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Fatigue failure characteristics of lead zirconate titanate piezoelectric ceramics

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Abstract

Mechanical properties and fatigue failure characteristics of lead zirconate titanate piezoelectric ceramic (PZT) have been investigated. Bending and fatigue strengths of PZT ceramic are directly attributed to the electrode status. Material hardening occurs in the PZT ceramic during the cyclic loading, which is influenced by domain switching occurring anywhere in the grains. The domain structure is clearly detected by electron back scatter diffraction analysis and etching techniques. It also appears that the poling direction causes the change of failure characteristics due to different domain and domain wall orientation. The domain orientation changes alternately from domain to domain by 90°. Moreover, the domain wall orientation is well regulated in the grains perpendicular to the poling direction. An acceleration of fatigue crack growth occurs as the crack propagates along the domain wall.

Keywords: PZT; Piezoelectric properties; Domain switching; Fatigue; Fracture

1. Introduction

The lead zirconate titanate (PZT) ceramics have been subjected to intensive research world-wide since the ceramic was developed in the middle of the twentieth century. The piezoelectric ceramic offers promising electrical applications in many smart structures, and PZT is regularly employed in a number of actuators and sensors. As the size of the actuator becomes smaller and the need for structural integrity and reliability increases, ceramics with good mechanical properties are needed.[1] The durability of ceramics in various conditions is also important to allow applications over a long period of time.[2] Because PZT ceramics in smart structures demands high material performance, an examination of the material response to the application is significant. The efficiency of the piezoelectric may change when the operational time increases, due to the change of material properties. There are various PZT ceramics with different (i) material characteristics (soft and hard); (ii) electrode materials (silver and nickel) and (iii) poling direction. In the study by Guillon et al., the fracture characteristics of soft and hard PZTs were examined.[3] From their work, differences in the fracture mechanism between hard and soft ceramics were clarified. The Weibull parameters in hard PZT were found to be higher than those for soft ones. In addition, it appeared that the crack propagates mainly through the grain in the hard sample (transgranular), while it grows in the grain boundary in the soft ceramic (intergranular).[3]

A number of electrode materials have been utilized for PZT ceramics, e.g., nickel and silver. The plating materials are printed on the substrate using different processes, a firing process for a Ag electrode and electroplating for a Ni electrode. In previous work, the effect of the Ag electrode on the fatigue properties of PZT was examined since the electrode materials are understood to play an important role in the mechanical properties of PZT ceramics.[4,5] It appeared that the electrode could make a reduction in the material strength of PZT. The reasons behind this are (i) microcracks generated from a porous region[3,5] and (ii) electrogeneration trapped at a defect.[6] Even though the influence of the electrode on the fatigue properties has been investigated for Ag–PZT samples, this examination has not been carried out for

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Ni–PZT samples. This is because the technique of Ni electrode attachment was newly proposed in recent years.

Several researchers have reported that the poling direction could change the crack growth and material properties of PZT ceramics. Zhao et al. have examined the crack growth characteristics of PZT, and they found that there exists a strong anisotropy of crack growth.[7] In the orientation perpendicular to the polarization direction, cracks grow readily whereas no obvious propagation is found parallel to the polarization direction. Fett et al. have examined the effect of the poling process on the material properties, and it appears that the PZT, poled perpendicular to the external load, shows a stronger plastic deformation than the unpoled material.[8] In the study by Okazaki, the crack extension mechanism in piezoelectric ceramics appeared to be variable because of the internal stress generated by the poling process.[9] His claims were, however, countered by the work

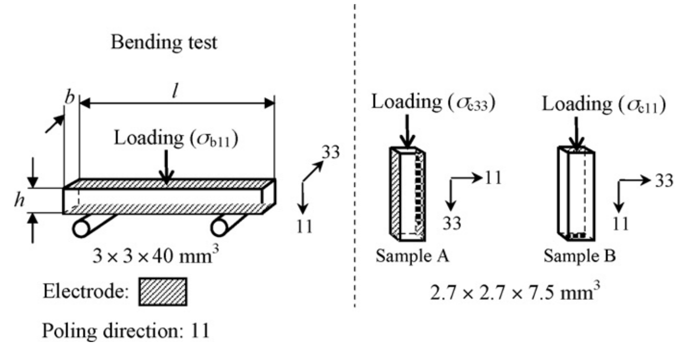

Fig. 1. Specimen samples for bending and compression tests.

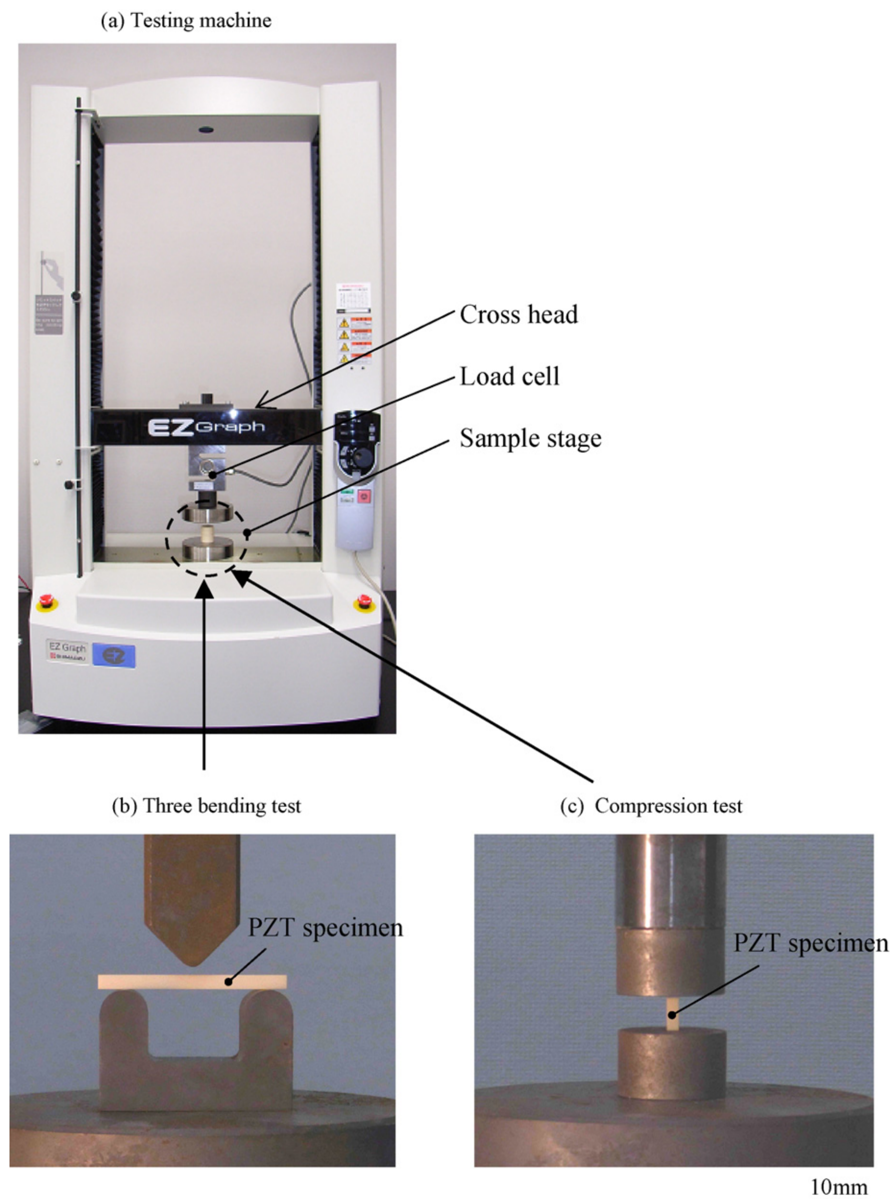

Fig. 2. (a) Screw driven type universal testing machine and (b) and (c) experimental setup for bending test and compression test.