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SHAPE FIXITY AND SHAPE RECOVERY OF SHAPE MEMORY POLYMER AND THEIR APPLICATIONS

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Summary The thermomechanical properties of polyurethane-shape memory polymer (SMP) foams were investigated experimentally. If the foam is compressed at high temperature, the rate of shape fixity is 100 % and that of shape recovery 98 %. Recovery stress is 80 % of the applied stress. The shape deformed at high temperature is maintained for six months under no-load at T_g-60 K without de-pending on maximum strain. If the deformed shape is kept at high temperature, secondary-shape forming appears. Applications of SMP are introduced.

INTRODUCTION

Shape memory polymer (SMP) is one of the high-performance materials which have been developed and used in practical applications. The shape fixity and shape recovery exist due to the glass transition. The shape fixity and shape recovery are used in the fields of technology, medical treatment, aerospace engineering, etc. Since the polyurethane-SMP foams have many superior functions, applications of the SMP foams are expected in the wide fields. In order to design SMP-foam elements rationally, it is important to evaluate the functional properties of the material. In the present paper, in order to study the thermomechanical properties of polyurethane-SMP foams, the shape fixity, shape recovery and recovery stress are investigated. The conditions which affect secondary-shape forming are discussed.

EXPERIMENTAL METHOD

The material used in the experiment was polyurethane SMP foam of the polyether polyol series (Diary MF 5520 : produced by Mitsubishi Heavy Industries, Ltd.). The foam was made by chemical foaming. The expansion ratio was about 14 and the structure was open cell. The foam was produced as slabstock. The specimen was a column with height of 20 mm and diameter 20 mm.

Experimental procedures

In order to investigate the thermomechanical properties, the following four kinds of compression test were carried out.
(1) Thermomechanical test
(2) Recovery-stress test
(3) Aging test held at low temperature
(4) Secondary-shape forming test held at high temperature

RESULTS AND DISCUSSION

Shape fixity and shape recovery

From the stress-strain curves obtained by the thermomechanical test, it can be seen that yielding occurs in the vicinity of a strain of 10 %, stress plateau appears thereafter till a strain of 60 % and the slope of the curve becomes steep above a strain of 60 %. In the region of the stress plateau for strain from 10 % to 60 %, buckling of cells propagates in the axial direction of compression. In the upswing region above a strain of 60 %, the material is compressed uniformly and deformation resistance increases. In the cooling process, stress disappears perfectly below T_g. Therefore maximum strain is maintained, resulting in a rate of shape fixity R_f of 100 %.
From the strain-temperature curves obtained by the thermomechanical test, it can be seen that strain is recovered significantly in the vicinity of T_g in the heating process under no load. Since the micro-Brownian motion of soft segments of SMP is frozen in the glassy region at temperatures below T_g, strain is maintained. Since the micro-Brownian motion becomes active if the material is heated up to temperatures in the vicinity of T_g, strain is recovered. The strain-temperature curves do not change under repetition. Irrecoverable strain remaining after heating is small without depending on the number of cycles, and a rate of shape recovery R_r is 99 %.

Recovery stress

From the stress-temperature curves obtained by the recovery-stress test, it can be seen that stress increases markedly in the vicinity of T_g in the heating process under constant strain. This behaviour occurs due to the fact that, though the micro-Brownian motion of soft segments of SMP is frozen at low temperature and molecular chain can not move, the micro-Brownian motion becomes active by heating up to the vicinity of T_g and recovery stress appears gradually with an increase in temperature.
Recovery stress is proportional to the applied maximum stress. Recovery stress is about 80 % of the applied stress. Since large change in volume can be obtained for SMP foam elements, they can be applied to the easily portable energy sources to use recovery stress.

Aging by holding at low temperature

It can be seen from the aging test held below T_g for maximum compressive strain that a rate of shape fixity R_f is larger than 99 % even if the time has passed for longer than 1000 hours. Although some amounts of shape are not fixed, these values are enough small. Therefore, the deformed shape can be fixed if it is held below T_g-60 K. A rate of shape recovery R_r is larger than 98 % without depending on the holding time. It is ascertained that a rate of shape fixity and a rate of shape recovery by holding the shape below T_g are larger than 98 % without depending the holding time and maximum strain, resulting in good performance.

Secondary-shape forming by holding at high temperature

In the process of the present study, it was found that, if SMP foam was deformed and the deformed shape was held for a long time above T_g, irrecoverable deformation appeared. That is, it was found that the deformed shape was not recovered and fixed. This phenomenon is called secondary-shape forming. From the experimental results obtained by the secondary-shape forming test held at high temperature, it is ascertained that the factors to affect secondary-shape forming are the holding strain, temperature and time. The cause of secondary-shape forming can be considered as follows. In the region of temperature above T_g, thermal motion of molecular chain (micro-Brownian motion) is active and therefore reorientation of molecular chain occurs during holding large strain for a long time.

In order to avoid secondary-shape forming for the deformed SMP foam, it is important to keep the foam under the appropriate condition by considering these conditions. One of the methods to prevent secondary-shape forming is to keep the foam below T_g. In the region of temperature below T_g, secondary-shape forming does not appear and both the rate of shape fixity and that of shape recovery are high. Therefore, holding at low temperature must be effective for applications of SMP foam elements.

APPLICATIONS OF SMP

The shape memory polymers of polyurethane series have many functions as smart materials and have been used for practical applications in many fields. Modulus of elasticity, volume expansion, gas permeability, refractive index and dielectric constant vary depending on variation in temperature. Shape fixity, shape recovery and recovery force appear depending on the thermomechanical properties of SMP. These properties can be applied in the fileds of medical treatment, aerospace engineering, car technology and electrification products.

CONCLUSIONS

Applying various thermomechanical loadings to polyurethane-SMP foams, the thermomechanical properties of the material were investigated. Applications of SMP were introduced. The results obtained by the experiments can be summarized as follows.

(1) The rate of shape fixity and that of shape recovery are 100 % and 99 %, respectively. Both rates do not depend on the number of cycles.

(2) If the SMP foam deformed above T_g followed by cooling is heated while holding the deformed shape, recovery stress appears. The recovery stress is about 80 % of the applied stress.

(3) If the SMP foam is compressed above T_g followed by holding at T_g-60 K, the deformed shape is fixed even if the material is kept under no load for six months. The fixed shape is recovered by heating thereafter. Both the rates of shape fixity and shape recovery are larger than 98 %, which do not depend on the holding time and maximum strain.

(4) If the deformed SMP foam is held above T_g, secondary-shape forming appears. The factors to affect secondary-shape forming are the holding strain, temperature and time.

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