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Journal of the European Ceramic Society 27 (2007) 4169–4171

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Properties of a hydrophone produced with porous PZT ceramic

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Abstract

Interconnected piezoelectric porous ceramics PZT have been tested for possible use in hydrophone applications. These materials consisted of: (1) ceramics with fine porosity having pores from 50 to 100 μm and (2) cellular ceramics having cavities of the order of the millimeters. Porous ceramics are coated with flexible polymer standard polyurethane for the hydrostatics tests. The effect of the size of the pores and porous volume on the sensitivity of the sensor is studied and the performances of the hydrophones devices are presented.

Keywords: PZT; Porosity; Sensors; Connectivity 3

1. Introduction

A hydrophone device is a piezoelectric transducer used to detect noises under water and convert the mechanical vibration of low frequency acoustic waves (<40 kHz) into electrical signal. The sensitivity of a hydrophone (Sh) is measured by the voltage that is produced per unit hydrostatic pressure. The hydrostatic piezoelectric voltage g_h coefficient relates the electric field of piezoelectric material to the applied hydrostatic stress and is a useful parameter for evaluating a material for using a hydrophone. The g_h coefficient is related to hydrostatic strain coefficient d_h, which describes the polarization resulting from a change in stress, by the relation: $g_h = d_h/\varepsilon_0\varepsilon_r$ where ε_r is the relative permittivity and ε_0 is the permittivity of the free space. A large g_h and d_h permit to have a better "figure of merit" which calculates by the product $d_h g_h$. Other desirable properties for hydrophone materials include: (1) low density for good acoustic matching with water, (2) little variation of d_h and g_h with pressure, temperature and frequency, (3) high physical compliance and flexibility so that the transducer can conform to curved surfaces, and exhibit improved mechanical shock resistance. The PZT ceramic has traditionally been used for hydrophone applications but has several disadvantages, low d_h and g_h, large impedance acoustic ($\sim$30 kg/m^2 s) necessitating the usage of matching layers, and finally, ceramics are brittle, nonflexible and no conformable. In recent years, it has been shown that the piezoelectric composite materials (piezocomposite) formed by ceramic and polymer or air, constitute a technological solution to improve the characteristics of theirs sensors.[1–5] This paper investigates the properties of porous ceramics for the sensors applications in water and to achieve this objective, the sensitivity of porous ceramics is measured and the hydrostatics characteristics are calculated.

2. Experiments

Transducers characterized in this paper were made from piezoelectric porous ceramic disk (diameter 25 mm, thickness 3–5 mm) fabricated from a commercial PZT. A fabrication procedure of porous PZT with 3-3 connectivity[6] has been reported earlier.[7] Two types of interconnected porous ceramics are used: (1) *ceramics with fine porosity* with less than 50% of cavities (50–100 μm) and (2) *cellular ceramics* having cavities of the order of the millimeters (Fig. 1). Samples are coated on the outer surface with polymer and of electrical wire of contact are welded beforehand, by an air-drying silver paint onto the two faces of the disk to carry out the recovery of the electric charges.

3. Measurements

The porosity P of the sample was calculated from the measured density d_r, using the equation:

$$\%P = \left(1 - \frac{d_r}{d_t}\right) \times 100 \tag{1}$$

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doi:10.1016/j.jeurceramsoc.2007.02.124

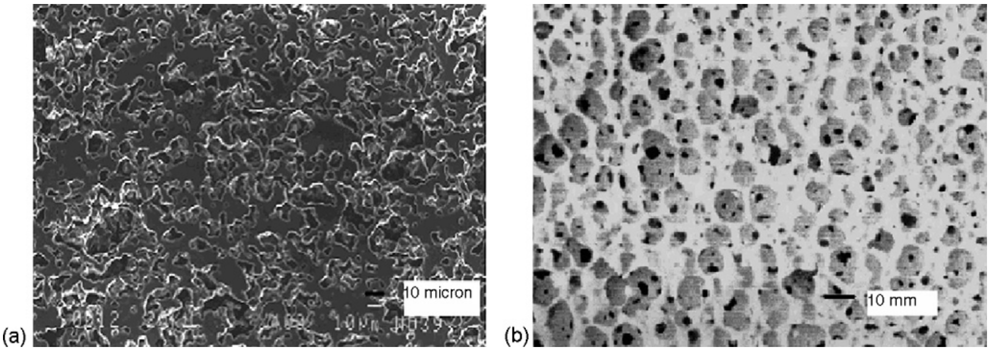

Fig. 1. Microstructure of porous ceramics: (a) ceramics with fine porosity and (b) cellular ceramics.

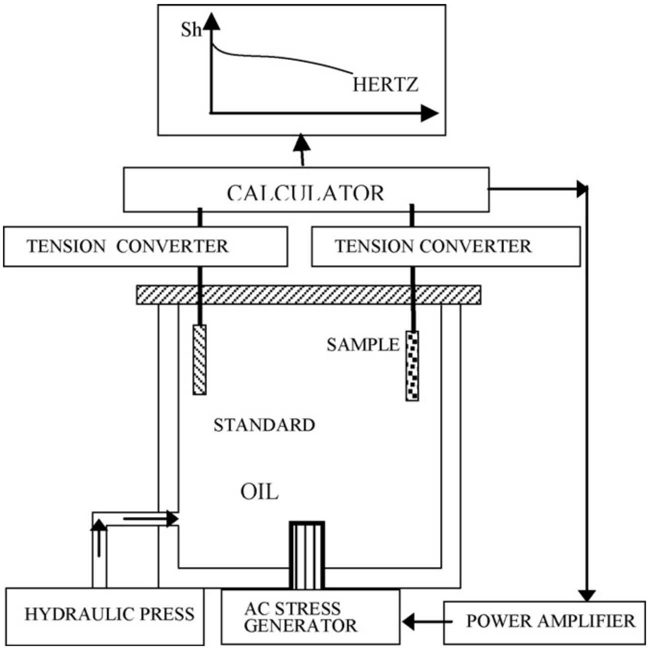

Fig. 2. Apparatus used to determine the sensitivity of samples.

where d_r and d_t are, respectively, real and theoretical density of ceramic ($d_t = 8$). The capacitance and the dielectric losses $tg\delta$ of disks samples were measured at 1 kHz using a LCR meter, and then the dielectric permittivity ε_r is calculated. To determine the hydrostatic properties, we measure the sensitivity of the samples by comparison, and then we calculate the d_h coefficient by using Eq. (2). Fig. 2 shows the apparatus used: the stress generator was driven at frequencies from 100 to 1000 Hz, producing hydrostatic pressure on the sample and standard. Signal from the sample and standard are fed through charge amplifiers into separate channels on a calculator, and the ration of the voltage produced from the sample and the standard is calculated at each point of the band of frequency (100–1000 Hz) to give the sensitivity Sh (dB).

$$d_h = 10^{\mathrm{Sh}/20} \times \frac{G_c}{G_{st}} \times \frac{1}{A} \tag{2}$$

where G_c (pC V^{-1}) and G_{st} (Pa V^{-1}) are the amplifier of tension value to sample and standard, respectively, and A is the surface of sample. A test of control of variation of d_h was carried out on a cellular ceramic until a pressure of 60 bar.

Determination of acoustic impedance and elastic constant is carried out by the impulse method developed by Lakestani et al.[8]

4. Results

The results of sensitivity, along with dielectric, piezoelectric and elastic characteristics are presented in Table 1. The d_h coefficient is improved for highly porous ceramics, but it decreases with an increase in frequency, especially in the case of cellular ceramics (Fig. 3). Fig. 4 shows that ceramics having over 50% of porosity the figure of merit and g_h coefficient are significantly improved. According to Fig. 5, the impedance acoustic Z_a and the elasticity constant C_{33} decrease clearly with the increase of

Table 1
Electro-acoustic properties of porous ceramics

Properties	Material					
	Dense PZT	Ceramic with fine porosity			Cellular ceramic	
Porosity, P (%)	5	30	40	50	70	80
Sensitivity, Sh (dB)	−207	−184.7	−181.4	−182.1	−187.3	−184.1
Permittivity, ε_r	1230	661	530	490	220	123
Loss dielectric, $tg\delta$ (%)	0.5	0.5	0.5	1.0	1.5	2.5
d_h (10^{-12} C)	47	128	150	188	195	255
g_h (10^{-3} V m/N)	0.18	2.48	4.20	5.0	16.2	52.90
$d_h g_h$ (10^{-15} m^2/N)	3.82	19.40	28.40	26.06	88.64	207.31
Acoustic impedance, Z_a (10^6 kg/m^2 s)	32.5	15.7	11	9.8	4.2	–
Elastic constant, C_{33} (10^6 N/m^2)	14.3	4.7	2.7	2.2	7.0	–

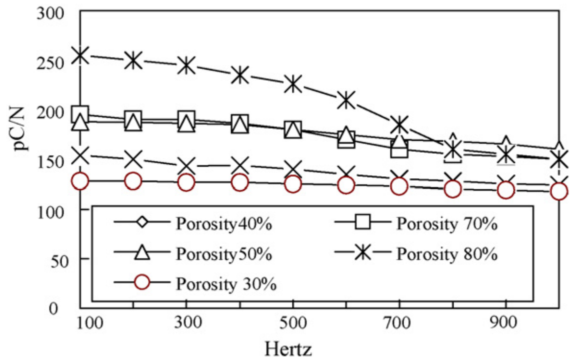

Fig. 3. d_h as a function of frequency.

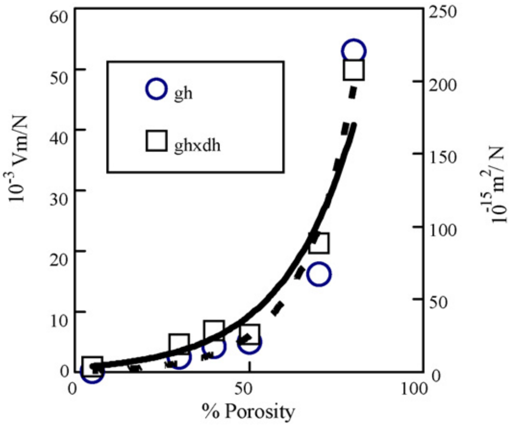

Fig. 4. $d_h g_h$ and g_h as function of porosity.

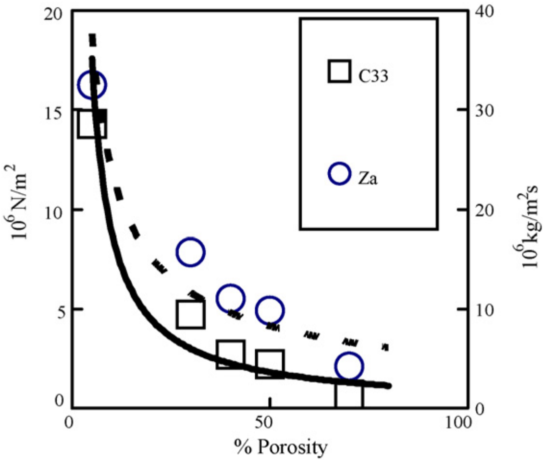

Fig. 5. Z_a and C_{33} as a function of porosity.

porosity and for cellular ceramics (over 50% of porosity), these characteristics decrease strongly. The resistance of pressure was carried out on cellular ceramic having 75% of vacuum, but the presence of bubbles of air in the polymer coating does not allow a pressure rise beyond 40 bar (Fig. 6).

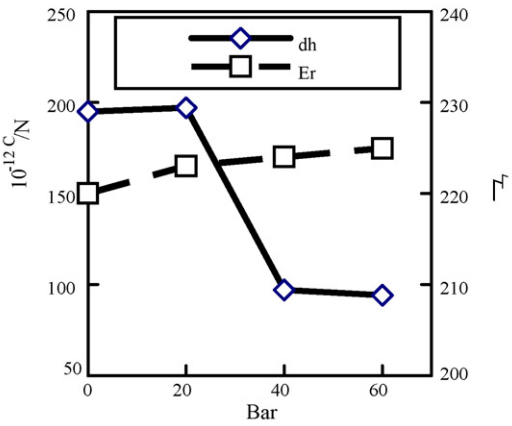

Fig. 6. d_h and ε_r vs. the pressure.

5. Conclusions

Porous PZT piezoelectric ceramics are promising materials for acoustic applications of sensors. The best performances are obtained by ceramics having porosity content of 50%. Cellular ceramics exhibit better hydrostatic characteristics than porous ceramics, but it is necessary to find the technique of coating the ceramic with a polymer without the presence of air bubbles.

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