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Finite element modelling on time dependent ferroelectric behaviour of 1–3 piezocomposites

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Abstract

Experiments are conducted to measure the effective properties and also the time dependent behaviour of 1–3 piezocomposites and bulk piezoceramics subjected to cyclic electric field at room temperature under quasi static loading condition in the non-linear regime. Experimental dielectric and butterfly hysteresis show that 1–3 piezocomposite exhibits the time dependent behaviour. Hence a viscoelastic based numerical model has been proposed to predict the time dependent effective properties of 1–3 piezocomposites and bulk piezoceramics. The predicted effective properties are incorporated in the proposed 3D finite element based micromechanical model to predict the time dependent non-linear electromechanical behaviour of 1–3 piezocomposites and compared with experimental observations. The experimental and simulated results show that the presence of epoxy polymer constituent in 1–3 piezocomposite has an influence on the non-linear time dependent electromechanical response of 1–3 piezocomposite.

Keywords: Viscoelastic behaviour; Electrical loading; 1–3 piezocomposites; Numerical model; Micro-mechanics

1. Introduction

Piezocomposites have become increasingly popular in devices used for structural health monitoring, medical diagnostic imaging, MEMS technology and precision manufacturing due to its superior properties over piezoceramics. The most commonly used fibre reinforced piezocomposite is 1–3 piezocomposite due to its tailor made electromechanical properties, tunable acoustic impedance, etc. [1]. In underwater and biomedical applications, 1–3 piezocomposites are optimised to exhibit low density, high hydrostatic piezoelectric response, high electromechanical coupling factor and better acoustic impedance matching. The acoustic impedance of 1–3 piezocomposites can be reduced by decreasing the fibre volume fraction [2]. A micromechanics based analytical model for capturing the complete electromechanical response of 1–3 piezoelectric composite system is developed. In this model both the matrix and fibre are considered to be elastically anisotropic and piezo electrically active [3]. The influence of connectivity and shape of the fibre and matrix on the effective coefficients of a two phase composite is studied using finite element modelling [4].

The fibre orientation dependent electromechanical behaviour of 1–3 piezocomposites is predicted and found to have a significant variation in the electric displacement and strain under mechanical and electrical loading conditions [5,6]. Experiments are conducted to measure the displacement of 1–3 piezocomposites under electric field with square and circular PZT fibres [7]. It is found that the behaviour of 1–3 piezocomposites is non-linear and also the displacement of square PZT fibres is more compared to circular PZT fibres. The viscoelastic response of 0.25 volume fraction of fibres is simulated using the phenomenological model incorporating time dependent effective properties obtained from micromechanical model [8]. The influence of temperature on the pyroelectric and thermal expansion coefficient of PZT wafers are reported [9]. Experiments are conducted to measure the effect of loading rate on the non-linear behaviour of PZT wafers [10]. A theoretical model is also developed using the

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Displacement Discontinuity Method (DDM) to evaluate multiple interface cracks in 1–3 composites [11]. Micromechanical model is proposed to investigate the nonlinear electro-elastic behaviour of piezoelectric fibre reinforced composite materials [12]. Modelling of the nonlinear behaviour of multiphase ferroelectric materials is performed with an incremental micromechanical analysis based on the homogenisation technique for composites with periodic microstructure [13].

Studies on 1–3 piezocomposites show that, the electromechanical response of 1–3 piezocomposites is influenced by the presence of epoxy polymer. Hence it is necessary to understand the electromechanical response of 1–3 piezocomposites in the non-linear regime. The presence of passive epoxy polymer in 1–3 piezocomposites is expected to exhibit a viscoelastic behaviour, therefore our objective is to understand the time dependent behaviour of 1–3 piezocomposites in the non-linear regime. In this paper, the effective properties are measured based on IEEE standards using weak field techniques and time dependent behaviour of 1–3 piezocomposites are measured experimentally subjected to pure electrical loading condition in the non-linear region. The numerical model is proposed to predict the effective properties using the commercially available finite element software ABAQUS and a viscoelastic solid model is developed to predict the time dependent material properties. A 3D finite element based viscoelastic micromechanical model is proposed to predict the time dependent non-linear behaviour of 1–3 piezocomposites for different fibre volume fraction subjected to cyclic electric field. The time dependent dielectric and butterfly hysteresis are simulated using FORTRAN and compared with the experimental observations.

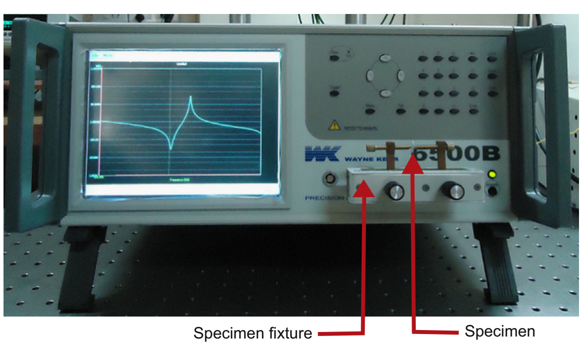

Fig. 1. Photograph of the experimental set up for measuring the material properties of 1–3 piezocomposites.

2. Experimental description

2.1. Measurement of effective properties

1–3 piezocomposite exhibits transversely isotropic property, hence ten different material constants have to be evaluated. The experiments are carried out on various fibre volume fractions of 1–3 piezocomposites and bulk piezoceramics based on IEEE standards [14] to measure the electro-elastic effective properties. A sample with appropriate dimensions and boundary conditions are chosen to measure various material properties of 1–3 piezocomposites and bulk PZT [15]. The resonance and anti-resonance frequencies are measured with impedance analyser (Waynekerr 6505B) is shown in Fig. 1 and the effective material constants (C, d, κ) for bulk PZT and 1–3 piezocomposites are calculated.

2.2. Measurement of time dependent electromechanical behaviour of 1–3 piezocomposites

Experiments are conducted to measure the time dependent electric displacement and longitudinal strain of piezoelectric composites with different fibre volume fractions subjected to AC electric field along the thickness direction. The experiments are performed on 100%, 80%, 65% and 35% PZT5A1 fibres embedded into the epoxy matrix which is passive to the applied electric field and poled along the fibre direction. The schematic representation of the experimental set up to measure time dependent electric displacement and strain under pure electrical loading is shown in Fig. 2. The specimen is kept in a specially designed specimen holder with top and bottom brass electrodes. To avoid arcing at elevated electric fields, the composite specimens are completely immersed in silicone oil bath which has a dielectric strength of 17 kV/mm. The input electric signal is generated using function generator and it is amplified to ± 2.5 kV using a high voltage amplifier. The high-voltage amplifier which provides output voltages in the range of ± 7.5 kV at different frequencies (up to 10 kHz) is connected to the upper electrode of the specimen to apply necessary electrical

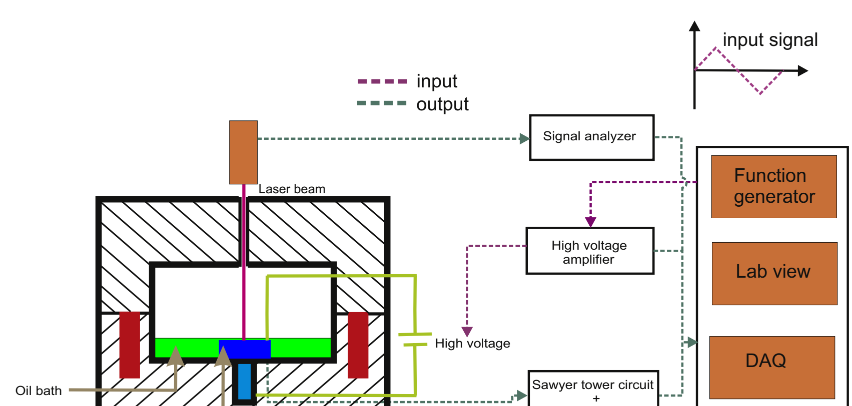

Fig. 2. Schematic diagram of electrical specimen holder and experimental set up.