MECHANICAL PROPERTIES OF SHAPE MEMORY ALLOYS, POLYMERS AND THEIR COMPOSITES

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1. Introduction

The functional subjects important to design the shape memory elements are the mechanical properties of the materials such as shape memory effect, superelasticity, shape recovery, shape fixity, fatigue, secondary shape forming etc. [1], [2]. These properties appear due to the phase transformation depending on variation in stress, strain and temperature. In the present paper, the main subjects discussed till now will be introduced for shape memory alloys (SMAs), polymers (SMPs) and their composites (SMCs). Following these mechanical properties of the materials, the advanced subjects in the mechanical properties of the materials will be discussed.

2. Deformation and fatigue properties of shape memory alloys

The important functions of SMAs in applications are the deformation and fatigue properties, which can be summarized as follows.

(1) The basic functional properties of the shape memory effect (SME) and superelasticity (SE) appear due to the martensitic transformation. With respect to the SME, not only the shape recovery but also the recovery stress are used in applications. The recovery stress of 400 MPa can be obtained by heating. The energy storage and dissipation are obtained in the SE.

(2) The cyclic deformation due to the R-phase transformation does not change during cycling. However, the upper stress plateau due to the martensitic transformation decreases during cyclic deformation.

(3)The return-point memory appears in the subloop loading under the low strain rate. However, the return-point memory does not appear in the stress-controlled subloop loading, and the transformation-induced creep and stress relaxation appear.

(4) The thin SMA tape can be easily twisted by simply grasping both ends. The simple rotary reciprocating actuators can be developed by using the torsional deformation of the SMA thin tape.

(5) The highelatic deformation with the almost linear stress-strain curve of the TiNi SMA can be obtained up to a stress of 1400 MPa and a strain of 4%.

(6) The relationship between strain amplitude and number of cycles in bending fatigue life can be expressed by a power function. The fatigue limit appears around a strain amplitude of 1%, which is in the R-phase transformation region. The bending fatigue life can be enhanced by the nitrogen ion implantation and the ultrasonic shot peening.

3. Deformation and long-time properties of shape memory polymers

The main mechanical properties of shape fixity and shape recovery of SMPs appears based on the glass transition of the materials. The important characteristics are as follows.

(1) The rigidity of SMPs is high and low at temperatures below and above the glass transition temperature, respectively. The deformed shape with high rigidity is obtained by cooling, shape fixity, and the original shape is recovered by heating, shape recovery.

(2) If the deformed shape is held at low temperature, it can be fixed under no-load for a long time and the original shape can be recovered by heating after that.

(3) If the deformed shape is held at high temperature, the original shape can't be recovered by heating and the irrecoverable strain appears, the secondary shape forming. If we use this property in applications, we can obtain the SMP elements with complex shape by the simple method without using metal molds.

4. Shape memory composites with SMA and SMP

The dependence of rigidity and yield stress on temperature is quite opposite between SMA and SMP. If the shape memory composite made of SMA and SMP is fabricated by using both materials, the novel functional materials, SMCs, can be developed. If we fabricate the SMCs by combing the SMA and SMP elements with different phase transformation temperatures and memorized shapes, the SMC actuator with three way motion during heating and cooling can be developed.

5. Advanced subjects of shape memory alloy and polymer

5.1 Functionally-graded shape memory material

(1) Functionally-graded shape memory alloy

The SME and SE appears due to the martensitic phase transformation. The elastic modulus and stress plateau vary depending on temperature. The phase transformation temperatures depend on the composition of SMAs. If the composition of SMA changes gradually in each position, the rigidity and yield stress change corresponding to the composition. The functionally-graded SMA therefore can be obtained by developing the fabrication method for changing the composition of SMA.

(2) Functionally-graded shape memory polymer

The polyurethane SMP has been used in the form of sheet, film and foam with various glass transition temperatures. In the case of foam, not only glass transition temperature but also density can be changed. Therefore, if we fabricate the laminated SMP with various glass transition temperatures and densities, the functionally-graded SMP can be developed. In the functionally-graded SMP, the deformation resistance varies in each layer and therefore the stepwise local deformation and recovery stress appear.

5.2 3D-printing of shape memory polymer

If we make a product with SMP using the 3D printer, the new device which is well suited to the individual complex shape can be developed without using expensive metal molds.The material used to fabricate the 3D-printing SMC belt was a SMP filament. The 3D-printed SMP belt was fabricated by the fused deposition modeling 3D printer. The shape fixity and shape recovery properties are obtained in the 3D-printed SMP as same as the SMP made by the general method. The thermomechanical properties of the 3D-printed SMP depend on the nozzle temperature, table temperature, printing rate and pattern of the each layer. These points are the future subjects.

6. Conclusions

The deformation and fatigue properties of SMA, SMP and SMC are important for the design of machine elements. The development of functionally-graded SMA and SMP and 3D-printed SMP is expected.

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References

[1] H. Tobushi, R. Matsui, K. Takeda and E.A. Pieczyska, *Mechanical properties of shape memory materials,* Nova Science Pub., 2013.

[2] Q.P. Sun, R. Matsui, K. Takeda and E.A. Pieczyska, *Advances in shape memory materials – In commemoration of the retirement of Professor Hisaaki Tobushi* -, Springer, 2017.