DEFORMATION PROPERTY OF FUNCTIONALLY-GRADED SHAPE MEMORY POLYMER

K. Takeda[1], R. Matsui[1], H. Tobushi[1] and S. Hayashi[2]
[1] Aichi Institute of Technology, Toyota, Japan
[2] SMP Technologies Inc., Tokyo, Japan

1. Introduction

In the intelligent or smart materials, the shape memory polymer (SMP) is fascinating new functional materials. In SMPs, the elastic modulus and the yield stress are high and low at temperatures below and above the glass transition temperature T_g, respectively. The recovery stress appears in the shape-fixed SMP foam at temperatures in the vicinity of T_g during heating. If the SMPs with various glass transition temperatures T_g are laminated, the functionally-graded shape memory polymer (FGSMP) can be developed. In the FGSMPs, the multistep recovery force can be used. In the nursing-care robots or actuators in the medical field, both the rigidity for supporting force and the flexibility of the elements coming into contact with body are requested. If the FGSMP is fabricated, the functional care equipment can be developed. In the present paper, the actuation of the FGSMP was discussed. The FGSMP was fabricated by the polyurethane SMP sheets and foam, and the indentation deformation properties of the FGSMP was investigated and compared with those of the finger.

2. Actuation of functionally-graded SMP foam

As an example of the deformation properties of the FGSMP foam, the shape recovery and recovery stress in the FGSMP foam laminated with the elements having four glass transition temperatures $T_{g\,1}$, $T_{g\,2}$, $T_{g\,3}$ and $T_{g\,4}$ are shown in Fig. 1. In Fig. 1, they are assumed as $T_{g\,1} < T_{g\,2} < T_{g\,3} < T_{g\,4}$. The element having low T_g is arranged on the upper side. The SMP foam having low T_g is easily deformed. In the FGSMP foam, the element having lower T_g is highly deformed in compression (1). The deformed shape is fixed during cooling (2). If the shape-fixed foam is heated, four-stepwise shape recovery motion (3) or four-stepwise recovery force (4) can be obtained during heating. Since the SMP foam element having lower T_g is easily deformed, the shape recovery or recovery force appears at lower temperature during heating. The multistep shape recovery motion can therefore be obtained by using the FGSMP foam having various glass transition temperatures during heating. We note that the deformation properties of the FGSMP foam in compression depend not only on T_g of each element but also on expansion ratio, cell structure and thickness of the foam.

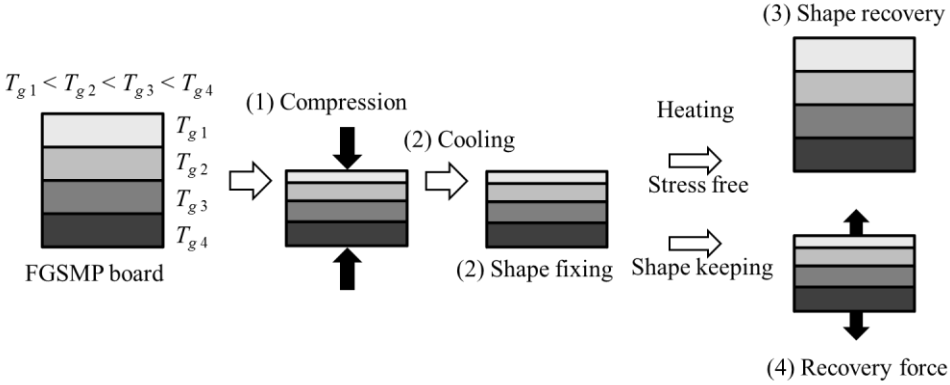
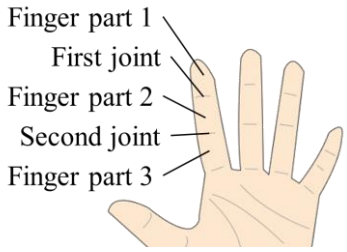


Fig. 1 Multistep shape recovery and recovery force of FGSMP foam having four glass transition temperatures

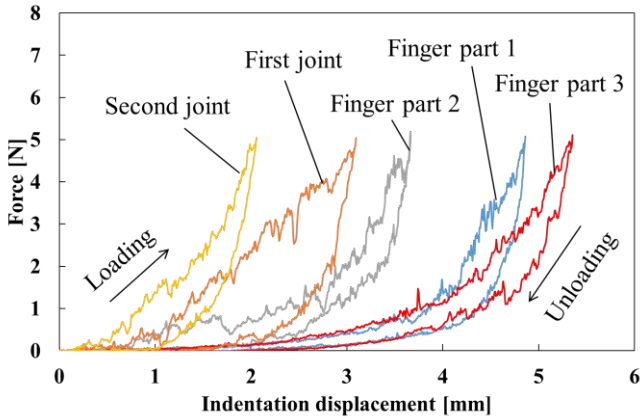
3. Functionally-graded SMP board made of sheet and foam

At first, we conducted the indentation test for the finger of the left hand of a young man. The indentation points on the index finger in the indentation test are shown in Fig. 2 (a). The relationships between force and indentation displacement for each part of index finger are shown in Fig. 2 (b). In Fig. 2 (b), various deformation properties are observed at each indentation points on the index finger. The deformation properties during loading and unloading are similar at finger part 1, finger part 2 and finger part 3 except for the amount of the indentation displasment. The residual indentation displacement appears at first joint and second joint after unloading.

The SMP foam and sheet having various glass transition temperatures T_g were laminated and the FGSMP board was fabricated. The photograph and structure of the FGSMP board are shown in Fig. 3. Two SMP foams with a thickness of 5 mm and T_g = 298 K and two SMP sheets with a thickness of 2 mm and T_g = 308 K and 328K were laminated. The indentation test was carried out for the FGSMP board. The relationships between force and indentation displacement obtained by the test for a maximum force of 5 N in five cycles are shown in Fig. 4. In Fig. 4, the result for the thumb is also shown. As can be seen, with respect to the thumb, force increases slightly till a depth of 3 mm and the slop of the curve becomes gradually steep thereafter during loading. Force decreases in the unloading process accompanying a large hysteresis loop of the force-indentation displacement curve in the loading and unloading processes. The deformation properties change slightly during cycling for the FGSMP board. The indentation curve of the FGSMP board is similar to that of the thumb.

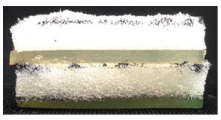


(a) Indentation points on index finger

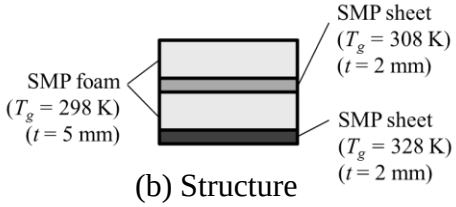


(b) Force-indentation displacement curves of index finger

Fig. 2 Indentation property of index finger



(a) Photograph



(b) Structure

Fig. 3 FGSMP board made by SMP foam and sheet

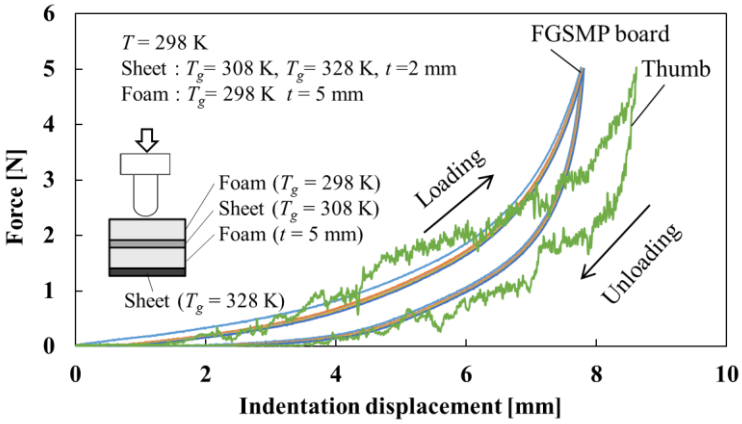


Fig. 4 Indentation curves of thumb and FGSMP board