COMPRESSION EXPERIMENT AND SIMULATION STUDY OF SHAPE MEMORY ALLOY LATTICE STRUCTURE

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ABSTRACT

As a new type of cellular metal material, pyramidal lattice structure has many excellent characteristics,such as light weight, high specific strength, high specific stiffness , good energy absorption and buffer performance, and has been applied in military and aerospace fields. Firstly, Ti-54%Ni shape memory alloy(Xi'an Saite Co., Ltd.) was used to fabricate the SMA pyramid lattice structure.The wire cutting method is applied to process lattice structure core with thickness of 1.1mm and 1.8m respectively.The lattice structure is assembled and bonded by epoxy resin. Then static compression experiment was carried out by Zwick 2010 universal testing machine. Secondly, the ultimate bearing capacity, failure mode and heat recovery effect of Ti-Ni shape memory alloy lattice materials at different compression speeds are studied by experiment and simulation. The finite element software of HYPERMESH and ANSYS are used to simulate compression process, and SMA element in ANSYS is applied. The stress-strain curves obtained by finite element simulation are compared with the stress-strain curves obtained by compression experiment. The results show that the simulation prediction agrees well with the experimental results. By comparing and analyzing the same size steel lattice structure, the elastic deformation mechanism of SMA lattice structure is discussed. After heating, the original shape is restored and the residual deformation is small.

1. INTRODUCTION

Intelligent materials are materials whose properties change dramatically under excitation. Intelligent structure is based on the integration of the sensing or driving functions of intelligent materials, so that the structure has bearing, transfer load, connection and other functions, but also according to the change of excitation to change their own properties and functions, to achieve the expected function. For example, shape memory alloy is affected by ambient temperature to restore its shape As a kind of porous metal material, lattice sandwich structure has the characteristics of light weight, high strength and good energy absorption. But lattice structure is generally made of steel, aluminum and other plastic metal materials, subjected to compression, impact and other load will produce permanent deformation. The porous sandwich structure made of shape memory alloy is a kind of light weight intelligent structure which can recover its shape by heat and has the potential of super-elastic recovery by stress.[1]

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1.1 Shape memory alloys

In 1932, Olander, a Swedish physicist who first discovered the solid-phase transition in SMA, determined that gold cadmium (au-cd) alloys plastic deform when they cool and return to their original shape when heated. Shape memory alloy （SMA for short)is a new type of intelligent material with both sensing and driving functions. It has two special functions of Superelasticity (Super-Elestic, SE)and shape memory effect(referred to as SME). TiNi shape memory alloy is widely used in different industries due to its low cost, easy preparation, good biocompatibility, corrosion resistance and fatigue resistance[2].

1.1.1 Shape memory effect

Thermoelastic martensite Shape Memory alloy, in the state of martensite, under the action of stress, has a certain plastic deformation. After the temperture exceeds A_S, the martensite begins to change into austenite phase transition, the residual strain disappears, and the original volume and shape are restored, which is called Shape Memory Effect (SME).

1.1.2 Superelasticity

When the stress loading is applied to the full austenite SMA($T > A_{\mathrm{f}}$), the plastic deformation occurs, the deformation completely disappears after unloading, the stress-strain loading and unloading curve is formed into a loop, and the residual strain is very small and return to the shape of the parent phase.

1.2 Shape memory alloy constitutive model

The improved Auricchio constitutive model can well describe the shape memory effect and superelastic behavior of the shape memory alloy materials, and has been well applied to ansys finite element analysis software. This model is used to simulate the deformation process of tensile specimens under compression, heating recovery and austenite loading and unloading cycles. The compression process of shape memory alloy lattice structure is simulated[3].

2. EXPERIMENTATION

2.1 Fabrication of shape memory alloy lattice structures

The speciment size is 65 × 65 mm, the specimen thickness is 10 mm, the core of lattice structure is made of Ti-54at% Ni shape memory alloy material, the section of cell core rod is 1×1 mm (measured 1.1 mm, manufactured by Xi 'an Saite company), the panel is made of 304 steel plate. The shape memory alloy materials was aging treated at 500 ℃for 1 hour, to memorize shape[4].Panel and core was incised by wire cut electrical discharge machine , cleaned by acetone, interlocking assembled and then bonded by epoxy resin, curing time is 24 hours (the epoxy resin cured under room temperature and can resist to high temperature of 130 ℃, Hei Longjiang petrochemical research institute developed). The strength of the speciment after bonded and interlocking assembled meets the experimental requirements, and no debonding occurs when the compression test reaches the limit load.

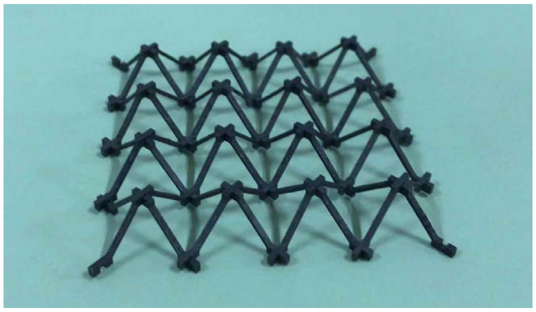

Figure1. SMA lattice core

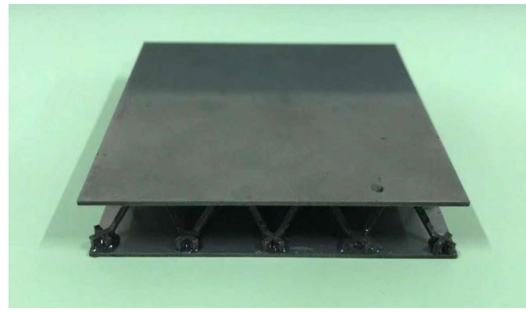

Figure 2. SMA lattice sandwich structure

2.2 Compression experiment on lattice structure

Test 1 was carried out at room temperature, the test standard referred to ASTM[5], Ziwic electronic universal testing machine was used for compression experiment, SMA material was in the state of full martensite ($T < M_S$) , the displacement load curve is shown in figure 3. The test speed was 1 mm/min. It can be seen from Figure 3. that the bars of lattice cells around 8500 N began to buckle until the maximum load reached 11149.50 N, at which time the compressive strength was 2.64 MPa. All bar buckling at this moment, we believe that the SMA bar completed martensite detwinning process and entered the stage of metal plastic yield, heated reply may be small, the cell rod yields gradually after the maximum load is reached and the core of lattice structure becomes densified, load stable gradually and the whole loading process does not appear debonding phenomena, the main failure mode is cell bar buckling.

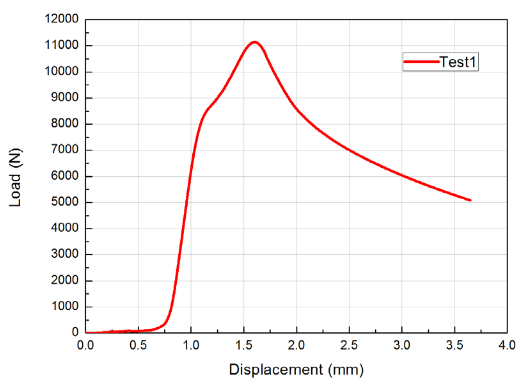

Figure 3. Collapse displacement load of SMA lattice structure and unloading during loading curve of lattice structure

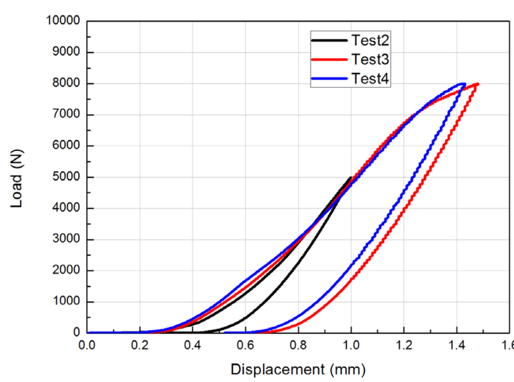

Figure 4. Displacement load curve of lattice structure

In test 2 , after the compression load was loaded to 5000 N, the residual deformation was about 0.2 mm, and the residual strain was about 1.6 %. According to figure 4. , it was speculated that the bar was in the martensite elastic stage of single variant at this time. After unloading, the residual deformation was caused by twin martensite dissolving twins, which would return to the original shape after heating. Since the deformation of test 2 was not obvious, test 3 and test 4 were loaded to 8000 N at 1 mm/min and 2 mm/min respectively and then unloaded. The residual strain was 4.2% and 5%, respectively. Although the residual deformation was larger than that of test 2 , we believe that the residual deformation will recover after heating. In comparison with literature [6], the curves of tests 1, 2 and 3 show a similar trend.In the literature [5], after the casting process reaches the ultimate load, the bar is fractured. In test 1, the core of lattice structure is fabricated by the interlocking process[7], and no debonding phenomenon occurs. Therefore, the curve after the maximum load is different. As can be seen from Figure 4, the trend of the curves of test 1 and test 2 almost overlaps, and the difference may be caused by the bonding process of the specimens. The curves of two kind of loading velocities are similar, so the effect of loading rate cannot be determined, and more loading rate tests are needed.

3. SIMULATION

By using Auricchio constitutive model in ANSYS, the hyperelasticity and shape memory effect can be solved by the improved constitutive model. In this paper, the single specimen and the lattice model are simulated by using this model. The size length and width of the specimen are 65×65 mm, and the cross section of the lattice core rod is 1×1 mm. It is convenient to simplify the model for calculation and integrate the lattice structure into an entity. The model is shown in figure 5., and the material parameters refered to the reference. [8]

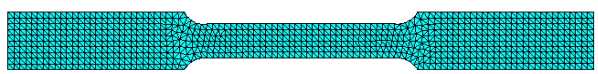

Figure 5.SMA tensile specimen model

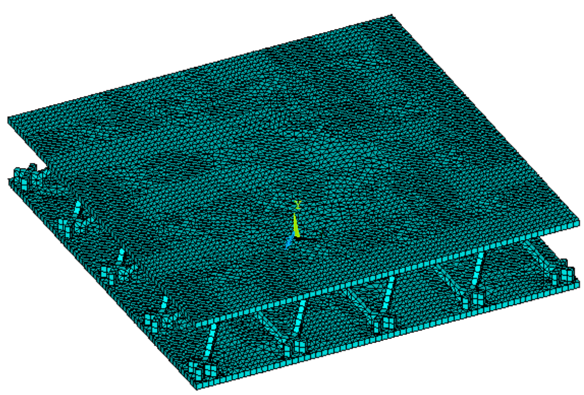

Figure 6. SMA lattice structure model

The material parameters of the shape memory alloy are shown in table 1, the elastic modulus in the austenitic state： E_X=70GPa , Poisson's ratio: 0.3.

Table1. Material parameters of shape memory alloy

C_1/MPa	C_2/K	C_3/MPa	C_4/MPa	C_5	C_6/MPa	C_7
500	253.15	45	7.5	0.03	$70E3$	0

4. RESULTS

First, in the austenite state ($T > A_f$), the specimens were subjected to tensile loading and unloading test under different loads. Displacement constraints were applied on one end of the specimens, and displacement loads were applied on the other end. The loads were 0.5 mm, 1 mm , 2 mm and 5 mm, respectively. Secondly, in the state of complete martensite ($T < M_f$), the speciments were stretched, and residual deformation existed after unloading, and then recovered after heated. Finally, the lattice structure was subjected to compression. Finally, 0.1 mm,0.2 mm,0.3 mm and 0.4 mm displacement loads were applied to the lattice structure, and the residual strain was about 1 %~4 % after unloading .After compression and unloading, the structure was heated. As can be seen from the displacement time curve, although the residual strain is small after unloading, it returns to its original shape.

4.1 Compression and heating recovery of specimen

The full martensite SMA speciment was simulated under different displacement loads for stretching, compression.After heated, the shape of speciment recovered,residual strain disappeared, as shown in the displacement time curve in Figure 7 .In time step 1, a tensile load of 3 mm (displacement control) is applied.In time step 2, the displacement is unloaded to 0. In time step 3, the heated speciment is recovered[9]. It can be seen from Figure 7. that the speciment almost completely recovered after heating. As can be seen from in Figure 8 , the residual strain of the speciment after unloading was about 2.4 %, which recovered after heating. Figure 9. shows the stress-strain curve of cyclic loading and unloading of the speciment in full austenite. The martensite transition induced by the stress returns to its shape after the stress is removed, and there is no residual strain. Single variant martensite becomes austenite and the speciment returns to its original shape after the stress is removed.

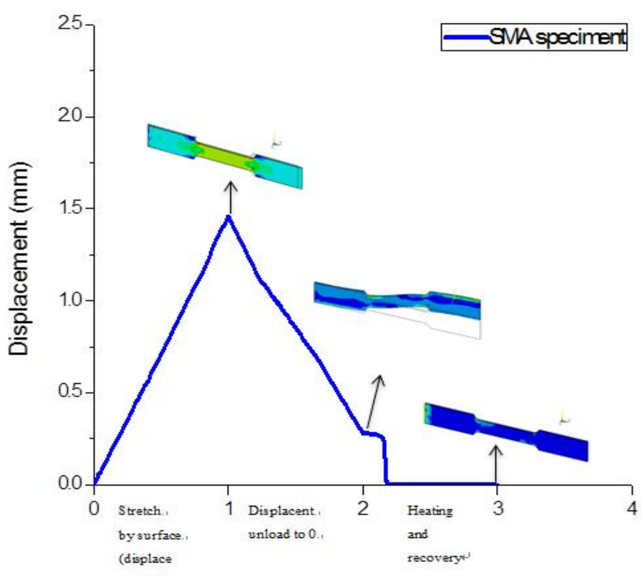

Figure 7. Displacement load curve of SMA speciment

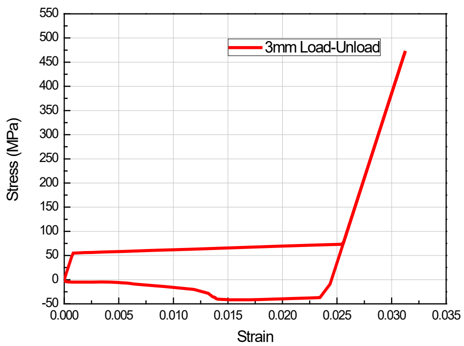

Figure 8. Stress and strain curve
of full martensitic SMA specimens

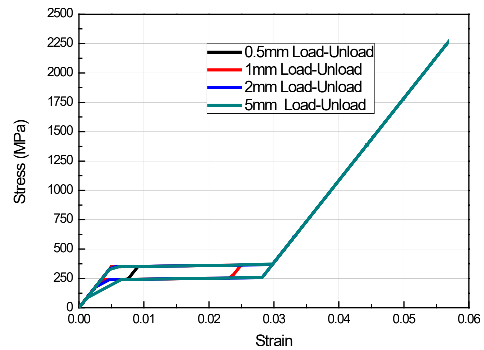

Figure 9. Stress and strain curve
of full austenite SMA specimens

4.2 Compression and heating recovery of lattice structure

The shape memory alloy lattice structure in full martensite state was subjected to compression simulation, and the applied displacement loads were 0.1 mm,0.2 mm and 0.3 mm, respectively, as shown in Figure 10. After unloading, the residual strain was 0.2 %, 0.36 % and 0.64 %, and the stress reached 32 MPa, 31 MPa and 36 MPa, respectively. As shown in the Figure 11, the displacement time curve under a 0.3 mm displacement load. Although the deformation is very small, we can still see that the residual strain after unloading is recovered.

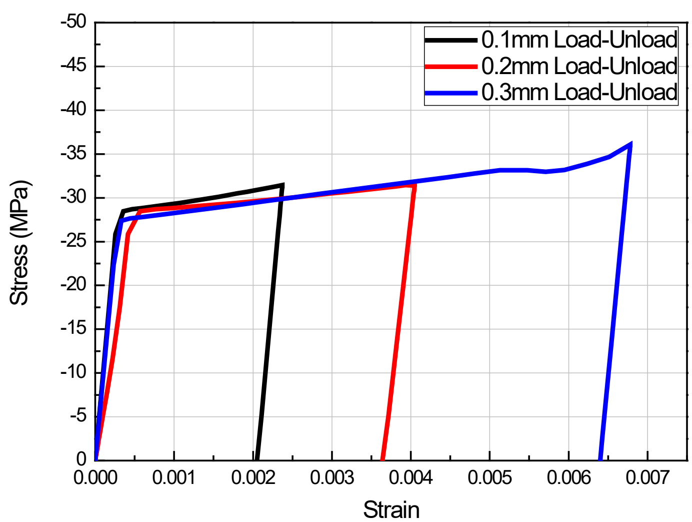

Figure 10. Stress and strain curves of SMA lattice structures with complete martensite under loading and unloading

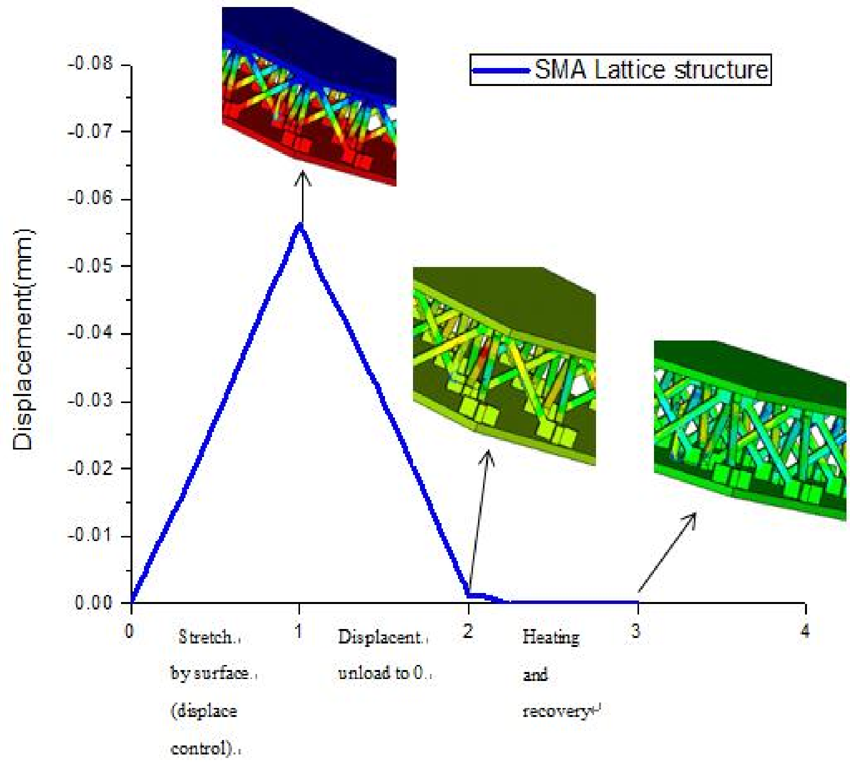

Figure 11. Displacement time curve of SMA lattice structure with complete martensite

5. CONCLUSIONS

Firstly, this paper conducted compression experiments on a latched SMA lattice structure. The core was in full martensite state at room temperature, and the maximum strength was 11149.5 N, which was loaded to 8000 N and 5000 N respectively and then unloaded. We believe that after heating, the residual strain will recover, which needs further research. Second, Auricchio SMA model of Ansys was used to study the full martensite state (the SME effect) of the deformation of specimens under tensile and compressive load.After heating, the shape recovered, and full austenitic (with PE effect) SMA under cyclic loading unloading.In further , the simulation on compression of full martensite SMA lattice structure was carried out and obtained the 0.1 mm and 0.2 mm, 0.3 mm stress-strain curve under the load as well as displacement-time curve. Since the residual strain of SMA lattice structure is not obvious, further study of SMA lattice with larger displacement loading is necessary.

6. REFERENCES

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