Multi-Functional Actuation of Shape Memory Composite

Kohei Takeda[*a)] , Hisaaki Tobushi[*], Yasuhiko Nishimura[*] & Shunichi Hayashi[**]
[*]*Department of Mechanical Engineering, Aichi Institute of Technology*
1247 Yachigusa, Yakusa-cho, Toyota, Aichi, 470-0392, Japan
[**] *SMP Technologies Inc., Ebisu 1-22-8, Shibuya-ku, Tokyo, 150-0013, Japan*

Summary In the shape memory alloy (SMA) and shape memory polymer (SMP), not only shape recovery but also large recovery stress, energy storage and energy dissipation can be used. If the shape memory composite (SMC) with SMA and SMP is developed, the new intelligent function of the SMC can be obtained. The SMC belt composed of two kinds of TiNi SMA with different phase transformation temperatures and polyurethane SMP was fabricated and the three-way reciplocating bend movement and recovery force were investigated. The multi-functional SMC with simple structure for intelligent actuators are highly expected.

INTRODUCTION

One of the main materials in the smart materials is the shape memory alloy (SMA). The shape memory polymer (SMP) has been also practically used. In SMAs, the elastic modulus and the yield stress are low at temperatures below the reverse transformation finish temperature A_f and high at temperatures above A_f. In SMPs, the elastic modulus and the yield stress are high at temperatures below the glass transition temperature T_g and low at temperatures above T_g. In order to use new and higher functions by combining the properties of both the SMA and the SMP, the development of the shape memory composite (SMC) is expected. In the present paper, the fabrication and mechanical properties of an SMC belt which shows the three-way reciprocating motion depending on temperature variation are investigated. The bend deformation and recovery force for the three-way reciprocating actuation in the SMC belt are discussed.

STRUCTURE OF SHAPE MEMORY COMPOSITE BELT

With respect to the SMA, two kinds of SMA tape were used. The SMA tape showing the shape memory effect was a TiNi SMA tape with a width of 5mm and a thickness of 0.32mm. The superelastic alloy (SEA) tape showing the superelasticity was a TiNi alloy tape with a width of 2.5mm and a thickness of 0.25mm. Both SMA tape and SEA tape were heat-treated to memorized the round shape with an outside diameter of 16mm. The reverse-transformation finish temperatures $A_{f,SMA}$ and $A_{f,SEA}$ of the SMA tape and the SEA tape were 342K and 309K, respectively. With respect to the SMP, a polyurethane SMP tape was used. The thickness was 0.1mm and the glass transition temperature T_g was 338K. The structure of the laminated SMC belt is shown in Fig. 1. The SMC belt was fabricated by using SMA tape, SEA tape and SMP tape. SMA tape and SEA tape were arranged facing for the shape-memorized round shape and were wrapped by a SMP sheet. Then the wrapped SMA tape and SEA tape were sandwiched between four SMP tapes from upper and lower sides respectively. The laminated materials were set in the mold for heat-treating into the SMC belt. The upper and lower molds were fastened through the bolts by a compressive stress of 26.0 MPa. The mold was held in the furnace at 443 K for 60 min followed by cooling in air. The laminated SMC belt without bubbles and gaps among the materials could be fabricated under these appropriate conditons: the number of SMP tapes, the fastening force, the heat-treating temperature and time.

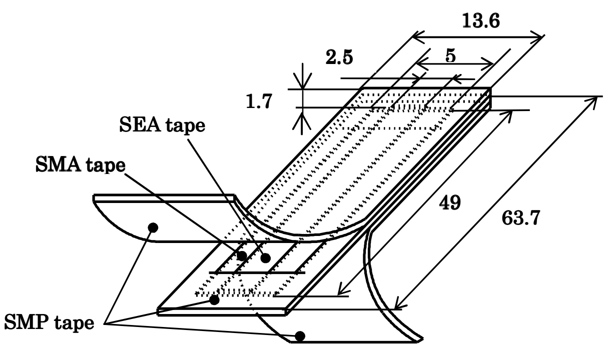

Fig. 1 Structure of SMC composed of SMA tape, SEA tape and SMP tape

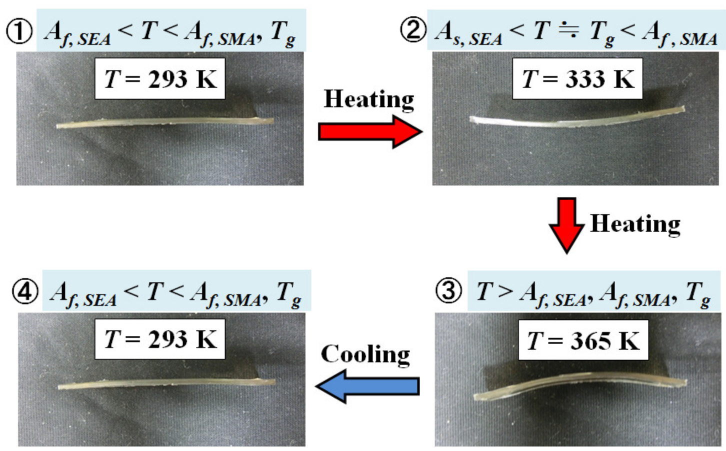

Fig. 2 Photographs of the three-way bend motion during heating and cooling

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a) Corresponding author. Email: q11801qq@aitech.ac.jp

THREE-WAY RECIPROCATING MOTION OF SHAPE MEMORY COMPOSITE BELT

The photographs of the three-way reciprocating bend motion of the fabricated SMC belt during heating and cooling are shown in Fig. 2. At 293 K ①, the SMC belt is almost flat in the initial state. If the SMC belt is heated ①－②, the SMP becomes soft and the SMC belt bends in the direction of the shape-memorized round shape of the SEA tape at temperatures around T_g ②. If the SMC belt is heated up above T_g ②－③, the SMP becomes easier to deform and the recovery force in the SMA tape increases at temperatures above $A_{f,\ SMA}$ and therefore the SMC belt bends in the direction of the shape-memorized round shape of the SMA tape, resulting in upward convex shape at 365 K ③. If the SMC belt is cooled thereafter ③－④, the recovery force in the SMA tape decreases and the recovery force in the SEA tape becomes higher. Therefore, the SMC belt recovers again to its original flat shape ④.

CHARACTERISTICS OF SHAPE MEMORY COMPOSITE BELT

The three-way reciprocating bend behavior was measured by the test for the simply supported SMC belt. At first, the SMC belt was set on the supports of the three-point bending test machine. The point of the punch contacted slightly the center of the SMC belt. Keeping the slight contact condition, the SMC belt was heated and cooled, and the displacement of the punch was measured. The relationship between the displacement and temperature is shown in Fig. 3. It should be noticed that if the center of the SMC belt moves downward, the displacement decreases. In the heating process ①－②, the displacement of the SMC belt decreases, since the SMP becomes soft. In the heating process ②－③, the displacement of the SMC belt increases, since the recovery force of the SMA tape increases at temperatures around $A_{f,\ SMA}$. In the cooling process ③－④, the displacement of the SMC belt decreases gradually with a decrease in temperature since the recovery force of the SEA tape becomes higher than that of other elements.

The relationship between the recovery force and temperature obtained by the three-point holding test with heating and cooling for the SMC belt in which the shape was held constant is shown in Fig. 4. Since the elastic modulus of the SMP decreases at temperatures around T_g ②, the recovery force of the SMC belt decreases. Since the recovery force of the SMA tape becomes stronger than that of the SEA tape at temperatures around $A_{f,\ SMA}$, the recovery force of the SMC belt appears. The recovery force of the SEA tape becomes stronger than that of the SMA tape at temperatures around $R_{s,\ SMA}$ in the cooling process, resulting in a decrease in recovery force.

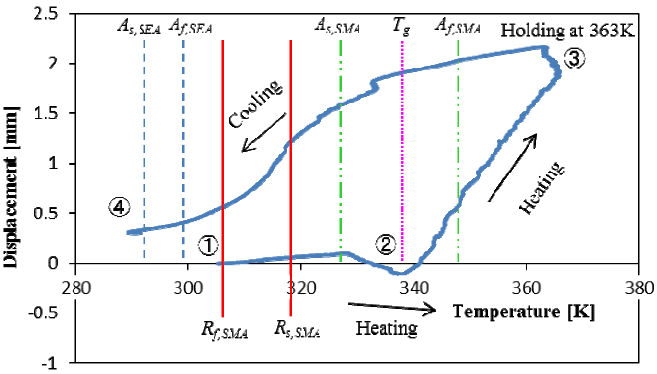

Fig. 3 Relationship between the displacement at the center of the SMC belt and temperature during heating and cooling in the simply supported SMC belt test

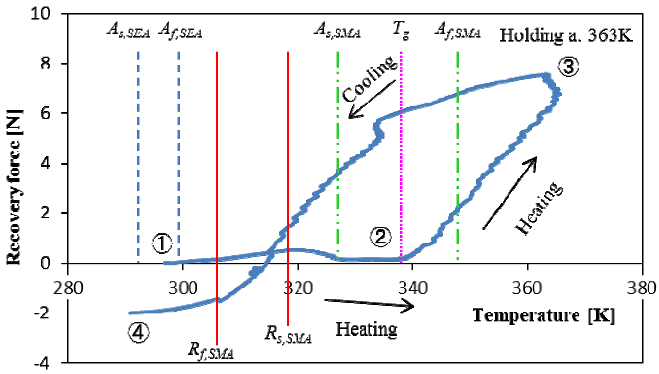

Fig. 4 Relationship between recovery force and temperature during heating and cooling in the three-point holding test for the SMC belt

CONCLUSIONS

In order to develop the multi-functional SMC actuator, the basic characteristics of the SMC belt was investigated. The result obtained can be summarized as follows.

1. The SMC belt was fabricated by laminating the SMA tape, the SEA tape and the SMP tape.
2. The three-way reciprocating bend movement and recovery force were achieved during heating and cooling based on the characteristics of the SMA tape and SEA tape and the SMP tape.
3. The development and application of multi-functional SMCs with simple structure for actuators are highly expected by the combination of the shape memory materials with various kinds of phase transformation temperature, memorized shape, volume fraction, composition and heating-cooling rate.