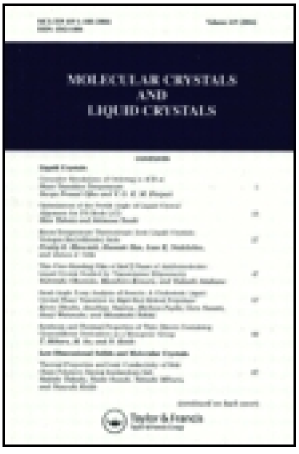

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Ceramic - Polymer Composite Materials for Underwater Distance Sensor

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CERAMIC - POLYMER COMPOSITE MATERIALS FOR UNDERWATER DISTANCE SENSOR

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Abstract The piezoelectric composite materials were made with PZT ceramics and epoxy polymer. The processing technique of the composite materials was the extrusin method, and the connectivity pattern of the two phase was the 1-3 type. Then PZT rods were extruded, dried on the vacuum chamber. For sintering, the PZT rods were cut into 4 cm length, PZT rods were sintered at 1270 °C. The PZT rods were aligned in the two racks, and it was under vacuum condition while the epoxy was poured into the plastic tube. The composites was cured at 70 °C for 8 hours, it was sliced by the diamond saw. The air-dried silver paste was adhered and the materials were poled in a 80 °C oil bath with a DC electric field of 2 KV/mm for 10 minutes. As a experimental result, the electromechanical coupling coefficient (k_t) of the materials was more than 0.65, and the resonance frequency of thickness vibration mode was 0.6 to 1.4 [MHz]. Acoustic impedance of the materials was 5.8-7.2 $\times 10^6$ [kg/m^{2}s]. The ultrasonic transducer using the PZT ceramics-epoxy polymer composites was manufactured, and it was known that the experimental result of measuring the underwater distance using the ultrasonic transducer was in good agreement with the actual measurement value. Therefore, the results demonstrate that the PZT-epoxy piezoelectric composite materials be possibility for underwater distance sensor.

INTRODUCTION

Piezoelectricity exhibited by polarized polymer films,piezoelectric ceramics and ceramic-polymer composite materials. Piezoelectric composite materials, which was prepared by the ceramics and polymers, have been observed for ultrasonic transducer applications.[1-5] Piezoelectric ceramics with high electromechanical coupling factors like lead zirconate titanate(PZT) ceramics of single phase are not adequated for ultrasonic transducer applications because of high acoustic impedance and narrow bandwidth. So, the concept of piezoelectric ceramics-polymer composites is utilized for the fabrication and design of ultrasonic transducer materials.[6] The properties of a piezoelectric composites are influenced by the connectivity of its components.[7]
Connectivity is defined as the number of dimensions in which each phase is continuous.[8] PZT ceramics-epoxy polymer composite materials with 1-3 connectivity is shown in Figure 1(c), and it was prepared by composites of PZT ceramic rods embedded in a three-dimensionally continuous epoxy matrix.[9] In present work, an experimental evaluation of ceramics-polymer composite materials and a fabrication of ultrasonic transducer for underwater distance sensor are investigated.

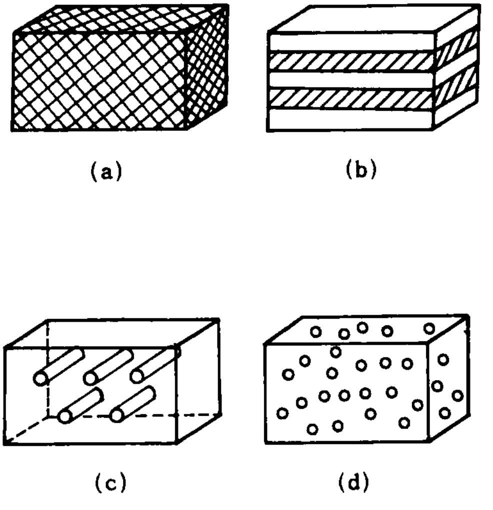

FIGURE 1. Model of composite materials by connectivity
(a)3-3 (b)2-2 (c)1-3 (d)0-3

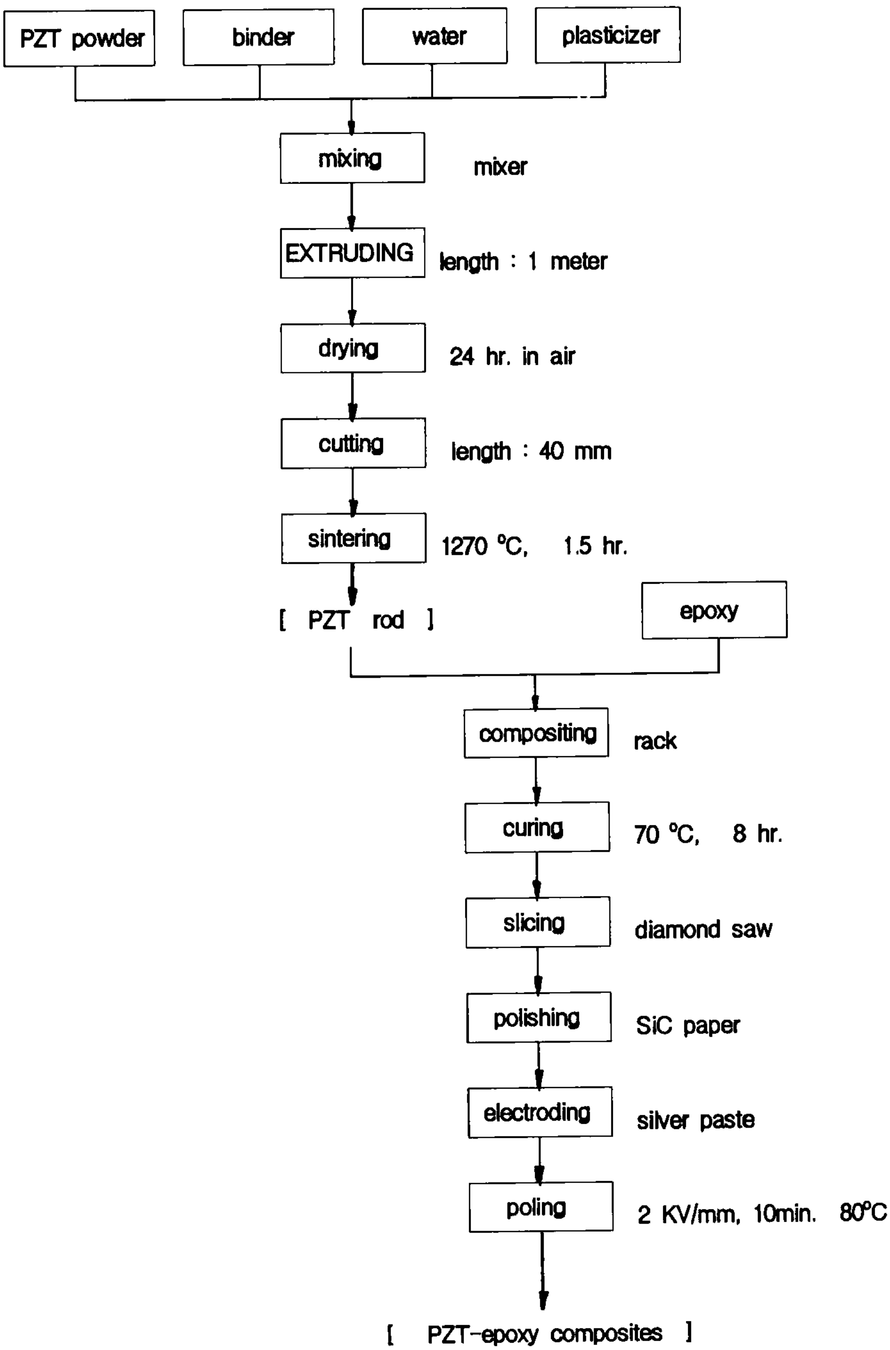

FIGURE 2. Flow diagram for the preparation of PZT ceramic-epoxy polymer composites

EXPERIMENTAL

Preparation of composites, fabrication of transducer

PZT ceramics used in the study was commercial powder(PZT501A, Ultrasonics Powders Inc, NJ) which was formed by mixing PbO, ZrO_2 and TiO_2, calcining. The flow diagram for the preparation of composites was shown in Figure 2. The PZT powder was mixed with binder(Hydroxy Propyl), plasticizer(polyethylene glycol) and water. Then PZT rods were extruded to downward at a constant rate of approximately 1.5 m/min., and the length of PZT rods was about 1.0 meter.

For sintering, the green PZT rods were cut into 40 mm length. The green PZT rods were sintered in a sealed alumina crucible by a soak period of one-half hour at 1270 °C. The polymer used in the study is called commercial Spurr epoxy(polyscience Inc, USA) which has very low viscosity(60 cps). The sintered PZT rods were aligned in the two racks, it was placed in a plastic tube with one closed ends, and it was under vacuum condition while the Spurr epoxy was poured into the plastic tube(Figure3).

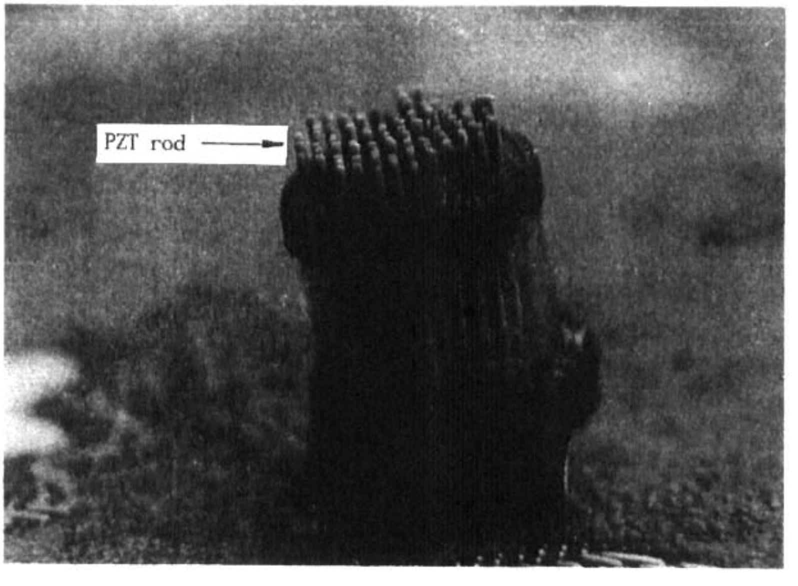

FIGURE 3. Compositing stage of PZT rod and epoxy

The composite was cured at 70 °C for eight hours, it was sliced by the electric diamond saw. After being slice, the ceramics-polymer composite of disc type were polished SiC paper. The air-dried silver paste was adhered and the composite were poled in a 80 °C oil bath with a DC electric field of 2 KV/mm for 10 minutes along the length of the PZT rods. The ultrasonic transducer used the composites was fabricated to test in the underwater,which was used with 20 mm diameter.

Measurement

The microstructure of interface of PZT ceramics and epoxy polymer was observed using scanning electron microscope. The electrical properties which are the relative permittivity and resonance frequency etc. were measured using LF impedance analyzer (HP4192A) and spectrum analyzer(HP8557A). The piezoelectric factor of the composites was measured with a d_{33} meter(CPDT 3300, Channel Products, Ohio). The impedance analyzer was used to measure the dielectric and resonance characteristics, the spectrum analyzer was used to measure the waveform of the resonance characteristics. The time-domain response[10] to an electrical pulse of an ultrasonic transducer made by the composites was measured with an ultrasonic transducer analyzer(UTA-4, KB-Aerotech, Penn.) and storage oscilloscope(TEK2445A). Experimental arrangement for underwater distance sensing is shown in Figure 4.[11]

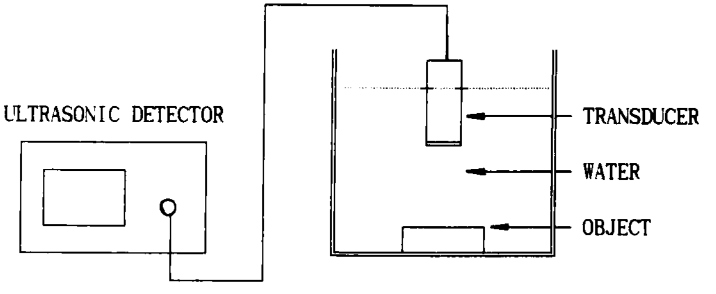

FIGURE 4. Measuring system of underwater distance

RESULTS AND DISCUSSION

Different piezoelectric composites with PZT ceramics and epoxy polymer were prepared with approximately 11 and 24 volume percent PZT ceramics using 0.85 mm diameter PZT rods. The composite materials were shaped as circular discs of diameter 20 mm and varying thickness from 0.9 mm to 2.5 mm. A photograph of typical 1-3 type piezoelectric composite materials with PZT rods embedded in epoxy is shown in Figure5. The PZT rods embedded in epoxy matrix has the regular periodicity and 1-3 connectivity. Dielectric and piezoelectric properties of PZT-epoxy composites are given in Table 1. Microstructure[12] of interfacial adhesion of PZT rods and epoxy observed using SEM is given in Figure 6. We knew that the physical cohesive condition of PZT rods and epoxy polymer was excellent.[13] Table 1 shows that the resonance frequency of thickness mode decreased with increasing composite thickness. In the thickness mode, PZT rods embedded in epoxy matrix vibrate in fundamental longitudinal 33 mode. The ultrasonic transducer fabricated with ceramic-polymer composite which the resonance frequency is 1.2 MHz in Table1 exhibits a very short impulse response and a very fast rise time(Figure 7).[14]

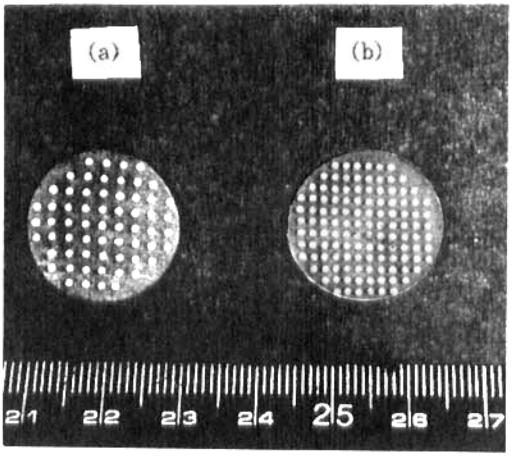

FIGURE 5.Composite materials with PZT rods embedded in epoxy
(a) 11 volume % PZT (b) 24 volume % PZT

TABLE 1. Electrical properties of PZT ceramic-epoxy polymer composite materials

factor \ sample	S-1	S-2	S-3	E-1
volume % PZT [%]	24.2	24.2	24.2	24.2
PZT rod diameter [mm]	0.85	0.85	0.85	0.85
sample thickness t [mm]	0.91	1.25	2.5	0.9
sample density ρ [g/cm^3]	2.26	2.32	2.25	2.24
relative permittivity ε_{33}	372.2	362.4	373.4	365.1
resonance frequency f_r [MHz]	1.41	1.20	0.6	1.42
coupling factor k_t	0.68	0.64	0.65	0.58
acoustic impedance Z_{ac} [Mrayl]	5.80	6.44	7.20	6.05

* S-1, S-2, S-3 : PZT-Spurr epoxy, E-1 : PZT-Eccogel epoxy

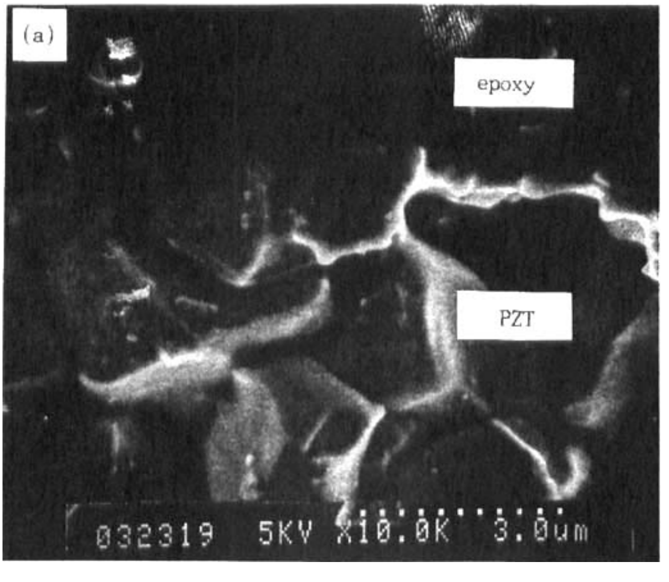

FIGURE 6. SEM micrograph of interface of PZT rod and epoxy

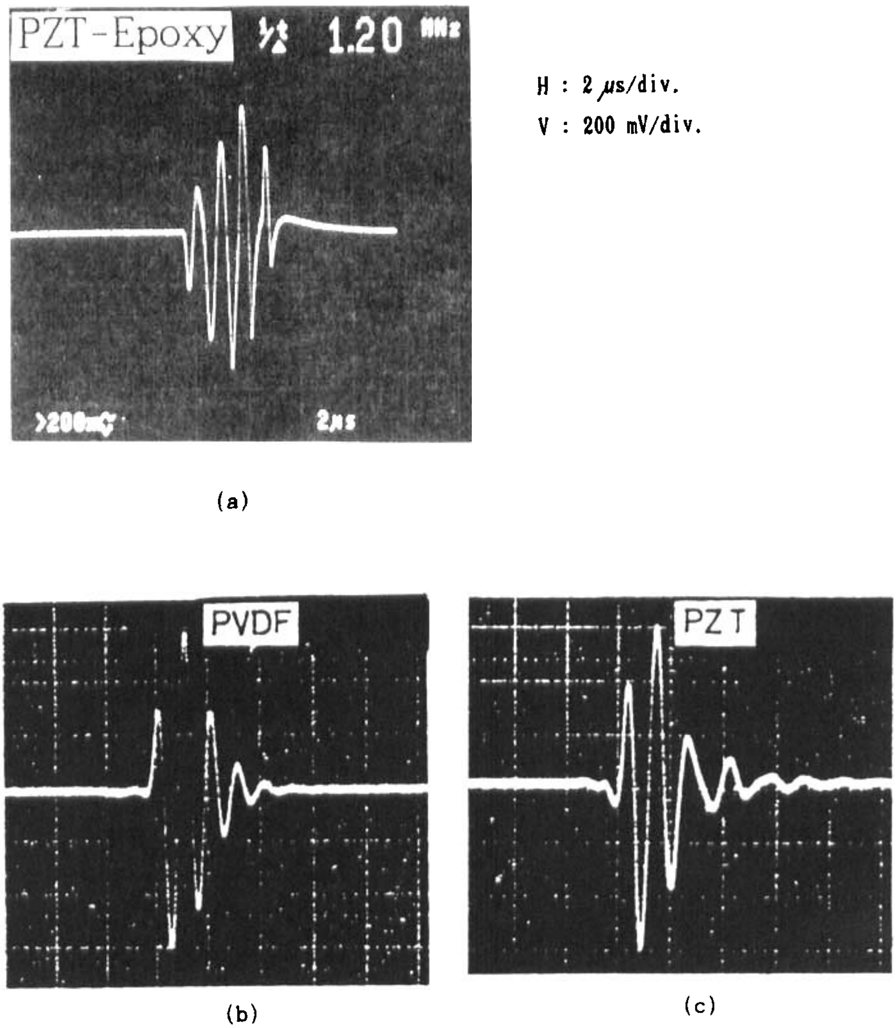

FIGURE 7. Pulse echo response characteristics of the ultrasonic transducer
(a)PZT-epoxy (b)PVDF (c)PZT

Photograph of measuring result of distance in underwater using ultrasonic transducer is shown in Figure4, and the ultrasonic transducer was mounted in a water tank.[15] Following movement of the transducer to upward or downward, it detects the distance from transducer to reflecter. Figure8 shows that the distance from transducer to reflecter is 46 mm, because the X-axis scale is 25 mm per division. Accordingly, the ultrasonic transducer fabricated with ceramic-polymer composite be possibility for underwater distance sensor.

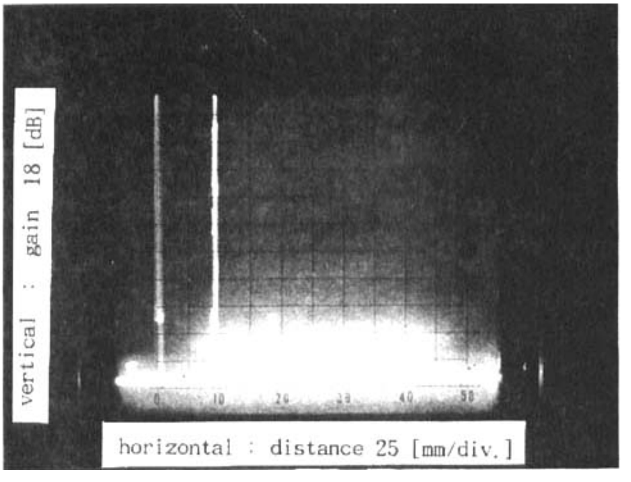

FIGURE 8. Waveform of measuring the distance in the underwater

CONCLUSIONS

In the study, we have been concerned with the preparation of the ceramic-polymer composite materials and the fabrication of the ultrasonic transducer for underwater applications. The PZT ceramic rods were formed by an extrusion method. In order to get good acoustic matching with water it is necessary to reduce the density of composite materials, i.e.acoustic impedance, to as close to the density of water as possible. The PZT ceramic-epoxy polymer piezoelectric composite materials have the densities ranging from 2.5 to 3.5 gm/cm^3. The resonance frequency of thickness mode of the composites is 1.2 MHz. In the pulse response patterns of the time-domain of the ultrasonic transducer, the rise time is very fast and the ringing is low. The ultrasonic transducer fabricated with PZT ceramic-epoxy polymer piezoelectric composites come into use as underwater distance sensor.

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