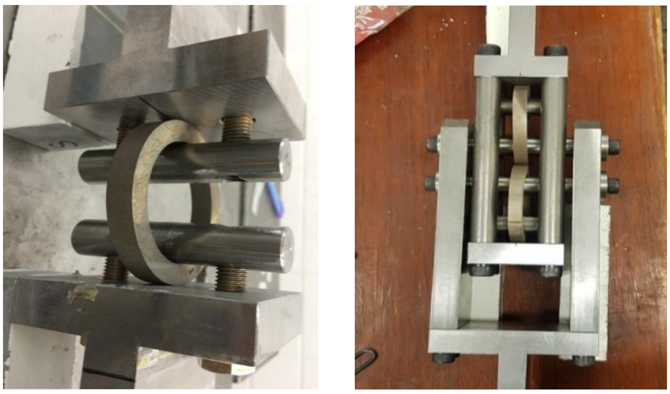

Figure 1. Damping devices.

3 RESULTS AND DISCUSIIONS

3.1 Cyclic behaviors of single ring systems

The MA ring showed hardening behavior in the pushing action although the behavior is not perfectly symmetric. SE ring show almost similar hardening behavior in pulling and pushing actions, and the hardening started at the displacement of 1.5mm that is 1.875% of the outer diameter. The SE ring showed initial stiffness of 4.75 kN/mm, and the hardening stiffnesses in pulling and pushing actions were 1.3 and 1.1 kN/mm, respectively. Thus, the hardening stiffness ratio of the SE ring is 1.18; this means that the hardening in pulling action is just larger by 18% than that in the pushing action. The SE ring shows the more symmetrical behavior in pulling and pushing actions.

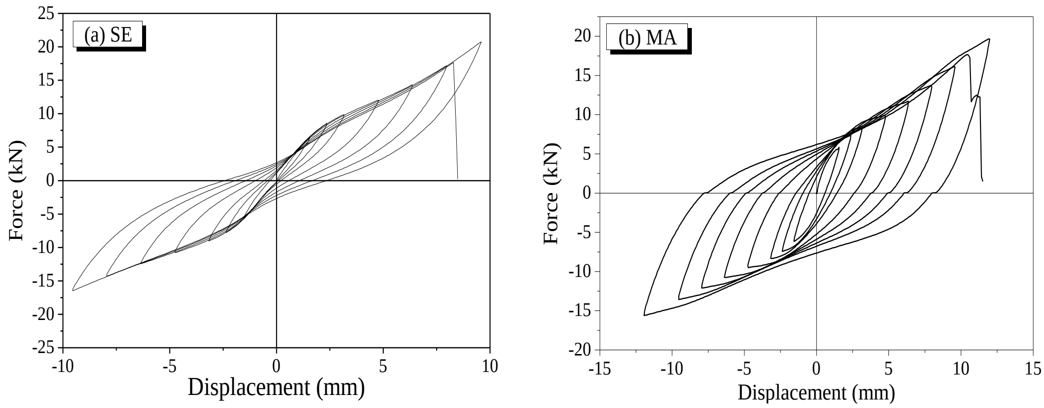

Figure 2. Cyclic behaviors of SMA single ring.

3.2 Cyclic behaviors of dual ring systems

For the SE-SE dual ring systems shown the initial stiffness is 7.2 kN/mm, which is consisted of the stiffnesses of the two rings. However, the value of 7.2 kN/mm is smaller than the twice of the initial stiffness of 4.75 kN/mm of the single SE SMA ring. However, the hardening force in pulling action is 12.4 kN at 1.89 mm displacement, which is almost twice of 6.4 kN of the single SE ring at 1.67 mm displacement. The hardening stiffness in pulling action is 2.7 kN/mm between 3 and 5 mm displacement, and the corresponding one in pushing action is 2.78 kN/mm; thus, the hardening stiffness ratio of this case is 0.97. Therefore, it is found that the SE dual ring system showed almost perfect symmetric behavior in pulling and pushing actions. The dual ring systems of the MA-MA also showed symmetric behavior, and its hardening stiffnesses in pulling and pushing actions are 2.43 and 2.27 kN/mm. For the hybrid combination of the SE-MA dual ring system, the hardening stiffnesses are 2.41 and 2.45 kN/mm in the both actions.

The noticeable observation on the MA-MA dual ring system is that pinching occurred from small displacement. The early pinching is mainly caused from initial gap between the two rings when they were set up. In addition, the pinching increased with large unrecovered deformation of the two MA rings. The pinching is observed in the MA-SE dual ring system because of the same causes. Meanwhile, the pinching is also observed in the behavior of dual SE rings. However, the pinching of the SE-SE rings is relatively small comparing with the pinching of MA-MA or MA-SE dual rings since the superelastic SMA rings remain relatively small unrecovered deformation compared with the martensitic SMA rings.

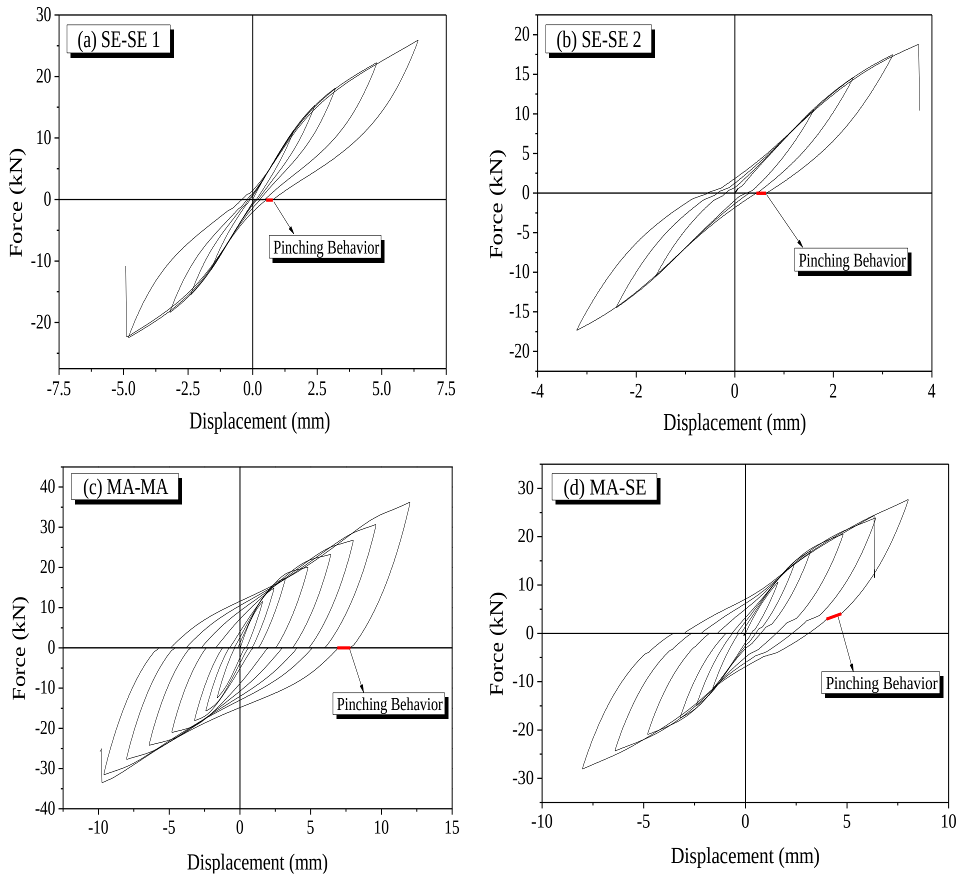

Figure 3. Cyclic behaviors of SMA dual rings.

3.3 Damping capacity

The SMA ring devices showed hysteretic behavior and, thus, they can provide energy dissipation capacity, which is generally expressed using damping ratio. To investigate the damping capacity of the ring systems, the following damping ratio (ξ) equation was utilized:

$$\xi = \frac{E_d}{4\pi E_e} \tag{1}$$

Where E_d is the dissipated energy, and E_e is the elastic energy stored in the SMA rings.

Figure 4(a). shows a comparison of the dissipated energy provided by the single ring systems of SE and MA SMA. As expected, the MA SMA ring showed great energy dissipation. Furthermore, the energy dissipation increased with increasing displacement. However, the figure of MA ring shows more rapid increase than that of SE SMA. In term of damping ratio, as shown in Figure 4(b), the MA SMA ring provided higher damping ratio than the SE SMA ring.

For the MA SMA ring, the maximum damping ratio is 25% at the displacement of 5 mm, and the corresponding value of the SE SMA ring is12% at 7 mm displacement. Based on the maximum damping ratio, the MA SMA ring showed twice damping ratio of the SE SMA ring.

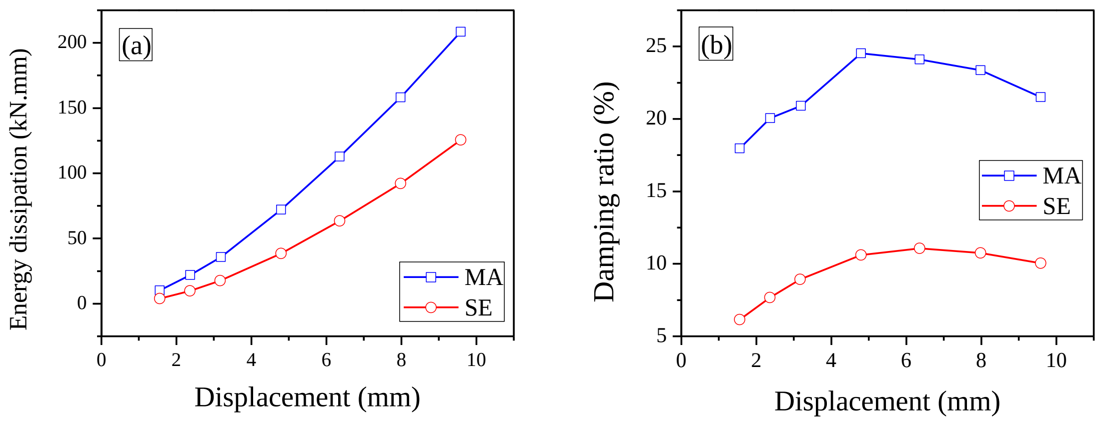

Figure 4. Energy dissipation and damping ratio of single SMA ring.

The MA-MA SMA rings provided the greatest energy dissipation as well as damping ratio among three dual rings systems, while the SE-SE SMA rings provided the lowest energy dissipation and damping ratio. The energy dissipation increased with increasing displacement. For damping ratio, the ratio of SE-SE increased until system failure, while the values of the other specimens increased sharply until displacement reached a specific value. . The maximum damping ratio of the MA-MA device is 25% at 6 mm displacement, and the MA-SE device showed 15% damping ratio at the same displacement. Thus, it is noted that the characteristic of damping is dominated by the MA SMA ring. For the SE-SE device, the maximum damping ratio is 8% at 5 mm displacement.

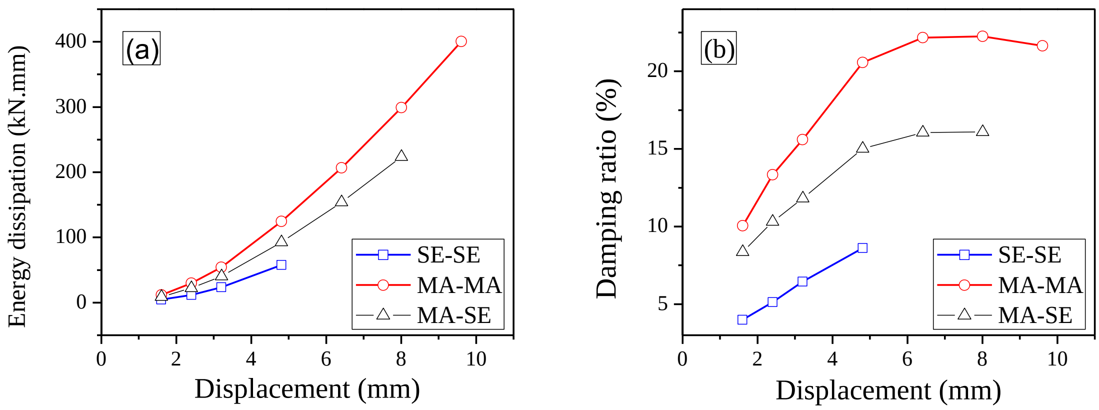

Figure 5. Energy dissipation and damping ratio of dual SMA ring systems.

3.4 *Self-centering capacity*

The self-centering capacity of the SMA rings was investigated through the displacement recovery ratio (DRR), which is the percentage of recovered displacement to applied displacement that occurred for each loading cycle.

The SE SMA ring showed almost perfect self-centering capacity in pulling at the initial cycle as the DRR reached up to 97%. Then, the value decreases sharply as the displacement increased. The MA SMA ring showed similar self-centering capacity in both pulling and pushing actions as the DRRs were almost equal under same cycle load. The maximum DDR of the MA SMA ring is 65% at the initial cycle. The DRRs of MA SMA ring were lower than those of the SE SMA ring at any displacement. Also the SE-SE rings showed the highest DRR among the three systems, while the MA-MA system showed the lowest DRR at a same displacement.
It is found that the SE-SE dual ring system improved symmetric behavior as well as self-centering capacity comparing with the single SE ring system. The MA-MA SMA rings showed relatively low DRRs beyond the displacement of 4 mm since the transformation started at the displacement, and the residual deformation remained.

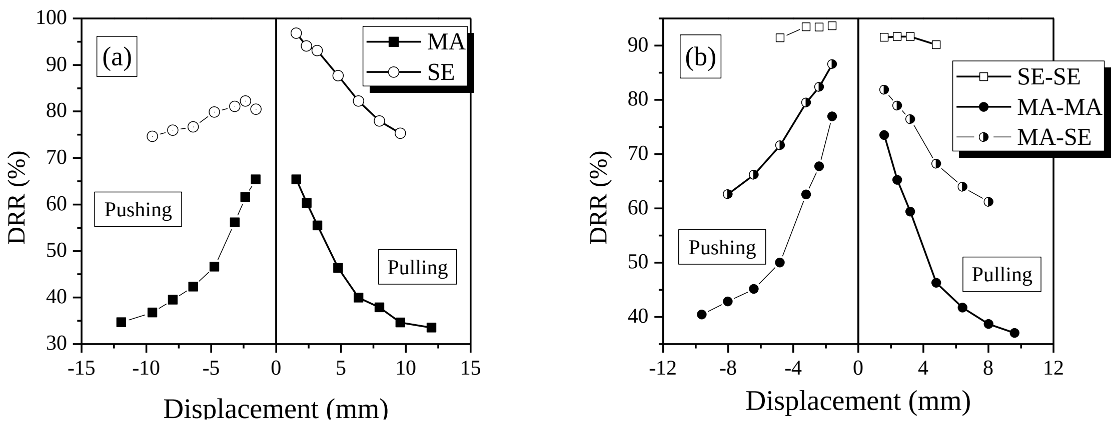

Figure 6. Displacement recovery ratio(DRR) of SMA ring systems.

4 CONCLUSION

SMA rings were investigated in this study for application as new damping or self-centering devices. The results showed that the dual SMA rings showed better symmetrical behavior in comparison to the single ring. Therefore, the dual rings system or the use of two rings should be used in structures which require the symmetrical behaviors. The single MA SMA ring shows higher dissipated energy and damping ratio in compared to the single SE SMA ring. In terms of dual rings, the use of MA ring increases the damping ratio while the use of 2 SE SMA rings provides a lowest damping capacity among dual specimens. Overall, the superelasticity SMA ring showed perfect self-centering capacity while the martensitic SMA ring provided high dissipation energy and damping ratio. Therefore, it was recommended to use SE SMA rings when providing the self-centering capacity is a priority. Whereas, when the requirement of damping capacity is more priority, the use of MA SMA is recommended. Finally, the use of MA-SE SMA rings systems could balance the self-centering and damping capacities.

5 REFERENCES

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