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FINITE ELEMENT ANALYSIS OF SMART COMPOSITE PLATE UNDER THERMAL ENVIRONMENT

[1]SANGAMESH B. HERAKAL, [2]SAI KUMAR DATHRIKA, [3]P.GIRIRAJ GOUD,[4]P. SRAVAN

[1]Asst. Prof Dept. of Mechanical Engineering, Holy Mary Institute of Tech and Science.

[2, 3, 4] B. Tech IV Year, Dept. of Mechanical Engineering, Holy Mary Institute of Tech and Science.

ABSTRACT-
The application of piezoelectric actuators for static shape control composite plate with different substrate layer configuration is investigated in this thesis. Electro-mechanically coupled mathematical model is used for the analysis. This project aims to present the structural and electrical chrematistics of piezoelectric actuators integrated with composite plate. The major section of this thesis is the static shape control. Shape control is defined here as the determination of shape control parameters, including actuation voltage and actuator orientation configuration, such that the structure that is activated using these parameters will conform as close as possible to the desired shape. A finite element model for shape control analysis of piezoelectric laminated composite plate using Ansys is presented in this thesis. Elastic field and electric field of the piezoelectric laminated composite plate has been coupled through the linear piezoelectric constitutive equations. Piezoelectric actuators and sensors are modeled as additional layers either to be surface bonded or embedded in the laminated composite plate. A finite element software Ansys is used to model and was successfully validated with experimental and numerical results that are readily available in the literatures. The effects of actuator voltage, actuator orientation, and substrate fiber orientation and actuator placement along the thickness direction have been simulated and analyzed using the present model. The present analysis shows that with the application of appropriate voltage to piezoelectric actuator, desired shape of the composite plate can be obtained.

KEYWORDS: *Composite plate, actuator, sensor, FEM.*

INTRODUCTION

The needs for structures with self-monitoring and self-controlling capabilities especially in aerospace applications have caused remarkable growth in the research and development of smart structures. A smart structure can be defined as a structure made up of purely elastic materials, called the substrate, integrated with surface mounted or embedded sensors and actuators that have the capability to sense and take corrective action Wang et al. (1997). In the present research, to make up the smart structure, piezoelectric material that has the capabilities to act as actuators and sensors due to direct and converse piezoelectric effect is chosen to be integrated into a laminated composite plate. The direct piezoelectric effect is the ability to generate electrical charge in proportion to externally applied mechanical force, and the converse piezoelectric effect is exactly the inverse of the direct effect. Laminated composite plate is chosen as the substrate for its high strength-to-weight and stiffness-to-weight ratios .These characteristics make the laminated composite plate suitable to be used in many applications especially in aerospace

SMART STRUCTURES

Materials science and structural engineering have entered a new age brought about by the development of adaptive materials and their applications in intelligent structures. Although the terms intelligent, smart and adaptive are often used interchangeably, only a few authors have defined each term distinctly. The basic requirements of an intelligent or smart structure are the following three capabilities: sensing, processing/control, actuating. Smart structures are receiving increasing attention in biomedical, aerospace structures, civil / construction, military, locomotion, flight control and numerous other fields. Their numerous applications range from vibration suppression in aircraft and large space structures, self-diagnostic applications for detection of cracks or defects within a structure or building; to application in "smart skis" that actively suppress the vibration on the ski surface. Truss structures that are subjected to varying loads might be improved by implementing buckling control. This involves activating the adaptive materials incorporated into the axial members in order to increase the effective critical `buckling load. Another application is shape control where the shape of the structure is modified to conform to a desired shape by actuating the appropriate actuators. The next section surveys the types of adaptive materials commonly used in smart structures.

MATHEMATICAL MODEL

This chapter includes constitutive equation of piezoelectric field and governing equation of finite element formulation for the intelligent structure

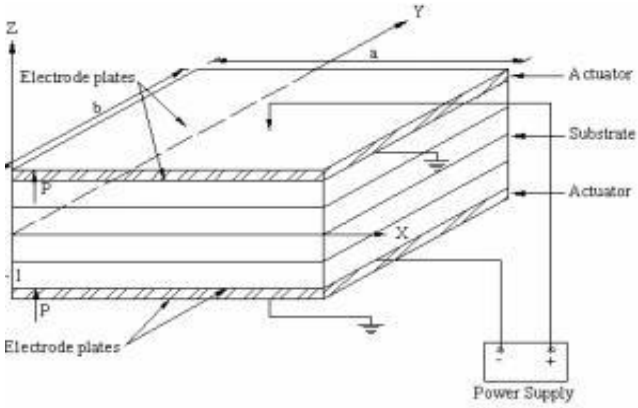


Fig1: Mathematical model

Finite Element Solutions

One of the earliest work in using the Finite Element (FE) technique for structural modeling that included piezoelectric effects was done by Allik& Hughes (1970).Since the beginning of research in the field of active/intelligent structures, several authors, most notably Tzou & Tseng (1988, 1990); Tzou et. al. (1990); have adopted the FE technique which is advantageous for cases when exact analysis is too complex.

The Element used in ansys are SOLID46 and SOLID5 .SOLID46 is a layered version of the 8 node structural solid designed to model layered thick shells or solids. The element allows up to 250 different material layers. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions.

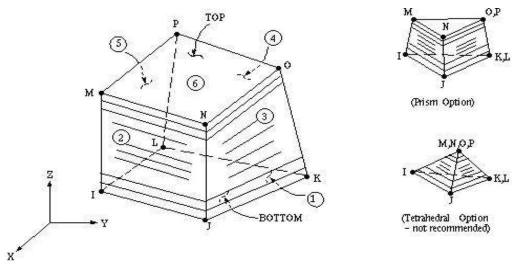


Fig 2: Solid 5 element

RESULTS AND DISCUSSION

In order to verify the accuracy of present model the deflection of Element SOLID46 for various side to thickness ratio is validated with Reddy (1997), and Table 1a to 1e reports maximum non dimensionlised deflection of simply supported square symmetric laminates under uniformly distributed load (UDL) for different side to thickness ratio

Material properties E1 = 25E2; G12 = G13 = 0:5E2; G23 = 0:2E2; _12 = 0:25 Comparison of non dimensionalised transeverse deflection of simply supported Symmetric cross- ply square plate subjected to uniformly distributed load show in the below table.

Orthotropic layer

a/h	Reddy(1997)	Present
10	0.9727	0.99
20	0.7581	0.7596
100	0.6874	0.6758

a/h	Reddy(1997)	Present
10	0.9519	0.949
20	0.7262	0.723
100	0.6528	0.642

a/h	Reddy(1997)	Present
10	1.025	0.991
20	0.7694	0.7601
100	0.6883	0.6762

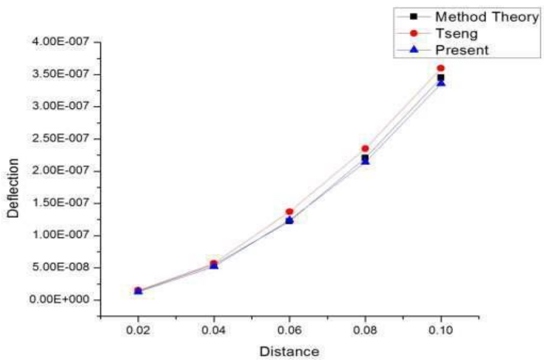
Table 1: Material properties

Property	PVDF(Wang.Z. 1997)	Graphite/Epoxy(Wang.Z. 1997)
E1	0.2E10 N=m^2	0.98E11 N=m^2
E2	0.2E10 N=m^2	0.79E10 N=m^2
G_{12}	0 .7752E9 N=m^2	0.56E10N=m^2
$_{12}$	0.29	0.29
$_{21}$	0.28	0.28
e_{31}	0.046 C=m^2	–
e_{32}	0.046 C=m^2	–
e_{33}	0.046 C=m^2	–
"$_{11}$	0.1062 E9 F / M	–
"$_{22}$	0.1062 E - 9 F / M	–
"$_{33}$	0.1062 E - 9 F / M	–

TABLE2: Deflection of the PVDF bimorph beam for a unit voltage (m)

Distance(m)	RPIM Theory	Tseng(1990)	Present FEM
0.02	1.40E-08	1.50E-08	1.29E-08
0.04	5.52E-08	5.60E-08	5.24E-08
0.06	1.22E-07	1.37E-07	1.19E-07
0.08	2.21E-07	2.35E-07	2.10E-07
0.1	3.45E-07	3.60E-07	3.30E-07

Fig 3: Tip deflection of bimorph beam V/S input volteges



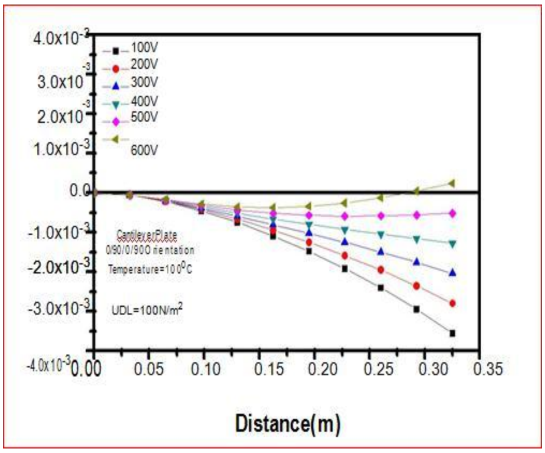


Fig 4: Centre line deflection of plate [P/0/90/0/90/P] for P=100N/m2,T=100C

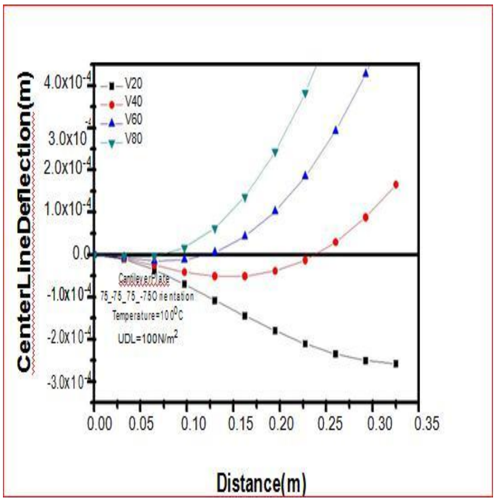


Fig 5: Centre line deflection of plate [P/75/-75/72/-75/P] for P=100N/m2,T=100 ^{0C}

CANTILEVER PLATE WITH UDL

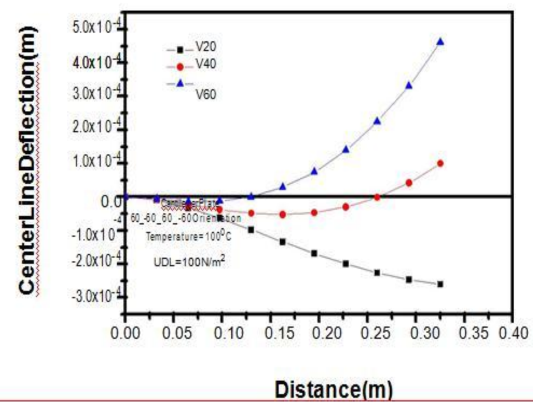


Fig 6: Centre line deflection of plate [P/60/-60/60/-60/P] for P=100N/m2,T=100_C

Property	PZT(Liu ,2004)	T300/976(Liu , 2004)
E_1	63E9	150E9
E_2	63E9	9E9
E_3	63E9	9E9
12	0.3	0.3
13	0.3	0.3
23	0.3	0.3
G_{12}	24.2E9	2.50E9
G_{13}	24.2E9	2.50E9
d_{31}	22.86	0
d_{32}	22.86	0
K_{11}	15.3E-9	0
K_{22}	15.3E-9	0
K_{33}	15.3E-9	0
Length (mm)	325	325
Width (mm)	325	325
Thickness (mm)	0.50	4

Fig 7: Centre line deflection of plate [P/45/-45/45/-45/P] for P=100N/m2,T=100_C

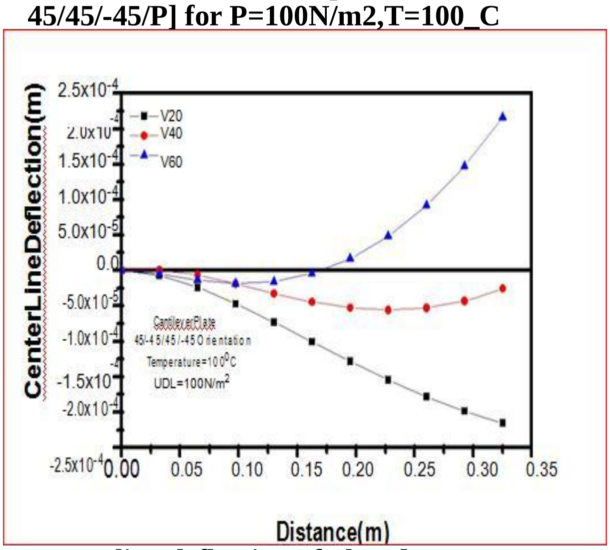


Fig 8: Centre line deflection of plate [P/30/-0/30/-30/P] for P=100N/m2,T=100C

CONCLUSIONS

Study of the behavior of piezoelectric laminated composite beams using FSDT shows promising results. A finite element formulation for the plate with distributed piezoelectric S/As is presented. A piezoelectric plate element is developed. Based on the plate element, a general method was developed for the static shape control of the intelligent structure. The input voltage and feedback gain making the shape of the intelligent structure reach the desired shape can be obtained by the present method. Similarly, the behaviour of a piezoelectric laminated cantilever beam is studied. As a summary, the behaviours of the beam subjected to electro, thermal and mechanical loading are listed below:

1. The deflections of the plate increases as applied voltage increases.
2. Mechanical and Thermal deflection can be minimised with increase in the actuator input voltage gradually and the shape control can be achieved.
3. As substrate fiber orientation increases centre line deflection also in-creases for fixed voltage.
4. The deflection of the plate due to uniform temperature are lesser com-pared to deflections due to varying temperature, These deflections due to mechanical and thermal loads are e ectively controlled by applying electric potential to piezoelectric layer of the beam, decrease and in-crease in the beam deflections depend on the polarity of the applied voltage.
5. By applying Thermal load to the anti-symmetric stacking scheme the twisting deformation occurs, and are suppressed by application of electric potential to piezoelectric layers.
6. It would be concluded that the deflections due to mechanical and ther-mal e ects can be e ectively controlled by applying appropriate volt-ages to the piezo layers and can be said that piezoelectric layers are useful in controlling deflections of beam under thermo-mechanical loadings.

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