Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 79 (2014) 189 – 193
Procedia Engineering
www.elsevier.com/locate/procedia

37th National Conference on Theoretical and Applied Mechanics (37th NCTAM 2013) & The 1st International Conference on Mechanics (1st ICM)

Bending Stress Analysis of Laminated Foldable Touch Panel

Meng-Kao Yeh[a,]*, Li-Yu Chang[a], Hsien-Chie Cheng[b], Pi-Hsien Wang[c]

[a]Department of Power Mechanical Engineering, National Tsing Hua University, 101, Sec. 2, Kuang Fu Road, Hsinchu 30013, Taiwan
[b]Department of Aerospace and System Engineering, Feng Chia University, 100, Wen Hwa Road, Taichung 407, Taiwan
[c]Display Technology Center, Industrial Technology Research Institute, 195, Sec. 4, Chung Hsing Road, Chutung 31040, Taiwan

Abstract

The touch panel technology has been developed in recent years, and the foldable touch panel is one of the newly attractive characteristics. This article focuses on the bending stress analysis of foldable touch panel, composed of plastic substrate PET, adhesive layer, plastic layer PI, organic layer and conductive layer ITO to form a seven-layer laminated structure. By applying four-point bending, the stress distribution of the touch panel under different radius of curvature was analyzed. The results show that the maximum von Mises stress occurred in the ITO layer and the maximum von Mises stress increased from 0.497 GPa to 1.242 GPa with decreasing radius of curvature. The region near the center of the touch panel has higher von Mises stress, and the relation between the radius of curvature and the maximum von Mises stress exhibits a non-linear feature.

Selection and peer-review under responsibility of the National Tsing Hua University, Department of Power Mechanical Engineering

Keywords: Foldable touch panel; four-point bending; radius of curvature; stress analysis

Nomenclature

κ	Curvature
ρ	Radius of curvature

---

* Corresponding author. Tel.: +886-3-574-2595; fax: +886-3-572-2840.
E-mail address: mkyeh@pme.nthu.edu.tw

Selection and peer-review under responsibility of the National Tsing Hua University, Department of Power Mechanical Engineering
doi:10.1016/j.proeng.2014.06.330

1. Introduction

The touch panel used in some high-tech products, like smart phone, tablet personal computer has become an important technology in recent years and the foldable characteristics of touch panel has attracted more attentions. To be foldable, the touch panel becomes thinner, less weight and however vulnerable to fail. When the touch panel is folded, the conductive thin layer might failed due to the large deformation under bending.

For the transparent and conductivity features in touch panel, the Indium Tin Oxide (ITO) is selected as the conductive material. Sim et al. [1] studied the crack reduction method through bending experiment by adding the aluminium buffer layer into the PET/ITO laminated structure. Alzoubi et al. [2] found that the radius of curvature and the number of bending cycle are the two main factors resulting in the fatigue behaviour of the conductive layer ITO in bending test of flexible substrate. Caims et al. [3] studied the mechanical property and the electrical failure of ITO with several substrates and found the crack number generated by bending would change with the deform shape of substrate. Oh et al. [4] used static bending and dynamic bending experiment to assess the failure mechanism of flexible substrate with ITO electrodes, the crack induced after experiment could affect the conductivity of ITO film. Lee and Lee [5] found that under compressive bending stress on polymer substrate, the cracks generated near the center of specimen and the crack number increased as the radius of curvature decreased. Sierros et al. [6] concluded that the combination of stress and corrosion by acrylic acid could cause ITO cracking at stresses lower than a quarter of those needed for failure without corrosion Yu et al. [7] added a silica buffer layer between plastic substrate PET and conductive layer ITO and found that after bending experiment the conductivity of ITO varied at different radius of curvature for both cases. Lan et al. [8] demonstrated that using a thermionic emission (TE) enhanced DC magnetron sputtering system to have ITO films deposited on polyethylene terephthalate (PET) substrates could improve electrical and optical properties under static and dynamic mechanical bending.

Leterrier et al. [9] showed that the internal stress and thickness of layer affected the failure mechanisms of flexible display by bending and fragmentation tests. Park et al. [10] studied the mechanical stability of externally deformed ITO films on polymer substrates. Gergo et al. [11] evaluated the bending method to test the flexible display and found the failure mode in flexible display. Chen et al. [12] assessed the flexibility and reliability of the flexible display in different use cases by failure analysis. Crawford et al. [13] used the flexible glass as substrate and ITO as the conductive layer in flexible touch panel to improve the life of panel by different circuit deployment. Li et al. [14] performed the thermal stress analysis of flexible panel with different temperature and humidity.

The bending behavior of the touch panel has been concerned in the most references mentioned-above. The bending stress analysis of the foldable touch panel are simulated in this study with different radius of curvature.

2. Finite element analysis

The finite element code ANSYS ® [15] was used to analyze the stress distribution of foldable touch panel in the form of laminated structure under different radius of curvature. The finite element method is a method to change the continuum of infinite degree of freedom to a domain with finite degree of freedom by discretizing a solid structure into many elements. Each element has several nodes with finite degree of freedom. The system simultaneous algebraic equations can be derived by variatioinal or weighted residual methods and the equations are solved by numerical analysis method [16-18]. The analysis procedure includes (1) defining the type of problem, (2) choosing the appropriate type of element, (3) building the analysis model with meshes, (4) applying the boundary conditions and loads, (5) solving the problem, and (6) display the results.

The element used in bending stress analysis of the foldable touch panel is Solid 45, which is a hexahedral element composed of eight nodes and each node has three degrees of freedom in x, y, and z directions. The touch panel with seven-layer laminated structure is composed of plastic substrate PET, adhesive layer, plastic layer Polyimide (PI), two organic layers and two conductive ITO layers. Fig. 1. shows the foldable touch panel with seven laminated layers. The thickness of each layer is shown in Table 1.

Table 1. The thickness and material properties of each layer in the touch panel

Material	Thickness	Young’s Modulus (GPa)	Poisson’s Ratio
ITO 2 (equivalent)	70 nm	36.4	0.475
ITO 1 (equivalent)	70 nm	24.1	0.475
Organic	1 µm	2.0	0.35
PI	15 µm	2.7	0.34
Adhesive	20 µm	3.2	0.35
PET	100 µm	4.8	0.3

The material properties of each layer are obtained from experiments and the related articles, as shown in Table 1. Because of the complicated geometric pattern in ITO layer, the equivalent material properties of ITO layer is used in this analysis. The Young’s moduli of the two ITO layers are different due to different geometric patterns. The size of the analysis model is a square with 2 cm in length and 2 cm in width. To avoid too slim elements in the model, the ratio of length to width in each element is restricted within 1:20. The total number of the elements is 83200 in finite element analysis.

The touch panel is under four-point bending and the boundary conditions used for this model are shown in the Fig. 2. The degrees of freedom at the side A are fixed in the y and z directions and the degree of freedom at the upper side B is fixed in the y direction only. In addition, the degrees of freedom at point A and B are fixed in the x direction. To apply four-point bending on the touch panel, the y-displacement in direction is prescribed at the two lines near the center with a span of 0.5 cm. The radius of curvature can be derived from the deflection curve of the touch panel and can be obtained from the simulated results and the following equation

$$\rho = \frac{1}{\kappa} = \frac{\left(1 + y'^2\right)^{3/2}}{|y''|} \qquad (1)$$

where ρ is the radius of curvature, κ is the curvature and y is the deflection curve of the touch panel.

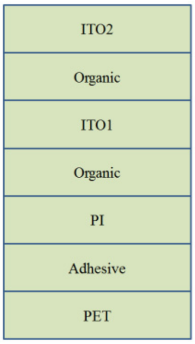

Fig. 1. The touch panel with seven laminated layers

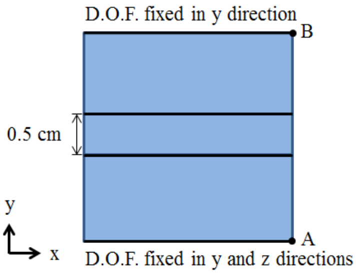

Fig. 2. Boundary conditions of the analysis model

3. Results and Discussions

After analysis the stress distributions of the foldable touch panel are obtained for each radius of curvature. The results for the radius of curvature 4.072 mm are presented here. The von Mises stress distribution and the details in lateral view are shown in Fig. 3. The maximum von Mises stress is 0.92 GPa on the top of ITO2 layer, which is in red color in Fig. 3. The second higher stress occurs in ITO1 layer, the other layers are in low stress values, below 0.12 GPa. The stress is higher near the center of the touch panel then decreased to a lower value at the boundary. For comparisons, the maximum von Mises stress obtained for the panel under four-point bending is lower than those obtained for the same panel under three-point bending.

As the radius of curvature decreases, the bending stress in the panel increases. The relation between the maximum von Mises stress in the touch panel and the radius of curvature are shown in Fig. 4 and the non-linear behaviour of this relation can be clearly seen. The maximum von Mises varies from 0.497 GPa to 1.242 GPa as the radius of curvature decreases from 0.755 mm to 0.296 mm.

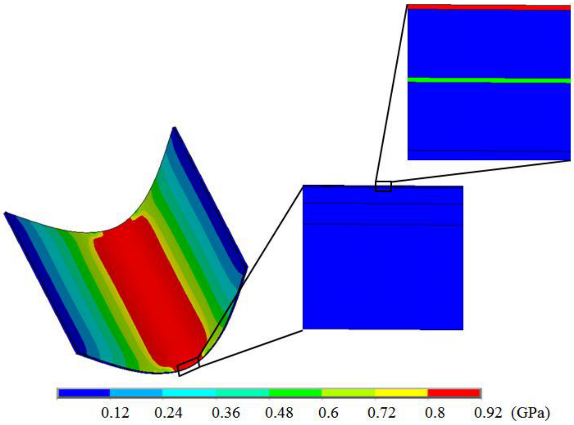

Fig. 3. The von Mises stress distribution of touch panel

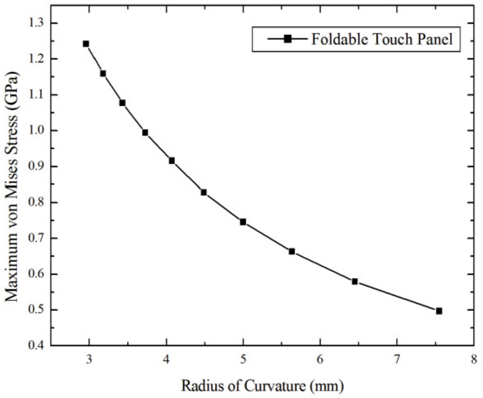

Fig. 4. The stress versus the radius of curvature

4. Conclusions

In this study, the bending behavior of laminated foldable touch panel under four-point bending was investigated using finite element method. The following conclusions are obtained.

(1) The maximum von Mises stress of the laminated foldable touch panel occurred in the ITO2 layer, for the layer arrangement studied.

(2) The value of maximum von Mises stress on the touch panel is 0.92 GPa when the radius of curvature is 4.072

mm. The stresses are higher near the central region of touch panel and decreased to a lower value at the boundary.

(3) The relation between the maximum von Mises stress of touch panel and the radius of curvature is non-linear; the maximum von Mises stress varies from 0.497 GPa to 1.242 GPa as radius of curvature decreases from 0.755 mm to 0.296 mm.

Acknowledgements

This work was supported by the cooperative project between the Industrial Technology Research Institute and National Tsing Hua University.

References

[1] B. Sim, E.H. Kim, J. Park, M. Lee. Highly enhanced mechanical stability of indium tin oxide film with a thin Al buffer layer deposited on plastic substrate, Surface & Coatings Technology 204 (2009) 309-312.

[2] K. Alzoubi, M. M. Hamasha, S. Lu, B.S. Sammakia, Bending fatigue study of sputtered ITO on flexible substrate, Journal of Display Technology 7, No. 11 (2011) 593-600.

[3]]D.R. Caims, D.C. Paine, G.P. Carwford, The Mechanical Reliability of Sputter-Coated Indium Tin Oxide Polyester Substrates for Flexible Display and Touchscreen Applications, MRS Proceeding 666, 2001.

[4] J.S. Oh, Y.R. Cho, K.E. Cheon, M.A. Karim, S.J. Jung, Failure mechanism of patterned ITO electrodes on flexible substrate under static and dynamic mechanical stresses, Solid State Phenomena 124-126 (2004) 411-414.

[5] S.K. Lee, J.U. Lee, The fracture distribution in ITO coating with compressive bending stress on polymer substrates, Transactions on Electrical and Electronic Materials 4, No. 6 (2003) 5-8.

[6] A. Sierros, N.J. Morris, K. Ramji, D.R. Carins, Stress–corrosion cracking of indium tin oxide coated polyethylene terephthalate for flexible optoelectronic devices, Thin Solid Film 517 (2009) 2590-2595.

[7] Yu, L. Xiang, W. Xue, H. Wang, The Bending Properties of Flexible ITO Films, IEEE Conference, 2007, pp. 148-150.

[8] F. Lan, W.C. Peng, Y.H. Lo, J.L. He, Durability under mechanical bending of the Indium tin oxide films deposited on polymer substrate by thermionically enhanced sputtering, Organic Electronics 11 (2010) 670-676.

[9] Y. Leterrier, C. Fischer, L. Médico, F. Demarco, J.A.E. Månson, P. Bouten, J. DeGoede, J.A. Nairn, Mechanical Properties of Transparent Functional Thin Films for Flexible Displays, 46th Annual Technical Conference Proceedings, 2003.

[10] S. K. Park, J.I. Han, D.G. Moon, W.K. Kim, Mechanical stability of externally deformed indium–tin–oxide films on polymer substrates, The Japan Society of Applied Physics 42, No. 2A (2003) 623-629.

[11] S. Grego, J. Lewis, E. Vick, D. Temple, Development and evaluation of bend-testing techniques for flexible-display applications, Journal of the SID 13, No. 7 (2005) 575-581.

[12] Q. Chen, L. Xu, A. Salo, Reliability Study of Flexible Display Module by Experiments, ICEPT-HDP IEEE, 2008.

[13] G.P. Crawford, Flexible Flat Panel Displays, John Wiley & Sons, Ltd., 2005.

[14] J. P. Li, P. Yang, J. Zhong, Thermal Analysis Based on the Environmental Tests of STN Display, EuroSimE IEEE Conference, 2009.

[15] ANSYS Release 12.1, ANSYS, Inc., PA, 2010.

[16] R.D. Cook, D.S. Malkus, M.E. Plesha, R.J. Witt, Concepts and Applications of Finite Element Analysis, 4th ed, John Wiley & Sons, 2006.

[17] L.J. Segerlind, Applied Finite Element Analysis, 2nd, Wiley, New York, 1984.

[18] ANSYS User's Manual, ANSYS Inc.