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TRANSIENT THERMAL BEHAVIOR OF IMPERFECT CONTACT TWO THIN WALLS

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ABSTRACT

The transient thermal behavior of conjugated imperfect contact under the effect of the dual-phase-lag heat conduction model is investigated analytically using Laplace transformation technique. The heat transfer mechanisms during rapid heating of two-layer composite slabs from a macroscopic point of view using the dual-phase-lag heat conduction model is studied. The composite slabs consist of two thin layers which may be in imperfect thermal contact. The effects of different parameters, such as thermal relaxation time, and interfacial heat transfer coefficient on the thermal behaviour of the composite slabs are investigated.

Key words: Conjugated, Conduction, Thermal Behavior.

INTRODUCTION

In a building skin heat arise through three techniques viz. internal heat, external heat and ventilation. Solar radiation strikes the on building envelope and generates external heat gains. This heat input does arise through opaque and transparent materials such as windows and openings. Internal heat generation produced inside the building refer to heat input from human body, electrical appliances and artificial lighting (Zain-Ahmed, 2002). The human body has ability to measure the thermal comfort by making judgments about a space is too warm, too cool or thermally comfortable. Human thermal comfort is effected by many reasons such as types of clothing worn, metabolic rate, energy radiation and heat loss from the physical surface such as walls and ceiling. There are four classical thermal environmental parameters to portend human thermal sensation (Fanger and Toftum 2002); air temperature, humidity, mean radiant temperature and air velocity. In the literature, there are basically four techniques that describe the mechanism of energy transport in very thin films or during short-pulse laser heating. The first technique is the parabolic one-step model, which is based on the classical Fourier law. This model assumes that the solid lattice and electron gas is in local thermal equilibrium and the heat flux merges instantaneously when the temperature gradient exists. The second technique used is the hyperbolic model (Kim *et al*., 1990 and Chen *et al*., 1994), which was first postulated by Maxwall (1967). In this technique, it is assumed that both solid lattice and electron gas are in local thermal equilibrium but the heat flux and the temperature gradient are non-local in time. This implies that the temperature gradient proceeds the heat flux by the relaxation time.

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The third and the fourth techniques are the parabolic and the hyperbolic models (Qui and Tien, 1992, Tzuo, *et al*., 1994). In these models it is assumed that solid lattice has different temperature than electron gas and the difference between these two temperatures depends on the coupling factor between both domains. Most previous investigations of conjugate heat transfer problems considered the one- dimension heat diffusion equation (i.e. the parabolic model). Early attempts (Siegel, 1959; Pellmutter and Siegel, 1961) to solve transient conjugate heat transfer problems neglect the heat conduction in the solid wall and its heat capacity. The results of such analysis are valid for flows in the thin-walled ducts, but not for thick walled conditions. Khadrawi, *et al*. (2002), investigated the thermal behavior of perfect and imperfect contact composite slab under the effect of the hyperbolic heat conduction model. Khadrawi *et al*. (2004) also investigated the Dual-phase-lag heat conduction model in thin slab under the effect of a moving heating source. Thermal behavior of a stagnant gas confined in a horizontal microchannel as described by the dual-phase-lag heat conduction model is investigated by Al-Nimr and Khadrawi (2004). The present work will be concerned in conjugated (composite thin walls) imperfect contact heat transfer problem under the effect of Dual-Phase Lag heat conduction model. Effect of different parameters, such as film thickness ratio, thermal relaxation time and interfacial heat transfer coefficient on the thermal behaviour of the composite walls are investigated.

CASE STUDY

Consider a composite slab (two layers) that consists of the first layer for $0 \le x \le m$ and the second layer for $a \le x \le n$, which are in imperfect thermal contact as shown in Fig. 1. Let k_1 and k_2 be the thermal conductivities, and α_1 and α_2 the thermal diffusivities for the first and second layers, respectively. Knowledge of the transient heat conduction in a tow-layer composite thin slab is of importance in a number of different applications such as coating, cladding, foils forming, semi-conductores and electric chips. Initially, the first and second walls are at temperature T_i. For *t > 0* the boundary surface at *x = 0* is kept at T_w and the boundary surface at *x = n* is kept insolated. The thickness of the two layers is assumed to be very small relative to the height of the slab, so it is reasonable to assume that the conducted heat is transferred in the x-direction only. In this case, the energy equations coupled at the interface have to be solved. These equations in the dimensionless form are written as:

$$\frac{\partial \theta_1}{\partial \eta} = -\frac{\partial Q_1}{\partial \xi} + G_1 \qquad \text{.................. (1)}$$

$$\frac{\partial \theta_2}{\partial \eta} = -\frac{1}{C_R}\frac{\partial Q_2}{\partial \xi} + G_2 \qquad \text{.................. (2)}$$

$$Q_1 + \tau_{q,1}\frac{\partial Q_1}{\partial \eta} = -\frac{\partial \theta_1}{\partial \xi} - \tau_{T,1}\frac{\partial \theta_1}{\partial \eta \partial \xi^2} \qquad \text{........................ (3)}$$

$$Q_2 + \tau_{q,2}\frac{\partial Q_2}{\partial \eta} = K_r\left[-\frac{\partial \theta_2}{\partial \xi} - \tau_{T,2}\frac{\partial \theta_2}{\partial \eta \partial \xi^2}\right] \qquad \text{............ (4)}$$

Combine Eqs. (1) and (3), (2) and (4), yields:

$$\frac{\partial^2 \theta_1}{\partial \xi^2} + \tau_{T,1}\frac{\partial^3 \theta_1}{\partial \eta \partial \xi^2} + \left[G_1 + \tau_{q,1}\frac{\partial G_1}{\partial \eta}\right] = \frac{\partial \theta_1}{\partial \eta} + \tau_{q,1}\frac{\partial^2 \theta_1}{\partial \eta^2} \qquad \text{.............................. (5)}$$

$$\frac{\partial^2 \theta_2}{\partial \xi^2} + \tau_{T,2}\frac{\partial^3 \theta}{\partial \eta \partial \xi^2} + \frac{C_R}{K_r}\left[G_2 + \tau_{q,2}\frac{\partial G_2}{\partial \eta}\right] = \frac{C_R}{K_r}\left[\frac{\partial \theta_2}{\partial \eta} + \tau_{q,2}\frac{\partial^2 \theta_2}{\partial \eta^2}\right] \qquad \text{.......................... (6)}$$

Where $\frac{C_R}{K_r} = \frac{\alpha_1}{\alpha_2} = \frac{1}{\alpha_r}$

Subject to the following initial and boundary conditions

$$\theta_1(\xi,0) = \theta_2(\xi,0) = 1.0,\ \frac{\partial \theta_1}{\partial \eta}(\xi,0) = \frac{\partial \theta_2}{\partial \eta}(\xi,0) = 0.0 \qquad \text{............ (7)}$$

$$\theta_1(0,\eta) = 0.0,\ Q_1(1,\eta) = Q_2(1,\eta),\ \ Q_1(1,\eta) = Bi\left[\theta_1(1,\eta) - \theta_2(1,\eta)\right],$$
$$\frac{\partial \theta_2}{\partial \xi}(R,\eta) = 0.0 \qquad \text{.......................... (8)}$$

Where $Bi = \frac{h\,m}{k_1}$ and $R = \frac{m}{n}$

The computational model used in this study is based on the above mentioned governing equations Eqs. (5&6) and corresponding boundary conditions Eqs. (7&8) that are numerically solved by the commercial CFD code, FLUENT. The SIMPLEC algorithm is used applying the default under-relaxation factors. Computations are carried out in double precision as a convergence criteria of order of 10^{-12} is required on the residuals of all equations.

RESULTS AND DISCUSSION

Figures 2 to 4 show the effect of the interfacial *Biot* number on the spatial temperature distribution within the two domains. It is clear from Figs. 2 and 3 that the temperature distribution for the imperfect contact case approaches that for the perfect contact case as *Bi* increases. Also, the interfacial temperature jump decreases as the *Bi* number increases. Using the thermal perfect contact assumption, is overestimated the temperature in the first domain, which is adjacent to the heat transfer boundary, i. e, the boundary at which the cooling effect is applied. On the other hand, the perfect thermal contact assumption underestimates the temperature within the second domain adjacent to the insulated boundary.

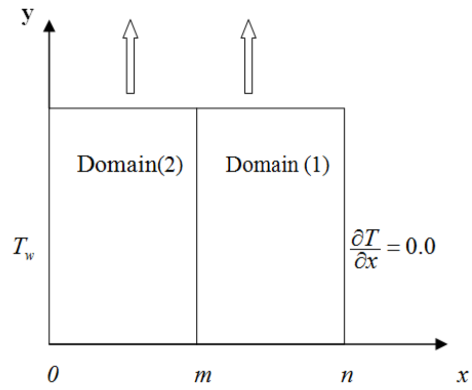

Figure 1. Schematic diagram of the problem under consideration

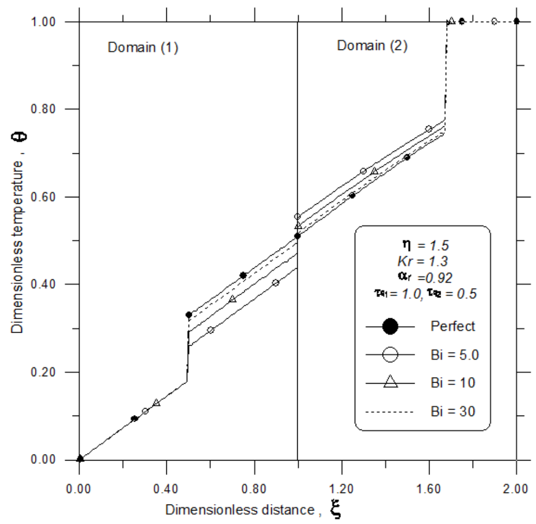

Figure 2. Spatial temperature distribution within the two domains for perfect and imperfect contact using the hyperbolic heat conduction model

The appearance of the discontinuity in the tempreture profile of Fig. 2 at $\xi = 0.5$ and $\xi = 1.7$ is due to the wavy nature of the hyperbolic heat conduction model. As mentioned previously, the hyperbolic heat conduction model assumes that heat propagates at a finite speed in the form of a wave. The appearance of these discontinuities depends on the specific location within slab, time and other_thermal properties of the two layers especially the thermal relaxation times τ_{q1} and τ_{q2}. For large thermal relaxation times τ_{q1} and τ_{q2} the appearance of these discontinuities is very likely. This is the reason why, for example, these discontinuities do not appear in Fig. 6 which assumes very small values of τ_{q1} and τ_{q2}.

Figure 4 shows that an interfacial *Biot* number larger than 50 yields predictions similar to that of the perfect contact model. Figure 5 shows deviations between the predictions of both perfect and imperfect contact models at different interfacial *Biot* numbers.

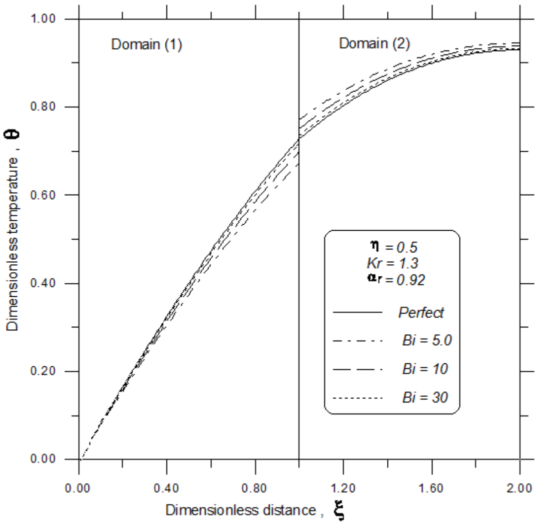

Figure 3. Spatial temperature distribution within the two domains for perfect and imperfect contact using the parabolic heat conduction model

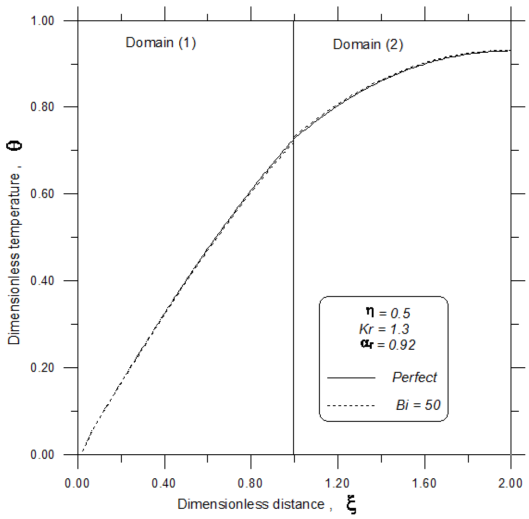

Figure 4: Spatial temperature distribution within the two domains for perfect and imperfect contact using the parabolic heat conduction model

It is clear that the division decreases as *Bi* increases. The deviation in the domain adjacent to the cooling boundary is larger than that in the domain adjacent to the insulated boundary. Also, the deviation has its maximum value at the contact plane. As a result, it is concluded that the deviation between both the perfect and the imperfect contact models is significant very near the contact plane and in locations having high heat transfer rates. Figure 6 shows the spatial temperature distribution using the perfect contact model at different thermal relaxation time τ_q. It is clear from this figure that for τ_q less than 0.01, the thermal relaxation time has insignificant effect on the prediction of the diffusion parabolic model which assumes that $\tau_{q1} = \tau_{q2} = 0$.

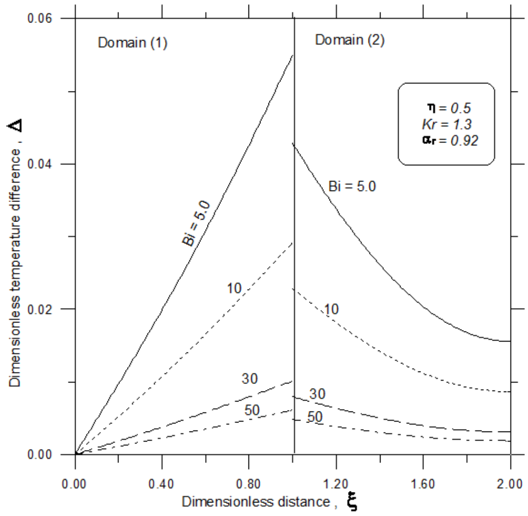

Figure 5. Effect of Biot number on the temperature distribution difference within the two domains for perfect and imperfect contact using the parabolic heat conduction model

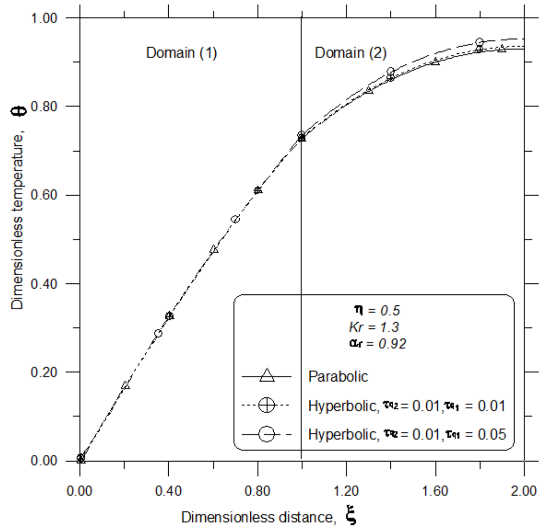

Figure 6. Spatial temperature distribution within the two domains using the parabolic and the hyperbolic heat conduction models

Conclusion

The thermal behavior of a two-layer composite slab under the effect of the dual-phase-lag heat conduction model is investigated. The layers in the composite slab are in perfect and imperfect thermal contact. It is found that the perfect contact model may replace the imperfect contact model for an interfacial *Biot* number larger than 50. The layer adjacent to the heat transfer boundary is more sensitive to the interfacial thermal boundary condition. Also, it is found that the deviation between the predictions of the perfect and the imperfect contact models is more significant in the domain adjacent to the heat transfer boundary and the deviation has its maximum value at the contact plane. The classical heat diffusion model can replace the dual-phase-lag model when the dimensionless thermal relaxation time of both domains is less than 0.01.

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