Piezoelectric and Acoustic Properties of Ultrasonic Sensor Using 2-2 Piezocomposites

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Abstract – We have investigated on the development of 2-2 piezocomposites that have better piezoelectric activity and lower acoustic impedance than those of conventional piezoceramics. In this study, we have investigated the piezoelectric and acoustic properties of 2-2 piezocomposites sensor which were fabricated using dice-and-fill technique for the different volume fraction of PZT. The resonance characteristics measured by an impedance analyzer were similar to the analysis of finite element method. The resonance characteristics and the electromechanical coupling factor were the best when the volume fraction PZT was 0.6. It also showed the highest result from the standpoint of sensitivity, bandwidth and ring-down property and so on at the same condition. The specific characteristics shows that the 2-2 piezocomposites turned out to be superior to the ultrasonic sensor composed by single phase PZT.

Keywords: Piezocomposites, electromechanical coupling factor, resonance, finite element method, sensitivity.

1 Introduction

Piezocomposites, usually made of PZT and polymer, is widely used ultrasonic transducer in medical diagnosis and underwater acoustic applications. The piezoelectric materials used in ultrasonic transducers should have several qualities, which performs the energy conversion between the mechanical form and electrical form, to have a high electro-mechanical coupling factor. The piezoelectric must be acoustically matched to tissue so that the acoustics waves in the transducer and tissue couple well both during transmission and reception. The electric properties must be compatible with the driving and receiving electronics. Conventional piezoelectric ceramics such as lead-zirconate-titanate, lead metaniobate and modified lead titanates are the most popular choices for medical ultrasonic transducers. These ceramics offer high electromechanical coupling, a wide selection of dielectric constants and low electrical and mechanical losses. However, these ceramic materials are not mechanically flexible and have large acoustic impedances, in consequence of which there is serious mismatch to soft materials, particularly to biological tissue and water [1]. To make an improvement with the above problem, the Newnham[2] showed his 10 phase connectivity to apply it, that provides and piezocomposites using piezoelectric ceramic having good piezoelectric properties. 2-2 type piezocomposites have low relative permittivity and high electromechanical coupling factor, also the research is being done actively. For the reasons of less induced electrical and mechanical loss and wide frequency bandwidth, these are expected in applications of high frequency transducer and ultrasonic transducer. N. Lamberti[3] analyzed the acoustic properties of piezocomposites caused by thickness variation of matching layer, while X. Geng[4] reported the electrical and acoustic properties for the high frequency 2-2 type piezocomposites featuring without matching layer with using the tape-casting technique. However, there has been a large number of precedents on modeling of acoustic properties and material-oriented approach of the piezocomposites. But there has been a scarce number of report on feasible design, construction of transducer, even ultrasonic one from piezoelectric composites. In this study, 2-2 piezocomposites sensor were fabricated, the piezoelectric and acoustic properties were investigated.

2 Experimental

2-2 piezocomposites were fabricated using the well known dice-and-fill technique [5]. When fabricating a piezocomposites, it is required that the polymer has low shrinkage rate, density and so on. To determine polymer which meets its requirements, we chose polymer of Araldite(Ciba Geigy), Epofix(Struers Corp.) and DEP(Dai Han Poly.) having low shrinkage, density and being widely used commercially. widely used Araldite(Ciba Geigy), Epofix(Struers Corp.) and DEP(Dai Han Poly.). Also, to decrease the shrinkage for polymer and to increase the PZT, TiO_2 filler of which amount is 10 wt% was added to the polymer, respectively. PZT-5A plates were fabricated by tape-casting techniques. The PZT plates were dried at room temperature for 12 hours. After drying, the PZT plates were sintered at 1180℃ for 2 hours for the heating rate was 3℃/min. Sintered plates were cutted to the size for 25×25×1.5 ㎜. Both sides of the PZT plates were electroded with the silver paste and backed at 580℃ for 30 min. PZT plates were subsequently poled in a silicon oil batch at 120℃ for 20min under a DC field of 2 ㎸/㎜. The poled PZT plates was grooved to 1 ㎜ depth by diamond saw with a thickness of 350 ㎛. PZT volume fraction was processed to 0.8, 0.6, 0.4 and 0.2 by a pitch width varies. The processed specimens were filled with a polymer mixed with a filler and then cured for 24 hours in an 30℃ to 100℃vacuum oven. Finally, it was cut into the size of 10×10 after adjustment of thickness to 1 ㎜. Silver wire was connected as a detector after application of a room temperature electrode on both polished surfaces of piezocomposites after washing.

3 Results and Discussion

Dielectric constants of 2-2 piezocomposites was then determined using the relationship ;

$$\overline{\varepsilon_{33}^{T}} = V_{PZT}\left[\varepsilon_{33}^{T} - d_{33}^{2}\frac{V_{polymer}}{V_{PZT}s_{11} + V_{polymer}s_{33}^{E}}\right] + V_{polymer}\varepsilon_{11} \quad (1)$$

Where ε_{33}^{T} and s_{33}^{E} are dielectric constant and elastic compliance of the PZT, ε_{11} and s_{11} are dielectric constant and elastic compliance of the polymer, respectively. Figure 1 shows the variation of relative permittivity with PZT volume fraction. The relative permittivity of piezocomposites was hardly influenced by any type of polymer and decreased with decreasing PZT volume fraction. It showed that the relative permittivity of piezocomposites depends on rater volume and permittivity of PZT than volume and permittivity polymer.

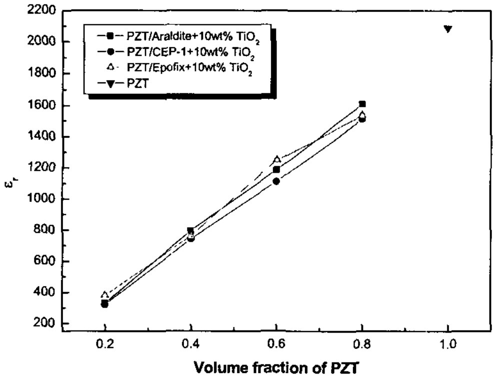
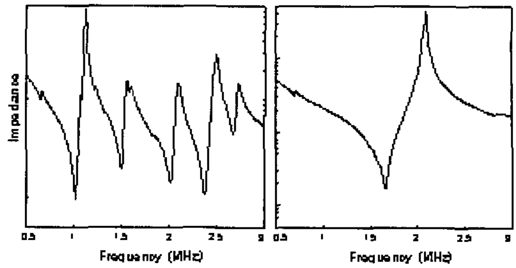
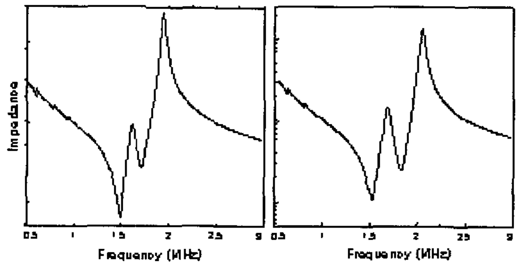


Figure 1. Variation of relative permittivity with PZT volume fraction.



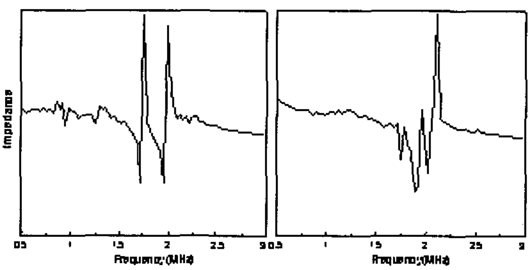
(a) $V_{PZT} = 0.8$ (b) $V_{PZT} = 0.6$



(c) $V_{PZT} = 0.4$ (d) $V_{PZT} = 0.2$

Figure 2.The measured impedance response for 2-2 piezocomposites.

(a) $V_{PZT} = 0.8$ (b) $V_{PZT} = 0.6$



(c) $V_{PZT} = 0.4$ (d) $V_{PZT} = 0.2$

Figure 3.The calculated by FEM impedance response for 2-2 piezocomposites.

To recognize the resonance characteristics of 2-2 piezocomposites sensor, figure 2 shows the resonance characteristics measured by the experimental, figure 3 shows the resonance characteristics by FEA. The electrical impedance was measured by an HP4194A impedance analyzer. As showing in figure 2 and 3, there is a tendency to have one resonance peak at volume fraction 0.6 but several lateral mode resonance peak at the rate of 0.8. It is analyzed that what causes the phenomenon is the overlap between thickness mode resonance and lateral mode resonance after the shear wave is sent to the polymer from vibration for PZT in thick ness mode [6]. At the PZT volume fraction rate of 0.2 and 0.4, two resonance peaks were shown in the range of 1.5 MHz to 2 MHz. It is a phenomenon that caused by the decrease of piezoelectric charge constants value when the major portion of the most of stresses from the outside of piezocomposites applied over polymer which is wider and broader than PZT. This method can be improved, controlling the width of polymer and PZT when the piezocomposites fabricated.

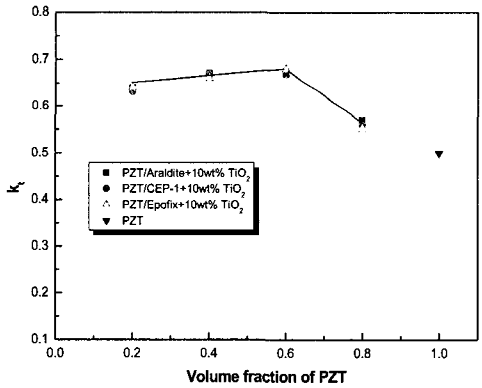


Figure 4. Variation of k_t with PZT volume fraction.

Figure 4 shows the electromechanical coupling factor for the thickness mode indicated by the variation of PZT volume fraction of piezoelectric composites using polymer and PZT-5A. The electro-mechanical coupling factor for the thickness mode, k_t, for a piezoelectric substrate can be obtained by measuring the antiresonant and resonant frequencies of the substrate with the formula (2)

$$k_t^2 = \frac{\pi}{2}\frac{f_s}{f_p}\tan\left(\frac{\pi}{2}\frac{f_p - f_s}{f_p}\right) \qquad (2)$$

The PZT volume fraction shows the fixed value, 0.64~0.68, approximately within the range between 0.2~0.6 while it is increased to decreased over the range. This phenomenon is due to decrease the k_t by clamping effects over PZT regarding polymer phase. The piezocomposites shows the higher electromechanical coupling factor for the thickness mode value, compared with the single phase PZT. It corresponded with the result of precedent experiments [7].

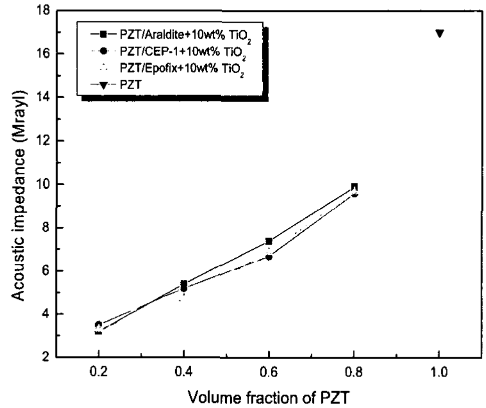
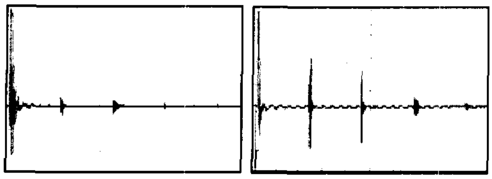


Figure 5. Variation of acoustic impedance with PZT volume fraction.

Acoustic properties of the 2-2 piezocomposites sensor was performed under water, using a stainless-steel block as a target. The system was composed of a Pulse/Reciver (5072PR, Panametrics), an oscilloscope (54624A, Agilent), a water tank, and the target. Figure 5 shows the acoustic impedance variation of piezoelectric composites in terms of PZT volume fraction. The acoustic impedance of 2-2 piezocomposites sensor was decreased proportionally due to the density decrease caused by the PZT volume fraction decrease. The piezocomposites acoustic impedance was 3.7 Mrayl between 0.2~0.6 allowing it to be used as a ultrasonic transducer. Figure 6 shows the time domain response of piezocomposites sensor. It was shown that the transmitting and receiving sensitivity of 2-2 piezocomposites sensor were more sensitive than that of single phase PZT. It is considered to be an improvement since piezoelectric constant d_h and g_h was higher than single PZT [8]. Figure 7 shows the frequency domain response of piezocomposites sensor. Bandwidth was recorded the widest and largest at the PZT volume fraction rate 0.6, it narrowed down 0.4 and 0.2. The decreased of sensitivity was credited to diminishing piezoelectric constants by diminishing PZT volume fraction. By increasing polymer volume, however better bandwidth was obtained from this case, comparing the sensor which is composed with single phase PZT, since the value of g_h is getting greater with decreasing piezocomposites permittivity.



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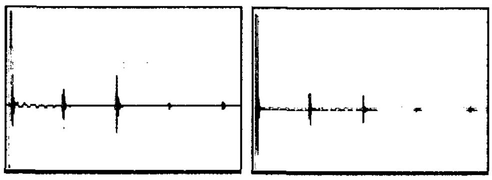
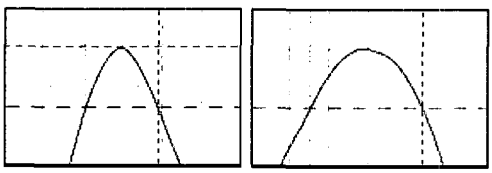


(c) $V_{PZT} = 0.4$ (d) $V_{PZT} = 0.2$

Figure 6. Time domain response of 2-2 piezocomposites sensor .



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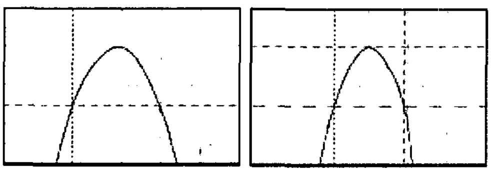

(c) $V_{PZT} = 0.4$ (d) $V_{PZT} = 0.2$

Figure 7. Frequency domain response of 2-2 piezocomposites sensor.

4 Conclusions

We fabricated piezoelectric composites by using the polymer and PZT-5A, and fabricated the transducer with it. The acoustic and electrical properties of the transducer we investigated are as follows : The resonance characteristics measured by an impedance analyzer were similar to the analysis of finite element method. The resonance characteristics and the electromechanical coupling factor were the best when the volume fraction PZT was 0.6. It also showed the highest result from the standpoint of sensitivity, bandwidth and ring-down property and so on at the same condition. The pulse-echo response of 2-2 piezoelectrics sensor was favourable as compared with the single phase PZT.

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