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Numerical Model for Thermal Stress Analysis of Bi-Layered Pan under Isothermal Loading

Mohammadreza Sedighi[1], Behnam Nilforooshan Dardashti[2]
[1] Young Researchers Club, Islamic Azad University Bueenzahra Branch, Bueenzahra, Iran
[2] Mechanics Department, Islamic Azad University Bueenzahra Branch, Bueenzahra, Iran
([1]MR.Sedighi67@gmail.com, [2] B.Nilforooshan@gmail.com)

Abstract- The bi-metal pan improved quality of cooking in comparison with single layer. Although the materials with different coefficients of thermal expansion and stiffness are bonded together cause thermal stress. These stresses deform the body of utensil. In this paper we studied on the body deformation. The numerical solution, Finite Element Method, of thermal stress is carried out for Cu/Ti, Cu/SSt, Al/Ti, Al/SSt, Cu/CrNi and Al/CrNi bi-metal pan. Base on results the Cu/SSt makes minimum body deformation.

Keywords- *Body Deformation, Bi-metal Plate,Isothermal loading, Thermal Stress*

I. INTRODUCTION

It is difficult for single material to meet a wide variety of demands such as superior thermal and chemical properties [1, 2]. Especially in cookware application MLP have many advantages in compared with single layer [17, 18]. Multi-layer cookware provides uniform temperature distribution on food preparation surface so in this manner hot spots are eliminated [3, 4, 18]. Another advantage is superior chemical properties by using higher inertness materials in surface that is exposed to food [5]. Heat retaining is another significant characteristic that MLP can improve it [18].

When the temperature of a component is increased or decreased the material respectively expands or contracts. If this expansion or contraction is not resisted in any way then the processes take place free of stress. If, however, the changes in dimensions are restricted then stresses termed temperature stresses will be set up within the material [6]. Although laminated plate provides improved application quality of utensil, it accommodates some disadvantage such as body deformation. The reason is materials with different coefficients of thermal expansion and stiffness are bonded together to form laminated plate [8, 9] .There are interfacial stresses in bi-metal structure. Valuable insight in to thermally-induced in heterogeneous structures, including interfacial stress have widely provided by many paper such as [10, 11].

Notes that since mid-1960 many investigators applied numerical, mainly finite element, methods to analysed bimetal structures, subjected to thermal loading [10]. There are many papers, used FEM to calculate thermal buckling of laminated plate subjected to uniform or non-uniform temperature [12-16]. An analytical model for thermal stress analysis of multi-layered thin stacks on a thick substrate under isothermal loading is proposed in [8].

Reference [9] has studied on bi-layer cookware including different metals under isothermal loading. It demonstrated bi-layer consists of Copper and Stainless Steel causes minimum body deformation.

In this paper we have surveyed on body deformation of bi-metal cookware that subjected to thermal loading. Two different structures are compared with each other. In one of them, the pan wall is made of second layer materials of plate. Whereas in another one, the metal of pan wall is as same as first layer metal. Body deformation and thermal stress of all applied metals are analyzed in steady state.

We have used Finite Element Method with ANSYS program to calculate body deformation of pan subjected to heating load.

TABLE I. SYMBOLS AND THICKNESSES

Metals	Symbols	Thicknesses(mm)
Copper	Cu	8
Aluminum	Al	8
Stainless Steel	SSt	2
Chromium- Nickel	Cr-Ni	2
Titanium	Ti	2

II. BOUNDRY CONDITION AND GEOMETRY

There is a geometrical symmetry so the system can be modeled by rectangle plane with length of the pan radius and a thin and long rectangle as wall of pan. We modeled bi-metal pan for studying on body deformation in steady state. At first the model is in ambient temperature degree. Then we assumed that all over the pan is heated and reached to uniform elevated temperature degree, 600K. In another word we analyzed thermal stress of the bi-layer cookware under isothermal loading. It is axisymmetric geometry so displacement and the temperature gradients at the centre of plate is zero. In this part we took the bottom layer and top layer thicknesses, 8mm and 2mm respectively for all metals. All materials properties are shown in Table 2.

Two different structures are compared with each other. In one of them, the pan wall is made of second layer materials of plate. Whereas in another one, the metal of pan wall is as same as first layer metal illustrated in Fig1, 2.

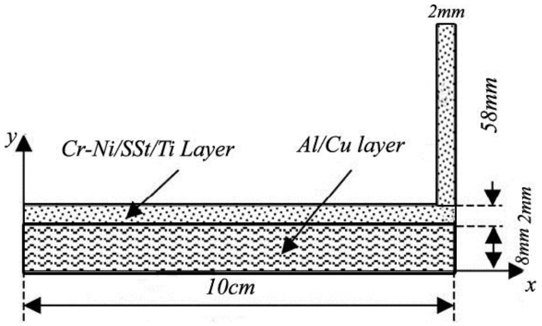

Figure 1. 2D bi-layer model in numerical analysis; model 1

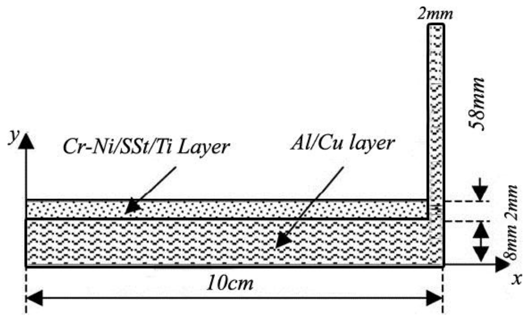

Figure 2. 2D bi-layer model in numerical analysis; model 2

TABLE II. MECHANICAL PROPERTIES OF METALS

Symbol	ρ(kg/m^3)	ν	E e+11	α e-6
Cu	8933	0.355	1.17	16.92
Al	2700	0.334	6.96	23.58
SSt	8055	0.305	1.93	17.28
Cr-Ni	8400	0.29	1.86	13.4
Ti	4500	0.32	1.13	9.54

The properties of applied metals are according to **[19].**

III. FINITE ELEMENT ANALYSIS

We analyzed the model by using different materials in steady state. In this part we want to analyze body deformation and thermal stress of bi-metal pan. We employed finite element method with ANSYS program to find the materials that provide minimum body deformation in the bi-metal plate. A numerical model for thermal stress analysis of multi-layered cookware under isothermal loading is studied.

The results of model 1 are proposed in [9]. In this paper we studied on model 2. Then this model is compared with model1.

IV. RESULTS

Al/CrNi has the maximum deformation due to maximum thermal stress. It is 1.032mm. The results are shown in Table 3. In addition SSt has the minimum deformation among applied metals in second layer in combination by both Al and Cu. Cu causes lower deformation compared with Al. It is clear because the thermal expansion of Al is greater than Cu. Consequently Cu/SSt has minimum body deformation.

Table III. THE CALCULATED DEFORMATION OF ALL METALS

Metals	Deformation (mm)
Al/CrNi	1.032
Cu/CrNi	0.944
Al/Ti	0.943
Al/SSt	0.845
Cu/Ti	0.75
Cu/SSt	0.581

The linear expansion of model 2 is compared with model 1 in Fig 3. It shows that model 2 provide lower mean body deformation than model 1. Althogh in some combination such as Al/SSt and Cu/SSt the model 1 is close to model 2 and even in Cu/CrNi the model 1 makes lower body deformation.

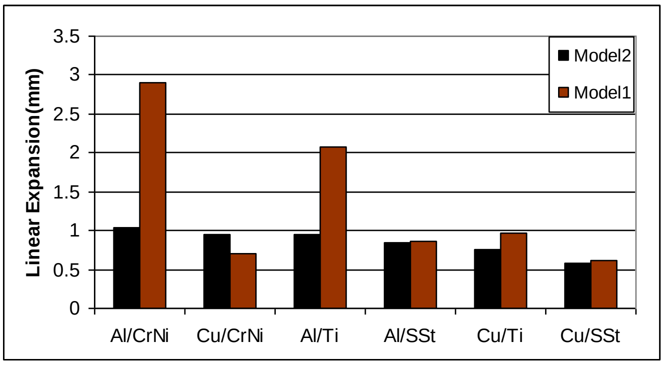

Figure 3. Linear expansion comparison of model 2 with model 1

The deformation of body in Cu/SSt is different than others. As the thermal expansion of SSt is greater than Cu, the body deformation is convex. In other combinations the deformation of body is concave because thermal expansion of Cu and Al that used in bottom layer are greater than the metals of second layer. Figure 4-9 show deformed shape with undeformed model of pan with the Von Mises stress contour.

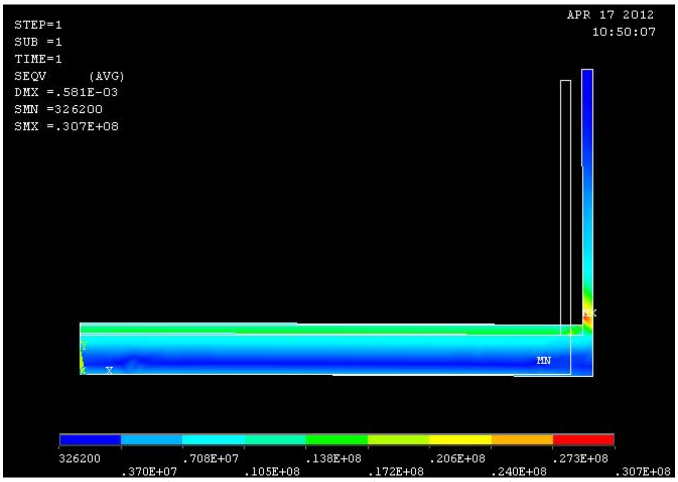

Figure 4. Deformed shape with undeformed model of Cu/SSt pan

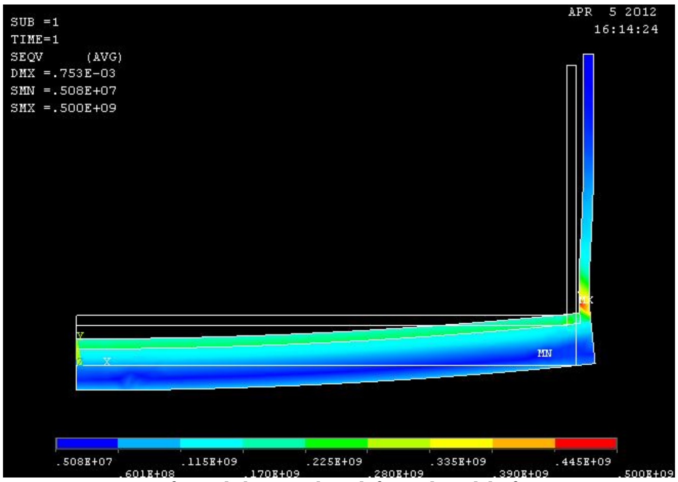

Figure 5. Deformed shape with undeformed model of Cu/Ti pan

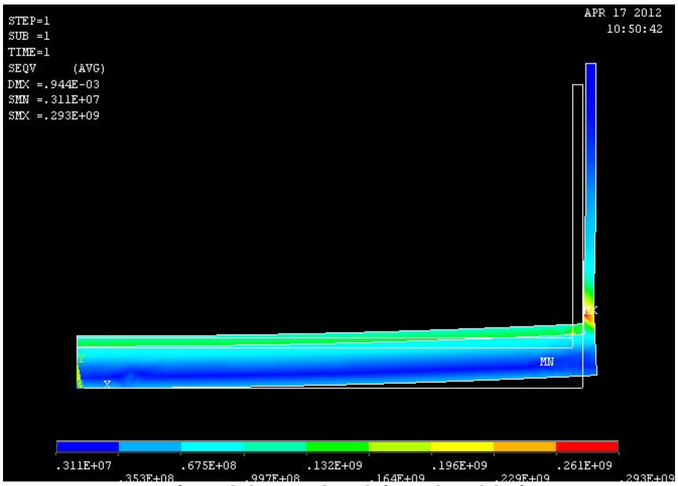

Figure 6. Deformed shape with undeformed model of Cu/CrNi

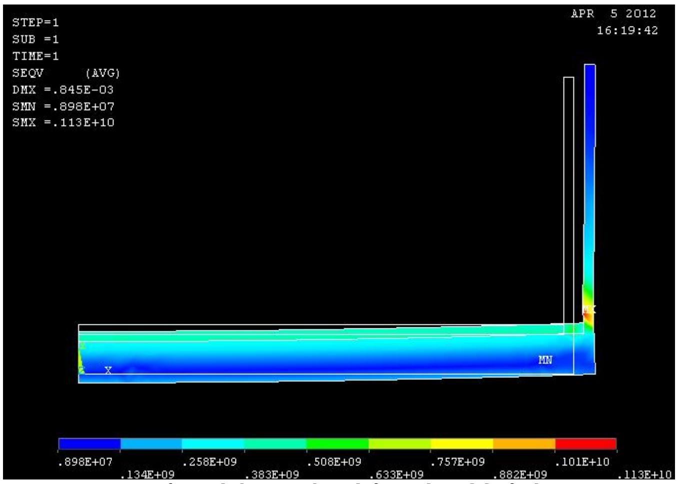

Figure 7. Deformed shape with undeformed model of Al/SSt pan

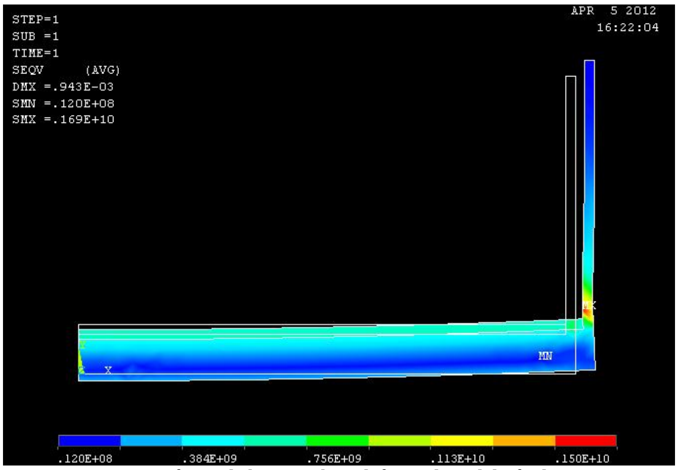

Figure 8. Deformed shape with undeformed model of Al/Ti pan

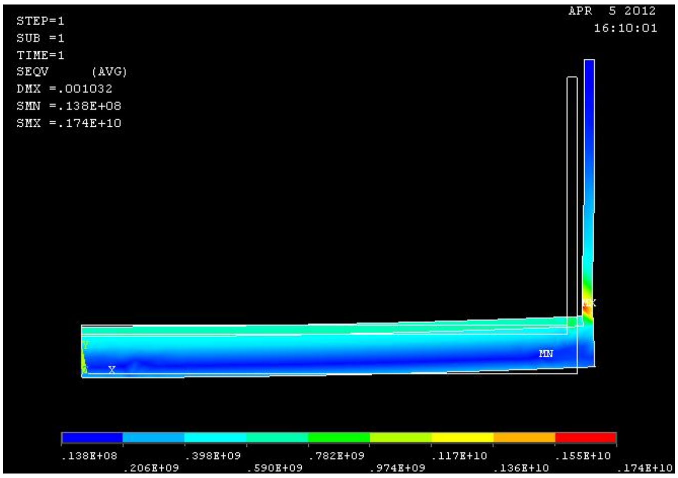

Figure 9. Deformed shape with undeformed model of Al/CrNi pan

V. CONCLUSION

This paper describes the steady state numerical, finite element method, analysis of thermal stress and body deformation of bi-metal pan.

We analyzed the body deformation of pan which the metal of pan wall is as same as first layer metal. Then we compared this model with the model which pan wall is made of second layer materials of plate.

Al/CrNi has the maximum deformation, 1.032mm, whereas we can meet minimum deformation in Cu/StS, 0.581mm, in both models. This behaviour makes the Cu/StS suitable structure for cookware production in both models.

From this analysis the result suggests that we should analyze the TD and thermal stress in model by thermal resistance contact consideration.

REFERENCES

[1] K Y Rhee, W Y Han, H J Park, et al. Fabrication of Aluminum/Copper Clad Composite Using Hot Hydrostatic Extrusion Process and Its Material Characteristics [J]. Materials Science and Engineering, 2004, 384: 70-76

[2] J E Lee, D H Bae, W S Chung. Effects of Annealing on the Mechanical and Interface Properties of Stainless Steel/Aluminum/Copper Clad-metal Sheets[J]. Journal of Materials Processing Technology, 2007, 187-188: 546-549

[3] Sarkar A, Erdogdu F, Singh PR. Measurement of spatial variations of heat transfer coefficient on flat surfaces for food processing applications. In: Conference of food engineering. American Institute of Chemical Engineers, New York, USA, 6 November 2001.

[4] Pan Z. Temperature distribution and heat transfer coefficient of a clam-shell grill. In: Conference of food engineering. American Institute of Chemical Engineers, New York, USA, 6 November 2001.

[5] WilliamA.Groll, *Stainless Steel-Carbon Steel Enamelized Cookware*, United States Patent, Pub No: US2010/0108690A1, May 6, 2010.

[6] E. J. HEARN, 1997, Mechanics of Materials Volume 1: An Introduction to the Mechanics of Elastic and Plastic Deformation of Solids and Structural Materials: v. 1, Butterworth-Heinemann; 3 edition (9 July 1997), pp:13.

[7] Rena L. Hecht, et al. *Thermal Transport Properties of Grey Cast Irons,* SAE 962126.

[8] Yujun Wen, Cemal Basaran, *An analytical model for thermal stress analysis of multi-layered microelectronic packaging*, Mechanics of Materials 36 (2004) 369–385, Elsevier.

[9] M. R Sedighi ,B. Nilforooshan Dardashti, Reza Sedighi, Study of Heat Retaining and Body Deformation of Bimetal Cookware, Advances in Natural and Applied Sciences(2012), unpublished.

[10] E.Suhir, Interfacial stresses in bimetal Thermostats, Transaction of ASME, Vol. 56, 1989, pp 595-600.

[11] J. W. Eischen, J. S. Everett, Thermal Stress Analysis of a Bimaterial StripSubject to an Axial Temperature Gradient, Journal of Electronic Packaging, Vols 111, Dec 1989, Transaction of ASME.

[12] Chen Lien-Wen, Chen Lei-Yi,*Thermal buckling analysis of laminated cylindrical plates by the finite element method*. ComputStruct 1990;34(1):71–8

[13] Noor AK, Peters JM, *Finite element buckling and postbuckling solutions for multilayered composite panels*, Finite Element Analysis and Design, 1994; 15(4):343–367.

[14] Chandrashekhara K, *Thermal buckling of laminated plates using a shear flexible finite element*. Finite Element Analysis and Design, 1992;12(1):51–61

[15] Kari R. Thangaratnam, *Thermal buckling of composite laminated plates*, Computers & Structure, v 53 (1994), pp 1193-1204, Elsevier, Available online 12 February 2003.

[16] S.Maloy K. Singha, *Thermal postbuckling analysis of laminated composite plates*, Composite Structure 54 (2001) 453-458, 2001 Elsevier Science Ltd.

[17] M. R Sedighi ,B. Nilforooshan Dardashti, *Heat Transfer Modeling in Multi-Layer Cookware Using Finite Element Method,* International Journal of Mechanical and Aerospace Engineering, Vol. 6, 2012, *pp 147-153.*

[18] B. Nilforooshan Dardashti, M. R Sedighi, *Numerical Solution of Heat Transfer In Single and Multi-Metal Pan,* Applied Mechanics and Materials Vols. 148-149 (2012) pp 227-231, Trans Tech Publications, Switzerland.

[19] Beer, Ferdinand P, Johnston, E. Russel, Mechanics of Materials (Book), 2nd ed. Mc Graw-Hill