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Static studies on Piezoelectric/Piezomagnetic Composite Structure under Mechanical and Thermal Loading

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Abstract

In this study, static analysis of Piezoelectric/Piezomagnetic materials, anisotropic and linear magneto-electro-thermo-elastic strip have been carried out by finite element method. The finite element model is derived based on constitutive equation of Piezoelectric and Piezomagnetic material accounting for coupling between elasticity, thermal, electric and magnetic effect. The present finite element is modeled with displacement components, electric potential and magnetic potential as nodal degree of freedom. The other fields are calculated by post-computation through constitutive equation. Numerical study includes the influence of the effect of stacking sequences on displacement, electrical potential and magnetic field under mechanical and thermal loading. In addition further study has been carried out on effect of pyroelectric, pyromagnetic coupling involved in materials under thermal loading.

Keywords: Piezoelectric, Piezomagnetic, magneto-electro-thermo-elastic, pyroelectric, pyromagnetic

Introduction

In recent years, intelligent or smart structures have become a new research field. These Piezomagnetic and piezoelectric materials have the ability to convert energy from one form, such as magnetic, electric, mechanical and thermal, to another. The intelligent or smart structures made of Piezomagnetic and piezoelectric materials exhibit the magneto-electro-thermo-elastic coupling effect by Harshe, Nan and Benveniste [1–3]. This effect is not present in the single Piezomagnetic or piezoelectric material. The coupling that exists between the thermoelastic and electric fields in piezoelectric materials provides a means for sensing thermomechanical disturbances from the measurements of induced electrical potential and magnetic induction. The magneto-electro-thermo-elastic coupling effect has considerable applications in the fields of sensors, transducers and the control of structural vibration.

One of the basic elements of these intelligent composite materials are laminated Piezoelectric/Piezomagnetic structures, and these structures are often operated in mechanical and thermal loading. Therefore, analytical studies concerned with piezothermoelasticity of these structures were developed by Tauchert and Ashida [4]. On the other hand, one of cause of damage in these laminated structures includes delamination. In order to evaluate this phenomenon, it is necessary to consider the transverse shearing stresses and the normal stress in the thickness direction. From the above concept, several exact solutions for the two-dimensional or three-dimensional piezothermoelastic problems of laminated composite plates were obtained by Xu et al. [5], Tauchert [6], Shang et al. [7], Kapuria et al. [8], and Tauchert and Ashida [4]. Pan [9] derived the exact solution for multilayered electro-magneto-elastic plates using a propagator matrix.

Exact solutions have been obtained by many researchers in studies of the piezothermoelastic problem subjected to steady-state temperature distribution [10, 11]. The piezothermoelastic behavior of distributed sensors and actuators subjected to a steady-state temperature field was investigated by Tzou and Ye [12]. Sunar et al [13] derived the linear constitutive equations of thermopiezomagnetism with the aid of a thermodynamic potential and a variational approach of obtaining general coupled field equations for thermopiezomagnetic composites. Ding and Jiang [14] carried out analytical solutions to two-dimensional magnetoelectro-elastic media in terms of four harmonic displacement functions. Ding et al [15] derived the two-dimensional Green's functions for two-phase transversely isotropic magneto-electro elastic media. Ootao and Tanigawa [16] investigated the behavior of a multilayered magneto-electro-thermo-elastic strip due to non-uniform heat supply.

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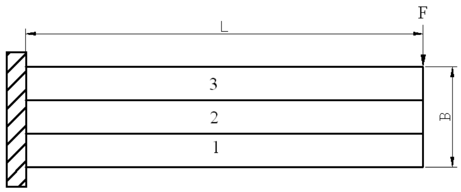

Fig.1: Geometrical model with mechanical boundary conditions

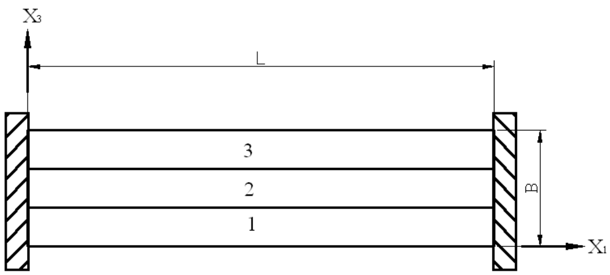

Fig.2: Geometrical model with thermal boundary conditions

Based on a literature survey, it is found that a limited number of studies have investigated magneto-electro-elastic strips in a mechanical and thermal loading. In this paper, we present the numerical solution for a three-layered magneto-electroelastic strip made of piezoelectric $BaTiO_3$ and Piezomagnetic $CoFe_2O_4$ materials. Pyroelectricity is another interesting of a cross property by Newnham et al [17]. Application of heat to composite results in thermal expansion and in turn to electric polarization when the mechanical strain is transferred to the piezoelectric phase. Even if the individual constituents of the composite do exhibit intrinsic pyroelectricity, the secondary product effect produced due to coupling of the different phases can make a significant contribution by Newnham et al [17]. Nan et al [18] represent product properties in composites in the following manner.

$$\text{Magnetoelectric} = \frac{\text{Magnetic}}{\text{Mechanical}} \times \frac{\text{Mechanical}}{\text{Electric}}$$

$$\text{Pyroelectric} = \frac{\text{Thermal}}{\text{Mechanical}} \times \frac{\text{Mechanical}}{\text{Electric}}$$

$$\text{Pyromagnetic} = \frac{\text{Thermal}}{\text{Mechanical}} \times \frac{\text{Mechanical}}{\text{Magnetic}}$$

The main aim is to study the influence of Piezoelectric/Piezomagnetic and Pyroelectric/Pyromagnetic constants on displacement, electric potential and magnetic potential static mechanical and thermal loading conditions.

Finite Element Formulation

Mechanical loading

For mechanical loading one end is fixed and other end is free condition. The layerwise mechanical loading condition is evaluated by solving the two-dimensional rectangular elements. The finite element matrix equation

$$[K_{uu}]\{u\} = \{F\} \quad (1)$$

Where, $[K_{uu}]$,$\{u\}$ *and* $\{F\}$ are the element matrix, displacement and force respectively.

Where the different stiffness matrices mentioned in the above equation are defined as.

$$[K^e_{uu}] = \int_v [B_u]^T[c][B_u]dv \; ; \{F^e\} = \int_v [B_u]^T[c]\,dv \quad (2)$$

Where, $[B_u]$ is derivative of the shape function matrix for strain displacement, $[c]$ are the elastic constant matrix.

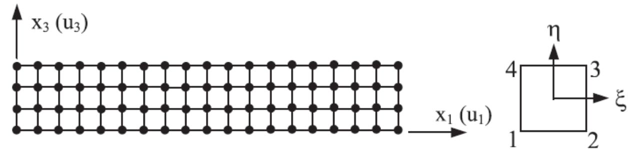

Fig.3: Discretization of Finite Element Model with Four Noded Elements

Coupled magneto – electro – elastic problem

The coupled constitutive equations for anisotropic and linearly magneto-electro-elastic solids can be written as

$$\begin{aligned} \sigma_i &= c_{ik}S_k - e_{ki}E_k - q_{ki}H_k \\ D_i &= e_{ik}S_k + \eta_{ik}E_k + m_{ik}H_k \\ B_i &= q_{ik}S_k + m_{ik}E_k + \mu_{ik}H_k \end{aligned} \quad (3)$$

Where σ_i, D_i and B_i are the components of stress, electric displacement and magnetic induction, respectively. c_{ik}, η_{ik} and μ_{ik} are the elastic, dielectric and magnetic permeability coefficients, respectively. e_{ki}, q_{ki} and m_{ik} are the piezoelectric, piezomagnetic and magneto-electric material coefficients respectively. E_k, H_k, are electric field, magnetic field, respectively. In the present analysis, the coupled three-dimensional constitutive equations (3) for a magneto-electro-elastic solid in the x_1-x_2 plane are assumed to be isotropic. The constitutive equations can be written in matrix form as

$$\begin{pmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\\ D_1\\ D_2\\ D_3\\ B_1\\ B_2\\ B_3\end{pmatrix} = \begin{pmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} & e_{11} & e_{21} & e_{31} & q_{11} & q_{21} & q_{31} & \propto_1\\ C_{21} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} & e_{12} & e_{22} & e_{32} & q_{12} & q_{22} & q_{32} & \propto_2\\ C_{31} & C_{32} & C_{33} & C_{34} & C_{35} & C_{36} & e_{31} & e_{32} & e_{33} & q_{31} & q_{32} & q_{33} & \propto_3\\ C_{41} & C_{42} & C_{43} & C_{44} & C_{45} & C_{46} & e_{41} & e_{42} & e_{43} & q_{41} & q_{42} & q_{43} & \propto_4\\ C_{51} & C_{52} & C_{53} & C_{54} & C_{55} & C_{56} & e_{51} & e_{52} & e_{53} & q_{51} & q_{52} & q_{53} & \propto_5\\ C_{61} & C_{62} & C_{63} & C_{64} & C_{65} & C_{66} & e_{61} & e_{62} & e_{63} & q_{61} & q_{62} & q_{63} & \propto_6\\ e_{11} & e_{12} & e_{13} & e_{14} & e_{15} & e_{16} & \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} & m_{11} & m_{12} & m_{13} & \xi_1\\ e_{21} & e_{22} & e_{23} & e_{24} & e_{25} & e_{26} & \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} & m_{21} & m_{22} & m_{23} & \xi_2\\ e_{31} & e_{32} & e_{33} & e_{34} & e_{35} & e_{36} & \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} & m_{31} & m_{32} & m_{33} & \xi_3\\ q_{11} & q_{12} & q_{13} & q_{14} & q_{15} & q_{16} & m_{11} & m_{12} & m_{13} & \mu_{11} & \mu_{12} & \mu_{13} & \omega_1\\ q_{21} & q_{22} & q_{23} & q_{24} & q_{25} & q_{26} & m_{21} & m_{22} & m_{23} & \mu_{21} & \mu_{22} & \mu_{23} & \omega_2\\ q_{31} & q_{32} & q_{33} & q_{34} & q_{35} & q_{36} & m_{31} & m_{32} & m_{33} & \mu_{31} & \mu_{32} & \mu_{33} & \omega_3\end{pmatrix} x \begin{pmatrix}S_1\\ S_2\\ S_3\\ S_4\\ S_5\\ S_6\\ E_1\\ E_2\\ E_3\\ H_1\\ H_2\\ H_3\\ T\end{pmatrix} \quad (4)$$

Where $\sigma_1 = \sigma_{x1}$, $\sigma_2 = \sigma_{x2}$, $\sigma_3 = \sigma_{x3}$, $\sigma_4 = \tau_{x2x3}$, $\sigma_5 = \tau_{x1x3}$, $\sigma_6 = \tau_{x1x2}$, $D_1 = D_{x1}$, $D_2 = D_{x2}$, $D_3 = D_{x3}$, $B_1 = B_{x1}$, $B_2 = B_{x2}$ and $B_3 = B_{x3}$. For plane stress problems, stress components $\sigma_2 = \sigma_4 = \sigma_6 = 0$, electric displacement $D_2 = 0$ and magnetic induction $B_2 = 0$ with thickness assumed as unity. The coefficients c_{ik}, η_{ik}, μ_{ik}, e_{ki}, q_{ki} and m_{ik} are strain displacement, electric field–electric potential and magnetic field–magnetic potential equations are used in the finite element analysis along with the constitutive equations. The strains S_{ij} are related to displacement u_i and can be written as

$$S_{ij} = ½ (u_{i,j}+u_{j,i}) \quad (5)$$

The electric field E_i and magnetic field H_i are related to the electric potential φ and magnetic potential ψ, and can be written as

$$E_i = -\varphi_{,i} \,;\; H_i = -\psi_{,i} \quad (6)$$

$$[K_{uu}]\{u\} + [K_{u\phi}]\{\phi\} + [K_{u\psi}]\{\psi\} = \{F\}$$
$$[K_{u\phi}]^T\{u\} - [K_{\phi\phi}]\{\phi\} - [K_{\phi\psi}]\{\psi\} = 0 \quad (7)$$
$$[K_{u\psi}]^T\{u\} - [K_{\phi\psi}]\{\phi\} - [K_{\psi\psi}]\{\psi\} = 0$$

Where the different stiffness matrices mentioned in the above equations are defined as.

$$[K^e_{uu}] = \int_v [B_u]^T[c][B_u]dv$$
$$[K^e_{u\psi}] = \int_v [B_u]^T[q][B_\psi]dv$$
$$[K^e_{u\phi}] = \int_v [B_u]^T[e][B_\phi]dv$$
$$[K^e_{\phi\psi}] = \int_v [B_\phi]^T[m][B_\psi]dv \quad (8)$$
$$[K^e_{\phi\phi}] = \int_v [B_\phi]^T[\eta][B_\phi]dv$$
$$[K^e_{\psi\psi}] = \int_v [B_\psi]^T[\mu][B_\psi]dv$$
$$\{F^e\} = \int_v [B_u]^T[c]dv$$

where $\{\alpha\} = \{\alpha_1\ \alpha_3\ 0\}^T$. $[B_u]$, $[B_\varphi]$ and $[B_\psi]$ are derivatives of the shape function matrix for strain displacement, electric field potential and magnetic field potential, respectively. $[c]$, $[q]$, $[e]$, $[m]$, $[\varepsilon]$, $[\mu]$, $[\lambda]$, and $[\eta]$ are the reduced elastic constant matrix, piezomagnetic coefficient matrix, piezoelectric coefficient matrix, magneto-electric coefficient matrix, dielectric coefficient matrix, magnetic permeability matrix, pyroelectric coefficient matrix and pyromagnetic coefficient matrix respectively. The shape function matrix used in equation (8) can be written with respect to the four nodded rectangular elements as

$$[B_u] = \begin{pmatrix} \frac{\partial N_1}{\partial x_1} & 0 & \frac{\partial N_2}{\partial x_1} & 0 & \frac{\partial N_3}{\partial x_1} & 0 & \frac{\partial N_4}{\partial x_1} & 0\\ 0 & \frac{\partial N_1}{\partial x_3} & 0 & \frac{\partial N_2}{\partial x_3} & 0 & \frac{\partial N_3}{\partial x_3} & 0 & \frac{\partial N_4}{\partial x_3}\\ \frac{\partial N_1}{\partial x_3} & \frac{\partial N_1}{\partial x_1} & \frac{\partial N_2}{\partial x_3} & \frac{\partial N_2}{\partial x_1} & \frac{\partial N_3}{\partial x_3} & \frac{\partial N_3}{\partial x_1} & \frac{\partial N_4}{\partial x_3} & \frac{\partial N_4}{\partial x_1}\end{pmatrix} \quad (9)$$

$$[B_\phi] = [B_\psi] = \begin{bmatrix} \frac{\partial N_1}{\partial x_1} & \frac{\partial N_2}{\partial x_1} & \frac{\partial N_3}{\partial x_1} & \frac{\partial N_4}{\partial x_1}\\ \frac{\partial N_1}{\partial x_3} & \frac{\partial N_2}{\partial x_3} & \frac{\partial N_3}{\partial x_3} & \frac{\partial N_4}{\partial x_3}\end{bmatrix} \quad (10)$$

The electric potential ϕ and magnetic potential ψ are eliminated from equation (7) by standard condensation techniques. The derived stiffness matrix $[K_{eq}]$ is used to solve the Eigen vectors

$$[K_{eq}]\{u\} = \{F\} \quad (11)$$

Where

$$[K_{eq}] = [K_{uu}] + [K_{u\phi}][K_{II}]^{-1}[K_I] + [K_{u\psi}][K_{IV}]^{-1}[K_{III}] \quad (12)$$

The component matrices in equation (12) are

$$[K_I] = [K_{u\phi}]^T - [K_{\phi\psi}][K_{\psi\psi}]^{-1}[K_{u\psi}]^T \quad (13)$$

$$[K_{II}] = [K_{\phi\phi}] - [K_{\phi\psi}][K_{\psi\psi}]^{-1}[K_{\phi\psi}]^T \quad (14)$$

$$[K_{III}] = [K_{u\psi}]^T - [K_{\psi\psi}]^T[K_{\phi\phi}]^{-1}[K_{u\phi}]^T \quad (15)$$

$$[K_{IV}] = [K_{\psi\psi}] - [K_{\phi\psi}]^T[K_{\phi\phi}]^{-1}[K_{\phi\psi}]^T \quad (16)$$

The electric potential ϕ and magnetic potential ψ can be computed as

$$\phi = [K_{II}]^{-1}[K_I]\{u\} \quad (17)$$

$$\psi = [K_{IV}]^{-1}[K_{III}]\{u\} \quad (18)$$

In the present analysis, the four point Gaussian integration scheme has been implemented to evaluate the integrals involved in different matrices. The coupled stiffness matrix of the system has been inverted to obtain the displacements. The coupling between electric and magnetic fields is neglected. The problem has been solved to obtain the electric and magnetic potential based on the effect of electroelastic coupling and magneto-elastic coupling.

Thermal Distribution

Uniform temperature distribution of an electro-magneto-elastic strip is assumed as shown in Fig.2. The temperature of the strip is 50oC. The layerwise temperature distribution is evaluated by solving the steady-state two dimensional Fourier heat conduction equation using two-dimensional rectangular elements.

$$\frac{\partial Ti}{\partial \tau} = k_{xi}\frac{\partial^2 Ti}{\partial^2 x^2} + k_{zi}\frac{\partial^2 Ti}{\partial^2 z^2}\text{; i=1,2,….,n} \quad (19)$$

Where the Ti is the temperature change of the i^{th} layer; k_{xi} and k_{zi} are thermal diffusivities in the x and z directions, respectively.

The finite element form of Fourier heat conduction leads to the following elemental matrix equation

$$[[K_1^e] + [K_2^e]]\{T^e\} = \{P^e\} \quad (20)$$

Where $[K_1^e], [K_2^e], \{T^e\}\ and\ \{P^e\}$ are the element conduction matrix, convection matrix, load vector due to convection and element nodal temperature vector, respectively. The temperature distribution within the domain is evaluated by solving equation (20).

Coupled magneto – electro – thermo – elastic problem

The coupled constitutive equations for anisotropic and linearly magneto-electro-elastic solids can be written as

$$\sigma_i = c_{ik}(S_k - \alpha_k) - e_{ki}E_k - q_{ki}H_k$$
$$D_i = e_{ik}S_k + \eta_{ik}E_k + m_{ik}H_k + \xi_i T \quad (21)$$
$$B_i = q_{ik}S_k + m_{ik}E_k + \mu_{ik}H_k + \omega_i T$$

Where σ_i, D_i, and B_i are the components of stress, electric displacement and magnetic induction, respectively. c_{ik}, η_{ik}, μ_{ik}, ξ_i, and ω_i are the elastic, dielectric, magnetic permeability, pyroelectric and pyromagnetic coefficients, respectively. e_{ki}, q_{ki} and m_{ik} are the piezoelectric, piezomagnetic and magneto-electric material coefficients respectively. E_k, H_k, α_k and T are electric field, magnetic field, thermal expansion coefficient and small temperature difference, respectively. In the present analysis, the coupled three-dimensional constitutive equations (21) for a magneto-electro-elastic solid in the x_1-x_2 plane are assumed to be isotropic. The constitutive equations can be written in matrix form as (4)

The thermodynamic potential G can be written as

$$G = \frac{1}{2}S_k^T c_{ik} S_k - \frac{1}{2}E_K^T \eta_{ik} E_k - \frac{1}{2}H_K^T \mu_{ik} H_k - S_K^T e_{ki} E_k - S_K^T q_{ki} H_k - H_K^T m_{ik} E_k - S_K^T \beta_{ki}\theta_k \quad (22)$$

Where β_{ki} is the stress–temperature coefficient. The strip is discretized using four nodded elements having four nodal degrees of freedom viz thermal displacement in the x_1 and x_3 directions, and electric and magnetic potentials. It can be represented by suitable shape functions, such as

$$u_i = [N_u]\{u\};\ \phi = [N_\phi]\{\phi\};\ \psi = [N_\psi]\{\psi\} \quad (23)$$

where $\{u\} = \{u_1\ u_3\}^T$, u_1 and u_3 are displacements in the x_1 and x_3 directions, respectively. Substituting equations (20), (5), (6), and (23) into (22), we get the following coupled finite element equations (after assembling the elemental matrices)

$$[K_{uu}]\{u\} + [K_{u\phi}]\{\phi\} + [K_{u\psi}]\{\psi\} = \{F_{th}\}$$
$$[K_{u\phi}]^T\{u\} - [K_{\phi\phi}]\{\phi\} - [K_{\phi\psi}]\{\psi\} = 0 \quad (24)$$
$$[K_{u\psi}]^T\{u\} - [K_{\phi\psi}]\{\phi\} - [K_{\psi\psi}]\{\psi\} = 0$$

Where the different stiffness matrices mentioned in the above equations are defined as (8) and (25)

$$\{F_{th}^e\} = \int_v [B_u]^T[c][\alpha]\theta dv \quad (25)$$

where $\{\alpha\} = \{\alpha_1\ \alpha_3\ 0\}^T$. $[B_u]$, $[B_\varphi]$ and $[B_\psi]$ are derivatives of the shape function matrix for strain displacement, electric field potential and magnetic field potential, respectively. [c], [q], [e], [m], [η] and [μ] are the elastic constant matrix, piezomagnetic coefficient matrix, piezoelectric coefficient matrix, magneto-electric coefficient matrix, dielectric coefficient matrix and magnetic permeability matrix, respectively. The shape function matrix used in equation (8) and (25) can be written with respect to the four nodded rectangular elements as (9) and (10).

The electric potential ϕ and magnetic potential ψ are eliminated from equation (8) by standard condensation techniques. The derived stiffness matrix $[K_{eq}]$ is used to solve the Eigen vectors

$$[K_{eq}]\{u\} = \{F_{th}\}$$
(26)

Where $[K_{eq}]$ in (12)

The component matrices in equation (12) are (13) to (16).

The electric potential ϕ and magnetic potential ψ can be computed as (17) and (18).

In the present analysis, the four point Gaussian integration scheme has been implemented to evaluate the integrals involved in different matrices. The coupled stiffness matrix of the system has been inverted to obtain the thermal displacements. The coupling between electric and magnetic fields is neglected. The problem has been solved to obtain the electric and magnetic potential based on the effect of electroelastic coupling and magneto-elastic coupling.

Results and Discussion

A three-layered electro-magneto-elastic strip made of piezoelectric ($BaTiO_3$) and piezomagnetic ($CoFe_2O_4$) materials with each having equal thickness. The piezoelectric $BaTiO_3$ and piezomagnetic $CoFe_2O_4$ are both transversely isotropic with their symmetry axis along the x_3 axis. The material coefficients for piezoelectric ($BaTiO_3$) and piezomagnetic ($CoFe_2O_4$) materials are listed in Table.1: One stacking sequence, $BaTiO_3/BaTiO_3/BaTiO_3$ (named B/B/B) is investigated. Further we will investigate $BaTiO_3$/ $CoFe_2O_4$/ $BaTiO_3$ (named B/F/B) and $CoFe_2O_4/BaTiO_3/CoFe_2O_4$ (named F/B/F). The length of the composite strip *(L)* = 0.06 m and the thickness *(B)* = 0.01 m. The discretization of the finite element model is shown in Fig. 3: for thermal and structural analysis.

A both ends are fixed multilayered composite strip constructed magneto-electro-thermo elastic materials subjected to a uniform heat supply in the width direction has been investigated.

Table.1: Material properties for piezoelectric ($BaTiO_3$) and piezomagnetic ($CoFe_2O_4$) materials

Parameter	$BaTiO_3$	$CoFe_2O_4$
Elastic constants		
$C_{11}=C_{22}$ (GPa)	166.0	286.0
C_{12}	77.0	173.0
$C_{13}=C_{23}$	78.0	170.5
C_{33}	162.0	269.0
$C_{44}=C_{55}$	43.0	45.3
C_{66}	44.5	56.5
Piezoelectric constants		
$e_{31} = e_{32}$ (C m^{-2})	-4.4	0.0
e_{33}	18.6	0.0
e_{15}	11.6	0.0
Piezomagnetic constants		
$q_{31} = q_{31}$ (N A^{-1} m^{-2})	0.0	583.0
q_{33}	0.0	699.7
q_{15}	0.0	550.0
Dielectric constant		
$\eta_{11}=\eta_{22}$ (10^{-9} C^2 N^{-1} m^{-2})	11.2	0.08
η_{33}	12.6	0.093
Magnetic permeability constants		
$\mu_{11}=\mu_{22}$ (10^{-6} N s^2 C^{-2})	5.0	-590.0
μ_{33}	10.0	157.0
Thermal expansion coefficients		
$\alpha_1=\alpha_2$ (10^{-6} K^{-1})	15.7	10.0
α_3	6.4	10.0
Magnetoelectric constants		
$m_{11}=m_{22}$ (N s V^{-1} C^{-1})	0.0	0.0
m^{33}	0.0	0.0
Thermal conductivity		
$\lambda_1=\lambda_2=\lambda_3$ (W m^{-1} K^{-1})	2.5	3.2

Validation of the present formulation

The electro-magneto-elastic strip is degenerated to a single piezoelectric ($BaTiO_3$) layer. The present formulation is validated with a mechanical and thermal loading condition. First, mechanical and thermal loading conditions are evaluated and compared with the commercial finite element package ANSYS. Figure 4 & 5 shows the displacement due to the mechanical and thermal load vector and electric potential obtained by the present formulation is compared using ANSYS.

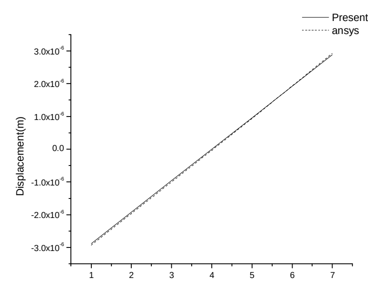

Fig.4: Variation of displacement piezothermoelastic strip subjected to fixed – fixed boundary condition

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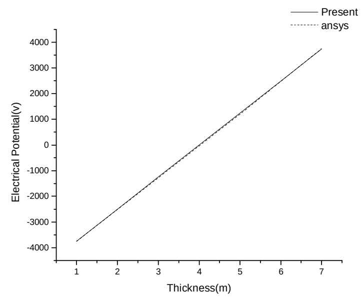

Fig.5: Variation of electrical potential piezothermoelastic strip subjected to fixed – fixed boundary condition

Mechanical loading

Fixed – free end boundary condition

In the present analysis, mechanical force F is assumed to be 2000 N acting on X_3 downward direction. Fig. 6&7 shows the compare the displacement along length and thickness direction for B/B/B, B/F/B and F/B/F stacking sequences and also Fig. 8 & 9 shows the comparison of electrical potential along thickness direction for B/F/B and F/B/F stacking sequence.

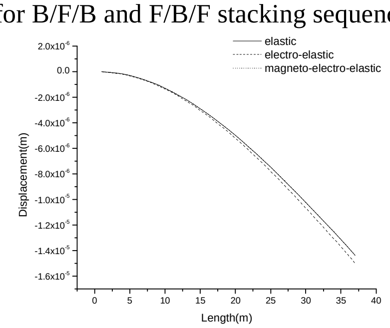

Fig.6: Compare the displacement along length direction for B/B/B, B/F/B and F/B/F stacking sequence

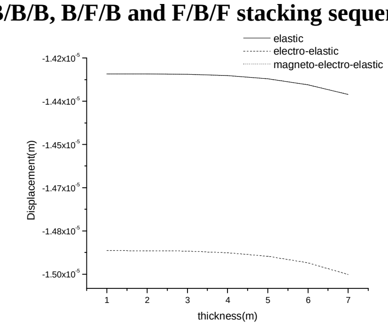

Fig.7: Compare the displacement along thickness direction for B/B/B, B/F/B and F/B/F stacking sequence

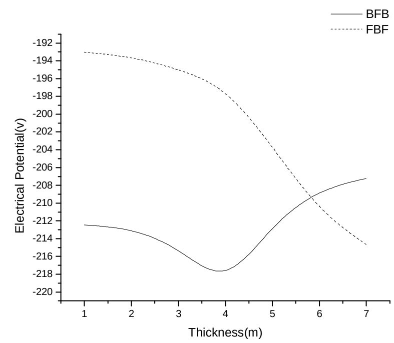

Fig.8: Compare the electrical potential along thickness direction for B/F/B and F/B/F stacking sequence

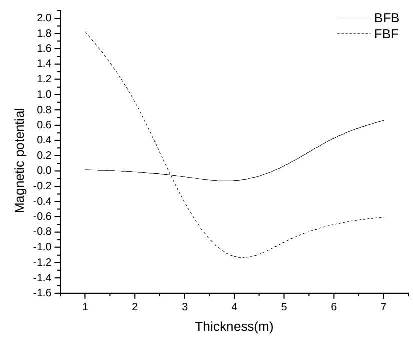

Fig.9: Compare the magnetic potential along thickness direction for B/F/B and F/B/F stacking sequence

Thermal loading

Fixed – fixed boundary condition

In the present analysis, the uniform temperature difference θ is assumed to 50^oC. Fig. 10: shows the compare the displacement in thickness direction for B/B/B, B/F/B and F/B/F stacking sequences and also Fig. 11 & 12 shows the compare the electrical potential and magnetic induction along thickness direction for B/F/B and F/B/F stacking sequence.

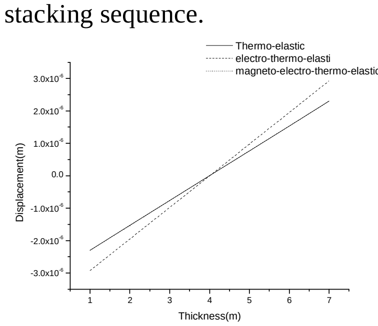

Fig.10: Compare the displacement along thickness direction for B/B/B, B/F/B and F/B/F stacking sequence

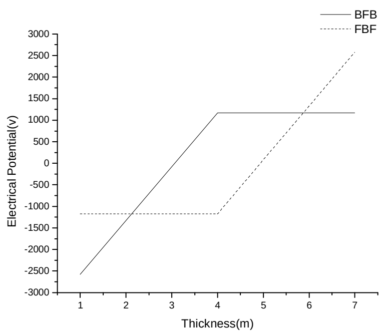

Fig.11: Compare the electrical potential along thickness direction for B/F/B and F/B/F stacking sequence

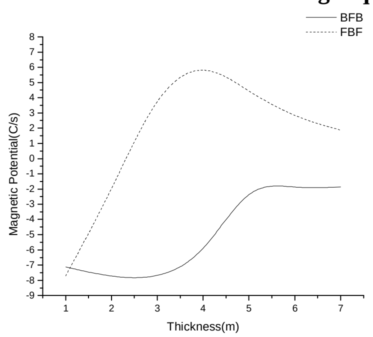

Fig.12: Compare the magnetic potential along thickness direction for B/F/B and F/B/F stacking sequence

Conclusions

In this study, the finite element procedure is used to investigate a three-layered electro-magneto-thermo-elastic strip along the thickness direction in mechanical and thermal loading conditions. As an illustration, we carried out calculations for a three layered composite strip composed of piezoelectric/piezomagnetic behaviors in the static study for mechanical load and temperature change, displacement, electrical potential and magnetic potential distributions. Furthermore, we have investigated the influence of pyroelectric/pyromagentic effect on displacement, electrical and magnetic potential. This study is considered to be useful in the design of magneto-electro-elastic sensors/actuators for smart structure application in the various mechanical and thermal loading conditions

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