DEVELOPMENT OF TWO-WAY ROTARY DRIVING ELEMENT USING TORSIONAL DEFORMATION OF TINI SHAPE MEMORY ALLOY THIN TAPE

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1. Introduction

Intelligent materials are attracting attention as materials having functions such as detection and judgment. One such intelligent material is TiNi shape memory alloy (SMA) [1]. The TiNi SMA has higher recoverable strain and stress owing to the shape memory effect and superelasticity. Therefore, it is being used to drive elements of heat engines or actuators [2]. If a TiNi SMA thin tape is used as a rotary driving element, we can easily achieve a large rotating angle with high recovery torque. Hence, herein, we propose a two-way rotary driving element consisting of a combination of a thin tape of TiNi SMA and a superelastic alloy (SEA). We investigate the fundamental torsional deformation properties of the SMA tape at various temperatures and those of the SEA tape at room temperature. In addition, we propose a design chart for the two-way rotary driving element based on the results of the torsion test. Furthermore, we develop a model by using the two-way rotary driving element and investigate its operating characteristics under heating and cooling of the SMA tape.

2. Two-way rotary driving actuation using SMA and SEA tape

Figure 1 shows an outline of the structure of the two-way rotary driving element. The element is composed of SMA and SEA tapes, which are memorized flat shapes, and these tapes are connected in series through a center shaft. The SMA tape is twisted to the designated angle of twist and attached to the shaft, and the flattened SEA tape is fixed to the opposite side of the shaft.
If the twisted SMA tape is heated, recovery torque is generated because of the tendency of the tape to return to the memorized flat shape, resulting in rotary motion of the shaft. This motion stops when the torque of the SEA tape is balanced with the recovery torque of the SMA tape. If the SMA tape is cooled, the recovery torque decreases, and the shaft turns to the opposite direction owing to the superelasticity of the SEA tape. This is the mechanism of the two-way rotary driving element, which can move by heating and cooling of the SMA tape.

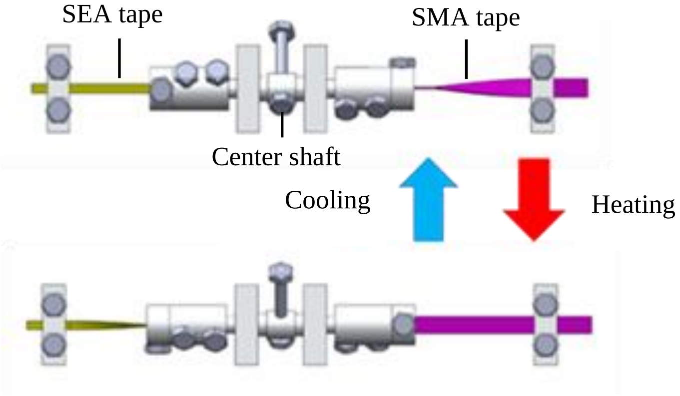

Fig. 1 Schematic of two-way rotary driving actuation using SMA and SEA tapes

3. Torsional deformation properties of thin strip of shape memory and superelastic alloys

To design the two-way rotary driving element, it is necessary to clarify its fundamental torsional deformation properties at temperatures considered to be useful in practical applications. Hence, we performed torsion tests to obtain the relationship between torque and angle of torsion for the SMA tape at various temperatures. Furthermore, we have proposed a design chart for the two-way rotary driving element by using the abovementioned relationships shown in the previous section.

The thickness, width, and length of the SMA tape were 0.35, 5.9, and 70 mm, respectively. Similarly, the dimensions of the SEA tape were 0.66 mm in thickness, 3.1 mm in width, and 70 mm in length. The torsion test was performed at the temperatures T = 293, 313, 333, 353, and 373 K for the SMA tape and 293 K for the SEA tape. The maximum twist angle per unit length $\theta_{\max}$ was 78.5 rad/m (which corresponded to 180°). After these tapes were twisted to the maximum angle, they were unloaded.

Figure 2 shows the relationship between torque and angle of twist per unit length. Although Fig. 2 includes the loading curve of the SEA tape as well, it is inverted to correspond to the curve of the two-way rotary driving element proposed in this study. From this figure, the maximum torque of the SMA tape increases with T. This is caused by the fundamental deformation property of the material. The starting stress of martensitic transformation increases with increasing temperature. In the case that T of the SMA tape is higher than the finishing temperature of austenitic transformation A_f = 338 K or around this temperature, the material shows superelasticity. We confirmed that the SMA tape shows the shape memory effect after unloading at T = 293 and 313 K. In this figure, the difference between the intersection point of an unloading curve of the SMA tape (e.g., T = 373 K) and loading curve of the SEA tape and the origin of the loading curve of the SEA tape is considered to correspond to the rotating angle of the two-way rotary driving element when it is heated from 293 to 373 K. Based on this assumption, we predicted that the rotating angle of the two-way rotating driving element is 25.2 rad/m in the case of a fixed angle, and the temperature change is the same as that shown in Fig. 2.

In further experimental investigation, we found that the two-way rotating angle of the shaft in the element can be predicted almost precisely from the corresponding design chart, as shown in Fig. 2.

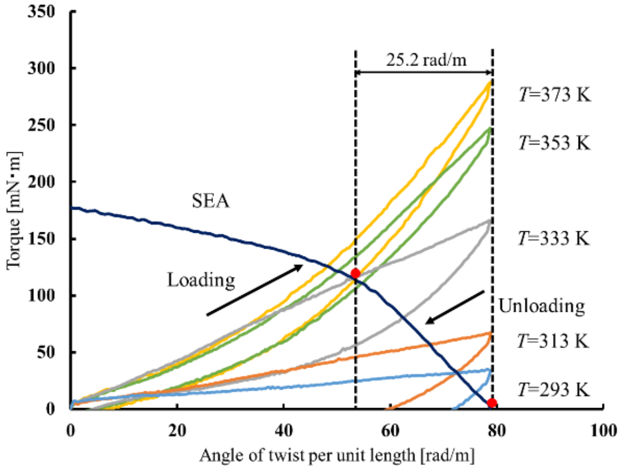

Fig. 2 Design chart of two-way rotary driving element for $\theta_{\max}$ = 78.5 rad/m

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