Energy Harvesting Performance of Polymer Composites dispersed Potassium Sodium Niobate Piezoelectric Particles

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Abstract. Piezoelectric composites have attracted much attention in terms of energy harvesting due to their flexibility and good power generation performance. This study fabricated sodium-potassium sodium niobate (KNN)-epoxy and KNN-glass fiber reinforced polymer (GFRP) composites. First, electromechanical properties were evaluated. It was found that the KNN-GFRP composites had high flexural strength and piezoelectric voltage constants. Next, damped bending tests and cyclic vibration energy harvesting tests were conducted. In the former, the KNN-epoxy failed, while the KNN-GFRP composite with a load capacity of 10 MΩ was able to generate 35 nJ of energy. In addition, the capacitors were successfully subjected to cyclic vibration tests. They could store charge in the capacitors, yielding a time constant of 347 seconds. This research contributes to the development of energy harvesting materials with good mechanical properties and evaluation methods.

Introduction

With the rapid development of the Internet of Things (IoT), demand for sensors is increasing year after year, but sensors require power to function [1]. While demand for electricity keeps growing, many countries, like Japan and the United Kingdom, have promised to being carbon neutral by 2050, necessitating the development of autonomous power sources that emit no carbon dioxide. Energy harvesting, which generates electricity from the surrounding environment via vibration and wind, can be accomplished by the use of piezoelectric materials transforming mechanical energy to electrical energy.

Ceramics are well-known piezoelectric materials, but they are very brittle. Combining them with polymeric materials can compensate for their shortcomings [2]. Glass fiber reinforced polymer (GFRP) and Carbon fiber reinforced polymer (CFRP) with piezoelectric materials have also been developed to withstand higher loads.

This study aims to develop GFRP composites with lead-free sodium potassium niobate (KNN) mixed with epoxy resin. Then, electromechanical properties such as Young's modulus, bending strength, and output voltage due to compression and bending stress will be evaluated. Finally, damped bending and cyclic vibration tests clarify the energy harvesting performance.

Experimental Procedure

Lead-free piezoelectric composites were fabricated using KNN particles (Nippon Chemical Industry Co., Ltd.) and epoxy resin. The fabrication method of lead-free piezoelectric composites is shown in Fig.1. Polling was performed by the corona polling method. Flexural strength (σ_f) was obtained by MSP testing [3]. Young's modulus (E_{11}) was obtained from the MSP test and Young's modulus in the thickness direction (E_{33}) from the nanoindentation test. The piezoelectric constant d_{33} was measured with a d_{33} meter. The piezoelectric voltage constant g_{33} was calculated from the relationship between applied compressive stress and output voltage.

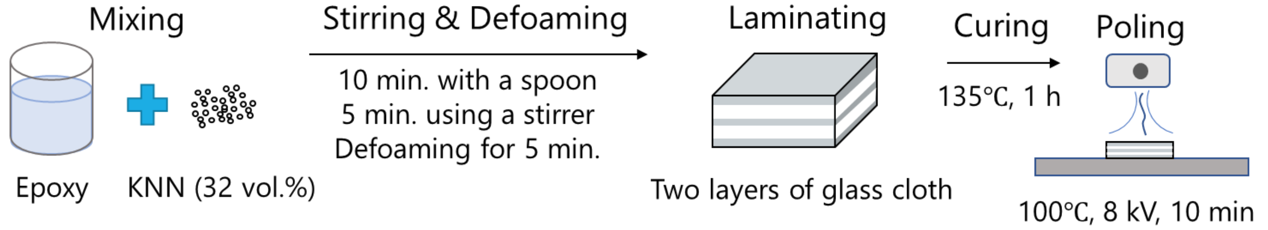

Fig. 1 Illustration of the lead-free piezoelectric composite fabrication process

Damped bending vibration energy harvesting and cyclic vibration energy harvesting tests were performed in Fig. 2(a) [4]. 10 × 45 × 0.6 mm^3 specimens (KNN-epoxy and KNN-GFRP) were cut, and gold electrodes were deposited using a sputtering system. The specimens were then attached to a 0.1 mm thick stainless-steel plate with conductive epoxy resin and polarized. The free length was 40 mm for the damped vibration test and 30 mm for the cyclic vibration test. The circuit used in the capacitor storage experiment is shown in Fig. 2(b).

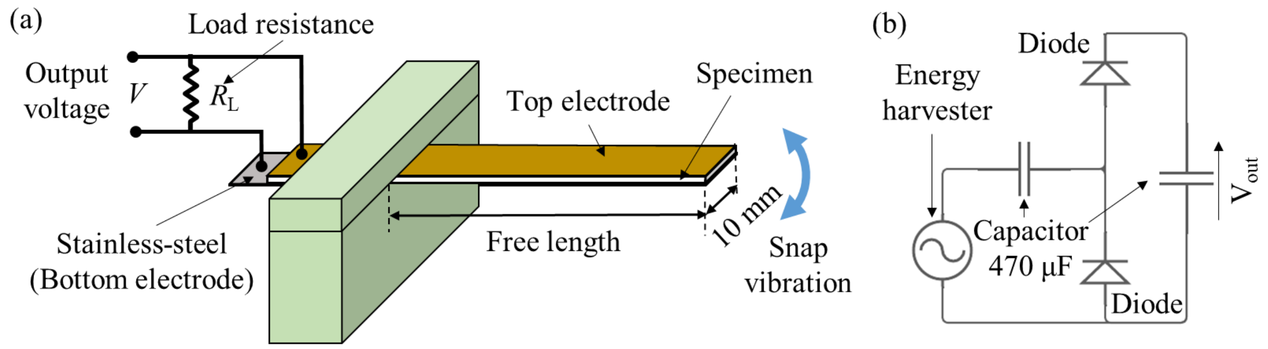

Fig. 1 (a) Schematic diagram of the vibration energy harvesting test. (b) Schematic diagram of the energy storage circuit to the capacitor

Results and discussion

The electromechanical properties obtained in this study are shown in Table 1. The higher flexural strength of KNN-GFRP compared to KNN-epoxy confirms that a robust piezoelectric composite material is fabricated with glass fiber reinforcement. Young's modulus was greater for KNN-GFRP at E_{11} and KNN-epoxy at E_{33}. KNN-epoxy was larger at d_{33}, but the values at g_{33} were almost the same. This result may be because KNN-epoxy broke during compression and could no longer withstand the load.

	σ_f [MPa]	E_{11} [GPa]	E_{33} [GPa]	d_{33} [pC/N]	g_{33} [V·m/N]
KNN-epoxy	106	5.14	4.73	8.9	26.5
KNN-GFRP	462	10.4	2.06	3.5	28.9

Table 1 The electromechanical properties obtained in this study.

A peak-to-peak of output voltage 8 V was obtained in a damped flexural vibration energy generation test. The maximum output power of 2 μW was obtained when the load resistance was set to 10 MΩ. Integration of the output power with the damping time yielded 35 nJ of harvested energy. Finally, we are conducting a cyclic oscillation energy harvesting test. Fig. 3(a) shows a waveform diagram of the voltages obtained by the oscilloscope, showing a peak-to-peak of output voltage 4.23 V. The smaller values compared to the damped flexural vibration test are due to the shorter free length and smaller amplitude. Fig. 3(b) gives the results of the storage experiments on the capacitor. The maximum potential difference of the capacitor is 700 mV, and a time constant of 347 seconds is obtained. These simple experiments show that energy can be harvested from ambient vibrations.

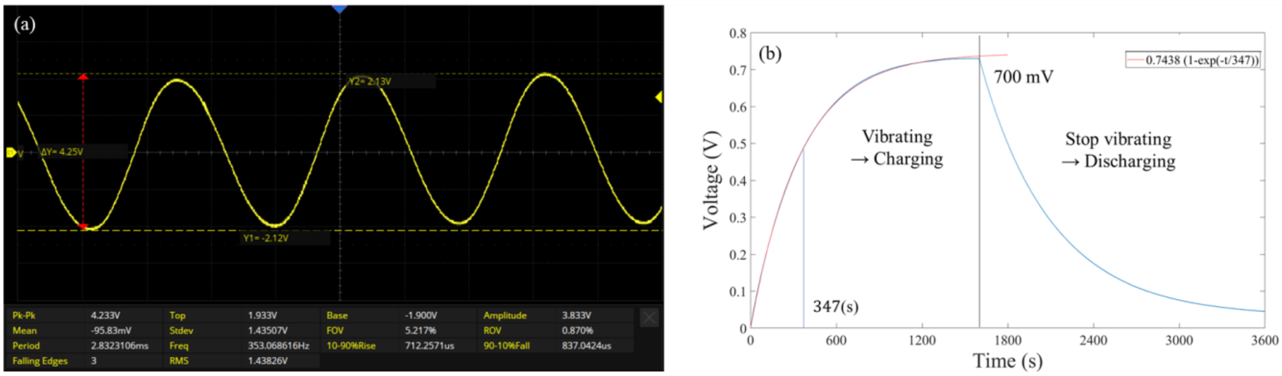

Fig. 2 Results of cyclic oscillation energy harvesting test on the KNN-GFRP samples: (a) measured voltage by an oscilloscope, (b) the results of the storage experiments on the capacitor.

Conclusion

This study reveals the electromechanical properties of glass fiber reinforced piezocomposites, and it was found to be one of the most effective energy harvesting materials. Flexible piezocomposites for wearable applications will be developed in the future.

Acknowledgements

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