Study on mechanical properties of SMA silk

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Abstract Bond-slip constitutive relation between shape memory alloy wires and concrete is a comprehensive reflection of the bonding properties and it is relevant to crack width, plastic hinge rotation capacity, shear failure and theory analysis of nonlinear finite element. It has important significance of the numerical model of bond-slip of shape memory alloy concrete structure to the theoretical analysis and actual design. However, it is still in the exploratory stage of the constitutive relation between these two materials at home and abroad. This paper made the following research: Mechanics performance test of SMA. Differential scanning calorimetry test were used to get the heat transfer rate and temperature relationship diagram of the SMA wires, so the phase transition temperature of SMA was determined. On the basis of this, pull-out test was carried on to know the mechanical properties of the SMA wires.

1. Introduction
The Differential Scanning Calorimeter (DSC) was performed on the ni-ti alloy wire, and the relation between the thermal flux and the temperature of the alloy wire was obtained, so as to determine the phase change temperature of the material. In order to ensure that there is no interference of other factors in the test, the alloy wire must be heat treated before the test to ensure the stability of the alloy wire. Due to the bond slip in this experiment, it is necessary to pull out the wire, so it is necessary to conduct tensile test on the alloy wire and obtain the stress-strain relationship curve, so as to have a more comprehensive understanding of the properties of the alloy wire used in this experiment.

2. DSC test of Ni-Ti alloy wire
Differential Scanning Calorimetry (DSC) is a more accurate method to determine the phase transition temperature of synthetic silk. It is a thermal analysis method to measure the relationship between the power difference between the input sample and the reference material and the temperature under program-controlled temperature conditions. Differential scanning calorimetry (DSC) was developed to indirectly express the change of heat (endothermic and exothermic) in the process of physical or chemical changes of an object in terms of the change of temperature difference (ΔT), and it was difficult to make quantitative analysis due to many factors affecting the curve of DSC. Differential scanning calorimetry and the application of differential thermal analysis function has many similarities, but as a result of differential scanning calorimetric method overcame the differential thermal analysis method to indirect express the defect of material heating, has advantages of high resolution, high sensitivity, and therefore able to quantitative determination of a variety of thermodynamic and kinetic parameters, and can work crystal micro structure analysis, etc.
2.1 Test materials and equipment
The test sample was cut from the original Ni-Ti alloy wire and alloy strand, weighed and then pressed down on a special plate by a tablet press. The differential scanning calorimeter is mainly composed of three parts: the sample reaction chamber, the heating device and the computer control system. The whole DSC scanner is through the computer program temperature control to control the heat flow input and output. Schematic diagram 2.1 shows how the differential scanning calorimeter works. In the reaction room of the instrument, there are a sample pool and a reference pool, as well as a separate heating device and thermosensitive element below, which are connected to a computer and controlled by a computer program for heating and data collection.

2.2 Test results and analysis
Differential Scanning Calorimeter was performed on two kinds of Ni-Ti alloy wires, and the shape memory alloy material was transformed from austenitic to martensite. The dashed line represents the heating process, when the shape memory alloy material changes from martensite to austenite. Table 2.1 shows the phase transition temperature of smooth alloy wire and alloy strand.

DSC test results are presented in the form of heat flow traces. The peak value means that there is a considerable amount of heat entering the material, and the peak value occurs within a small range of temperature changes, indicating that the alloy material has a good ability to store energy.

| Material          | Phase transition temperature |
|-------------------|------------------------------|
| Smooth alloy wire | Mf  -10.3 Ms  6 As  -4.5 Af  10.0 |
| Alloy wire        | Mf  -15 Ms  1.6 As  -8.4 Af  4.2  |

3. Preliminary heat treatment of Ni-Ti alloy wire
In order to verify the correctness of theoretical formula derivation, finite element analysis and theoretical calculation were used for comparison. In the finite element analysis, both matrix and substrate materials were made of steel plates with sizes of 40mm × 15mm × 3mm and 20mm × 5mm × 2mm, fiber length was 20mm, adhesive thickness was 0.2mm, slot width was 1mm, colloid elastic modulus [15] was 1GPa, 3GPa, 5GPa, 7GPa and 10GPa, and fiber elastic modulus was 72 GPa. The solid model was established, and the fiber grid was divided into 8-node cells. The finite element model is shown in figure 6. Bare fiber, colloid, substrate and matrix are considered as isotropic linear elastic materials. The sample with a length of 150mm was placed in boiling water and normal temperature water for 5 minutes to ensure the complete transfer of heat, and then the cold and hot cycle was carried out for 10 times to ensure the stability of the Ni-Ti alloy wire. Finally, before the experiment, the wire...
was naturally cooled to room temperature to ensure that the wire could be completely in austenitic state. Figure 2.3 shows the alloy wire after heat treatment.

Figure 2. Wires after heat treatment

4. Tensile test of ni-ti alloy wire

4.1 Test materials and equipment

Two kinds of ni-ti alloy wires were used in the experiment. One was ordinary round section wire with smooth surface and a diameter of 2mm. Another for Ni Ti alloy wire, the wire by the seven root monofilament diameter of 0.75 mm of Ni - Ti alloy wire, consists of 6 outer Ni Ti alloy wire around a center Ni - Ti alloy wire along the direction of a kink, every Ni Ti alloy SiDou and longitudinal stress direction to form a certain Angle, stranded wire twisting system diagram as shown in figure 3 (a), the physical diagram as shown in figure 3 (b). The Ni and Ti of the two kinds of silk are of equal atomic proportions.

(a)                                                                 (b)

Figure 3. Ni-Ti alloy strands

4.2 Test content

Use universal testing machine. The length of the silk material used in the test is all 150mm. During the test, clamp the two ends of the silk material on the test machine, adjust the parameters of the testing machine, use strain control to stretch, and then carry out drawing test on the alloy wire (as shown in figure 4). Firstly, tensile tests with different strain amplitudes were carried out on the two types of alloy wire, and a loading and unloading cycle was carried out. The strain amplitudes were 2%, 3% and 5%, respectively, to understand the influence of strain amplitudes on mechanical properties of the wire. Then, the cyclic loading test with constant strain amplitude was carried out on these two types of alloy wire, and the set strain amplitude was also 2%, 3% and 5%, so as to understand the mechanical properties of the wire under cyclic load.
4.3 test results and analysis

Effect of strain amplitude on mechanical properties of Ni-Ti alloy wir: In order to verify the mechanical properties of Ni-Ti alloy wire under different strain amplitude conditions, the tensile test was conducted on two kinds of super-elastic Ni-Ti alloy wire. The hysteretic curve of the smooth alloy wire is shown in figure 5. As can be seen from the figure, the hysteretic curve of smooth Ni-Ti alloy wire is smoother than that of the relationship between force and strain of Ni-Ti alloy wire. Two wire material hysteresis curve with the increase of strain amplitude, the height of the loading period of yield platform basic didn't happen too big change, and two kinds of wire unloading yield platform height is different, smooth and Ni-Ti alloy silk yield platform height down quickly, and Ni-Ti alloy wire unloading period of yield platform height change is not obvious.

Effect of cycle times on mechanical properties of Ni-Ti alloy wire: In order to understand the mechanical properties of the wire under cyclic loading, the two types of alloy wire were tested under cyclic loading with equal strain amplitude, respectively. The strain amplitude was set at 2%, 3% and 5%. In order to make an effective comparison, the hysteretic curves of smooth alloy wire and stranded wire with strain amplitude of 5% are selected for comparison (as shown in figure 6).
Figure 6. Mechanical properties under cyclic loading

As can be seen from FIG. 2.7, the hysteretic curve of the two kinds of silk gradually becomes smooth as the number of cycles increases. The upper yield platform of the two shape memory alloy wires is basically unchanged after the number of cycles exceeds 20, while the lower yield platform has been stabilized after the number of cycles exceeds 5, and the smooth ni-ti alloy wire is higher than the lower yield platform of the ni-ti alloy wires. For the ni-ti alloy stranded wire, when the strain is less than 0.5%, the stress increase is not obvious, while the smooth ni-ti alloy wire does not appear such phenomenon. The reason is that there is a certain gap between the single wires that make up the ni-ti stranded wire, and the initial strain results in the error of the initial strain.

5. conclusion
Tensile tests under different strain amplitudes, tensile tests under cyclic loads and differential scanning calorimetry tests were carried out on the ni-ti alloy wires and ni-ti alloy wires. The following conclusions are drawn from the experiment:

(1) various phase transition temperatures of two kinds of alloy wires were obtained by differential scanning calorimetry.

(2) two kinds of wire material hysteresis curve with the increase of strain amplitude, the height of the loading period of yield platform didn't happen too big change, and two kinds of wire unloading yield platform height is different, smooth shape memory alloy silk yield platform height down quickly, and the shape memory alloy wire unloading yield platform height variation is not obvious.

(3) with the increase of the number of cycles, the hysteretic curve of the two kinds of silk gradually becomes smooth. The upper yield platform of the two shape memory alloy wires is basically unchanged after the number of cycles exceeds 20, while the lower yield platform has been stabilized after the number of cycles exceeds 5, and the smooth ni-ti alloy wire is higher than the lower yield platform of the ni-ti alloy wires.

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