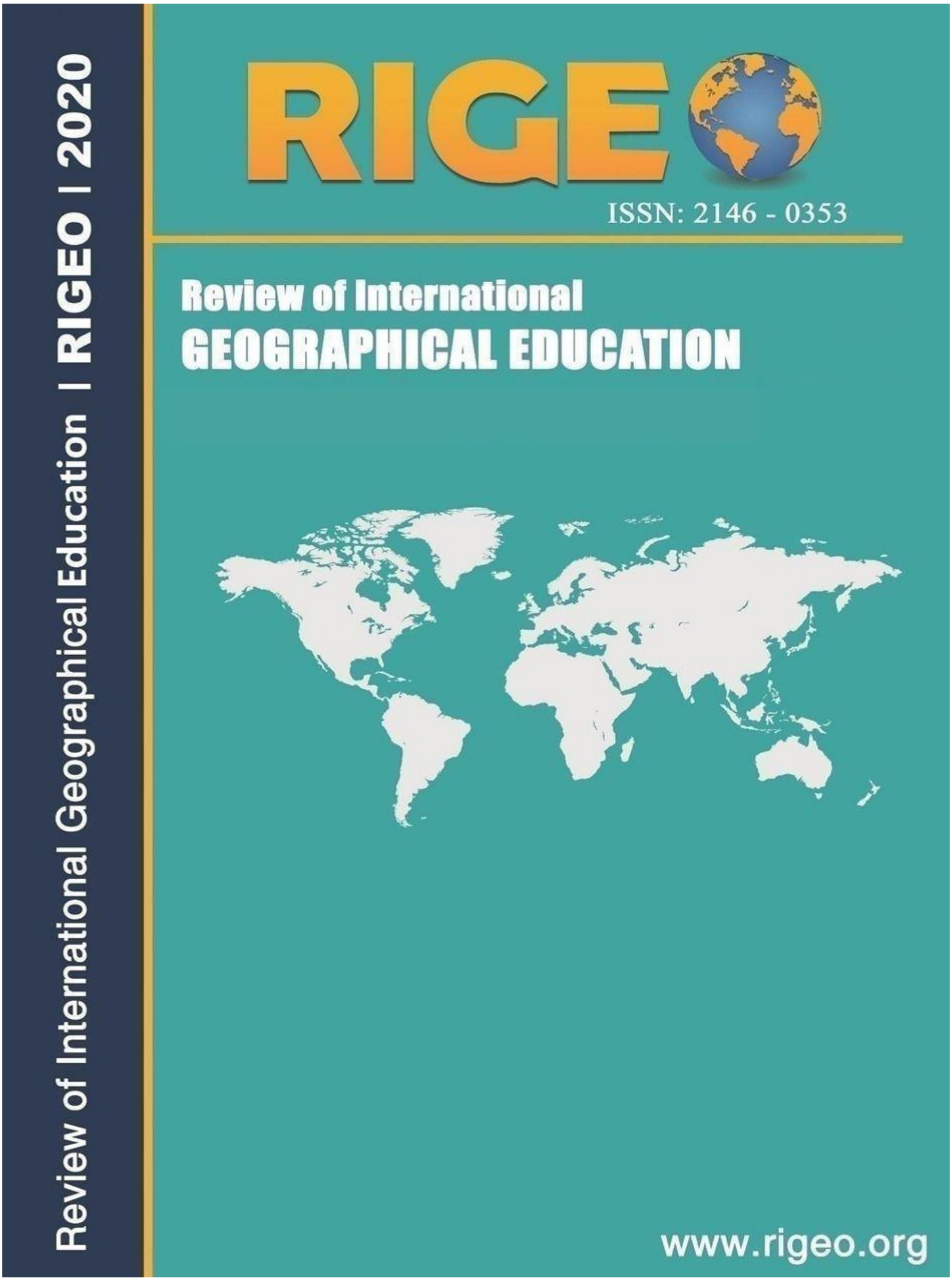
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"A Comprehensive Review of Thermal and Mechanical Behavior in Single and Bi-Layer Plates"

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Abstract.

Cookware appliance thermal and mechanical characteristics are reviewed in this research. Data on thermal stress, body deformation, heat retention, and temperature distribution (TD) are compiled numerically. We use the Finite Element Method in the ANSYS software. We detailed various mechanical and thermal outcomes for Al/Cr-Ni, Al/SSt, Al/Ti, Cu/Cr-Ni, Cu/SSt, Cu/Ti, GCI, CSt, and iron. The chemical and thermal characteristics of the laminated plate are better than those of the single-layer counterpart. This study's findings point to the Cu/SSt bi-metal structure as the superior choice for cookware.

1. Introduction

To improve the performance of cookware, it is vital to measure temperature and its distribution (TD) on the surface that comes into contact with food. For optimal performance, cookware should have a non-reactive, sturdy, corrosion-resistant surface and thermal conductivity to distribute and retain heat. Lamination, or bonding, of metals with different properties is what makes it possible [1]. Cookware made of bonded metal composites has a lower coefficient of thermal conductivity than conventional cookware, allowing heat to first saturate one layer before transferring it to the next. This improves the appliance's performance by removing hot spots from the cooking surface [2]. Additionally, we must ensure that the materials used in our cookware do not react with food in a way that alters its flavor [3]. The most effective combination was formed by mixing metals with different levels of heat conductivity and inertness, such as different alloys of stainless steel (SSt) or titanium (Ti), with metals with lower thermal conductivity, such copper (Cu) or aluminum (Al) [1]. Cookware made of Al and Cu improves thermal performance, allowing food to be heated more quickly and uniformly, while SSt and Ti provide superior chemical and corrosion resistance [4].

Cast iron, in contrast, outperforms most metals when it comes to heat capacity. The cast-iron pan's hefty metal structure ensures that food remains heated even after you take it off the burner. In addition For a variety of dishes, it's simple to use and maintain. Its superior cooking performance is due to these features [5]. Researchers Rena L. Hecht et al. (1996) and W. L. Guesser et al. (2005) examined the thermal characteristics of gray iron and GCI experimentally.

While laminated plates do enhance the utensil's application quality, they do come with some drawbacks, such body deformation. The formation of the laminated plate is due to the bonding of materials with varying coefficients of thermal expansion and stiffness [8]. In a bi-metallic system, interfacial tension exists. Helpful information about

Several papers, notably [9, 10], have extensively discussed thermally-induced stresses in heterogeneous materials, which may include interfacial stress.

Observes that several researchers have used numerical approaches, particularly finite element methods, to study bimetal structures that have been thermally loaded since the mid-1960s [9]. The thermal buckling of laminated plates exposed to uniform or non-uniform temperatures has been calculated in several articles using finite element methods [11–15].

Research on bi-layer cookware using various metals has been conducted in reference [16]. The results showed that compared to other applicable metals like Al/SSt, etc., a bi-layer consisting of copper and stainless steel had greater heat retention ability, a more uniform temperature distribution, and a higher maximum temperature degree. It used the GCI as a starting point for evaluating the heat storing capabilities of various metals. When it comes to the surface area of a pan that comes into contact with food, stainless steel and titanium both provide about equal TD [17].

Reference [19] used ANNs to foretell the TD on metal plate stacks. The bottom layer, which may be made of various aluminum or copper alloys, has an optimal thickness and material. Copper has an ideal thickness of 8 mm and aluminum of 6-7 mm, according to the results. In [18], the authors suggest using a numerical model to examine the thermal stress of multi-layered cookware subjected to isothermal loading.

Several facets of cookware have been examined in this work, with an emphasis on previous studies. Summarized below are numerical findings from TD, heat retention, thermal stress, and body deformation.

Table 1. Symbols and thicknesses of metals

Metals	Symbols	Thicknesses
bi-layer		
Copper	Cu	8 mm
Aluminium	Al	6.5 mm
Titanium	Ti	2 mm
Chromium- nickel	Cr-Ni	2 mm
Stainless steel	SSt	2 mm
single layer		
Grey cast iron	GCI	10 mm
Carbon steel	CSt	10 mm
Iron	-	10 mm

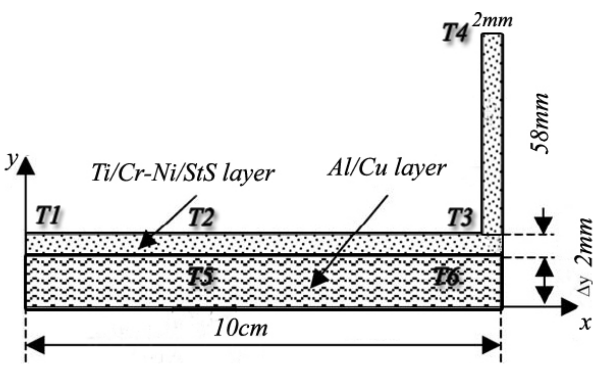

Fig. 1. 2D bi-layer model in numerical analysis and positions of different selected nodes, named T1-T6.

2. Boundary and geometry conditions

Annular part of the circular surface of bottom side pan, which illustrated in Fig. 1 as Δr is constrained, 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 centre of plate along the y-axis have zero value. Hence there is no heat flux at the centre of plate along the y-axis. Side of pan has convection heat transfer with air in ambient temperature. Thickness of layers have been taken according to Table I Δr is 2 cm. 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 with boiling temperature, and the coefficient of heat transfer between the pan and the water is 50 W/ (m^2 K).

In another part is modelled 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, 600 K. 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, 8 mm and 2 mm respectively for all metals. All materials properties are shown in Table 2.

Table 2. Mechanical and thermal Properties of metals [6, 20, 21].

Symbol	Density, kg/m^3	Conductivity, W/m K Specific heat, J/ kg K	Conductivity, W/m K Specific heat, J/ kg K	Poisson's ratio	Elasticity, GPa	Thermal expansion, 10^{-6}/ °C,
		T = 400 K	T = 600 K			
Cu	8933	393 397	379 417	0.355	1.17	16.92
Al	2700	240 949	231 1033	0.334	6.96	23.58
SSt	8055	17.3 512	20 559	0.305	1.93	17.28
Cr-Ni	8400	14 480	16 525	0.29	1.86	13.4
Ti	4500	20.4 551	19.4 591	0.32	1.13	9.54
CSt	7854	56.7 487	48 559	0.295	1.9	10.8
Iron	7870	69.5 490	54.7 574	0.29	2.11	11.8
		T = 293 K	T = 773 K			
GCI	7340	55 490	31 675	0.21	0.69	12.1

3. Results

A. TD of single layer in comparison with bi-layer structure. In this part the TD of Cu is compared with Cu/SSt. These used results are published in [16]. It's obviously when the model reached to steady state, the maximum temperature on upside surface of Cu pan is higher than Cu/SSt, its 771.618 K and 769.66 K respectively. But the difference between maximum and minimum temperature on food preparation surface of Cu and Cu/SSt pan in steady state is 32 and 25 degrees respectively. It showed that TD in Cu/SSt multi-layer pan is more uniform than Cu single layer pan. In Fig. 2 the differences between maximum and minimum temperature during analysis time are illustrated. It is observed that this difference for Cu in beginning of analysis is about 80 degrees greater than Cu/SSt and it is decreased to 7 degrees in steady state. Figure 2 represents that MLP provides more uniform TD upside surface of multi-layer pan than single layer.

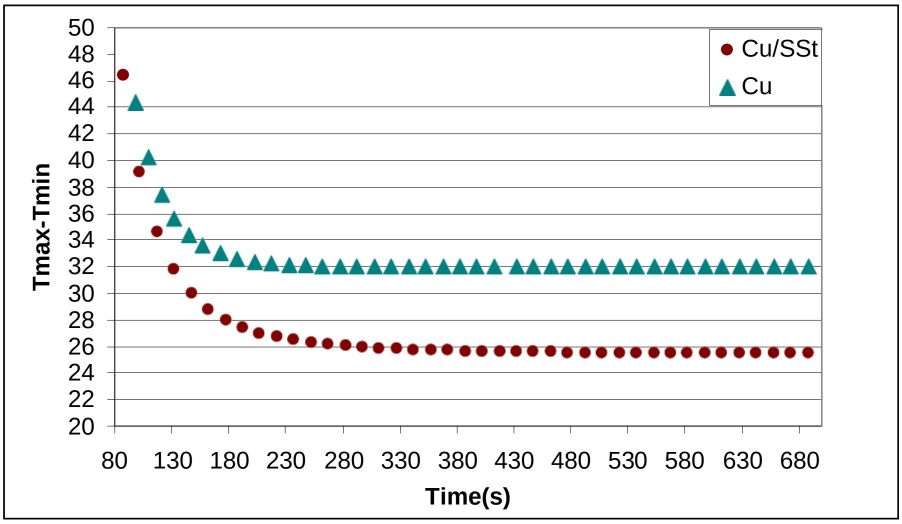

Fig. 2. Time variation of differences between maximum and minimum temperature on food preparation surface of Cu and Cu/SSt pan.

B. TD in different materials. Reference [16] has analysed the TD of combinations of metals in bi-layer structure consist of Cu/SSt, Cu/Cr-Ni, Al/SSt and Al/Cr-Ni. In addition it analysed GCI in single layer structure as compared with bi-layer. It is predictable that minimum temperature observed at edge of wall. There is highly temperature gradient so it represented high convection heat transfer side of pan. We have the regular and uniform TD in all MLP as compared with single layer and between these MLP, Cu/SSt combination has maximum temperature profile. The minimum temperature in Cu/SSt is greater than minimum temperature of other combinations and it’s about 451.1 K illustrated in Fig. 3.

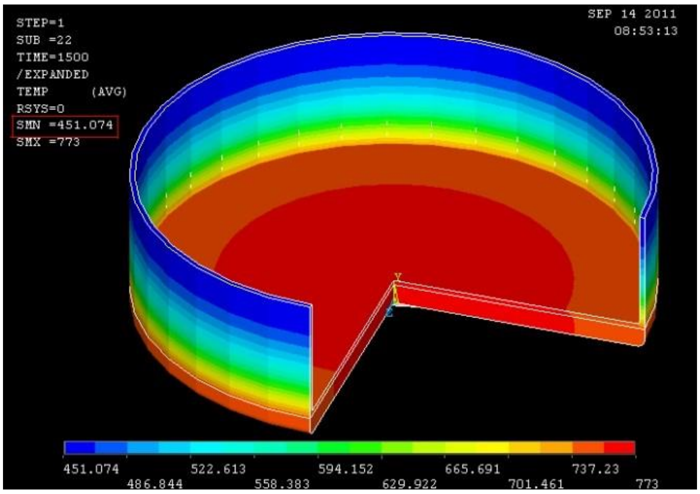

Fig. 3. 3D TD of Cu/SSt bi-metal pan at steady state.

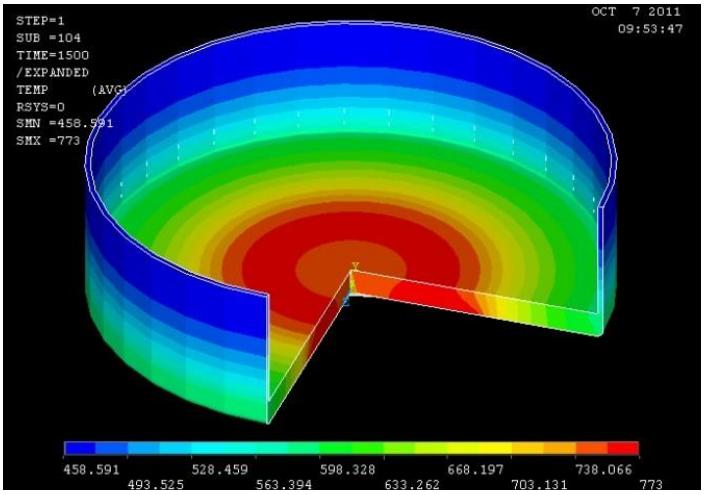

Fig. 4. 3D TD of single layer GCI pan at steady state.

Transient response of T4 node with all combinations is compared. Temperature variations of T4 node in all combinations during first 100 seconds are the same approximately. After this time we observed some differences between bi-layer pan containing SSt and bi-layer pan including Cr-Ni layer obviously. Insofar as after 500 seconds it is apparent about 17 degree differences between them as shown in Fig. 5 [16].

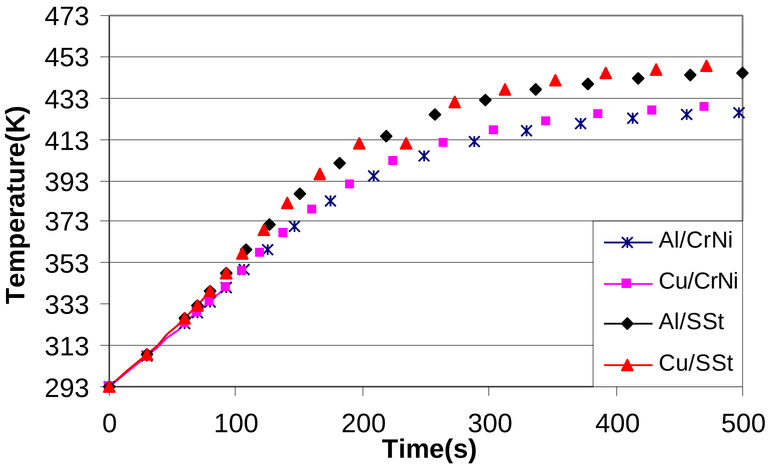

Fig. 5. Temperature variation comparison of T4 node for all combination of bi-layer pans.

C. TD comparison of different metals on food preparation surface of pan. Numerical solution by [17] show that the maximum temperature and most uniform TD occurred in Cu/Ti and Cu/SSt bi-layer structure whereas GCI provides irregular TD as shown in Fig. 6. Figure 6 shows the steady state results of TD on food preparation surface of pan for all metals. It is clearly illustrated that TD in single layer such as GCI is not regular and uniform so it's derived that single layer cases are not suitable for pan.

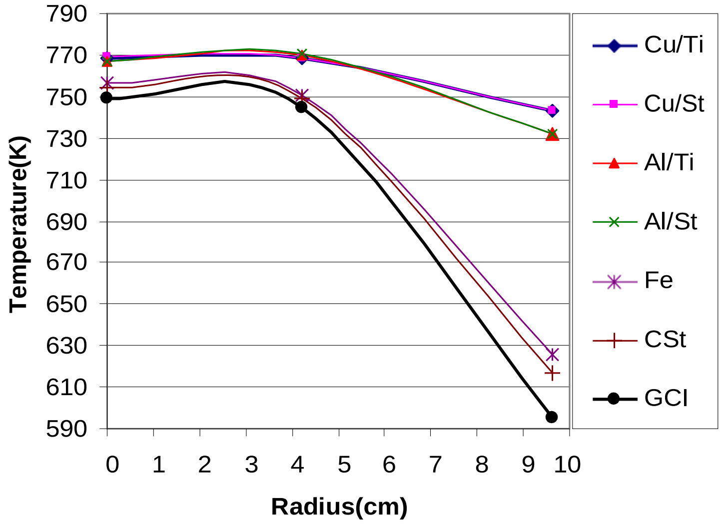

Fig. 6. TD on food preparation surface of pan for all metals in steady state.

D. Heat retaining.

After the model reached to steady state, the boundary conditions of pan are changed to analysing the heat retaining of the model. Hence the heated pan ismodeled to transfer the heat just with air at ambient temperature for cooling [16].

The T5 node of model with all applied metals is compared as shown in Figs. 7, 8. These results are published by [16]. It represents the heat storing differences of studied cases clearly. It shows that the pans consist of Cu can store the heat better than others even GCI. But the cookware containing Al cannot retain the heat well in compare with Cu and GCI. In the other hand SSt has better heat retaining characteristics than Ti in second layer and almost is same with Cr-Ni. Consequently bi-metal structures containing Cu/SSt and Cu/Cr-Ni have the best heat storage ability among others. The GCI has the almost equivalently behavior compared to other single layer such as Iron and CSt. You see that temperature of T4 node first increase and then it decrease because T4 node has minimum temperature in compared with all over the pan so there is a heat flux from high to low temperature degree. In the other hand conduction coefficient of metals is very greater than convection coefficient of air.

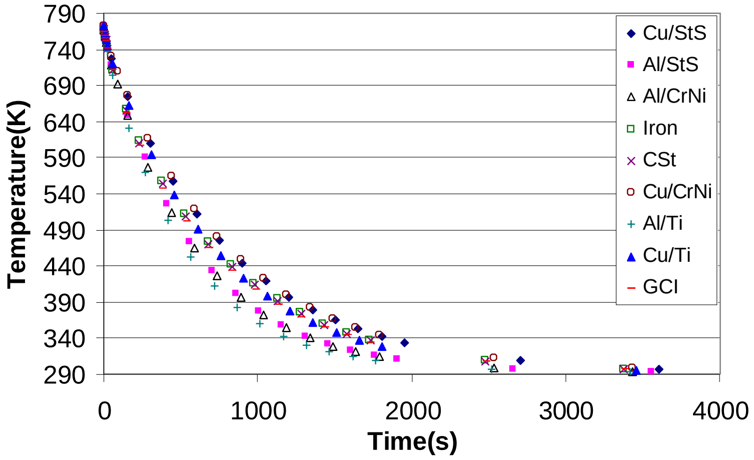

Fig. 7. Temperature variation comparison of T5 node for all metals in cooling step.

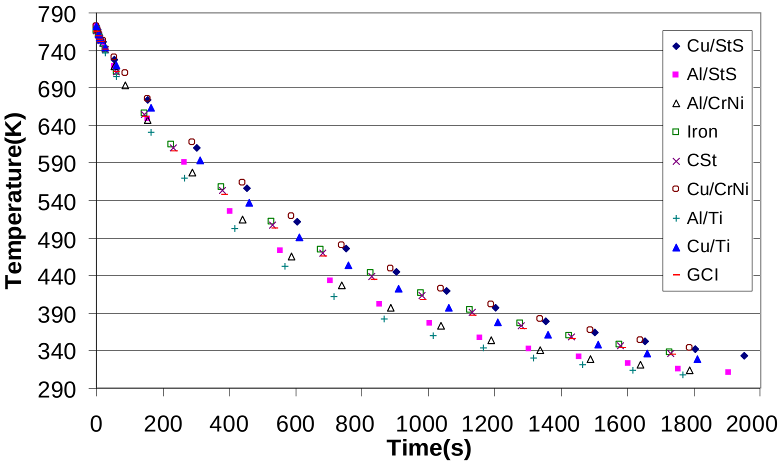

Fig. 8. Temperature variation comparison of T5 node for all metals in cooling step.

E. Thermal stress and body deformation.

The numerical solution of thermal stress is carried out for Cu/Ti, Cu/SSt, Al/Ti, Al/SSt, Cu/CrNi, Al/CrNi, CSt, GCI and iron illustrated in Figs. 9-14. In this part we used some results of [18].

Al/CrNi has the maximum deformation due to maximum thermal stress. It is 2.9 mm. The results are shown in Table 3. It is demonstrated that the Al has the maximum deformation in bottom layer and CrNi accompanied by Al causes greater deformation in top layer between Ti and SSt. In the other hand Ti in combination by Cu has higher body deformation in top layer between CrNi and SSt. The reason is that Cu/Ti has greater stress than Cu/CrNi. In addition SSt has the minimum deformation among applied metals in second layer in combination by both Al and Cu. Cu causes minimum deformation compared with Al. It is clear because the thermal expansion of Al is greater than Cu. Consequently Cu/SSt has minimum body deformation. Base on Table 3 deformation in Cu/SSt pan is almost close to single layer. Figures 9-14 show deformed shape with undeformed model of pan. 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.

Table 3. The calculated deformation of all metals.

Metals	Von Mises stress, MPa	Deformation, mm
Al/CrNi	704	2.9
Al/Ti	569	2.07
Cu/Ti	294	0.961
Al/SSt	461	0.859
Cu/CrNi	227	0.706
Cu/SSt	24.4	0.609
Iron		0.5
GCI		0.424
CSt		0.387

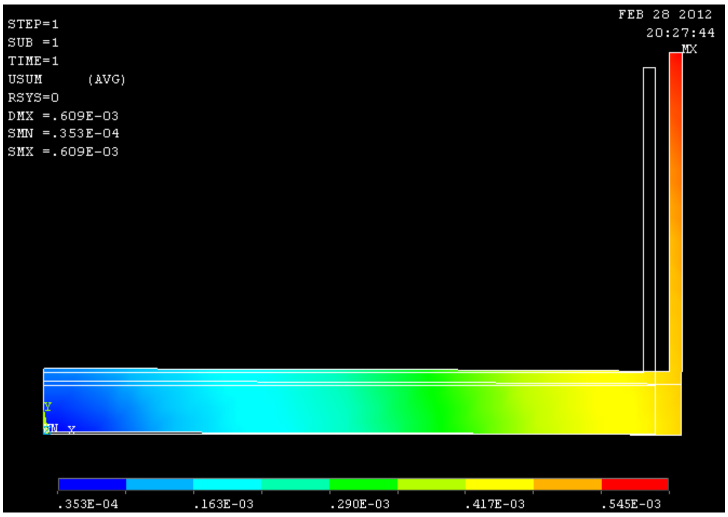

Fig. 9. Deformed shape with undeformed model of Cu/SSt pan.

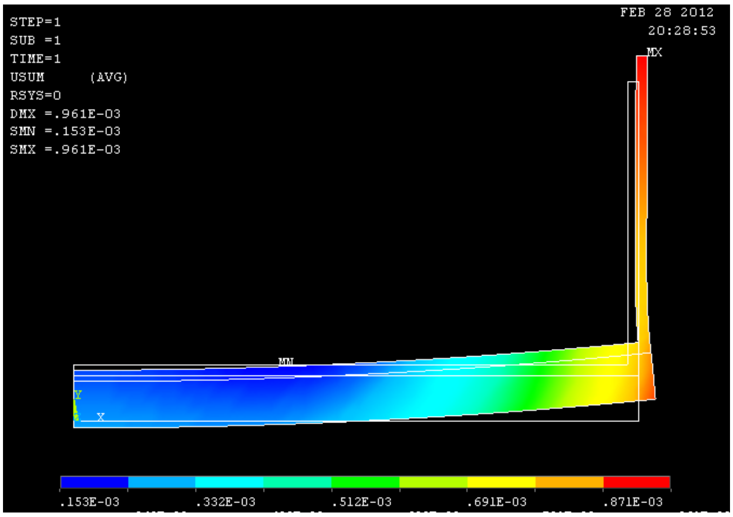

Fig. 10. Deformed shape with undeformed model of Cu/Ti pan.

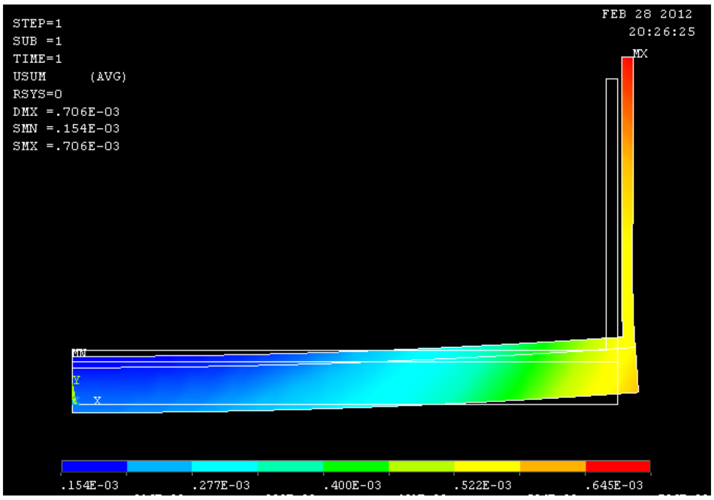

Fig. 11. Deformed shape with undeformed model of Cu/CrNi.

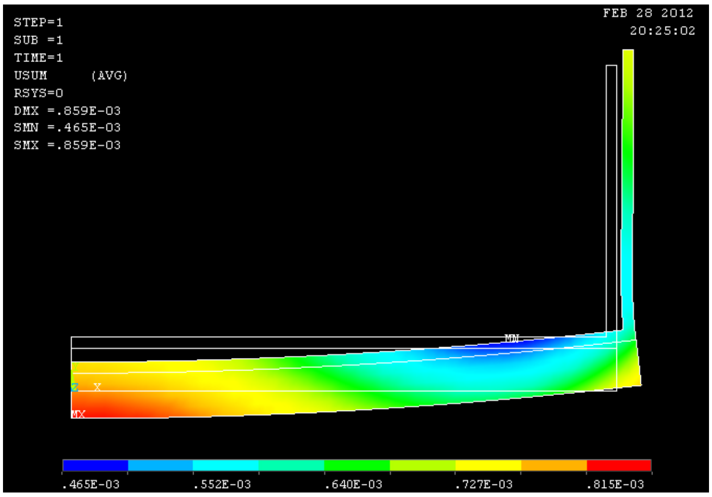

Fig. 12. Deformed shape with undeformed model of Al/SSt pan.

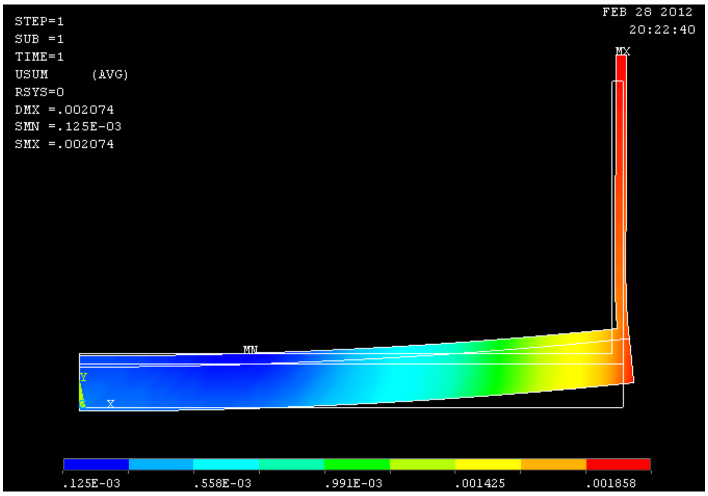

Fig. 13. Deformed shape with undeformed model of Al/Ti pan.

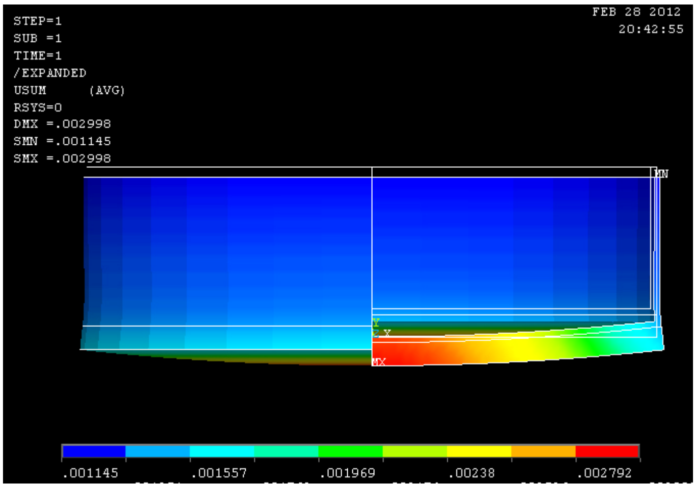

Fig. 14. Deformed shape with undeformed model of Al/CrNi pan.

4. Conclusions

In cases when there both academic and practical interest, the laminated plate is still useful. This study provided a synopsis of the mechanical and thermal evaluations of bi-metal cookware. The temperature is measured on the underside of the pan using the TD method. The most consistent TD food preparation surface and greatest temperature degree are both provided by Cu/SSt MLP. Also covered in the other sections are topics like heat retention and bodily distortion. The heat storage of Cu/SSt and Cu/CrNi is much higher than that of Cu/Ti and Al/SSt, among others.Furthermore, we examined the heat forces that cause the pan's body to distort. The bi-metal structure Al/CrNi exhibits the highest degree of distortion, whereas Cu/SSt satisfies the lowest degree of deformation. The findings showed that using laminated plates to make the pan was beneficial. The Cu/SSt MLP structure is ideal for making cookware because of its mechanical, chemical, and thermal properties.

References

[1] First published as US Patent No. US2010/0108690A1 by William A. Groll. William A. Groll // United States Patent, Publication No. 2004/0058188A1. (Springer-Verlag, Berlin-Heidelberg-New York, 2001) by Peter Barham, The Science of Cooking.

U.S. Patent No. 2006/0283844A1, authored by Stanley Kin Sui Cheng.

cast-iron cooking for dummies by Tracy Barr (Indiana, 2011: John Wiley & Sons).

This is referenced in the following work: [6] Hsin Wang, Ralph B. Dinwiddie, Wallace D. Porter, and Rena L. Hecht // SAE Technical Paper 962126 (1996) in the cited work.

In their 2005 article "Revista Matéria 10 (2) 265", W.L. Guesser, I. Masiero, E. Melleras, and C.S. Cabezas discuss this topic.

In Mechanics of Materials 36 (2004) 369, Yujun Wen and Cemal Basaran (#8) authored the paper. Reference: [9] E. Suhir // J. Appl. Mech. 56 (1989) 595.

This is reference number ten from the Journal of Electronic Packaging, written by J.W. Eischen and J.S. Everett in 1989.

[11] In Computers & Structures, L. Lien-Wen and L. Lei-Yi (eds.), 34(1) (1990), 71.

The article "Finite Element Analysis and Design 15(4) (1994) 343" was written by Ahmed K. Noor and Jeanne M. Peters.

K. Chandrashekhara's article from 1992 in Finite Element Analysis and Design, volume 12, issue 1, page 51.

"Computers & Structure 53 (1994) 1193" [14] M.R. Prabhu, R. Dhanaraj.

Article cited as "Composite Structure 54" by Maloy K. Singha, L.S. Ramachandra, and J.N. Bandyopadhyay

453, 2001.

In the International Journal of Science and Engineering Investigations, volume 1, issue 1, pages 97–98, in 2012, Mohammedreza Sedighi and Behnam Nilforooshan Dardashti published an article.

In their 2012 article "Applied Mechanics and Materials" (pp. 148–149), Behnam Nilforooshan Dardashti and Mohammad Reza Sedighi discuss this topic.

In their article "Advances in Natural and Applied Sciences," M.R. Sedighi and B. Nilforooshan Dardashti [18] discuss

2012, paper presented.

[19] In Energy Conversion and Management 47 (2006) 2361, Tahir Ayata, Abdullah Çavuşogˇlu, and Erol Arcaklıogˇlu wrote the article.

[20] "Fundamentals of Heat and Mass Transfer" (Frank P. Incropera, David P. DeWitt, Theodore L. Bergman, Adrienne S. Lavine, 2006, Hoboken, New Jersey: John Wiley & Sons).

Mechanics of Materials, edited by Ferdinand P. Beer, E. Russell Johnston, John T. Dewolf, and David F. Mazurek, was published in 2008 by McGraw-Hill in New York.