MICROWAVE ACTIVATED SHAPE MEMORY POLYMER

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Abstract

In this paper the tetra-needle-shaped zinc oxide whisker (T-ZnO_w) was filled in the shape memory polymer (SMP) with different weight fraction and the T-ZnO_w/SMP composite obtained the ability of microwave absorption while maintaining the basic thermal mechanical properties and shape memory characteristics. The absorbed microwave energy could be transferred into heat efficiently and the remote actuation of complex shape transitions of the T-ZnO_w/SMP by microwave is possible.

1 General Introduction

Shape memory polymers (SMPs) are polymeric smart materials that have the ability to return from a deformed state (temporary shape) to their original (permanent) shape induced by an external stimulus. Large bulky device made of SMPs could thus potentially be introduced into the body in a compressed temporary shape by means of minimally invasive surgery and then be expended on demand to their permanent shape to fit as required[1]. The transition from the temporary shape to permanent shape could be initialed by an external stimulus, increasing the temperature over the transition point is the common way to activate the shape memory effect. Since the device used in minimally invasive surgery is very small and should be activated in body, how to initial the shape transition effectively and conveniently is one of the key problems to the clinic operation. The use of electricity to activate the shape memory effect of SMPs is desirable for applications where it would not be possible to use heat directly. Jinsong Leng et al[2][3] and Nanda Gopal Sahoo[4] obtained conductive SMP by mixing some conductive material such as carbon blacks, carbon nanotubles and short carbon fibers. Upon application of an electrical current, the temperature increased as a result of the high ohmic resistance of this kind of composite so as to triggle the shape memory effects once the temperature is over the transition temperature T_g. Géraldine M Baer, et al [5] [6] and Small et al [7] developed a way to activate the shape memory polymer vascular stent and shape memory polymer intravascular thrombectomy device by laser. The laser was introduced and coupled into SMP by an optical fiber and the light was transferred to heat because of the photo-thermo effect. The fact that the the named examples need electrodes and lead line strongly restricts the use of these systems in biological environments.

An alternative technique being investigated involves the use of surface-modified super-paramagnetic nanoparticles. When introduced into the polymer matrix, remote actuation of shape transitions is possible. Annette M, et al [8] and described the synthesis and properties of special SMP composites by incorporation of magnetic nanoparticles into shape-memory thermoplastics and the remote actuation of the thermally induced shape-memory effect was realized by applying an alternating magnetic field respectively. Compared with those with the contact electrodes, the remote stimulation is much more convenient and have a greater future in clinical operation.

In this paper, a new way to activate the shape memory composite remotely was realized. By mixing with T-ZnO_w [9] particles, which can absorb microwaves because of its special microstructure, T-ZnOw/SMP composites possess the ability of microwave absorption while maintaining the shape memory properties. The absorbed microwave energy could be transferred into heat efficiently so as to active the shape memory effects once the temperature is higher than T_g. The heating efficiency and the heating homogeneity are determined by the content fraction and the desperation of the T-ZnOw particles in the composite. Comparing with the magnetic—nanoparticles/SMP composites, which could be activated by a 5.0 KW commercial HF generator[2], the T-ZnOw /SMP obtained in this paper could be heated and activated by a 100W microwave, which means that the way to activate the shape memory device introduced in this paper is easier and safer than that described in [3] and [4].

2 Material and Methods

2.1 Specimens preparation

The T-ZnO$_w$ (5.96 g/cm3) was purchased from Jing Yu Corporation in China. The length of each needle of T-ZnO$_w$ is about 10~20 µm, and the diameter of each needle at the growth point is about 1~5 µm. The tensile strength and elastic modulus are $10^4 Mpa$ and $3.5\times10^4 Mpa$ respectively. All the material parameters mentioned above were provided by the production corporations.

To prepare the composite specimens, the T-ZnO$_w$ was put into the acetone coupling agents little by little and dispersed for 2 hours by ultrasonic vibration. The SMP resin and the hardener were mixed with the weight ratio of 10:4, the dispersed T-ZnO$_w$ was mixed into the SMP mixture and the whole mixture was stirred fully and then was cast into a stainless steel model and cured for 24 hours in room temperature. Be sure mixing the mixture gently in case to break the micro needles in T-ZnO$_w$. Five types of the specimens were prepared with the different content ratio of T-ZnO$_w$, which were 10%, 20%, 30%, 40% and 50%.wt. The pure SMP specimens were also prepared.

2.3 Recovery strain and recovery stress test

The shape memory characters of T-ZnO$_w$ /SMP composite were examined by the shape fixity, shape recovery ratio and shape recovery stress. There were three steps to investigate the fixity and shape recovery properties. (1)The spacemen was tensioned to certain strain level ε_m at higher temperature $T_h > T_g$ by the test machine. (2) The specimen was cooled to the low temperature $T_l < T_g$ while maintain the tensioned strain, kept for 10 minutes and then unloaded, where small unloading strain ε_u occurred and the most of the strain $\varepsilon_f = \varepsilon_m - \varepsilon_u$ was fixed. The fixed strain was measured as the index of shape fixity property of T-ZnO$_w$/SMP composite. (3) Then the specimen was heated again from T_l to T_h under unload state and the recovered strain was measured as the index of shape recovery property. There were also three steps to test the recovery stress, the first and second steps were similar to that in recovery strain test. However in the third step, the recovery strain was constrained and the recovery stress was measured with a load cell when the specimen was heated again in temporary shape.

2.3 The microwave heating

To test the microwave absorption and heating transformation ability in T-ZnO$_w$ /SMP, the rectangular plant specimens with different T-ZnO$_w$ fraction were exposed to microwave radiation generated by a medicine microwave curing machine operated at 3.3Gz with a power of 100w respectively .The temperature on the surface of the specimens was measured with a hand infrared radiation thermometer. The temperature was recorded by hand for every 5 second. To test the effectivness of the shape memory initiation by the low power microwave, two rectangular strip specimens with the dimension of $20\times5\times2\text{mm}$, one with 40% .wt. T-ZnO$_w$ ratio and the other with none, were used. The specimens were rolled up at the temperature of 50^{o}C which was higher then glass transition temperature T_g and then cooled down in cool water to keep the temporary shape. After this programming process, the specimens kept the helical shape in the absence of external forces as can be seen in Fig. 5. The two specimens were exposed to microwave as described above. The shape transition was recorded with a digital camera and the temperature on the surface of the specimens was measured with a hand hold infrared radiation thermometer.

3 Results and Discussion

3.1 the transation temperature

The schema of Yong's modulus—temperature curves for two kinds of composite with two T-ZnO_w weight fraction and SMP bulk were shown in Fig.1. It was obviously that the Young's modulus increased with the T-ZnO_w fraction while the glass transition temperature T_g decreased. For the composite with the 20% T-ZnO_w weight fraction, the glass transition temperature was about 32^{o}C and for the 10% T-ZnO_w weight fraction composite the T_g was about 36^{o}C while the T_g of the pure SMP was about 40 ^{o}C.

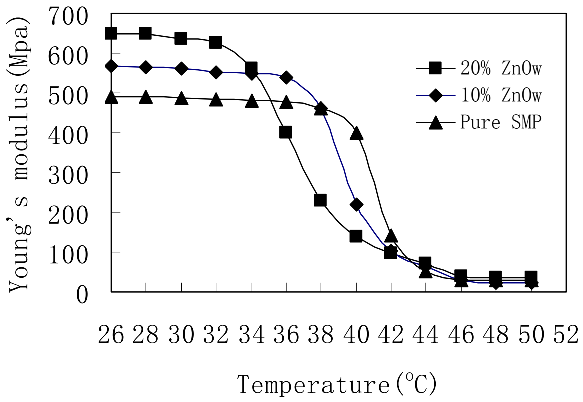

Fig.1. The elastic modulus ver different temperature

3.2 The strain recovery ratio and recovery stress

Fig.2 showed the recovery strain at different stretched ratio with the different T-ZnOw fraction.

It can be seen that the mixture of the T-ZnO_w influence the shape recovery ability slightly, especially for the lower T-ZnO_w fraction this influence could be ignored. The relationship between the recovery stress and the T-ZnO_w fraction was shown in Fig.3. It is clear that the recovery stress increased with the T-ZnO_w fraction when the T-ZnO_w .wt.%<30%. However, when T-ZnO_w exceed a specified amount, since the interaction carry out between T-ZnO_w and shape memory polymer and also between T-ZnO_w particles, the internal stored elastic strain energy may waste so the recovery stress decreases. From the above experimental and analyse results it can be conclude that the T-ZnO_w /SMP maintain the shape memory prosperities.

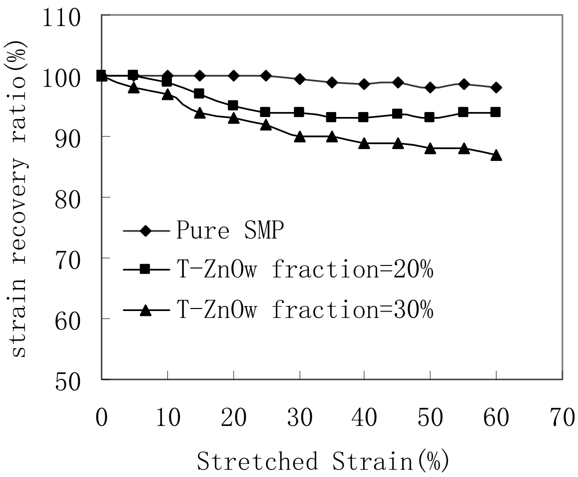

Fig.2. The strain recovery ratio ver stretch strain for different T-Zno_w fraction

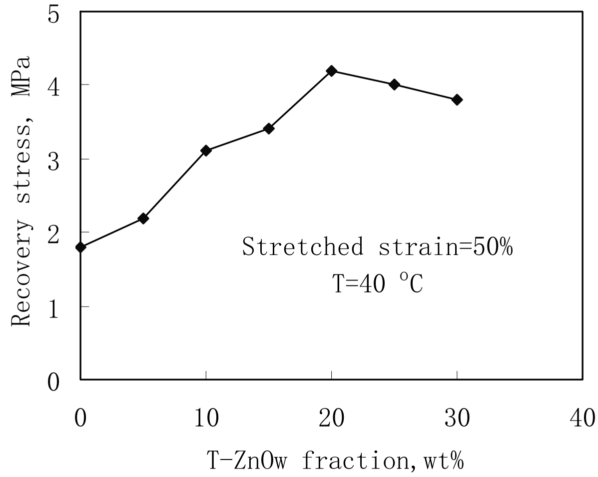

Fig.3. The recovery stress ver T-ZnO_w fraction

The average temperatures on the surface of the T-ZnO_w /SMP plants with the exposing time were shown in Fig.4. For the pure SMP plant, the temperature changes slightly during the whole exposing time. For the T-ZnO_w /SMP composite plants, the temperature increasing speed got quickly with the increasing of T-ZnO_w fraction.

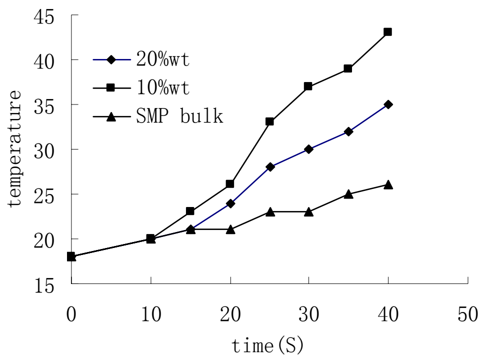

Fig.4. The temperature in SMP exposed in microwave field

In Fig.5, the photo series documents the microwave activated shape memory effect of ZnOw/SMP sample. After 20 seconds, the starting conversion of the ZnOw/SMP helix was observed and taking another 10 s to be completed, the temperature increased from room temperature (22^{o}C, below T_g) to 42^{o}C(above T_g) at the same time while the reference specimen remained the helix shape and the temperature had no obviously change.

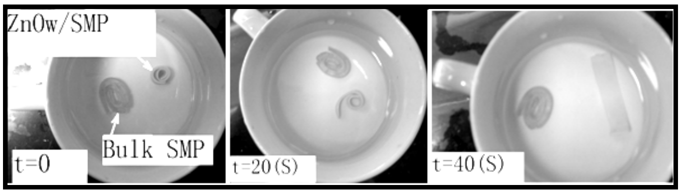

Fig.5. The shape memory movement of the T-ZnO_w under microwave field

4 Conclusions

We have demonstrated that by the incorporation of T-ZnO_w particles in a shape memory polymer matrix, it is possible to initiate an originally thermally activated shape memory effects by a touchless and highly selective microwave stimulus, while the basic materials properties in terms of thermal and mechanical behavior are maintained. The novel materials are of interest for medical applications as well as in sensor and actutator systems.

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