Influence of Air Gap on Thermal Performance of Composite System

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Abstract – Composite is a material that consists of at least two constituents of distinct phases or combination of phases which are bonded together along the interface in the composite, each of which originates from a separate ingredient material which pre-exists the composite. Many engineering applications of practical utility involves heat transfer through a medium composed of two or more materials of different thermal conductivity arranged in series or parallel. The composite systems such as the walls of refrigerator, hot cases, I.C. engine combustion chambers, cold storage plants, hot water tanks. Which always have some kind of insulating material between the inner and outer walls. A hot fluid flowing inside a tube covered with a layer of thermal insulation is another one of a composite system because in this case the thermal conductivities of tube metal and insulation are different. The problem of heat transfer through the composite systems can be solved by the applications of thermal resistance concept. The procedure for solving one dimensional, steady state heat conduction problems for composite systems comprising parallel plates, coaxial cylinders, or concentric spheres. In general in this cases, the resistance due to interface contact is consider due to imperfect thermal contact between series and parallel layers in the composite systems. In this paper evaluated actual and theoretical resistance of composite wall system and influence of air gap resistance on thermal performance of composite system. Heat transfer is increased with decreases in air gap resistance of composite system obtained.

Index Terms – Composite system,heat transfer conduction, air gap, thermal resistance.

1. INTRODUCTION

The study of composite materials thermal behaviour is useful for determination of heat transfer rate and heat flux. These composite materials which can be implemented to many applications such as thermal ventilations, insulators, metallic multiwall thermal protection systems, etc. Composite system consists of two or more layers of different materials attached in a series, parallel and both combinations. They have wide range of applications in industries. Composite systems are used in cold storage walls, walls of I.C. engine combustion chambers. Therefore it is necessary to study about the heat transfer through of the composite plane wall. It is very difficult to calculate and analyze with precision the thermal behaviour of the walls of different materials attached to each other. Conduction is a process of heat transfer generated by molecular vibration within an object (1-3).The object has no motion of the material during the heat transfer process. Thermal conduction is a mechanism of heat propagation from a region of higher temperature to a region of low temperature with in a medium (solid, liquid or gaseous) or between different medium in direct physical contact (4-6). Conduction does not involve any movement of macroscopic portions of matter relative to one another. The thermal energy may be transferred by means of electrons which are free to move through the lattice structure of the material. In addition, or alternatively, it may be transferred as vibrational energy in the lattice structure. Irrespective of the exact mechanism, the observable effect of conduction is an equalization of temperature. Heat conduction is due to the property of matter which allows the passage for heat energy, even its parts are not in motion relative to another (7-9). Conduction is the transfer of heat from one part of a substance to another part of the same substance, or from one substance to another in physical contact with it, without appreciable displacement of molecules forming the substance. In solids, the heat is conducted by the two mechanisms such as by lattice vibration, it is that the faster moving molecules or atoms in the hottest part of a body transfer heat by impacts some of their energy to adjacent molecules. By transport of free electrons, it is that the free electrons provide an energy flux in the direction of decreasing temperature for metals, especially good electrical conductors, the electronic mechanism is responsible for the major portion of the heat flux except at low temperature. Since conduction is essentially due to random molecular motion, the concept is termed as microform of heat transfer and is usually referred to as diffusion of energy (10-12). Heat transfer in metal rods, in heat treatment of steel forgings and through the walls of heat exchange equipment is some examples of heat conduction and also boilers, steam turbines blades, gas turbines blades, condensers, refrigerators, heat exchangers, steam nozzles.

2. EXPERIMENTAL METHODOLOGY

The composite system consists of three circular slabs made up of copper, asbestos and brass having equal diameter and thickness. They are connected together in series. In all a total of twelve thermocouples are provided on the two extreme faces and on the two mating surfaces of the composite slab system.Heating of the composite slab system is accomplished by means of a heater placed underneath the composite slab system. The dimmerstat such as heat input to the system can be regulated by means of a voltage regulator included in the circuit. The upper surface of the slab is provided with a coolant tank containing water flowing at constant known discharge. Three types of slabs are provided on heater which forms a composite structure. A small hand press frame wire provided to ensure the contact between the slabs. A dimmerstat used for varying the input to the heater and the voltmeter and ammeter readings were recorded. The heat is transferred through the slabs by conduction and then by convection from upper most slab to water. By giving to heat input to the composite system we can evaluated theoretical resistance of slabs, heat transfer through system, actual resistance of two slabs each in system, resistance due to air gap between the slabs in system.

Heat flow through a multi layer composite system are made on the presumption that

a) There is perfect contact between adjacent layers

b) The temperature is continuous at the interface although there is discontinuity in temperature gradient.

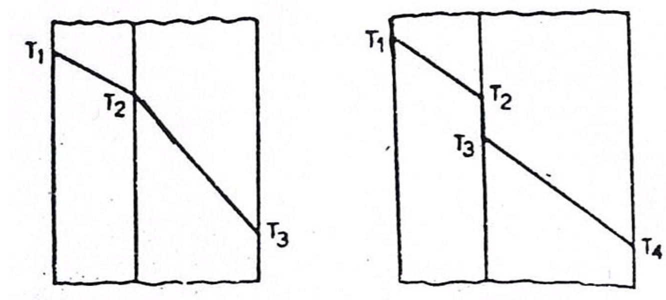
c) There is no fall of temperature at the interface

However in real systems, the contact surfaces touch only at a discrete locations due to surface roughness, interspersed with void spaces which are usually filled with air. Obviously, there is not a single plane of contact. This implies that the area for heat flow at the interface will be small compared to the geometric area of the face. Due to this apparent decrease in the heat flow area and also due to the presence of air voids, there occurs a large resistance to heat flow at the interface. This resistance is referred to as thermal contact resistance and it causes temperature drop between two materials at the interface. The Fig.1 shows status of temperatures at interface of plane surfaces.

Let T_2 and T_3 represents the temperature at the theoretical plane surface obtained by consideration of heat flow in materials either side. Then for a give wall area A, thermal contact resistance R_c is defined as

$$R_c = \frac{T_2 - T_3}{Q}$$

The value of metallic contact resistance depends on the metals involved. The surface roughness, the contact pressure and temperature and the matter occupying void spaces. The values of contact thermal resistance are obtained through experiment.



(a) No Temperature drop at interface (b) Temperature drop at interface

Figure. 1 Status of Temperature drop at interface of plane surfaces

Temperature drop at interface $T_2 - T_3$, $R_c = \frac{\delta}{kA}$, Where δ is thickness of air gap contact or thickness of air gap, R_c is also called thermal resistance of air gap, k is thermal conductivity of air, A area of heat flow through air gap.

$$\therefore R_c = \frac{T_2 - T_3}{Q} = \frac{\delta}{kA}$$

3. RESULTS & DISCUSSION

The Thermal analysis of composite system, the following parameters are considered for evaluation of theoretical resistance, actual resistance and air gap resistance of composite system, heat transfer through system.

Composite System input Voltage V = 100V and

Current I = 0.9 Amp

Thermal conductivity of copper k_1 = 379 W/mK

Thermal conductivity of Asbestos k_2 = 0.74 W/mK

Thermal conductivity of Brass k_3 = 110 W/mK

Diameter of each slab d = 10cm = 0.1m

Area of each slab Area $A = \frac{\pi}{4} d^2$

$$= \frac{\pi}{4} \times (0.1)^2 = 7.85 \times 10^{-3}\ m^2$$

Thickness of each slab x = 6mm = 0.006m

3.1 Theoretical resistance of two slabs

(i) Copper and Asbestos

$$R_{th(1)} = \frac{x}{A}\left(\frac{1}{k_1}+\frac{1}{k_2}\right)$$

$$= \frac{0.006}{7.85\times10^{-3}}\left(\frac{1}{379}+\frac{1}{0.74}\right)$$

= 1.034 K/W

(ii) Asbestos and Brass

$$R_{th(2)} = \frac{x}{A}\left(\frac{1}{k_2}+\frac{1}{k_3}\right)$$

$$= \frac{0.006}{7.85\times10^{-3}}\left(\frac{1}{0.74}+\frac{1}{110}\right)$$

= 1.039 K/W

Discharge of water Q = 200ml/min = $12\text{x}10^{-3}$ m^3/hr

Density of water ρ = 1000 kg/m^3

Mass flow rate m = ρ Q = 1000 x 12x 10^{-3}

= 12 kg/hr

Average Temperature at each slab

$$T_1^1 = \frac{T_1+T_2+T_3}{3} = \frac{255+260+255}{3} = 256.66\ ^0C$$

$$T_2^1 = \frac{T_4+T_5+T_6}{3} = \frac{190+190+205}{3} = 195\ ^0C$$

$$T_3^1 = \frac{T_7+T_8+T_9}{3} = \frac{105+125+115}{3} = 115\ ^0C$$

$$T_4^1 = \frac{T_{10}+T_{11}+T_{12}}{3} = \frac{85+65+75}{3} = 75\ ^0C$$

Where T_1,T_2,T_3 ----- copper slab surface temperatures

T_4,T_5,T_6 ----- Interface temperatures of copper and asbestos

T_7,T_8,T_9 ----- Interface temperatures of asbestos and brass

T_{10},T_{11},T_{12} ----- brass slab surface temperatures

Heat conducted through the each slab is equal to heat conducted through entire composite system

Therefore

Heat conducted through the composite system

$$Q = mc_p\left(T_o - T_i\right)$$

$$= \frac{12\times4.18\times10^3\times(31-26)}{3600} = 69.67 \text{ Watts}$$

where

specific heat of water c_p = 4.18×10^3 *J/kgK*

mass flow rate of water m = 12kg/hr

water temperature at inlet of system T_i = 26°C

water temperature at outlet of system T_o = 31°C

3.2 Actual resistance of two slabs

(i) Copper and asbestos

$$R_{act(1)} = \frac{dT_1}{Q} = \frac{T_1^1 - T_3^1}{Q}$$

$$= \frac{256.66-115}{69.67} = 2.033 \text{ K/W}$$

$$\therefore \quad R_{act(1)} = 2.033 \text{ K/W}$$

(ii) Asbestos and brass

$$R_{act(2)} = \frac{dT_2}{Q} = \frac{T_2^1 - T_4^1}{Q}$$

$$= \frac{195-75}{69.67} = 1.722 \text{ K/W}$$

$$\therefore \quad R_{act(2)} = 1.722 \text{ K/W}$$

3.3 Air gap resistance

(i) Between copper and asbestos

$$R_{air(1)} = R_{act(1)} - R_{th(1)}$$

= 2.033 – 1.034 = 0.989 K/ W

$$\therefore \quad R_{air(1)} = 0.989 \text{ K/W}$$

(ii) Between asbestos and brass

$$R_{air(2)} = R_{act(2)} - R_{th(2)}$$

$$= 1.722 - 1.039 = 0.6835 \text{ K/W}$$

$$\therefore \quad R_{air(2)} = 0.6835 \text{ K/W}$$

The results of composite system presented in Fig.2 for various heat input (voltage) given to system and calculated heat transfer rate through system and air gap resistance of system. Air gap resistance between copper and asbestos is decreasing with increases in heat transfer through system and also air gap resistance between asbestos and brass is decreasing with increases in heat transfer through system. Heat transfer rate is depends on heat input such as voltage and current to composite system. Heat transfer rate through composite system is higher level when heat input to system is in high. So higher the voltage to system, high in heat transfer obtained.

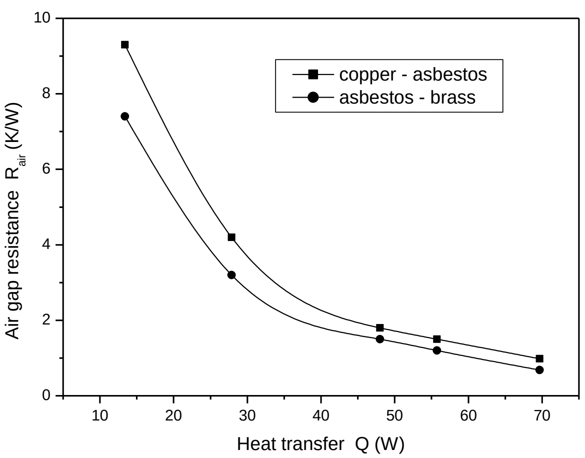


Figure 2 Effect of air gap resistance on heat transfer through composite system

4. CONCLUSIONS

- The heat input to the composite system is directly proportional to the heat transfer through the composite system. The heat input to the system is voltage and current.
- The resistance due to air gap decreases with the increase in heat input to slabs in composite system. At very low inputs it is high and therefore it must be considered to obtain better results. But whereas at higher heat inputs it is very low and its effect can be neglected. Moreover it depends on the total force exerted on the contacting surfaces, physical nature of the bond, and the quality of fluid trapped in the contacting surfaces.
- Air gap resistance between copper and asbestos is decreased with increasing in heat input and heat transfer to the system.
- Air gap resistance between asbestos and brass is decreased with increasing in heat input and heat transfer to the system.
- Heat conducted to the system, the air gap resistance between copper and asbestos is greater than the asbestos and brass.
- Mass flow rate of water for entire system is 12kg/hr.
- Actual resistance of copper and asbestos is greater than asbestos and brass.
- The air gap resistance of composite system is inversely proportional to the heat transfer through the system.
- Thermal contact resistance is decreases with increasing interface pressure. Because the high spots are deformed under load and create greater contact area.
- Thermal contact resistance is increases with increasing surface roughness and waviness, because the voids are enlarged and the surface do not come into good contact.
- The temperature profile in a composite wall with along thickness of slabs is non linear due to the air gap resistance.

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