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LAYER NUMBER DEPENDENCE OF TEMPERATURE DISTRIBUTION IN MULTI-METAL COOKWARE

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Abstract. Multi-layer plate improves thermal, chemical and mechanical properties. Multilayered structure which is exposed to non-uniform heater provides uniform temperature distribution on other side. Numerical modeling using the finite element method has been performed to study the dependence of thermal behavior of multi-metal cookware, which is exposed to irregular heating, on number and thicknesses of layers, materials and diameter of plates. We have studied the behavior of the two important parameters in cooking including mean temperature degree and uniformity on cooking surface through variations of geometric and thermal properties. We have applied Cu, Al, SSt, CrNi, and Ti through one to four layers. The results address that bi-layer plate has the better thermal performance than one, three and four layers as cookware function.

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].

There are a few academic papers, used experimental or numerical method to study cookware performance. A computer code, finite difference, has been developed to study a single pan stove [6]. Ashman et al. [7] used an experimental method to study the behavior of efficiency and pollution dissipation from the burning head. Sabilvo et al. [8] used a finite element method to simulate conduction heat transfer through the dish wall. They also studied the effect of conductivity on cooking quality. An analytical model has been used to simulate convection heat transfer from the burning head to the dish by Jugjai and Rungsimuntuchart [9]. They found the high efficiency by using the swirling central flame. Lucky and Hossain [10] conducted an experimental research on Bangladeshi cook stoves. They found that the pan has higher efficiency than pot. Jeddi et al. [11] used finite element method to model heat transfer through burners to pan. Tahir Ayata [12] has used finite element, ANSYS program, to model the temperature distributions in a copper and aluminium layered base of a chromium nickel saucepan. M. Sedighi and B. Nilforooshan [13] studied the dependence of heat transfer on materials.

In the current work, a numerical simulation of the system has been carried out using the finite-element method to study the dependence of heat transfer on the thicknesses, number of layers, materials and geometric properties.

It seems that the thermal analysis of multi-metal cookware with one to four layer and different materials is applied for the first time. The intention of this investigation is to try to bridge the information gap.

2. Materials and methods

Since we want to model irregularly heating, we constrained annular part of the circular surface of bottom side of pan by constant temperature about 773 K. 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. Because of the symmetry, the temperature gradients at the center of plate along the y-axis have zero value. Hence there is no heat flux at the center of plate along the y-axis. The side of pan has convection heat transfer with air at ambient temperature. The thickness of plate is 10 mm. The analysis has been extended for four, three and two layers as well as single layer. In four layers, all layers have same thicknesses as 2.5 mm. In three layers, one layer has 5 mm and the two other have 2.5 mm. The layer thicknesses in two layers are 7.5 and 2 mm.

The ambient temperature and the coefficient of heat transfer have been assumed as 293 K and 17 W/ (m^2 K), respectively. 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/ (m^2.k).

We have applied copper (Cu), aluminum (Al), chromium nickel (CrNi), titanium (Ti) and stainless steel (SSt) in each layer. A loop was defined to change the five materials through four layers. Overall, 625 models were analyzed. The properties of applied metals are according to F.P. Incropera et al. [14].

3. Results

Inthis part, copper, aluminum, chromium nickel, titanium and stainless steel were used in each layer to find the behavior of two parameters of mean temperature (Tmean) and temperature differences (DT=Tmax-Tmin) on cooking surface of plate. The last case that has been studied is plate diameter versus the two parameters.

3.1. Effects of layer numbers and materials on temperature distribution.

A. The mean temperature on cooking surface. Figure 1 illustrates the mean temperature on cooking surface of cookware. The maximum point occurs when all four layers are copper. It means that copper single layer plate provides the highest mean temperature degree. As shown in Fig. 1 the mean temperature on cooking surface increases with using conductive metals. Hence aluminum in compare with titanium, stainless steel and chromium nickel provides higher mean temperature.

Figure 2 illustrates the unsorted mean temperature through different structure and materials. The legends of the figures show the materials of first and second layers. The x-axis is related to the materials of the third and fourth layers.

The plates which their first layers are conductive metals such as copper and aluminum have definitely different behavior through the plates which their first layers are low-conduction metals. Mean temperature on cooking surface of plates which their first layer is from chromium nickel and titanium is as same as stainless steel shown in Fig. 2. The maximum points of curve for stainless steel, chromium nickel and titanium are on 14 point as 737.3 K, 735.7 K and 735.15 K respectively.

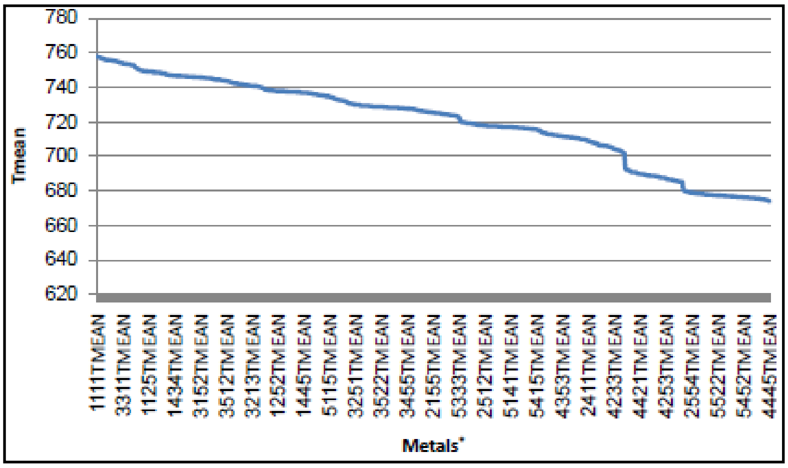

Fig. 1. Mean temperature on cooking surface of multi-metal plates.
*The order of numbers shows the materials of first to forth layer. The numbers show the metals as following: 1=Cu; 2=SSt; 3=Al; 4=CrNi; 5=Ti.

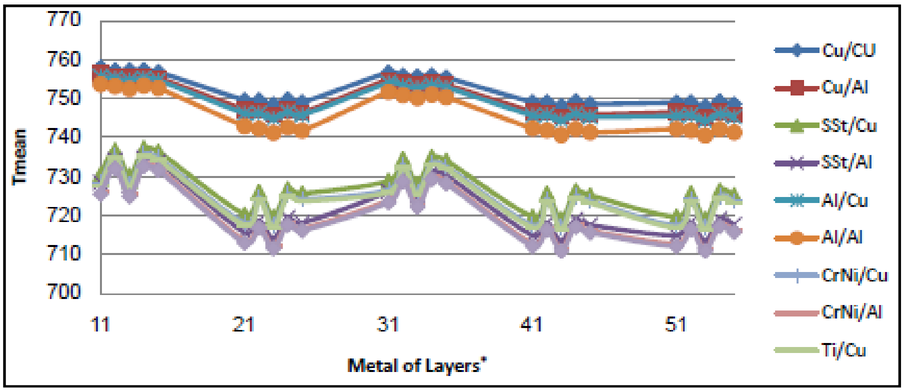

Fig. 2. Unsorted mean temperature on cooking surface of plates versus other applied metals through other three layers.
*The legends of the figures show the materials of first and second layers. The x-axis is related to the materials of the third and fourth layers. The numbers show the metals as following: 1=Cu; 2=SSt; 3=Al; 4=CrNi; 5=Ti.

B. The temperature uniformity on cooking surface. The difference of maximum and minimum temperature on top surface of multi-metal plates is shown in Fig. 3.

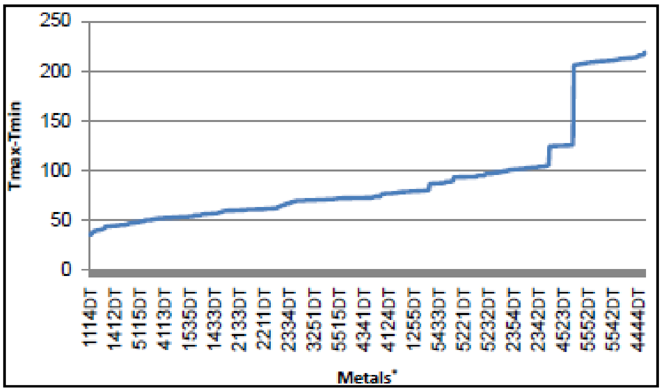

Fig. 3. Temperature differences on cooking surface of multi-metal plates.
*The order of numbers shows the materials of first to forth layer. The numbers show the metals as following: 1=Cu; 2=SSt; 3=Al; 4=CrNi; 5=Ti.

The minimum temperature difference is belonged to Cu/CrNi (1114 or Cu/Cu/Cu/CrNi) as low as 35.2 K. It means that the bi-layer plate including Cu and CrNi layers which their thicknesses are 7.5 mm and 2.5 mm respectievly, provides the most uniform temperature distribution on cooking surface.

Figure 4 illustrates the unsorted temperature differences through different structure and materials. The legends of the figures show the materials of first and second layers. The x-axis is related to the materials of the third and fourth layers. The plates which their first layers are conductive metals such as copper and aluminum have lower temperature differences than the plate which their first layers are low-conduction metals.

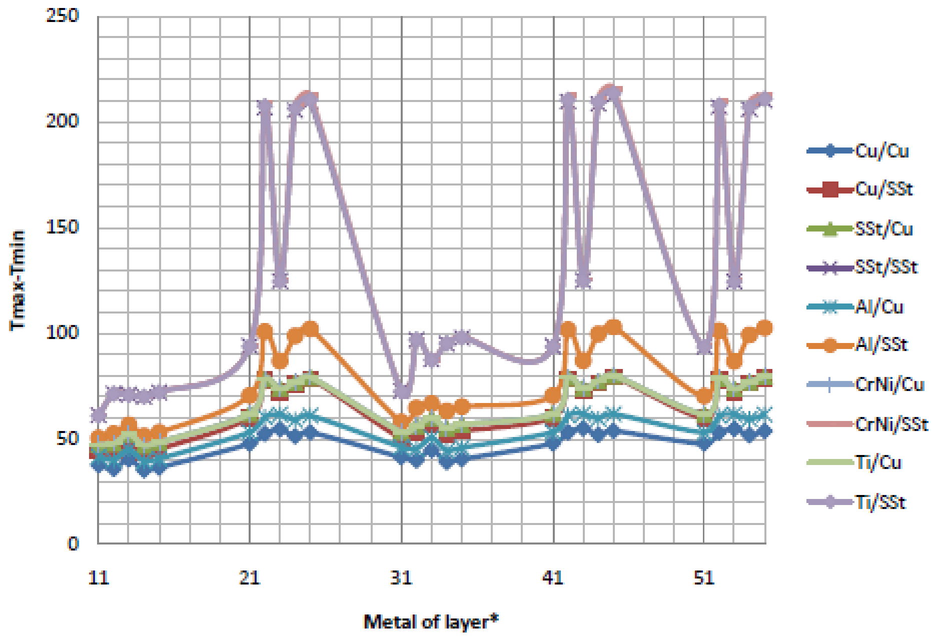

Fig. 4. Difference of maximum and minimum temperature on cooking surface of plates.
*The legends of the figures show the materials of first and second layers. The x-axis is related to the materials of the third and fourth layers. The numbers show the metals as following: 1=Cu; 2=SSt; 3=Al; 4=CrNi; 5=Ti.

3.2. Plate radius. The last case that has been studied is effect of plate diameter on uniformity and mean temperature on cooking surface. The radius of plate takes values ranging from 5.5 to 15 cm by increment of 0.5 cm. As shown in Figs. 5-6, larger radius yields higher temperature differences and lower mean temperature degree on cooking surface of plate.

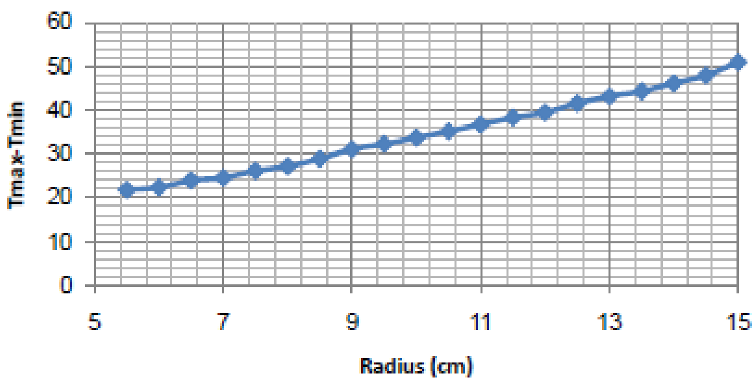

Fig. 5. Differences between maximum and minimum temperature on cooking surface versus radius variations

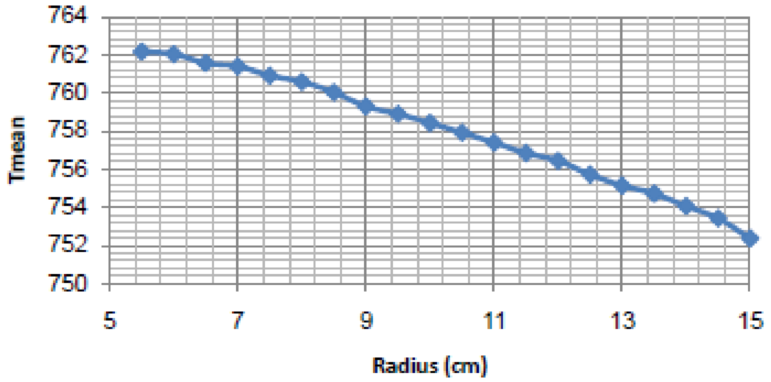

Fig. 6. Mean temperature on cooking surface versus radius variations.

4. Discussion

The study has been extended for copper, aluminum, stainless steel, chromium nickel and titanium in one to four layers. The results show that when the first layer which is exposed to heat source, is conductive metals like copper or aluminum, provide higher mean temperature degree and uniformity on cooking surface. The data of Table 1 has been selected through the 625 models which have higher values than others. According to this table, single layer plate of copper provides highest mean temperature degree on cooking surface. Although the bi-layer plates including Cu/CrNi, Cu/SSt, Cu/Al, Cu/Ti and three layer plates including Cu/Al/Cu, Cu/Al/CrNi and Al/Cu/SSt provide high mean temperature degree too respectively.

Table 1. Mean temperature degree and temperature differences on cooking surface of selected plates.

Metals*	Tmean	DT	Metals*	Tmean	DT
1111	758.0082	37.61687	1331	754.782	45.38596
1114	757.2483	35.19641	3113	754.6477	45.03116
1112	757.2213	35.83858	3115	754.6413	40.63268
1113	757.2164	40.28539	1334	754.0766	43.71586
1115	756.7444	36.40339	1332	753.9688	44.59857
1131	756.6134	41.24785	3131	753.9323	46.10216
1311	756.3964	41.01728	3311	753.6231	45.91908
1134	755.8908	39.04713	1333	753.5736	49.68836
1132	755.8272	39.80419	1335	753.499	45.14755
1314	755.7871	38.72077	3134	753.4489	44.37377
1312	755.7236	39.46157	3132	753.329	45.26532
1133	755.6343	44.66116	3314	753.2758	44.05708
3111	755.586	41.69657	3312	753.1544	44.93259
1313	755.4528	44.31465	1214	749.0477	45.14755
1135	755.3544	40.3582	1414	748.596	45.26532
1315	755.252	40.01501	1514	748.4439	45.38596
3114	755.1855	38.72077	1211	746.5662	45.91908
3112	755.1099	40.08198	1411	745.8267	46.10216

*The order of numbers shows the materials of first to forth layer. The numbers show the metals as following: 1=Cu; 2=SSt; 3=Al; 4=CrNi; 5=Ti.

How much the temperature differences (DT) be lower, the uniformity will be higher. Based on Table 1, Cu/CrNi bi-layer plate provides the most uniformity on cooking surface. After it, Cu/SSt, Cu/Ti, Cu single layer plate and four-layer plate of Cu/Al/Cu/SSt have high uniformity respectively.

Table 2 demonstrates the normalized data of Table 1 to find the plate which provides the highest Tmean and lowest DT.

Table 2. Normalized mean temperature degree and temperature differences of Table 1.

Metals	A*	B**	A*B	Metals	A*	B**	A*B
1114	1	0.990987	0.990987	1313	0.950352	0.969689	0.921545
1112	0.996503	0.990667	0.987203	1334	0.953612	0.953365	0.90914
1111	0.986821	1	0.986821	3113	0.94645	0.96014	0.908725
1115	0.993428	0.98501	0.978536	1331	0.944518	0.961733	0.908374
1113	0.972291	0.990608	0.963159	1332	0.948806	0.952086	0.903345
1314	0.98081	0.973654	0.95497	3134	0.95003	0.945921	0.898653
1134	0.979033	0.974884	0.954444	3314	0.951754	0.943867	0.898329
1131	0.96705	0.983456	0.951051	1335	0.945816	0.946514	0.895229
1312	0.976776	0.972901	0.950307	3131	0.940619	0.951654	0.895144
1311	0.968306	0.980881	0.949793	3132	0.945175	0.944498	0.892716
1132	0.974911	0.974131	0.94969	3311	0.941616	0.947986	0.892639
3114	0.98081	0.966518	0.947971	3312	0.946987	0.942427	0.892466
1315	0.973763	0.967308	0.941928	1333	0.921092	0.947399	0.872641
1135	0.971894	0.968522	0.941301	1214	0.945816	0.893716	0.845291
3112	0.973398	0.965621	0.939934	1414	0.945175	0.888357	0.839653
3111	0.964607	0.971269	0.936893	1514	0.944518	0.886553	0.837366
3115	0.9704	0.960064	0.931646	1211	0.941616	0.864281	0.81382
1133	0.948465	0.971842	0.921758	1411	0.940619	0.85551	0.804708

*Normalized mean temperature; **normalized temperature differences.

According to Table 2, bi-layer cookware of Cu/CrNi has the best performance versus two parameters of mean temperature and uniformity. After it, Cu/SSt, Cu/Ti, Cu single layer plate, Cu/Ti, Cu/Al and four-layer plate of Cu/Al/Cu/SSt have suitable behavior with respect to the two parameters as cookware respectively. These results are match with research results of Tahir Ayata et al. [15]. They have applied numerical modeling of different alloys of aluminum and copper layered base of a CrNi saucepan. They found that the Copper has better performance than aluminum as bottom layer.

5. Conclusions

In this article, the thermal behaviours of multi-metal plates, heating non-uniformly, were numerically investigated, at steady state-conditions. The analysis has been extended through number of layers, thicknesses of layers, materials and radius of plates. We have applied Cu, Al, SSt, CrNi, and Ti through one to four layers for finding two parameters of mean temperature degree and uniformity on cooking surface of plates. In this part 625 models were analyzed.

Results clearly showed that, when the first layer which is exposed to heater is conductive metals like copper or aluminum, provide higher mean temperature degree and uniformity on cooking surface. Through 625 models and one to four layers, we found that bi-layer plates of Cu/CrNi and Cu/SSt have the better performance than others as cookware function. The effects of plate radius variations on the two parameters were determined. Increasing plate diameter yields lower mean temperature degree and uniformity.

We hope that the results obtained from this study will be useful in the design of efficient cookware.

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: *Conference of food engineering* (American Institute of Chemical Engineers, New York, USA, 2001).

[4] Z. Pan, In: *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] S Kohli, J. Stubington, H.S. Mukunda // *International Journal of Heat Mass Transfer* **36** (1993) 4049.

[7] P.J. Ashman, R. Junus, J.F. Stubington, G.D. Sergeant // *Combustion Science and Technology* **103** (1994) 283.

[8] C.M. Sabilov, B.E. Farkas, K.M. Keener, In: *IFT Conference* (2001).

[9] S. Jugjai, N. Rungsimuntuchart // *Experimental Thermal and Fluid Science* **26** (2002) 581.

[10] R.A. Lucky, I. Hossain // *Energy* **26** (2001) 221.

[11] M.K. Jeddi, S.K. Hannani, B. Farhanieh // *Numerical Heat Transfer, Part B: Fundamentals: An International Journal of Computation and Methodology* **46** (2004) 387.

[12] T. Ayata // *Applied Energy* **80** (2005) 341.

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

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

[15] T. Ayata, A. Çavuşogˇlu, E. Arcaklıogˇlu // *Energy Conversion and Management* **47** (2006) 2361.