

# INTELLIGENT STRUCTURAL ELEMENTS COVERED BY PIEZOELECTRIC HIGH-POLYMER FILM

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*Abstract- If a piezoelectric material is deformed, the local electric field is caused by the electromechanical interaction. When a structural element with surface defects is subjected to the stress, the strain distribution appears also on the opposite surface to the defects. Such localized strain distribution can be measured by the electric potential distribution on a piezoelectric film mounted on the smooth surface. This paper shows that back-surface defects in typical structural elements can be visualized by mounted PVDF thin film.*

**Index terms:** Piezoelectric material, surface defects, nondestructive evaluation technique, structural elements.

## I. INTRODUCTION

Piezoelectric effects are the interaction between the mechanical and the electric fields in a special class of dielectric materials. In particular, piezoelectric high-polymer film has low stiffness and high sensitivity, so that it is suitable for the strain or the strain-rate sensors, cf. Lee [1] and Tzou [2]. Direct measurement of the polarized voltage at a point of a piezoelectric film gives us the information on the local strain. Egashira et al [3] measured the local strains in notched plates in tension from the voltages of mounted piezoelectric films. Biwa et al [4] presented the method to obtain the surface strain distribution by measuring the electric potentials of two piezoelectric films mounted in different directions. Matsumoto et al [5] visualized back-surface defects of a plate in compression by absorption of charged powder to the mounted piezoelectric film, and Komagome et al [6] simulated the above visualization technique of the defect by analysing the loci of charged particles in the electric field near the piezoelectric film. This paper attempts to visualize back-



reflects the sizes and the shapes of back-surface defects, see Figure 1. In other words, such defects can be inspected by visualizing the electric potential distribution. In this section, we examine the applicability of the proposed technique and the validity of simulation by the structural analysis using FEM.

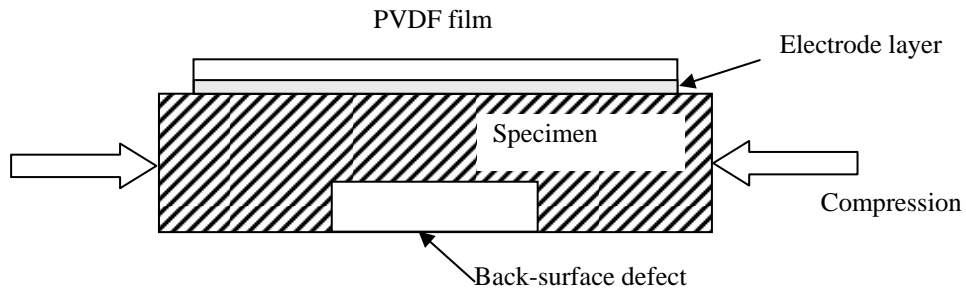


Figure.1 Sketch of NDE using PVDF film

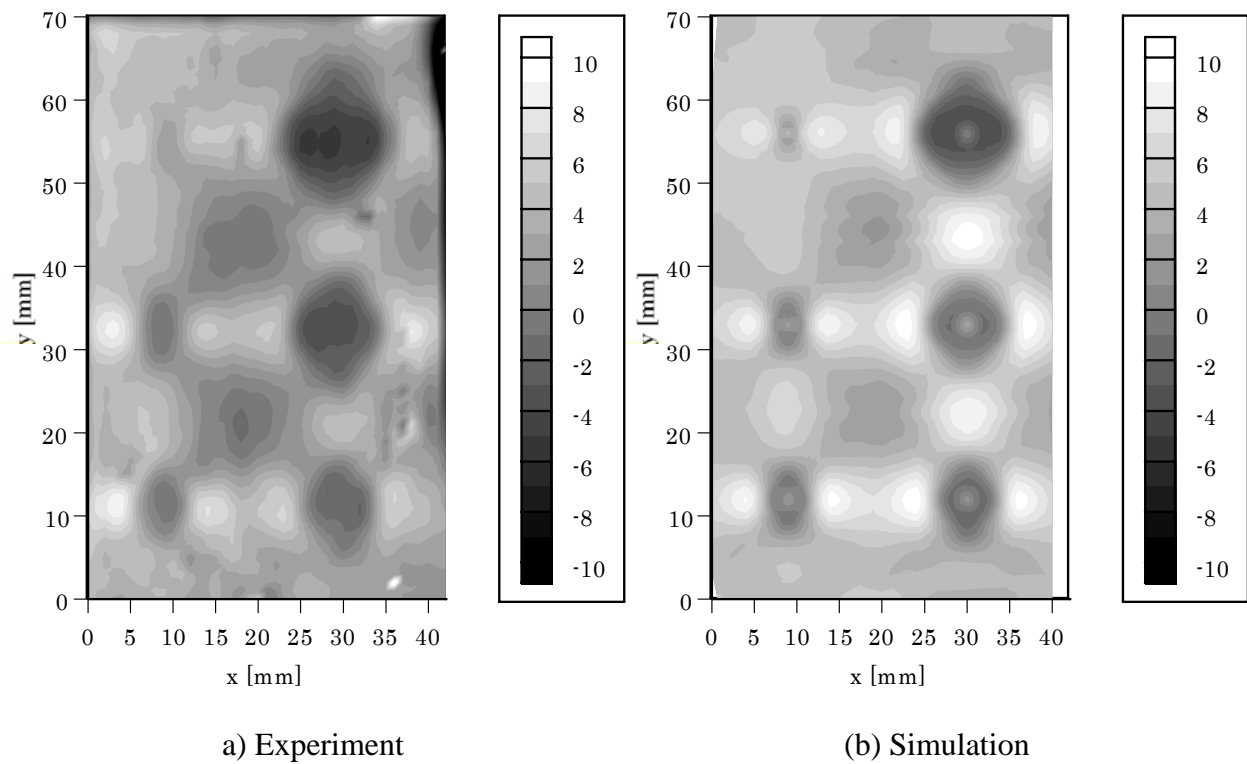


Figure.2 Resolution of defect by NDE using PVDF film

To examine the resolution of back-surface defects, we prepare a specimen having several sizes of cylindrical grooves. The thickness of the specimen is 10mm, the depth of each groove is 8mm, and



indicates the same one as in Figure 2. In the case of defects such as a crack or a slit, the surface strain distribution depends on the angle between the directions of the defect and the stress. To examine the applicability of NDE using PVDF film to such cases, we prepare specimens with surface defects (slit-like back-surface grooves) with different directions. In Fig.3,  $\theta$  is the angle between the directions of the groove and the compressive stress. As easily expected, the strain distribution is not much disturbed when the defect is parallel to the stress, so that it is not easy to detect such a defect by the potential distribution on the PVDF film. Matsumoto et al [7] showed that such a directivity of inspection ability is resolved by laminating PVDF films with different sensitive directions and they [8] applied to inspection of cracks and back surface defects. In the following discussions, it will be shown that a single layer film is enough to visualize invisible defects when the stress is multiaxial as in the following typical structural elements.

#### IV. SIMULATED NDE USING PVDF FILM FOR TYPICAL STRUCTURAL ELEMENTS

In this section, we apply proposed NDE using PVDF film to other typical structural elements. In each case, there exists a surface defect on the below or the inside surface of the element. We analyze the deformation of each structural element by FEM, and obtain the electric potential distribution on PVDF film mounted onto the other smooth surface from (1).

Let us first consider a cantilever beam with size 300mm×50mm×5mm, and apply 2mm deflection at the free end as in Fig. 4(a). It is known that the normal stress varies linearly between both surfaces of the beam, differently from the plate in compression. A surface defect with size 14mm×2mm×2mm is located on the below surface of the beam. From Figs. 4(b) and (c), the defect can be detected in both cases from the calculated potential distribution.

We next consider a cylindrical pipe subjected to internal pressure as in Fig. 5(a), where the internal diameter and the length are 100mm, and the thickness is 5mm. In the case of such a thin-walled pipe, the hoop stress is dominant. Figures 5(b) and (c) show the calculated potential distributions in the case where the sensitive axis of the film is parallel to the pipe axis. We see that both defects with parallel and normal directions to the pipe axis can be detected by the PVDF film.



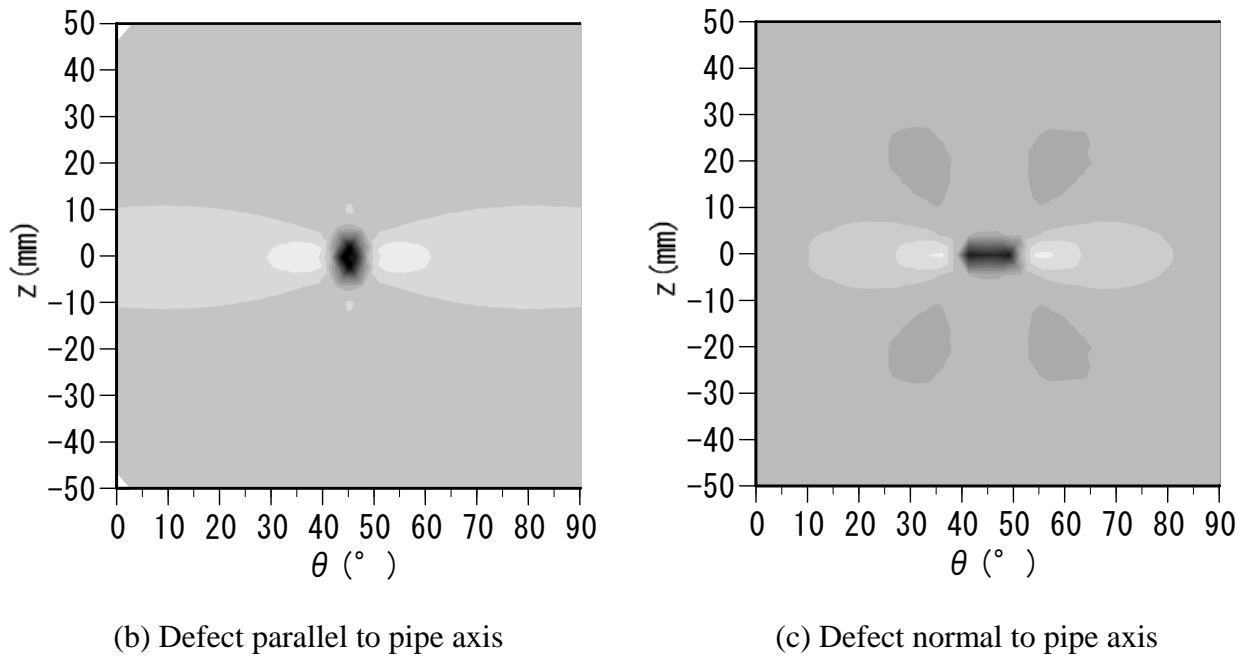
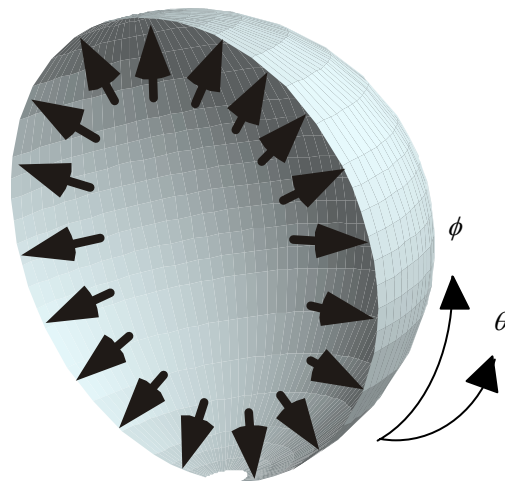


Figure.5 NDE of defect for cylindrical pipe subjected to internal pressure

In the case of a spherical shell subjected to internal pressure, two-dimensional isotropic tension is dominant, see Figure 6. The internal diameter of the shell is 1000mm, and the thickness of the wall is 5mm. In this case, the isotropic surface stress is dominant. A surface defect with size 14mm×2mm×2mm is located on the inside wall, where its orientation is in  $\phi$ -axis. In each case such that the sensitive axis of the PVDF film is normal or parallel to the defect, the potential distribution reflects the shape of the defect on the inside wall.



(a) Geometrical situation





will be promising to obtain the patterns of the potential distribution. Such applications are left as future subjects.

The conclusions obtained in this paper are summarized as follows.

- (1) Resolution and directional sensitivity of back-surface defects are examined for the nondestructive visualization technique using PVDF film mounted onto the smooth surface of the specimen.
- (2) Simulated patterns in the potential distribution on PVDF film by FEM are found to be in good agreement with the experimental results obtained in section 3.
- (3) It is verified from simulation by FEM that as well as plates, the proposed NDE technique using PVDF film can be applied to typical structural elements, a beam, a cylindrical pipe and a spherical shell. These elements covered by a piezoelectric layer may be called intelligent structures because they inform their invisible defects by the electric potential distributions on the front surfaces.

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