PIEZOELECTRIC AND MECHANICAL PROPERTIES IN PIEZOELECTRIC CERAMICS UNDER REPEATED ELECTRICAL PULSE

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Abstract
Repeated electrical pulse dependence of piezoelectric properties, such as piezoelectric coupling factor (k_{31}, k_{33}) and mechanical quality factor (Q_m), were studied in four kinds PbTiO_3 - PbZrO_3 - ABO_3 piezoelectric ceramics with different Q_m (Q_m = 1600 to 60) and Curie point (T_c = 360 to 120°C). The k_{31} and k_{33} values were constant, however Q_m values were decreased in high Q_m (Q_m = 1600) and high T_c (360°C) material, with increasing the cycles of electrical pulse, and were broken around 24,000 cycles as a standard value by the application of electrical pulse of 380 V at the resonant frequency. On the other hand, the k_{31}, k_{33} and Q_m were constant in low Q_m (Q_m = 60) and high T_c (360°C) under the same experimental condition as those in high Q_m and high T_c, and were not broken. The temperature in both materials was elevated around 40°C by the application of repeated electrical pulse.

1. Introduction
Recently, piezoelectric ceramics have been gave attention to utilization under a high power, such as a power actuator in automobile and ultrasonic washing in semiconductor process. On the other hand, piezoelectric materials have been mainly developed in electronics field, such as a resonator and several kinds sensors. In those small signal devices, piezoelectric properties were constant during in action, except for aging. However, in the high power applications, it has been predicted that temperature in material was elevated. There still remains unclear programs. In this paper, four kinds piezoelectric ceramics were prepared from the viewpoints of mechanical quality factor (Q_m) and Curie point (T_c). Piezoelectric and mechanical properties were measured as a function of both voltage of electrical pulse and cycle of repeated electrical pulse. Moreover, fracture mechanism under the application of repeated electrical pulse was compared with mechanical strength in three point bending test.

2. Experimental procedure
The mechanical quality factor (Q_m) and Curie point (T_c) of four kinds PbTiO_3 - PbZrO_3 - ABO_3 piezoelectric ceramics were shown in Table 1. Figure 1 shows the flow chart for measurement of piezoelectric properties. As illustrated in schematic figure of repeated electrical pulse in Fig. 1, the frequency shown in mark f was 50 kHz, and voltage was changible by 124, 250, 300, 540 V. The repeated pulse in this paper means cycles of one block illustrated by 1, 2, 3 cycles etc. in Fig. 1 and those pulses were counted automatically. Poled ceramics were cut into rectangular bar with a resonant frequency of 50 kHz. Firstly, piezoelectric properties, such as k_{31}, Q_m, resonant resistance, resonant and anti-resonant frequencies, capacitance at 1 kHz were automatically measured. Next, after the application of several hundred cycles of repeated pulses, the above-mentioned piezoelectric properties were again measured with in one second. The temperature change of measured sample was simultaneously measured by the thermocouple attached on the side surface of rectangular bar.

3. Result and discussions
Most unique properties measured in four kinds materials used in this study, k_{31} and Q_m, were shown by a function of cycles of repeated electrical pulse in Fig. 2 and can be classified and considered by values of Q_m and T_c. At the same time, Figure 3 shows the relations between temperature and k_{31} in sample (3). Temperature of the sample was elevated around 40 to 50°C in every samples by an increase in cycles of electrical pulse. The simultaneous decrease of
both $k_{31}$ and $Q_m$ as shown in Fig. 2(c) was yielded from temperature elevation by application of electrical pulses. As well known, $k_{31}$ and $Q_m$ was not independent, but united constants. The resonant and anti-resonant frequencies were shifted toward lower frequency range in the same proportion and as a result, the $k_{31}$ was constant, while the increase of resonant resistance was 89% in the contribution ratio for decrease of $Q_m$. When compared with values of $Q_m$, the $k_{31}$ and $Q_m$ were constant in high $T_c$ and low $Q_m$ material, although temperature of a sample was elevated around 50°C. Moreover, the $k_{31}$ and $Q_m$ were constant in middle $Q_m$ and high $T_c$ material as shown in Fig. 2(d). Moreover, sample (1) was broken into two or three pieces when the cycles of electrical pulse application were over a value. Figure 4 shows the Weibull plots of applied pulse cycles until fracture. Figure 5 shows the Weibull plots of fracture position. As can be seen, it was considered that the origins of fracture mechanism was cycles two. Figure 6 shows the voltage dependence of applied pulse for the standard fracture and fracture ratio.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$k_{31}$</th>
<th>$Q_m$</th>
<th>$T_c(°C)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>0.30-0.31</td>
<td>1600-1800</td>
<td>360</td>
</tr>
<tr>
<td>(2)</td>
<td>0.36</td>
<td>70-80</td>
<td>340</td>
</tr>
<tr>
<td>(3)</td>
<td>0.35-0.37</td>
<td>40-50</td>
<td>120</td>
</tr>
<tr>
<td>(4)</td>
<td>0.30-0.31</td>
<td>800</td>
<td>340</td>
</tr>
</tbody>
</table>

Table I $k_{31}$, $Q_m$ and $T_c$ for four kinds PbTiO$_3$-PbZrO$_3$-ABO$_3$ ceramics

![Flow chart for measurement of piezoelectric properties](image)

![Fig. 2 $k_{31}$ and $Q_m$ as a function of cycles of repeated electrical pulse](image)
Fig. 3 $K_{31}$ and sample temperature as a function of cycles of repeated electrical pulse

Fig. 4 Weibull plots for fracture

Fig. 5 Weibull plots for fracture position