Experimental analysis of thermal contact resistance across different composite material pair using different interface material in ambient pressure condition

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Abstract— The Practical study of heat transfer through surface contact resistance is very essential for advancement of thermal applications. It is required to understand the heat transfer between composite pair having same as well as different interface material. The outcomes will be very essential for design of different heat transfer thermal applications. The sole objective of this research work is to reduce the Thermal Contact Resistance (TCR) and increases thermal efficiency of the application. To minimize thermal contact resistance, the study of heat transfer with composite material pair & Thermal Interface Material (TIM) has been carried out experimentally in absence of pressure (ambient) condition.

The Experimental work includes effective pairs of circular plates of aluminum (HE30/6082) and copper (EC101) alloys. To avoid radial losses during experiments, plates are designed and manufactured in circular disc form 184 mm diameter with 5mm thickness each. Each of plate having four groove, Pencil k type thermocouple (Tip length: 70mm & diameter: 3mm) placed inside that grove which measured average temperature of surfaces with the help of 8 channel temperature indicator. The various effective pair of metal alloys disc has been considered during practical where air and brass foil are used as TIM for particulate pair. The average temperature of plate surface is measured under the steady state condition at 40°C-70°C temperature interval. An experiment has been conducted with some specific conditions to achieve ideal results.

With experiment, it is possible to analyze and identify suitable thermal interface material with minimum thermal contact resistance between two plates. Selection of proper TIM will lead towards higher heat transfer rate.

Keywords- Heat transfer, thermal applications, thermal contact resistance, thermal interfacial material, ambient pressure, temperature, circular plate and radial heat losses

1. INTRODUCTION

Heat transfer across a contact interface formed by any two solid bodies is usually accompanied by a measurable temperature difference because there exists a thermal resistance to heat flow in the region of the interface. The temperature difference at the contact interface is obtained by extrapolating the steady state unidirectional temperature distribution from regions far from the contact plane.

When two surfaces come into contact as shown in Figure1.1, they remain separated by their roughness elements. A gas or a liquid may also fill the spaces between the surfaces, and if the interface fluid has a lower thermal conductivity than the surface materials a contact resistance may exist that can become a design consideration.Figure1.1 also illustrates the type of temperature distribution that is encountered in such situations where a sharp temperature gradient across the small interfacial separation distance is caused by the contact resistance.
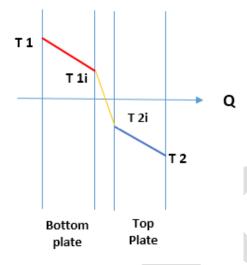
Figure 1.1 Interfacial Contact

Thermal resistance is thermal property of a material and it indicates how it resists heat at a specific thickness. As shown below, thermal resistance is proportional to the thickness of the material, but it can be affected by gaps that occur between contact surfaces. These gap create contact resistance, contributing to additional thermal resistance.

A) Methods to Reduce Contact Resistance [28]
For solid of high thermal conductivity, the contact resistance may be reduced by the following two methods:
 1) Increasing the area of contact spots, accomplished by
-Increasing contact pressure which will "flatten" the peaks and valley of the micro roughness
-Reducing the roughness & waviness and increasing the flatness of surface
2) Using the Thermal interface material (TIM) of high thermal conductivity. Any interfacial material that fill the gap between contacting two surfaces, whose thermal conductivity exceed that of air

B) Various Types of Interface Material [28]

1) No fluidic interfacial material:

-Metallic Foils i.e., brass, copper, tin, lead, gold, indium etc.

-Metallic and Nonmetallic Coatings

-Polymers i.e. thermosets, thermoplastic, elastomers etc.

-Cements, Adhesives

2) Fluidic interfacial material:

- Phase change material, silicon (Thermal grease)

3) **Gases i.e.** hydrogen, nitrogen, Helium, carbon dioxide, argon, mixture of helium + argon etc.

4) **Vegetable oil**

C) Ideal Thermal Interface Material (TIM) Characteristics [28]

1) Minimum thickness is required.

2) It should have high thermal conductivity

3) It should be Non-toxic

4) It would not leak out of the interface zone

5) Easily deformed by small contact pressure so that uneven areas of both contacting surface become a flat

6) Manufacturing friendly means easy to apply and remove

7) It would maintain performance indefinitely

2. REVIEW OF PUBLICATIONS

A comprehensive literature review of thermal contact resistance has been provided in references [1-27]. Thermal contact resistance is very essential for design of heat transfer industrial applications. Various parameter influences on thermal contact resistance i.e. thermal interface material, surface morphology, pressure, metal thermal conductivities, material hardness etc. Surface morphology such as flatness, roughness and waviness have a maximum impact on the thermal contact resistance. It decrease with increasing flatness and decrease with waviness & roughness. Many investigator worked associated with two solid surfaces pressed together under ambient as well as applied load. C.V. Madhusudana [2] found out the effect of various interstitial fluid on thermal contact resistance. He concluded contact resistance improves in presence of good conducting medium in between two surfaces. P.W. O'Callaghan et al. [3] developed computer based mathematical model for interface material which will minimize the thermal contact resistance. A.M. Khounsary et al. [8] measured the thermal contact resistance across silicon-copper interface by using various interface foil and also concluded softer the interface material, lower the thermal contact resistance. D.D.L Chung [11] reviewed material for thermal conduction include materials exhibiting high thermal conductivity as well as thermal interface materials and Carried out materials of high thermal conductivity are needed for the conduction of heat for the purpose of Heating or cooling. J.P. Gwinn et al. [13] carried out performance and testing of interface material and surface characteristic & interface material most critical parameter affecting on thermal contact resistance.

The objective of this study was to experimental analysis of thermal contact resistance across different composite (Al-Al, Al-Cu) material pair using different interface material (Air, Brass foil). Experimental variables including ambient condition, position of top and bottom plate, temperature interval, interfacing material etc. Finally, experimentally investigated the composite metallic pair most suitable to minimize thermal contact resistance.

3. METHOD OF APPROACH

3.1 Apparatus

Experimentations has been conducted to find out the thermal contact resistance for same and different form of composite & thermal interface materials. The experimental setup is illustrated in Figure 2.1 and 2.2. Experimental setup consists of various components i.e. circular type electric heater (diameter: 200 mm, Height: 110 mm from the datum), pair of test specimen Copper (Grade: EC101), Al (grade: HE30/6082) (diameter: 184 mm & thickness: 0.5mm), 8 channel Temperature indicator (Model: MS1208, 4 digit-LED, 0.56'',3 digit-LED, 0.4''), Continuous variable autotransformer (Temperature Variac, ISO 9001:2000), Digital Multimeter (DMM, 200-300V), 8 no of pencil K type Nickle-Cronel thermocouple (-270°C-1260°C), Brass foil (thickness: 0.1mm) as thermal interface material etc.
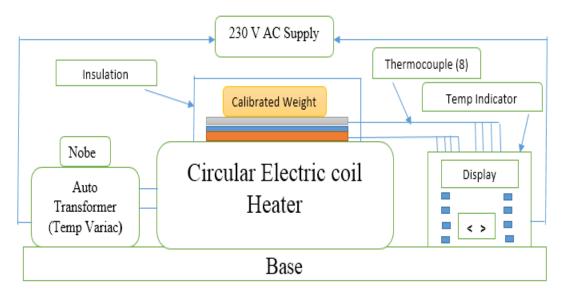
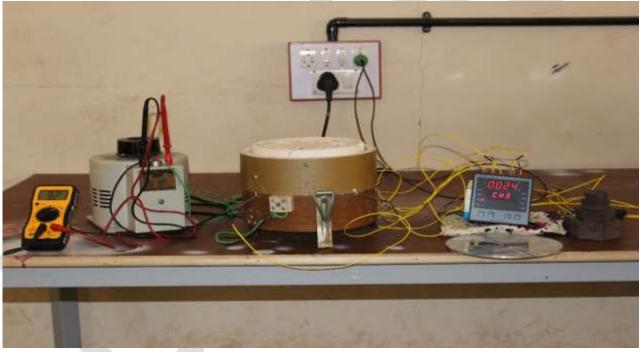Figure 3.1 Schematic line diagram of experimental setup

Figure 3.2 Schematic actual diagram of experimental setup

3.2 Experimental Test Procedure

A circular form of Copper (EC 101) and Aluminum (HE30/6082) plate of size (diameter: 184 mm & thickness: 0.5mm) are taken for experimentation. A circular form of copper plate is placed on heat source of circular type electric heater (diameter: 200 mm, Height: 110 mm from the datum) having ceramic alloys material (insulation) which prevents the losses. In which, Cu (Bottom) - Al (Top) composite pair with interface material is placed on electric coil heater. Each of plates has four grooves, 'k' types thermocouple are placed inside that grove which measures the temperature difference (T1i-T2i) between top surface of copper plate and bottom surface of aluminum plate with the help of 8 channel temperature indicator.

One more thermocouple is also placed at bottom surface of Copper plate its temperature (T1) remains constant 40°C–70°C means constant heat flow is maintained by varying voltage of continuous variable autotransformer which is directly connected with electric coil heater. Also, one thermocouple is mounted on top surface (T2) of Al top plate. Both of these temperatures (T1 & T2) are also measured with the help of temperature indicator.

The average temperature of plate surface is measured under the steady state condition at 40°C-70°C temperature interval. An experiment has been conducted with some specific conditions i.e. steady state conditions, one dimensional heat transfer, assuming constant Environment Temperature, avoiding convection losses, avoiding Radiation losses, minor Experimental errors avoided, proper Insulation, surfaces are clean and contact is static, thermal conductivities are uniform etc. to achieve ideal results. Same experiments are performed orientation wise in which changes the position of top & bottom plate with different interface material in ambient pressure condition. Same experiments test procedure was repeated for Al-Al composite pair with different interfacial material in ambient condition.

4. RESULTS AND DISCUSSION

Based on experimental work on TCR, Five experiments were performed with same and different composite material pair using different interface material in absence of pressure conditions as well as same experiments were performed orientation wise. In which Source temperature (T1) remains constant at 40°C -70°C interval. When upper surface of bottom plate (T1i) and lower surface of top plate temperature (T2i) attained the steady state condition, average temperature (T1i, T2i and T2) was measured. Outcome of these experiment results are illustrated graphically & in tabular form. Considering,
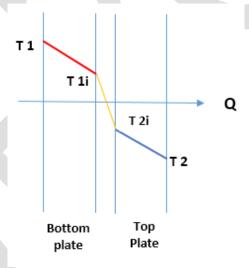

Figure 4.1 Composite metallic pair

Where;

Q = Total Heat Flow (W),

T1 = bottom surface temperature of bottom plate (^{o}C)

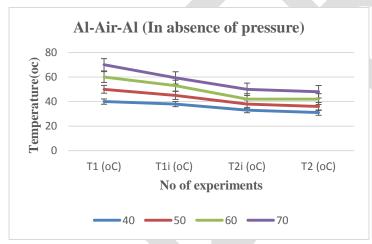T1i =Top surface of bottom plate (^{o}C),

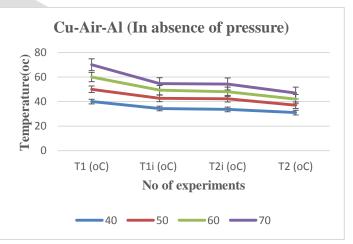T2i =bottom surface of top plate (^{o}C),

T2 =Top surface of top plate (^{o}C)

Table 4.1. Experimental Results at 40°C-70°C

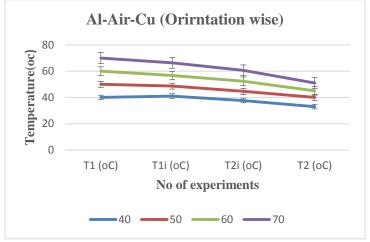|	Experimental Results at 40°C-70°C					
	Experiment	Exp-1	Exp-2	Exp-3	Exp-4	Exp-5
	Temp. Range	Al-Air-AL	Cu-Air-AL	Al-Air-Cu (O)	Cu-Brass-AL	Al-Brass-Cu(O)
T1	40	40	40	40	40	40
	50	50	50	50	50	50
	60	60	60	60	60	60
	70	70	70	70	70	70
T1i	40	38	34.33	41	39.66	36.66
	50	45	42.66	48.66	49.66	47.33
	60	53	49.33	56.66	59.33	56.33
	70	59.33	54.66	66.33	68.33	63.33
T2i	40	33	33.66	37.66	39.33	34.33
	50	38	42.33	44.66	40	44.33
	60	42	48	52.33	46	51.66
	70	50	54.33	60.66	51	58.33
T2	40	31	31	33	32	33
	50	36	37	40	37	41
	60	42	42	45	38	46
	70	48	47	51	49	52

Note: (O) indicates orientation Wise (Changes the position of top and bottom plate)
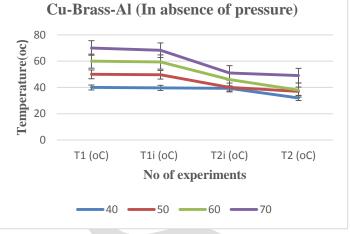

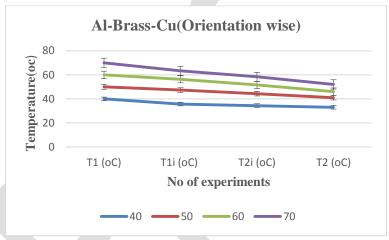Experiment: 1 Al-Air-Al (In absence of Pressure)

Experiment: 2 Cu-Air-Al (In absence of Pressure)

Experiment: 3 Al-Air-Cu (O) (In absence of Pressure)

Experiment: 4 Cu-Brass-Al (In absence of Pressure)

Experiment: 5 Al-Brass-Cu (O) (In absence of Pressure)

OBSERVATIONS:

Experiment 1: From the outcome results of Al-Air-Al pair in absence of pressure condition, it was observed that, Al was taken as bottom and top plate and air was taken as thermal interface material, Temperature drop of bottom Al plate & air gap increased with increase in temperature however temperature drop of top plate remains constant.

Experiment 2 In case of Cu-Air-Al composite pair, when Cu was taken as bottom plate and Air was taken as thermal interface material, Temperature drop of bottom Cu plate and top Al plate increased with increase in temperature. However, temperature drop of interface material (air) remained constant. It was clearly seen that high Cu thermal conductivity has significant effect on heat transfer.

Experiment 3. In Al-Air-Cu (Orientation wise) composite pair, Al was taken as bottom plate and Air was taken as thermal interface material same as previous first experiment (Al-Air-Al). In this case temperature drop of bottom Al plate, intermediate zone & top Cu plate is increased with increase in temperature it was observed that temperature drop for Al-Air-Cu (Orientation) composite pair is high compared to previous experiment Cu-Air-Al (2).

Experiment 4. In case of Cu-Brass-Al pair was taken as bottom, interface and top plate, results were become very interesting. Temperature drop for copper plate remains constant but temperature drop for intermediate zone and top plate increased with increase in temperature. As previous results and ideal conditions, when increasing the temperature, temperature drop supposed to be decreased

at intermediate zone but this phenomena did not occurred due to unevenness of brass foil which created the air gap on both side of brass foil in experimental setup**.**
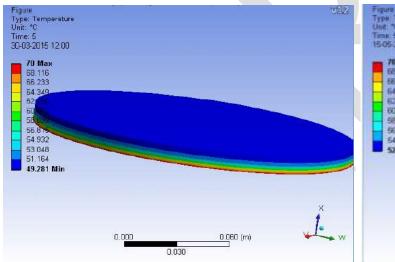
Experiment 5. It was observed that when Al-Brass-Cu (Orientation wise) pair were taken as bottom, interface and top plate, graphical presentation showed that temperature drop for Al, brass and Cu plate increasing with increase in temperature. Also, observed that Intermediate temperature drop for Al-Brass-Cu was less compare to experiment: 4 (Cu-Brass-Al).

5. VALIDATION:

Based on performing five experiments with same and different composite material pair & interface material, Brass foil offered minimum thermal contact resistance compared to air. Experimental 4 & 5 results were validated in ANSYS workbench'12 software through static thermal analysis. Outcomes results are illustrated graphically and in tabular form which are very close to experimental results

Table 5.1 Validated Experimental and ANSYS results of Cu-Brass-Al and Al-Brass-Cu (O)

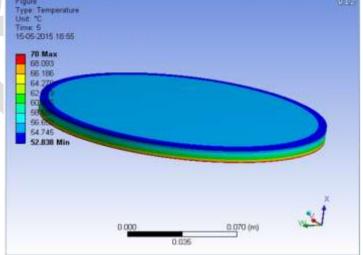| Source Temp	Cu-Brass-AL		Al-Brass-Cu(O)	
T1	T2 Exp	T2 ANSYS	T2 Exp	T2 ANSYS
40	32	32.204	33	33.468
50	37	37.886	41	39.89
60	38	43.579	46	46.347
70	49	49.281	52	52.838

Figure 5.1 Temperature distribution profile Cu-Brass-Al (Left) and Al-Brass-Cu (O) (Right)

The figure 4 shows variation of temperature distribution pattern for Cu-Brass-Al (Left) and Al-Brass-Cu (O) (Right) composite pair. It depicts how to temperature distribution profile gradually occurs from bottom plate to top plate which are obtained in ANSYS workbench'12. The red color regions indicates bottom source plate temperature which identify higher (Maximum) value of temperature. The dark (left) & light (right) bluish regions indicates top sink plate temperature depicts lower (minimum) value of temperature. In case of Cu-Brass-Al (left) pair, top plate attained dark bluish color whereas Al-Brass-Cu (O) pair attained light bluish

color. This phenomena occurred because of source plate. It can be observed from graphical temperature distribution profile, outcomes ANSYS workbench results very close to experimental results in both cases.

6. MICRO OBSERVATION:

Comparison between Al-air-Al, Cu-Air-Al, Al-Air-Cu (Orientation Wise), Cu-Brass-Al, Al-Brass-Cu (Orientation wise) pairs in absence of pressure at 70°C temperature with orientation wise are illustrated in tabular as well as graphical representation in following ways respectively

Table 6.1 Experimental results of Al-air-Al, Cu-Air-Al, Al-Air-Cu (Orientation Wise), Cu-Brass-Al, Al-Brass-Cu (Orientation wise) at 70°C

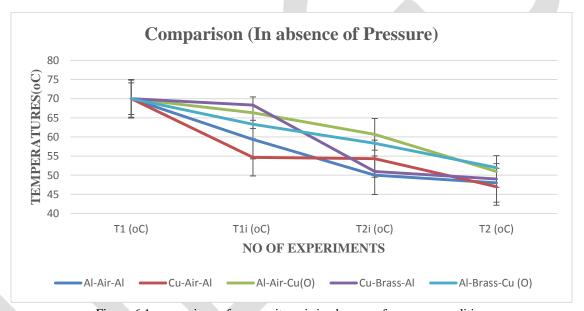| EXPERIMENTAL RESULTS				
Composite pair	T1 ($^{\circ}$C)	T1i ($^{\circ}$C)	T2i ($^{\circ}$C)	T2 ($^{\circ}$C)
Al-Air-Al	70	59.33	50	48
Cu-Air-Al	70	54.66	54.33	47
Al-Air-Cu(O)	70	66.33	60.66	51
Cu-Brass-Al	70	68.33	51	49
Al-Brass-Cu (O)	70	63.33	58.33	52

Figure 6.1 comparison of composite pair in absence of pressure condition

Table 6.2 Temperature difference overall, bottom, intermediate and top zone

Composite pair	T1-T2 ($^{\circ}$C)	T1-T1i ($^{\circ}$C)	T1i-T2i ($^{\circ}$C)	T2i-T2 ($^{\circ}$C)
Al-Air-Al	22	10.67	9.33	2
Cu-Air-Al	23	15.34	0.33	7.33
Al-Air-Cu(O)	19	3.67	5.67	9.66
Cu-Brass-Al	21	1.67	17.33	2
Al-Brass-Cu (O)	18	6.67	5	6.33

Table 6.3 Best pair results of air and brass as interface material in ambient condition

Sr No	Temperature Drop Zone Application	Best Pair	
		Air (interface material)	Brass (interface material)
1	Bottom to Top Zone (ΔT)	Al-Air-Cu(O)	Al-Brass-Cu (O)
2	Bottom Plate (ΔT1)	Al-Air-Cu(O)	Cu-Brass-Al
3	Intermediate Zone (ΔTi)	Cu-Air-Al	Al-Brass-Cu (O)
4	Top Plate Zone (ΔT2)	Al-Air-Al	Cu-Brass-Al

After performing five experiments in absence of pressure & orientation conditions, it was observed from the outcome of the results listed in table and graph,

- When temperature drop is required minimum for particular bottom to top overall application (ΔT) in case of air was used as interface material, best results obtained through Al-Air-Cu pair (Orientation wise) whose temperature drop is minimum compare to others in which Al-Air-Cu were taken as bottom, interface and top plate respectively. Thus, Al-Air-Cu is the best composite pair compare to others.

- When temperature drop is required minimum for particular bottom to top overall application (ΔT) in case of brass foil was used as interface material, best results obtained through Al-Brass-Cu pair (Orientation wise) whose temperature drop is minimum compare to others in which Al-Brass-Cu were taken as bottom, interface and top plate respectively. Thus, Al-Bras-Cu is the best composite pair compare to others.

It was also observed at micro level from the graph and outcome results in absence of pressure conditions, Heat transfer phenomena is effected not only overall temperature drop (ΔT) but also effected on all intermediate temperature drop zone i.e. ΔT1, ΔTi, and ΔT2. Thus, there is relationship between the same & different composite metal pair and used different interface material. In short, there is relationship between bottom plate - interface material and interface material - top plate.

- When temperature drop is required minimum for particular base plate application (ΔT1) in case of air was taken as interface material, better results obtained with Al-Air-Cu pair (Orientation wise) in which Al should be preferred as bottom and Air should be preferred as interface material. In case of brass foil was taken as interface material, better results obtained with Cu-Brass-Al pair in which Copper should be used as bottom and Brass should be preferred as interface material.

- When temperature drop is required minimum for particular interface contact zone application (ΔTi) in case of air was taken as interface material, better results obtained with Cu-Air-Al pair in which Cu-Air-Al should be preferred as bottom, interface and top plate respectively. In case of brass foil was taken as interface material, better results obtained with Al-Brass-Cu (Orientation wise) pair in which Al-Brass-Cu should be preferred as bottom, interface and top plate respectively.

- When temperature drop is required minimum for particular top zone application (ΔT2) in case of air was taken as interface material, better results obtained with Al-Air-Al pair. Thus, Air should be chosen as interface material & Al plate should be chosen as top plate. In case of brass foil was taken as interface material, better results obtained with Cu-Brass-Al pair. Thus, brass should be preferred as interface material and Copper should be preferred as top plate.

7. CONCLUSION:

- It was concluded from (experiment :1) when both top and bottom plate kept as aluminum, Temperature drop of bottom Al plate & air gap increased with increase in temperature however temperature drop of top plate remains constant. This happened due to heat transfer from the bottom Al plate to the air in the intermediate zone, thus heating the air. Now this heated air due to high temperature goes out of the gap & cold air from outside gets in thus filling the intermediate zone.

- Also when Cu was taken as source (Bottom) plate instead of aluminum plate (experiment: 2), Temperature drop of bottom Cu plate and top Al plate increased with increase in temperature. However, temperature drop of interface material (air) remained constant. It was clearly seen that high Cu thermal conductivity has significant effect on heat transfer. It absorbs maximum heat due to its high thermal conductivity.

- Besides, when changes the position of bottom and top plate (orientation wise) as Al & Cu respectively, temperature drop of bottom Al plate, intermediate zone & top Cu plate is increased with increase in temperature. It was observed that temperature drop for Al-Air-Cu (Orientation) composite pair is high compared to experiment Cu-Air-Al (2). This phenomena happened due to properties of Al plate which was taken as heat source or base bottom plate. Temperature drop is less compare to Al-Air-Al (Exp: 1) pair. This happened due to copper was taken as top plate.

- Finally, It was concluded that from observation of five experiments, two specific conditions i) When Air was taken as interface material & copper was taken as bottom plate.2) When brass was taken as interface material & Aluminum was taken as bottom plate transferred the maximum heat at minimum thermal contact resistance.

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