Journal of Data Acquisition and Processing
ISSN: 1004-9037
https://sjcjycl.cn/
DOI: 10.5281/zenodo.777666

EXPERIMENTAL INVESTIGATIONS ON THERMAL CONTACT RESISTANCE OF SIMILAR / DISSIMILAR MATERIALS UNDER DIFFERENT OPERATING CONDITIONS

Amey A. Bapat[1], Nilesh T. Dhokane[2], Mandar M. Lele[3]
[1]PG Student, School of Mechanical Engineering, MIT-WPU, Pune 411038
[2]Assistant Professor, School of Mechanical Engineering, MIT-WPU, Pune 411038
[3]Professor, School of Mechanical Engineering, MIT-WPU, Pune 411038
Email: amey.bapat99@gmail.com, nilesh.dhokane@mitwpu.edu.in, mandar.lele@mitwpu.edu.in
*Corresponding author: Amey A. Bapat
Email: amey.bapat99@gmail.com

Abstract:
An experiment was conducted to investigate the thermal contact resistance (TCR) of similar and dissimilar materials under different operating conditions such as pressure and heat input. Results for Al-Al show that under pressure ranges of 1.5 bar to 6 bar and heat input ranges of 5W to 30W, thermal contact resistance decreases up to 43% for pressure and heat input ranges of 1.5 bar and 2 bar, respectively, and further decreases by 21% as pressure rises from 2 bar to 6 bar. For pressure and heat input ranges of 1.5 bar to 2 bar and 10W to 30W, respectively, the findings for Al-Cu show that the thermal contact resistance is lowered up to 43%, while when pressure rises from 2 bar to 6 bar, the percentage of thermal contact resistance further reduces by 21%. The results for aluminium-brass show that there is a reduction of up to 70% when heat input varies from 5 to 20 Watts under 1.5 bar to 3 bar of pressure. When pressure is increased from 3 bar to 6 bar and heat input is increased from 20 Watts to 30 Watts, there is a percentage change in thermal contact resistance up to 13%.

Keywords: Thermal Contact Resistance, Directional Effect of Dissimilar Materials, Steady-state method, Aluminium, Copper, Brass

Introduction:

Thermal contact resistance (TCR) is a measure of the heat transfer resistance between two surfaces in contact with one another. It is an important parameter that determines the overall heat transfer performance of a system. TCR is an important parameter in applications such as cryogenics, heat exchangers, electronic packaging, I. C. Engines, etc. In order to understand the TCR between similar and dissimilar materials under different operating conditions, numerous methods have been conducted.

Zhang et al., [2] proposed a method by minimizing additive errors by using the harmonic mean value of TCR in two directions of the heat flow. Based on this methodology, an experimental device was designed and established to measure TCR of solids accurately.

Different types of methods are used to determine the contact resistance between contacting bodies in which steady-state and transient methods are commonly used among researchers which include Raman-based techniques, infrared thermography measurements, laser-flash measurements, photoacoustic techniques, the 3ω method and transient thermos-reflectance techniques under transient methods, whereas, conventional steady-state measurements are still recognized as a technology for measuring TCR in bulk materials, and recent changes and improvements have increased their accuracy and reliability [3].

Another way to decrease the thermal contact resistance is by applying the thermal interface materials (TIMs) suggest that when the temperature exceeds the phase change point, the ITR of the PCMs and LMPAs decreases significantly. When the surface roughness is 0.8 μm, aluminium's thermal contact resistance is 189 mm^2 K/W to 0.2 MPa and 153 mm^2 K/W to 0.4 MPa, but the thermal pads have an ITR of 136 – 395 mm^2 K/W to 0.3 MPa and carbon-based material has an ITR of 165 mm^2 K/W to 0.5 MPa [4].

Kneer, Fieberg [5] determined thermal contact resistance by the transient method. Infrared thermography method is used as the transient method. Combustion engine was used as a experimentation medium as there is more temperature distribution which highly influences thermal contact resistance. Heat transfer coefficient of materials used in experimentation is taken into consideration as it plays an important part in determining thermal contact resistance is based on transient infrared temperature measurements. The findings indicate a nearly linear relationship between the contact heat transfer coefficient and the contact pressure, whilst the impact of temperature for the investigated temperature range appears to be minimal.

Surface roughness of the materials was taken into consideration when Hu et al. [6] conducted their experiment on thermal contact resistance using copper and indium, as this factor is crucial in microelectronic devices. Copper and indium are utilised as an interface in the application of electronic packaging, and numerical techniques are used to analyse thermal contact resistance. The copper-indium contact model's temperature field is calculated using the finite element method. The results showed that when determining the thermal contact resistance of copper-indium under the impact of air and grease, the thermal resistance would grow fast with an increase in pressure, while the cost-effectiveness ratio would fall.

Sidappa and Tariq [7] used copper-copper to study the thermal contact conductance (TCC) at various cryogenic temperatures. A unique experimental setup was employed for the experiments, with values ranging from 50 to 300K for temperature and 0.5 to 8MPa for pressure. The range of surface roughness was similarly 0.8 to 10 m. This experiment's primary goal is to determine TCC's nonlinear relationship to temperature and pressure. It was suggested that lower dimensionless TCC and dimensionless pressure and temperature are correlated empirically.

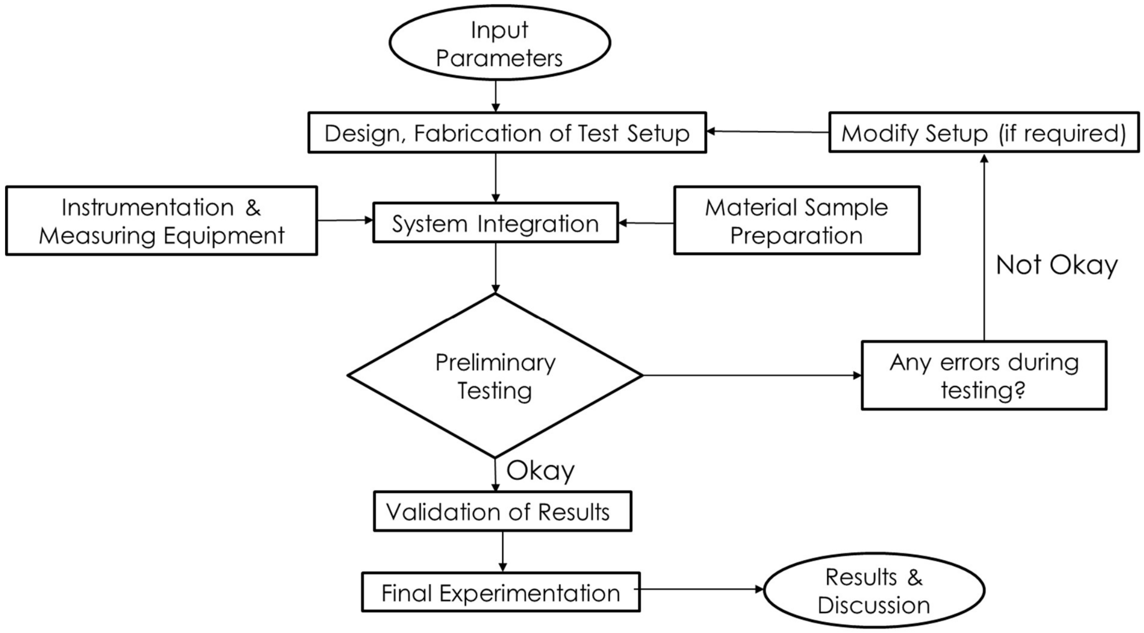


Figure 1: Methodology of experimentation on thermal contact resistance

Figure 1 represents the methodology of experimentation on thermal contact resistance of similar/dissimilar materials under different heat input and pressure respectively.

1. <u>Experimental Procedure</u>

The most often used technique for calculating the TCR of solids is the steady-state approach, as seen in the picture. Stable-state approaches are more accurate than transient methods since it is a routine procedure to estimate the TCR. The ASTM Standard D5470-06 [1] is the foundation of it. The key benefit of utilising the steady-state approach over the transient methods is that the steady-state methods are more accurate. The steady-state technique has the following shortcomings:

a) In order to acquire the contact bodies' steady state measurement condition, a lengthy waiting period of around 7 to 8 hours is needed.
b) Because intrusive temperature measurement techniques involving the insertion of sensors affect the behaviour of the contact bodies to achieve steady-state, extremely thin contact bodies are not an option.

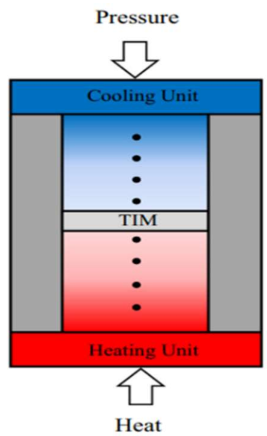


Figure 2: Schematic of a typical ASTM Standard D5470-06 setup

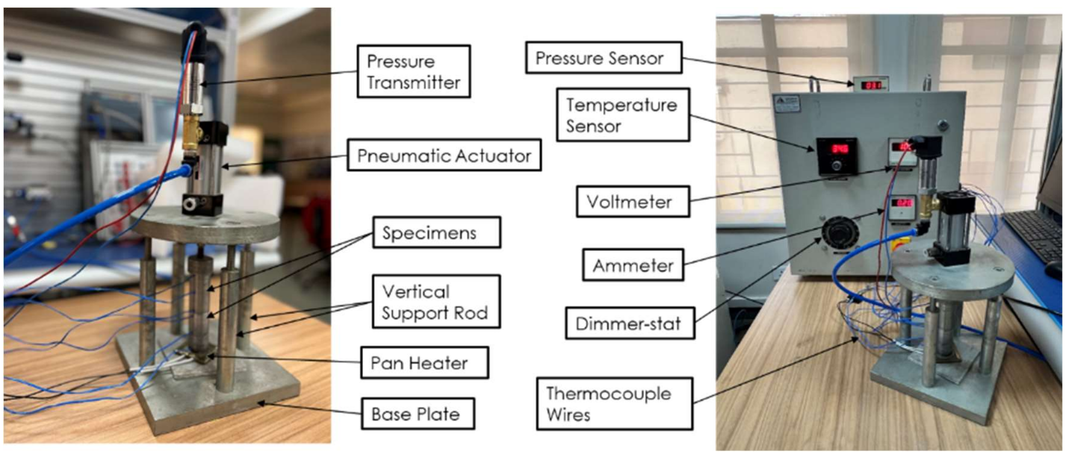


Figure 3: Experimental Test Setup

The surface roughness value used in the trials is 1.5 m, and different amounts of pressure and heat are applied at different times. As seen in the Figure 3, the electric control panel allows for pressure control while the pressure device controls the heat input. To stop heat loss during experimentation, polystyrene sheet is put around the test apparatus (not visible in the photograph).

K-type thermocouples are inserted into holes (2 mm in diameter) bored into the specimens 5, 25, and 55 mm apart to detect temperatures. Air is present at the contact interface since all testing are conducted in an atmosphere. The conduction of contact gases increases as air conductivity rises with temperature. The electrical heater's power is adjustable and can reach up to 230V. In experiments, the voltage is set to 50V (5 Watts) as the initial voltage, then adjusting it to 75V (10 Watts), 100V (20 Watts) & 125V (30 Watts) respectively.

The pneumatic load is gradually modified from 1.5 bar to 6 bar by adjusting the pressure valve applied to the specimens and is measured by the digital indicator. The temperature along the specimens is measured on the axis by a 6 K-type thermocouple located at a distance equal to the axis, as shown in the Figure. Experiments were conducted by varying pneumatic pressure from 1.5 to 6 bar by changing heat input from 5W to 30W for every pressure.

As the method of experimentation is steady-state method, the test rig is kept on for 8 hours to obtain accurate results. Measured temperature values are used to calculate the thermal contact resistance at the interface.
3 holes of 2mm diameter each are drilled for each specimen to measure the temperature. Thermocouples are inserted in these holes to identify the temperature. T1, T2, T3, T4, T5 & T6 are the temperature points at the distance of 5, 25 & 55 mm for each specimen. To measure the contact resistance at the interface, T3 & T4 points are used.

$$\Delta T = T3 - T4$$

Heat Flux is calculated where heat input is divided by the cross-sectional area at the interface,

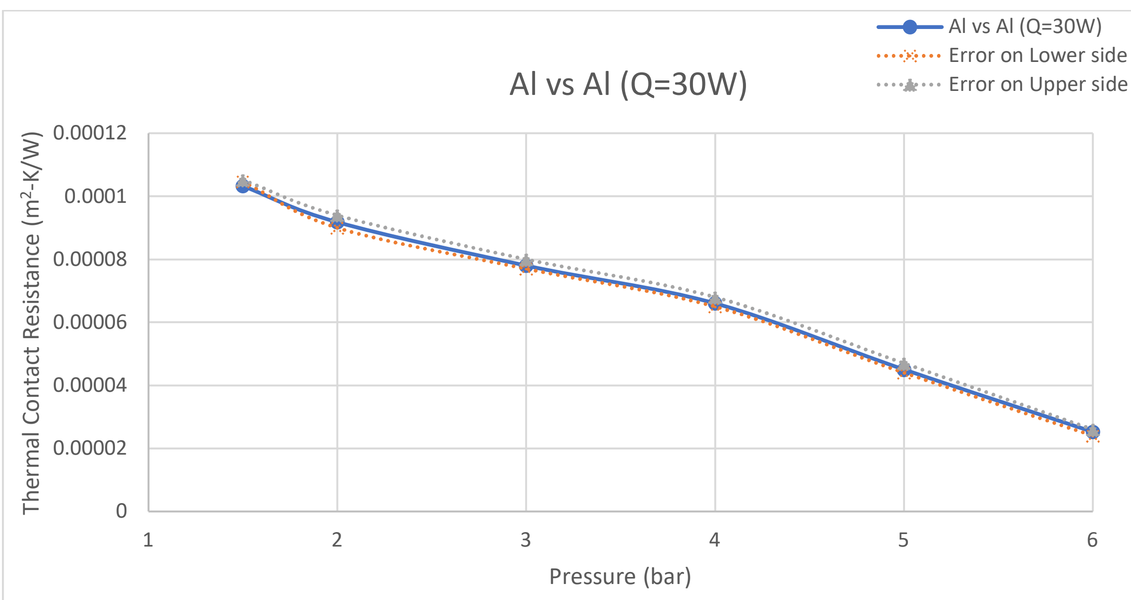
$$\dot{Q} = \frac{q}{A}$$

The thermal contact resistance is calculated by combining the above equations,

$$R_{th} = \frac{\Delta T}{\dot{Q}}$$

2. Error Analysis

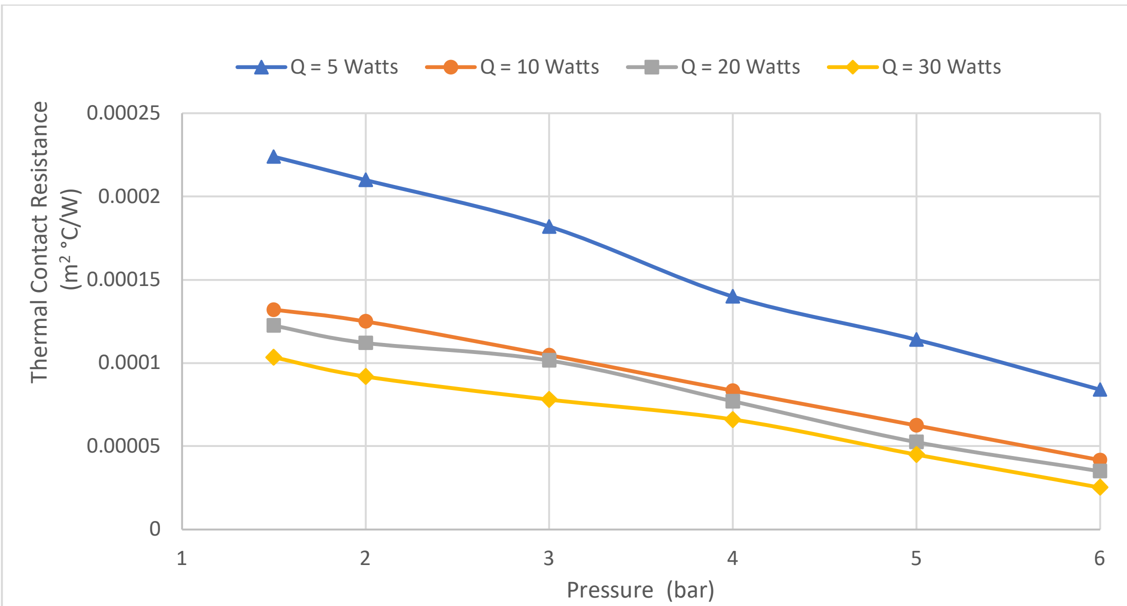
Based on the law of error propagation, the relative error of TCR can be estimated as follows. Type-K thermocouples present an uncertainty level of ±0.75% in the range of 0–400 °C and pressure transmitter presents an uncertainty of ±0.5% in the range of 1 bar to 10 bar. Figure 15 shows error analysis done for Al-Al when Q = 30W for pressure ranging from 1.5 to 6 bar.
By conducting error analysis, it can be assumed that there is up to ±5% change in the thermal contact resistance when pressure gradually increases that is applied to the specimen. Whereas, by changing the heat input, the thermal contact resistance deflects up to ± 6%.

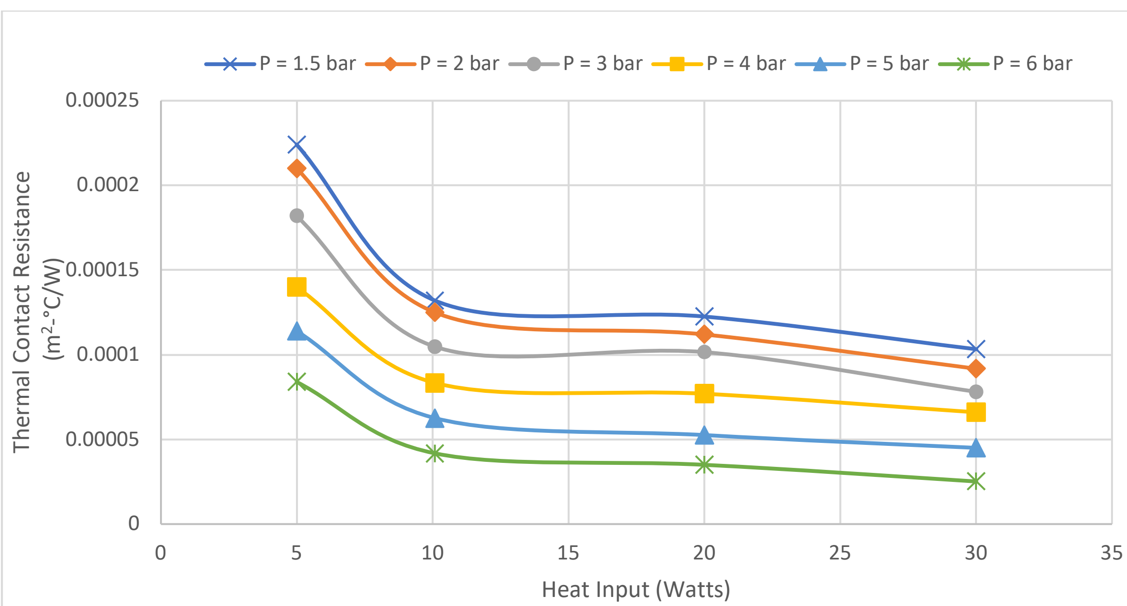


Results and Discussion

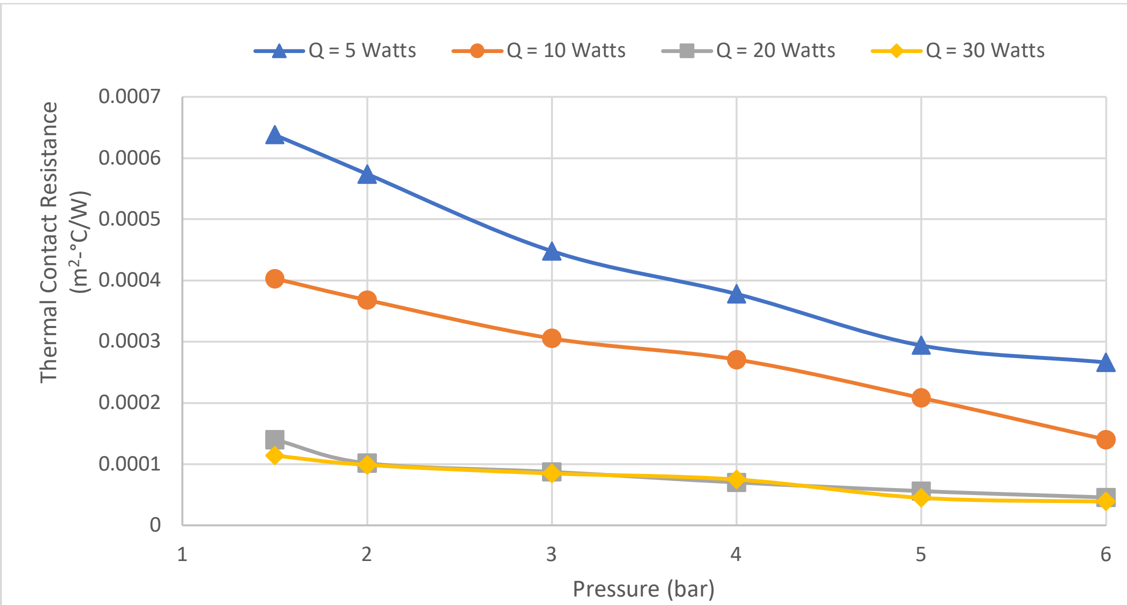
Experimentations are done on Aluminium and Copper specimens by varying pneumatic pressure and heat inputs. Based on the calculated data, thermal contact resistance at various operating conditions, graphs are plotted.

Figure 3 & 4 shows the variation of thermal contact resistance for similar combination (i.e., Aluminium – Aluminium) at different pressures and heat inputs respectively. By observing the plot of TCR vs Pressure, it shows that when pressure increases the thermal contact resistance decreases. From Figure 3, it is observed that the thermal contact resistance is found to be decreasing when the pressure increases from 1.5 to 6 bar. This reduces the gaps consisting of air which happens to be a hinderance at the interface. At 1.5 bar & 5 Watts, the thermal contact resistance for Aluminium-Aluminium is 0.000224 m^2-°C/W, whereas at 6 bar & 30.5 Watts, the thermal contact resistance is 0.0000252 m^2-°C/W.





From Figure 4, results suggest that the thermal contact resistance suddenly decreases from 5W to 10W when pressure is 1.5 bar to 6 bar i.e., there is an average of 43% decrease in thermal contact resistance when heat input goes from 5 Watts to 10 Watts for all the pressure range.
After increasing the heat input from 10W to 30W, there is a minimal deflection in thermal contact resistance. This clearly indicates that the temperature distribution is uniform for the higher loads because when the load is applied between the interfaces, the air gaps are minimized and the mating is perfect and the surface helps to conduct more heat and the temperature increases at the interface.
Figure 5 & 6 represents the variation of thermal contact resistance for dissimilar combination (i.e., Aluminium – Copper) at different pressures and heat inputs respectively. By observing the plot of TCR vs Pressure, it shows that there is decrease in thermal contact resistance when there is increase in pressure.



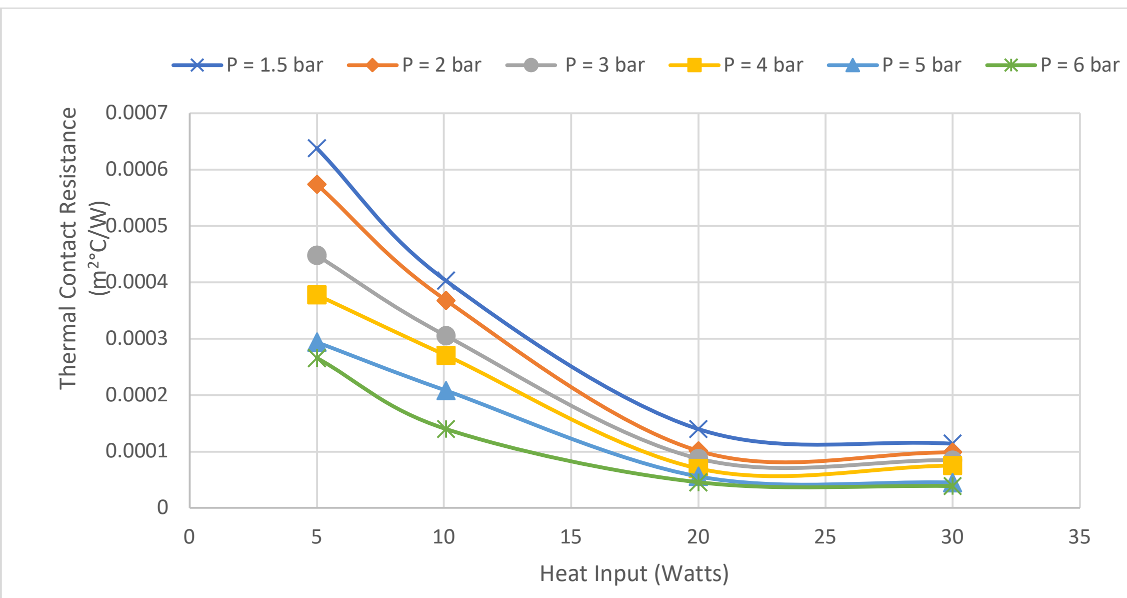
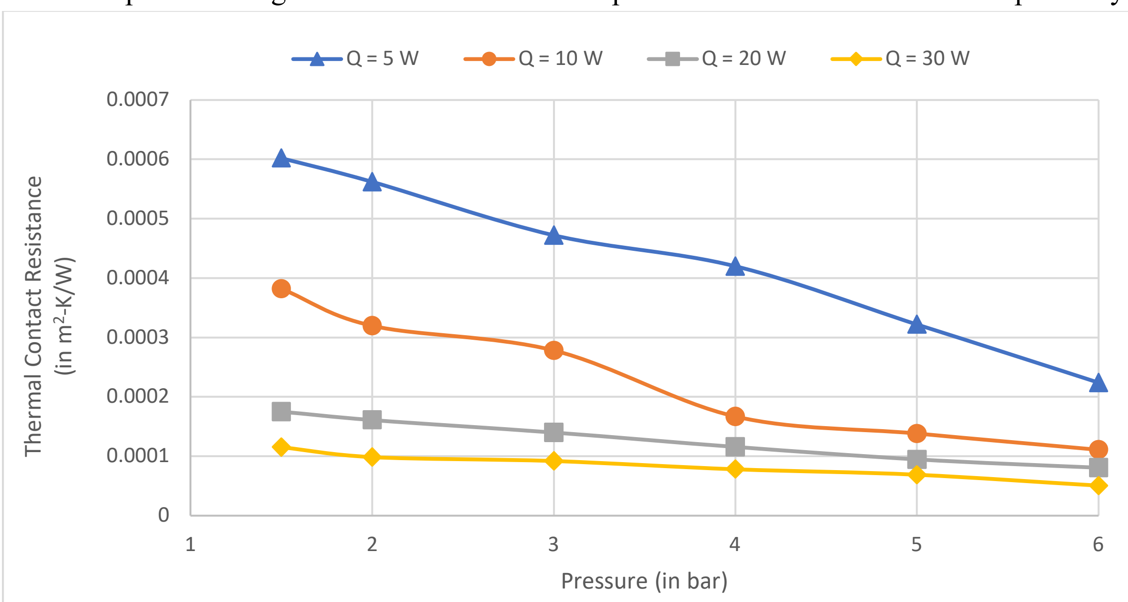


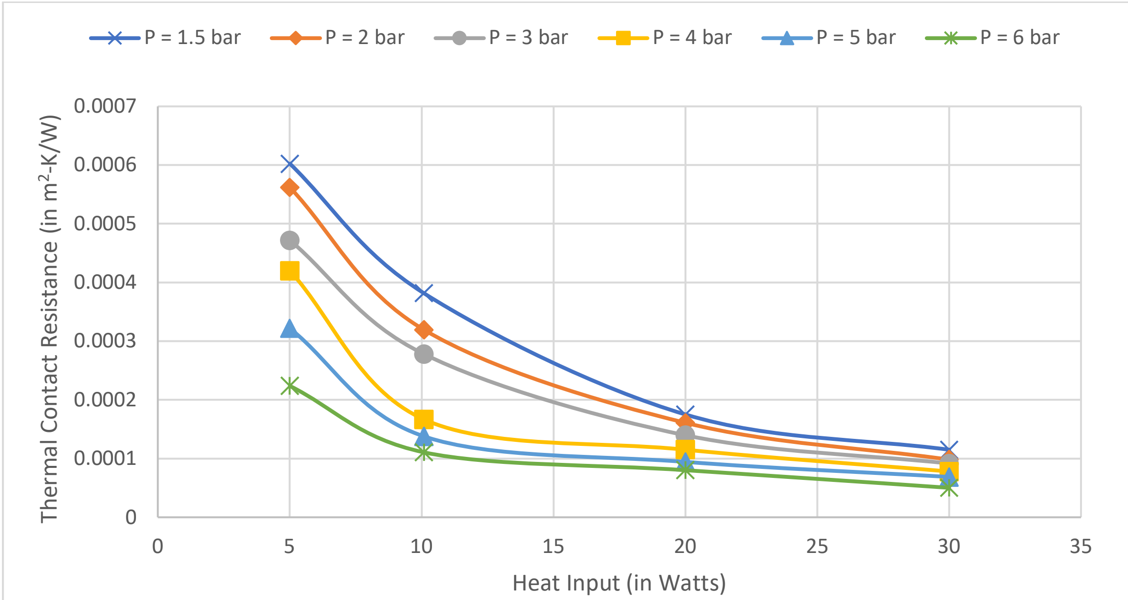
Figure 5 shows variations in thermal contact resistance under different pressures applied on the specimen. The thermal contact resistance for Al-Cu ranges from 0.000638 to 0.000039 m^2-°C/W. As pressure continues to increase, the thermal contact resistance decreases at a significantly slower rate. After the pressure exceeds 4 bar for heat input ranging from 20 Watts to 30 Watts, the thermal contact resistance is almost constant. Even if pressure increases continuously, it had a negligible effect on interface thermal resistance. In Figure 6, the thermal contact resistance has a nature of curve is steep till the point it reaches to 20 Watts. After 20 Watts, there is a minimal change in thermal contact resistance. This occurs as a result of the direction of heat flow being dependent on the value of thermal contact resistance between two different metals.

Figure represents the variations in thermal contact resistance for dissimilar combination (i.e., Aluminium – Brass) at different heat inputs and pressures respectively. By observing the plot of TCR vs Pressure, it shows that there is decrease in thermal contact resistance when there is increase in pressure.

Figure shows variations in thermal contact resistance under different pressures applied on the specimen. The thermal contact resistance for Al-Brass ranges from 0.000602 to 0.00005049 m2-K/W. As pressure continue to rise, the thermal contact resistance decreases at a significant rate when pressure ranges from 3 to 6 bar & heat input from 20 Watts to 30 Watts respectively.



From Figure 4, results suggest that the thermal contact resistance suddenly decreases from 5W to 10W when pressure is 1.5 bar to 6 bar i.e., there is an average of 43% decrease in thermal contact resistance when heat input goes from 5 Watts to 10 Watts for all the pressure range. After increasing the heat input from 10W to 30W, there is a minimal deflection in thermal contact resistance. This clearly indicates that the temperature distribution is uniform for the higher loads because when the load is applied between the interfaces, the air gaps are minimized and the mating is perfect and the surface helps to conduct more heat and the temperature increases at the interface.



Conclusion

The objective of this experimentation is to determine the thermal contact resistance of similar/dissimilar materials under different operating conditions.

Results indicate that:

a) Thermal contact resistance for Aluminium - Aluminium decreases by up to 43% when the heat input is increased from 5 to 30 watts and the pressure at the interface rises from 1.5 to 2 bar. The thermal contact resistance only decreases by up to 21% when pressure goes from 2 bar to 6 bar. By comparing the aforementioned findings, it can be seen that the thermal contact resistance, regardless of the change in heat input, is precisely proportional to an increase in pressure. When heat input is between 10W and 30W, the slope of the thermal contact resistance curve seems to be flat, however it is steep when heat input is between 1.5 and 2 bar and 5 to 10W at the interface.

b) When pressure is 1.5 to 2 bar at the interface and heat input is 5 to 20W, there is a decline in thermal contact resistance for Aluminium - Copper of up to 54%. When heat input varies from 20W to 30W for pressure ranges from 1.5 bar to 6 bar, the change in thermal contact resistance as a percentage can reach up to 19%. Taking into account the aforementioned findings, the slope of the thermal contact resistance curve becomes flat when heat input is between 20W and 30W, however the slope is steep when pressure and heat input are between 1.5 and 2 bar and 5 to 20W at the interface.

c) The results for aluminium-brass show that there is a reduction of up to 70% when heat input varies from 5 to 20 Watts under 1.5 bar to 3 bar of pressure. When pressure is increased from 3 bar to 6 bar and heat input is increased from 20 Watts to 30 Watts, there is a percentage change in thermal contact resistance up to 13%. The experiment's original parameters show a significant deviation when the results described above are taken into account. Thermal contact resistance shows a little deflection for the latter values, indicating that the slope is flat as the parameters rise.

d) Additionally, it has been noted that the thermal contact resistance barely changes when the heat input is raised from 10W to 30W. It is abundantly obvious that the temperature distribution is uniform for larger loads since the air gaps are reduced and the mating is perfect when weight is placed between the interfaces, the surface aids in more efficient heat transmission, and the temperature increases at the interface. The final conclusion states that Aluminium-Aluminium as a similar material combination exhibits better performance the Aluminium-Copper & Aluminium-Brass as dissimilar material combination. This suggests that the directional effect of similar materials shows dependency on its surface roughness and material properties.