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THERMAL ANALYSIS OF BIMETAL PLATES AS COOKING POTS: COMPUTATIONAL COMPARISON OF TWO GEOMETRIES

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Abstract. Multi-layer-plate (MLP) provides improved thermal, chemical and mechanical properties. High temperature degree, uniform Temperature Distribution (TD), heat capacity and inertness of utensil material are significant parameters in cooking. In this study the main objective is analysis of the TD all over the two different structure of cookware. Analyzed structures have different behavior so we can use them in different propose. In another part we concerned about heat loss from heated cookware. We compared the insulated pan with non-insulated pan. Based on results the insulator improved the heat retaining of pan. It reduces the energy consumption. We employed Finite Element Method (FEM) for analyzing transient thermal behavior of models.

1. Introduction

We can meet the wide variety of demands such as superior mechanical and thermal properties by using multi materials together [1, 2]. Multi-layer structure and material properties of the layers have high impact on improving thermal behavior of cookware. It can optimize the energy consumption. The energy obtains mainly from burning gas and electrical resistivity. The heat is not uniformly spread over the pan in both methods. Using multi-layer plate causes regular TD on the top while bottom heated irregularly [3-5].

Kitchens are one of the places where deals with this phenomenon daily in cookware application. This leads us to two considerations: thermal diffusivity and reactivity. Thermal diffusivity determines how fast the pan will heat up. We do not have to concern ourselves with the thermal properties of materials only, but we need to make sure that the materials we use in our cookware do not harm us or adversely affects the taste of our food [6]. For this reason, in addition to the high thermal diffusivity, we would also like non-reactive materials. Copper and aluminum have high thermal diffusivity but both of them reacts readily to foods while some materials like stainless steel, the least reactive of all popular materials used in cookware, also has the low thermal diffusivity. Stainless steel is durable, non-porous, nonreactive and resistant to rust, corrosion and pitting. Titanium has good corrosion and chemical resistance too. Consequently, the pan should be constructed of conductive metal in bottom layer such as copper and aluminum that are great conductor of heat and non-reactive metal such as stainless steel or titanium therefore safe to use with any food product in layer of pan which is exposed to food [7, 8].

In addition, it is also assumed that the pan is filled up by water at boiling temperature, and the coefficient of heat transfer between the pan and the water is 50 W/ (m² K).

Two different structures are compared with each other. In one of them, the pan wall is made of low conductive second layer material of plate (Fig. 1), whereas in another one, the metal of pan wall is as same as high conductive first layer metal as shown in Fig. 2.

After that the model reached to steady state we changed the boundary conditions of pan to analyzing the heat retaining of the model. Hence we modeled the heated pan to transfer the heat only with air in ambient temperature for cooling.

In last part we surveyed the influence of insulator on enhancing the heat retaining of cookware. We chose only model 2 for analyzing. We covered the side of pan by insulator illustrated in Fig. 3. In addition, we assumed the pan has a lid so the heat loss will not take place in inner space of pan.

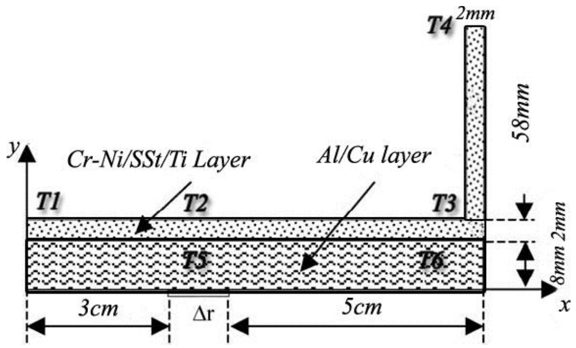

Fig. 1. 2D bi-layer model in numerical analysis and positions of different selected nodes, named T1-T6; model 1.

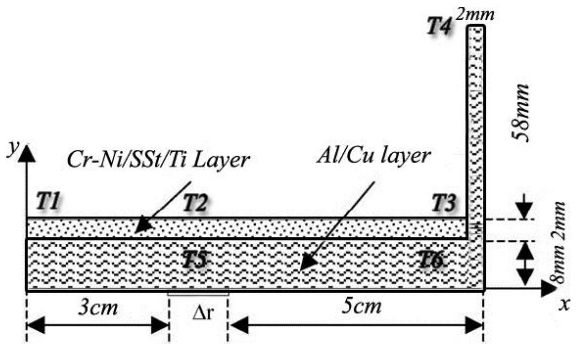

Fig. 2. 2D bi-layer model in numerical analysis and positions of different selected nodes, named T1-T6; model 2.

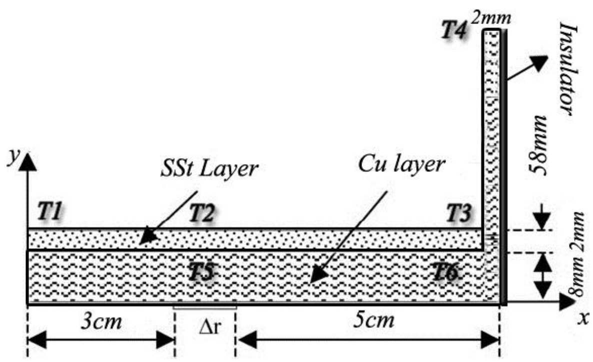

Fig. 3. 2D bi-layer model which is covered by insulator in numerical analysis and positions of different selected nodes, named T1-T6; model 2.

Figure 6 represents the differences between time variation of temperature of T2 node in model 1 and model 2. The heat tends to transfer through the copper layer which has high thermal conductivity. Hence the wall of model 2 is heated faster and higher than model 1. Figure 6 shows the temperature of T2 node in model 2 is greater than model 1. The reason is the temperature of model 2 wall is higher than model1 wall so temperature gradient in model 2 becomes less than model 1. Subsequently the low temperature of wall in model 1 causes the high heat flux to the side of pan. Hence the heat distributes from center to side. In another word the temperature of T3 zone in model1 is lower than model 2 so the heat distributes from the T2 zone to T3 zone. Subsequently the temperature of T2 zone in model 1 is lower than model 2 while T3 zone temperature in model 1 is higher than model 2 but in model 2 the heat is concentrated in T2 zone. Consequently the T2 node in model2 has higher temperature degree than model1 whereas the T3 node has lower temperature than model1 illustrated in Fig. 7.

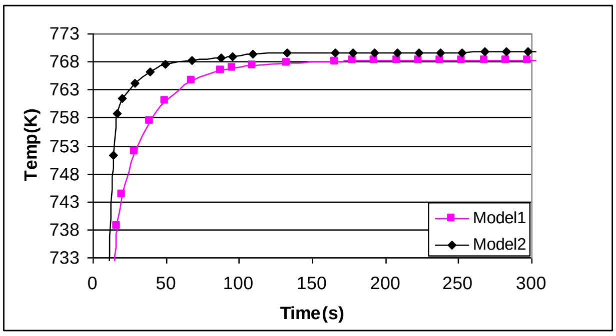

Fig. 6. T2 node temperature changes of model 1 and model 2 over time in the range of 733 to 773 K.

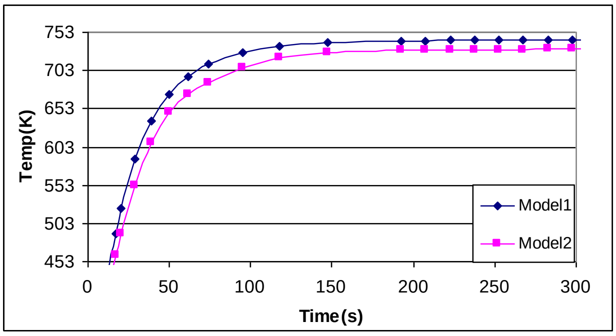

Fig. 7. T3 node temperature changes of model 1 and model 2 over time in the range of 453 to 753 K.

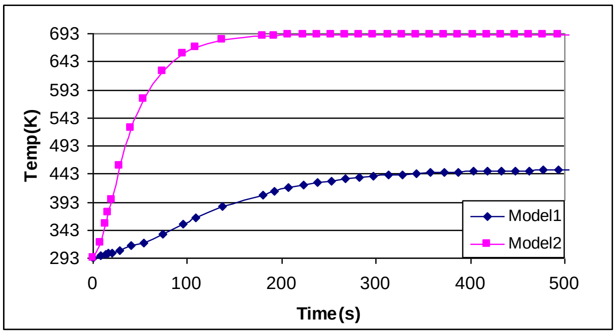

Fig. 8. Time variation of T4 node temperature in model 1 and model 2.

cooling step is up to 20 K shown in Fig. 11. In all nodes we observed that insulated pan has higher temperature degree than non-insulated pan. It is clear insulated pan can store the heat better than non-insulated. We observe that all nodes have relatively same temperature variation.

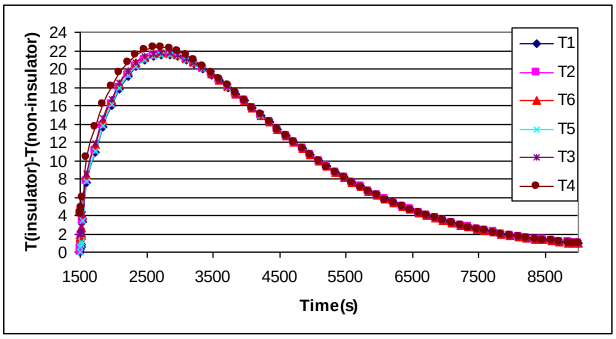

Fig. 11. Time variation of differences between temperature of T1-T6 nodes of insulated and non-insulated pan in cooling steps.

4. Discussion

We analyzed the result of mode l1 and model 2. The temperature distribution of model 1 on cooking surface is more uniform than model 2. We compared the uniformity of temperature distribution on cooking surface of Cu/SSt model 1 with Cu/SSt model 2 as shown in Fig. 12. This figure shows that the temperature distribution of model1 at some time near 50 degrees and at steady state about 15 degrees is more uniform than model 2.

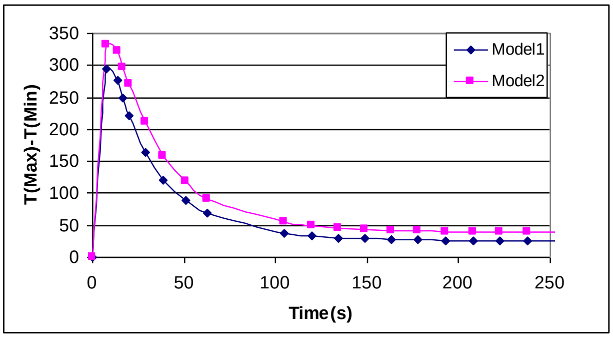

Fig. 12. Time variation of differences between maximum and minimum temperature on food preparation surface of Cu/SSt in model 1 and model 2.

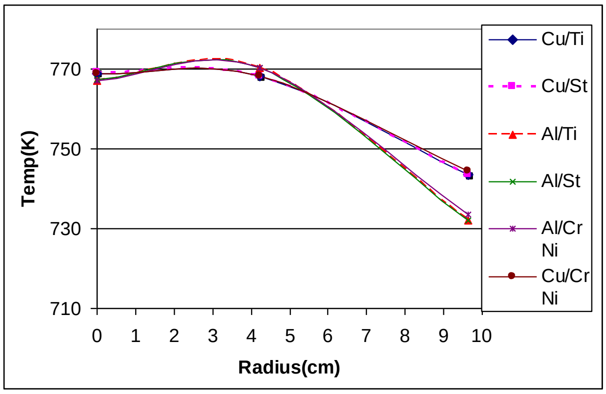

Fig. 13. Temperature distribution on food preparation surface of pan for used metals at steady state in model 1.

Figures 13 and 14 present the temperature distribution on food preparation surface of cookware for all used metals in steady state in model 2 and model 1. These figures show that temperature distribution of model1 is higher and more uniform than model 2. In addition the uniformity of bimetal structures consist of copper is higher than aluminum.

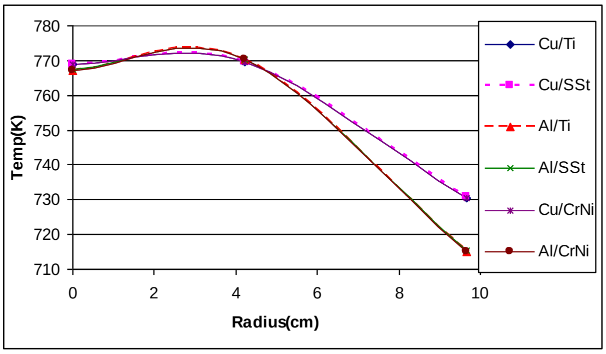

Fig. 14. Temperature distribution on food preparation surface of pan for used metals at steady state in model 2.

The temperature of T2 zone in model 2 is higher than model1 while T3 temperature is lower. Hence we compared these two temperature points with each other to find which model provides higher temperature degree on the cooking surface. First, we calculated the temperature differences of T2 zone between model1 and model 2 over time. Then we calculated this differences for T3 node too. Finally, we subtracted the temperature differences of T3 zone between two models from T2 as represented in equations 1-3 and Fig. 15.

$$T2(t)_{Model1} - T2(t)_{Model2}, \quad (1)$$

$$T3(t)_{Model1} - T3(t)_{Model2}, \quad (2)$$

$$(T3_{Model1} - T3_{Model2})_t - (T2_{Model1} - T2_{Model2})_t. \quad (3)$$

Figure 15 compared the variations of temperature differences of T2 between model 1 and model 2 with the temperature differences of T3 node between these two models over time. According to the figure it is observed that average temperature of model 1 is greater than model 2.

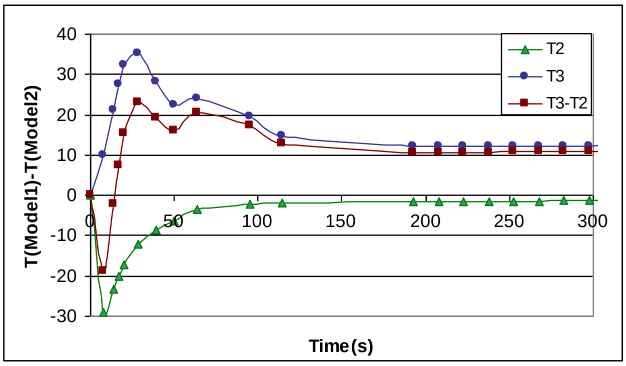

Fig. 15. Time variation of differences of T2 temperature in model 1 and model 2 with the differences of T3.

5. Conclusion

This paper describes the numerical, finite element method, analysis of transient thermal behaviors of multi-layer plate. We analyzed the temperature distribution of cookware which the metal of pan wall is as same as high conductive first layer metal (model 2). Then we compared this model with the model which pan wall is made of low conductive second layer material of plate (model 1). Based on results thermal behavior of plate could be improved by slightly changing in structure. Model 1 provides more uniform temperature distribution on cooking surface than model 2. In addition average temperature on cooking surface of model 1 is higher than model 2 although the temperature of side (wall) of model 1 is lower than model 2. Model1 stores the heat better than model2 too. Consequently model 1 has better performance as cookware which has frying, roasting, etc. application. In this application, cooking surface play key role in cooking and the food do not expose to side of cookware like frying pan, skillet, etc. In the other hand although the temperature degree and uniformity of temperature distribution of model 2 is not as good as model 1 but wide amount of energy can be transferred to food by side (wall) of model 2. Therefore we can use the structure of model 2 to produce such a cookware that is contained water, milk, rice, etc., which is exposed to side of cookware like pot, Dutch oven, saucepan, etc.

Then we insulated the side of model and compared the result with non-insulated model. It is observed that differences between temperature of insulated and non-insulated pan in some minutes during cooling step is up to 20 K.

References

[1] Y. Rhee, W.Y. Han, H.J. Park, S.S. Kim // *Materials Science and Engineering: A* **384** (2004) 70.

[2] J.E. Lee, D.H. Bae, W.S. Chung, K.H. Kim, J.H. Lee, Y.R. Cho // *Journal of Materials Processing Technology* **187-188** (2007) 546.

[3] A. Sarkar, F. Erdogdu, P.R. Singh, In: Proceeding of the Conference of Food Engineering (American Institute of Chemical Engineers, New York, USA, 2001).

[4] Z. Pan, In: Proceeding of the Conference of Food Engineering (American Institute of Chemical Engineers, New York, USA, 2001).

[5] M.R. Sedighi, B. Nilforooshan Dardashti // *International Journal of Mechanical and Aerospace* Engineering **6** (2012) 147.

[6] M. Chu, *Commons Materials of Cookware* (http://www.cookingforengineers.com, Equipment & Gear, 2005).

[7] P. Barham, In: *The Science of Cooking* (New York, USA, Springer-Verlag Berlin Heidelberg, 2001), p. 58.

[8] P. Prip // *US Patent No: US6,644,176 B2, Nov. 2003*.

[9] Tahir Ayata, Abdullah Çavuşogˇlu, Erol Arcaklıogˇlu // *Energy Conversion and Management* **47** (2006) 2361.

[10] B. Nilforooshan Dardashti, M.R. Sedighi // *Applied Mechanics and Materials* **148-149** (2012) 227.

[11] F.P. Incropera, D.P. Dewitt, T.L. Bergman, A.S. Lavine, *Introduction to Heat Transfer* (Wiley & Sons, Inc., New York, 2002).

[12] M.R. Sedighi, B. Nilforooshan Dardashti // *Materials Physics and Mechanics* **14** (2012) 37.