Experimental study on self-reset properties of RC beams with different proportions of SMA wires

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Abstract: In order to explore the influence of SMA concrete beams with different proportions of SMA wires (unidirectional memory and hyperelastic) on the bearing capacity, five SMA concrete beams were made in this experiment. Twelve SMA wires with a diameter of 1mm were placed in the tensile zone of beams, which were reinforced according to different proportions of SMA. The experimental results show that: Within the range of 0-10kN (25% of the ultimate load of beams), the concrete beams with 70% hyperelastic SMA and 30% unidirectional memory SMA has the best stiffness. But in general, the concrete beams with 30% hyperelastic SMA and 70% unidirectional memory SMA has the best stiffness; After the first load, the concrete beams strengthened by SMA wires were heated to make the unidirectional memory SMA wires in the beams recover the deformation, and the second load was carried out. The results show that the beams bearing capacity can be improved when the SMA wires recover deformation after heating. The higher the SMA of unidirectional memory, the improvement of load bearing becomes better. However, it is necessary to adjust the proportion of the unidirectional memory SMA wires and the hyperelastic SMA wires to achieve the best effect on the stiffness and resilience of the beam.

1. Introduction

Shape memory alloy (SMA) is an alloy material which can eliminate the deformation and restore the original shape before the deformation after heating up, which is the alloy with "memory" effect. In architectural structure, SMA has two characteristics, one is the shape memory effect and the other is generating large driving force to repair the cracks that have been created.

The unidirectional memory of SMA refers to that the shape of SMA can be restored after being deformed at a lower temperature after heating. The phenomenon of shape memory which only exists in the heating process is called unidirectional memory effect. Hyperelasticity of SMA refers to the alloy at higher temperature exceeds the elastic limit stress under the action of external force and induces material transformation. The stress continues to increase and the deformation also occurs. When the stress is reduced, the phase transition is reversed and disappears permanently.

Domestic and foreign scholars have carried out many experiments for the above two characteristics, Sun Li [1] applied prestress to SMA with the pretensioning method, and then embedded SMA as main reinforcement in concrete. The experimental results showed that the greater the prestress, the repair effect becomes better; Xue Weichen [2] used SMA as external prestressing reinforcement and placed...
it outside the reinforced concrete beams. The results show that the deformation and crack of concrete beam can be effectively controlled by controlling the temperature of SMA. Cui Di [3] applied post-tension to the SMA and loaded the test beams. The results show that prestressing the SMA can improve the cracking load and bearing capacity of beams.

The current tests [4-7] show that SMA can improve the bearing capacity. However, there are relatively few studies on the placement of different proportions of SMA wires concrete beams in the tensile zone. Therefore, this paper combines unidirectional memory SMA and hyperelastic SMA in five proportions, and carries out three-point loading tests on beams. Through the tests, the bearing capacity of SMA concrete beams with different proportions of unidirectional memory SMA and hyperelastic SMA is obtained, and explore which proportion is most beneficial to the configuration of the beams.

2. Experiment design

2.1. Component design
In this experiment, 5 reinforced concrete specimens were produced, numbered from L1 to L5, with geometric dimensions of 400 mm× 100 mm× 100 mm. Two φ6 tension longitudinal bars were set on the bottom of the beam, and two φ6 vertical bars in the upper compression zone. The concrete protective layer is 20 mm thick. Parameter changes of the specimen are the proportional combination of unidirectional memory SMA and hyperelastic SMA. The detailed configuration of the beam is shown in Table 1, and the structure of the specimen is shown in Figure 1.

![Figure 1 The detailed dimensions and construction of the test piece](image)

| No. | SMA proportion |
|-----|----------------|
|     | unidirectional memory SMA | hyperelastic SMA |
| L1  | 100%            | 0%             |
| L2  | 0%              | 100%           |
| L3  | 50%             | 50%            |
| L4  | 70%             | 30%            |
| L5  | 30%             | 70%            |

2.2. Experimental materials
The concrete design strength value is C20, the mix ratio is 0.175:0.343:0.621:1.261. In the test, Ni-Ti shape memory alloy wire was used, with a diameter of 1mm, the tensile strength of SMA is $R_m=40.3$ MPa, the average yield strength is $f_y=450$ MPa.

2.3. Experience plan
The RC beam flexural performance test adopts three-point symmetrical static loading. The loading device adopts 200 tons of pressure machine to load uniformly along the width direction of the mid-span. During the test, a 4 cm solid steel pipe was set at the center of the test beam in order to
transmit the line load. After resetting the instrument to zero, it is officially loaded. When the loading load reaches 40% (22kN) of the ultimate load of the beam, the loading is stopped and the test ends. After loading, four beams L1, L3-L5 containing unidirectional memory SMA were heated for 20min, and the second loading test was carried out. The loading method was the same as the first test.

3. Test results and analysis

3.1. Test result and failure mode

Although the stiffness of the five beams is different, the crack generation time is similar. Cracks are generated when the load is 4.5s, and the load at this time is 13.5kN. However, the failure modes of the five beams are different, as shown in Figure 2.

![Figure 2. Failure mode of beam](image)

3.2. Mid-span deflection

3.2.1. The first loading experiment.

As shown in Figure. 3, in the range of 0-5kN (10% of the ultimate load of the beam), the curves of L4 and L5 beams grow synchronously. In this stage, when the loading loads are the same, the displacement of L4 and L5 are less than those of L1-L3 beams, indicating that the rigidity of L4 and L5 beams in this stage is better and the ability to resist deformation is stronger. In the range of 5kN-10kN (25% of the ultimate load of the beam), the curve of L2 beam grows rapidly, and when the load reaches 8kN, the curve of L2 basically coincidences with that of L4 and L5, indicating that the stiffness of L2, L4 and L5 beams is much better than that of L1 and L3 beams in this stage. It can be found that the deformation of L5 beam is slightly smaller than that of L4 beam in the range of 0-10kN. In the range of 10kN-22kN (40% of the ultimate load of the beam), the curve of L4 beam grows faster. When the load reaches 15kN, the stiffness of L2 beam is obviously better than that of L4 beam. As can be seen from the image of the whole process, the optimal proportion of SMA of concrete beams varies in different load ranges. In the range of 0-10kN (25% of the ultimate load of the beam), the concrete beam with 70% hyperelastic SMA and 30% unidirectional memory SMA has the best stiffness, but in general, the concrete beam with 30% hyperelastic SMA and 70% unidirectional memory SMA has the best stiffness. Concrete beams with 50% hyperelastic SMA and 50% unidirectional memory SMA have the worst stiffness.
3.2.2. The second loading experiment.

After heating, the beam was loaded again, and the loading method was the same as the first loading.

As shown in Figure. 4(a), for L1 beam, within the range of 0-2KN, the curves of the first load and the second load are basically the same, but within the range of 2KN-22KN, the curves of L1 beam under the second load rise sharply. The results show that the bearing capacity of L1 beam is significantly improved after heating.

As shown in Figure.4(b), in the two loading tests of L3 beam, when the loading loads were the same, the displacement generated in the second test was far less than that generated in the first test. The results show that the bearing capacity and deformation resistance of the L3 beam are greatly improved after heating.

Comparison between Figure. 4(c) and Figure. 4(d) shows that the trends presented in the two figures are roughly the same: within the range of 0-5kN, the change trends of the curves of the first load and the second load are basically the same. In the range of 5kN-10kN, the bearing capacity of the concrete beam after heating has a slight increase, but in the range of 10kN-17.5kN, the bearing capacity of the concrete beam after heating is weaker than the concrete beam without heating. In the range of 17.5 kN to 22 kN, the bearing capacity of the concrete beam after heating is slightly better than that of the concrete without heating. Such a result may be due to the small proportion of unidirectional memory SMA in L4 and L5 beams, and the driving force generated after heating is not enough to significantly improve the bearing capacity of beams.

According to the above conclusion, the bearing capacity of the beams can be improved after heating the loaded SMA beams.
As shown in the Figure 5, by comparing the load displacement curves of L1, L3, L4 and L5 under the second loading, it can be seen that the bearing capacity of L1 beam after heating is the best, followed by L4 and L3, and L5 is the worst. The improvement range depends on the number of unidirectional memory SMA in the beam. The higher the SMA of unidirectional memory, the improvement of load bearing becomes better.

4. Conclusion
(1) The optimal proportion of SMA of concrete beams varies in different load ranges. In the range of 0-10kN (25% of the ultimate load of the beam), the concrete beam with 70% hyperelastic SMA and 30% unidirectional memory SMA has the best stiffness, but in general, the concrete beam with 30% hyperelastic SMA and 70% unidirectional memory SMA has the best stiffness.

(2) The deformation of the SMA wires in the beams can be recovered after heating, and the bearing capacity of the beam can be improved. The higher the SMA of unidirectional memory, the improvement of load bearing becomes better. However, it is necessary to adjust the proportion of the unidirectional memory SMA wires and the hyperelastic SMA wires to achieve the best effect on the stiffness and resilience of the beam.

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