NC STATE UNIVERSITY

Mechanical Engineering Systems
BSE At Havelock

(MES-400 Engineering Lab)

Thermal Conductivity

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I have neither given nor received any unauthorized assistance on this report.

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Abstract

In this experiment the Armfield linear conduction module was used to demonstrate heat conduction. Eight thermocouples were placed along the test device and an unknown specimen was placed in the middle of the test device. The test device was composed of two brass cylinders on the top and bottom and the unknown specimen in the middle. The brass cylinders and unknown cylinders were insulated and only the top and bottom planes were exposed so the only heat transfer mode was through conduction. Once the specimen was installed in the system, the voltage was set to 9 volts and current to 0.85 amps. The product of the voltage and current was used as to conduct heat to the system. Once the system was in steady state the thermocouple temperatures were recorded and for thermocouple's 4 and 5, the temperature was calculated by plotting the temperatures of thermocouple 1-3 and 6-8 as a function of distance and this was used to calculate the values for thermocouple 4 and 5. This was done for all the specimens and the entire temperature profile was plotted for the specimens. The thermal conductivities and resistance were also calculated.

The stainless-steel specimen had the most resistance to heat transfer, then followed by the brass specimen, and aluminum was the least resistive to heat. The aluminum specimen was able to conduct heat the fastest with steel conducting heat the slowest. Further research shows that aluminum is used in the material for heat sinks [1] due to its ability to conduct heat quickly.

Introduction

Objective

The objective of the experiment is to determine the heat transfer coefficients for all the unknown specimens.

Background

Heat conduction is important to study since it is used in applications that require heat to be transferred in or out, some examples are the heat pump of your house, computer fans, car radiators.

Relevant Theory

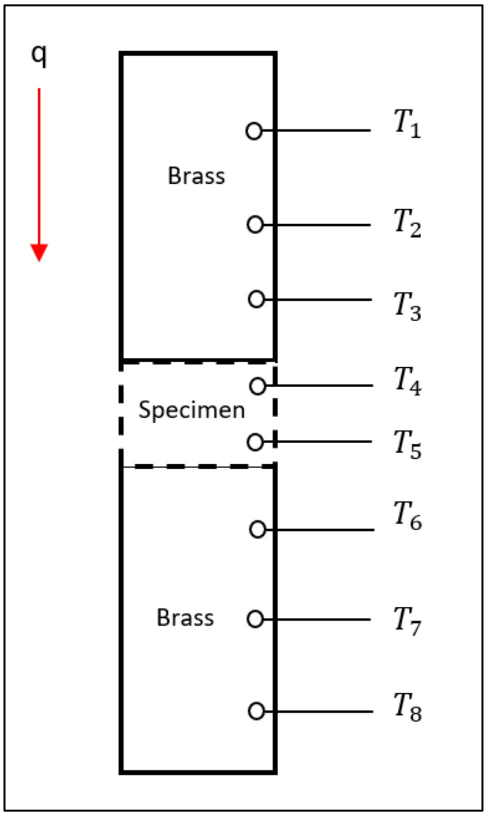


Figure 1: Experiment Configuration

Figure 1 shows the experimental system, the heat is transferred from the top brass cylinder through the unknown specimen(s) and transferred to the lower brass cylinder. There are eight thermocouples and labeled with appropriate notation. The heat q is simply the voltage multiplied by the current of the power supply. The system was heated with the unknown specimen in place until it was estimated to be in steady state condition. The distance between each thermocouple was measured later in the experiment and used in the calculations.

Fourier's law for 1-D steady state conduction is [2]:

$$q = kA\frac{\Delta T}{L} \tag{1}$$

Where: q is the heat rate, k is the thermal conductivity of the material, ΔT is the temperature difference, A is the cross-sectional area of the material, L is the length of the section.

The thermal conductivity can be solved for and is given by [2]:

$$k = \frac{ql}{A\Delta T} \tag{2}$$

ΔT can be calculated using interpolation of the hot and cold boundaries and forms a linear equation given by [2]:

$$\Delta T = mL + c \tag{3}$$

The resistivity is given by [2]:

$$R = \frac{L}{KA} \tag{4}$$

Where L is the length of the specimen, K is the thermal conductivity of the material, A is the cross-sectional area of the specimen.

<u>Methods</u>

1. The thickness or length of the unknown specimen were measured and recorded.
2. The thermocouple distances were measured and recorded.
3. The HT 11 Linear heat conduction unit was turned on.
4. Time was allowed for the specimen to reach steady state heat transfer.
5. The thermocouple temperatures were recorded.
6. The next specimen was placed and steps 4-5 were repeated until the final specimen was completed.

Results/Discussion

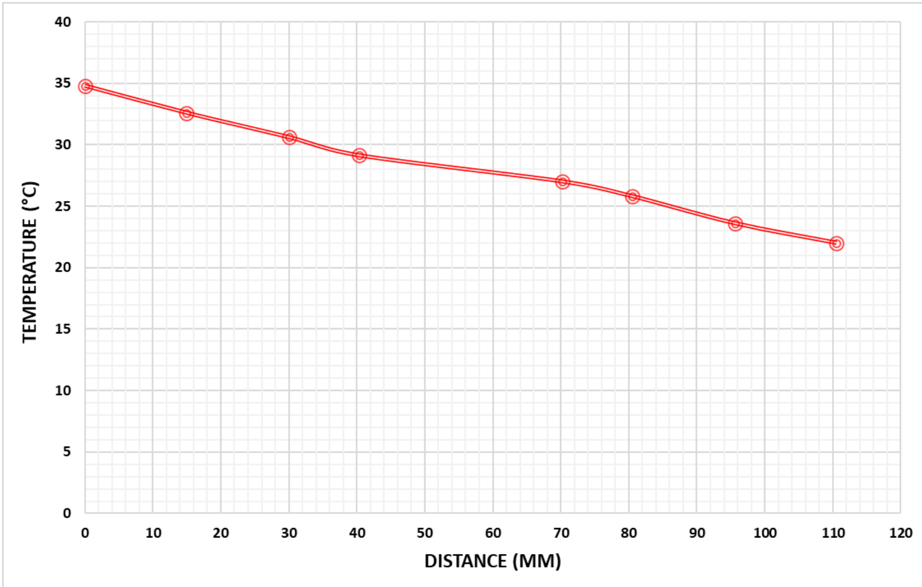


Figure 2: Aluminum Temperature Profile

Figure 2 is the temperature profile of the aluminum specimen. As the distance increases the temperature decreases. The thermocouples are placed along the distances. At distance 40 mm the temperature drops because of the specimen resistivity that the system encounters. The hot brass cylinder ends at 40 mm and the cold brass cylinder starts at 70 mm, the specimen is placed in the middle and has a thickness of 30 mm. There is not a lot of temperature difference between the hot and cold side of the aluminum. It can be inferred that the aluminum is a good heat conductor.

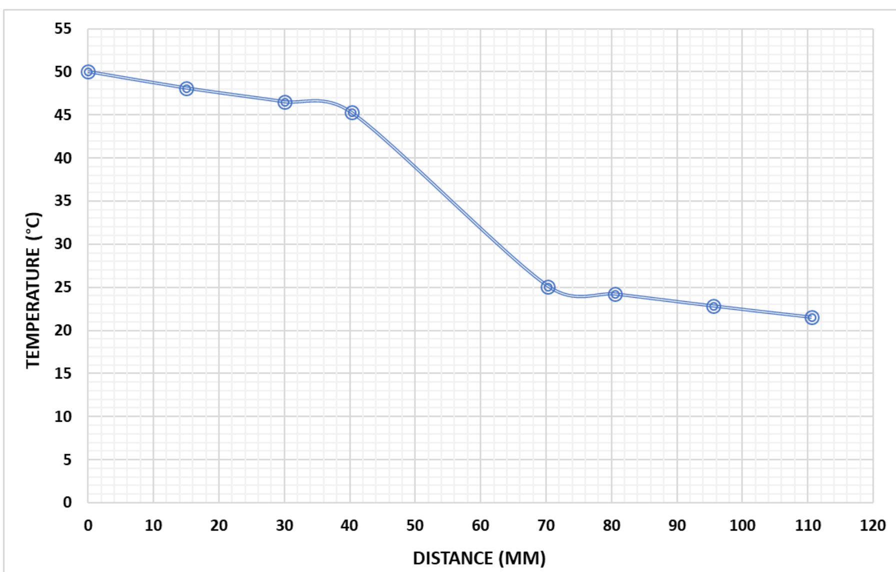


Figure 3: Stainless Steel Temperature Profile

Figure 3 is the stainless-steel specimen temperature profile. At distance 40 mm where the test brass specimen ends, the temperature profile has a dramatic drop and there is a difference of 20 degrees C between distance 40 mm and 70 mm, these are thermocouple numbers 4-5. Compared to the aluminum specimen, the temperature drop is more pronounced. This suggests that steel is not as conductive as aluminum is.

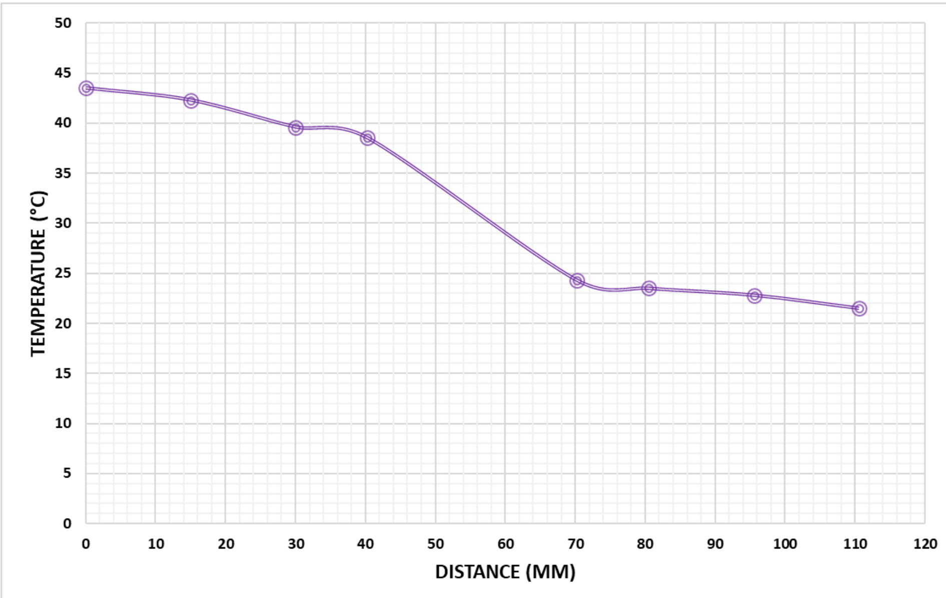


Figure 4: Brass Temperature Profile

Figure 4 is the brass specimen's temperature profile. The temperature drops from thermocouple 4 to 5 is roughly 15 degrees C. This is more than the steel and less than the aluminum which suggests that brass is in the middle of the two in terms of heat conductivity. It can also be noted that the brass has a smaller diameter and area than the aluminum and steel specimens.

Table 1: Thermal Conductivity Calculation

Material	Specimen	Diameter (m)	Length (m)	Area (m^2)	Q (W)	K (W/m-K)
Aluminum	1	0.025	0.03	4.91E-04	7.65	218
Stainless Steel	2	0.025	0.03	4.91E-04	7.65	23
Brass	3	0.013	0.03	1.35E-04	7.65	119
Top and Bottom Brass	N/A	0.025	0.03	4.91E-04	7.65	134

Thermal conductivity of a material is defined as a measurement of the material to conduct heat [5]. Fourier's law for heat conduction (equation 1) was used to calculate the thermal conductivities. Table 1 is the thermal conductivities for the specimens. The diameter and length were measured with calipers and the conductivity of the specimens were calculated using equation 2. The stainless steel has the least heat conductivity, and the aluminum has the most thermal conductivity. The brass was the second most conductive after the aluminum specimen despite having a smaller diameter. The heat transfer conductivities are also close to what was found in the pre-lab. The aluminum and brass are slightly lower than the tabulated values, this is possibly due to the system not being in perfect steady state conditions. It be noted that the top and bottom brass have slightly different thermal conductivities than the test specimen and this is most likely due to being in steady state longer.

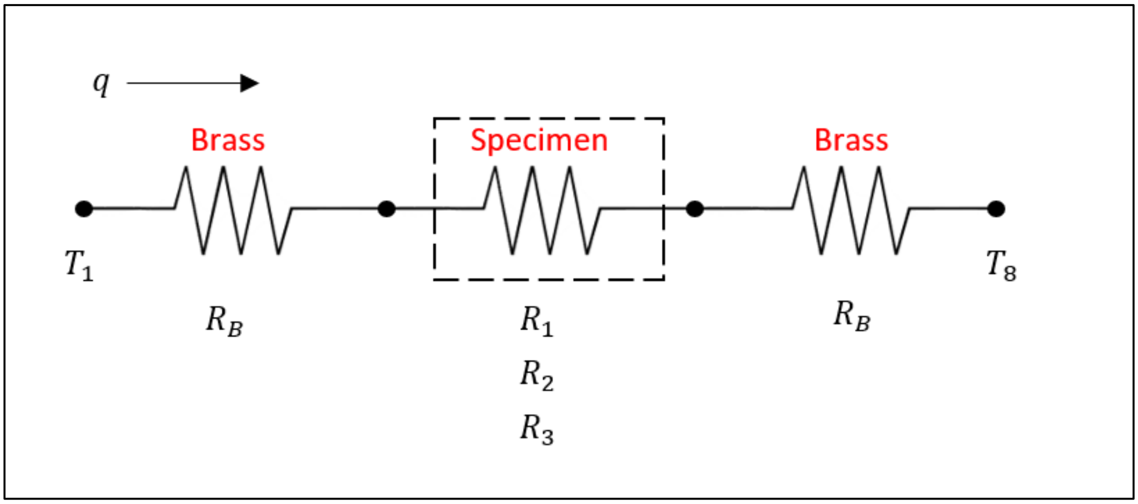


Figure 5: Thermal Resistance Schematic

Figure 5 shows the thermal resistance schematic of the experimental system. The resistors to the left and right represent the brass specimens, the resistor in the middle are the specimens that are switched. The heat transfer occurs from the hot side (left) and goes to the cold side (right). All the specimens are insulated around the outer walls, so the only heat transfer mode is through conduction and not radiation or convection.

Table 2: Thermal Resistivity

Material	Specimen	Resistivity (K/W)
Aluminum	1	0.280
Stainless Steel	2	2.750
Brass	3	1.880
Top and Bottom Brass	N/A	1.880

Thermal resistance is a property of the material to resist heat, this can be quantified for different materials [6]. The resistivity is calculated in Table 2. The stainless steel has the most resistivity to the heat transfer, followed by the brass, and the aluminum specimen has the least resistivity. The resistivity data is further reinforced by figures 2-4 in which the temperature drops visually as the distance increases. From the figures the aluminum is the least resistive and the temperatures conduct from one side to the other with minor heat losses.

Conclusions

Based on the lab data it can be concluded that aluminum can transfer more heat than the stainless steel and brass specimen. Aluminum is commonly used for heat sinks [1] because of its thermal conductivity and in plastics processing in injection molded machines, the curing time of the part is dependent on the thermal conductivity of the material [3] which is why aluminum is used.

The resistivity schematic was made to show the similarity between heat transfer and electrical conductivity. It was learned that stainless steel is the least thermally conductive out of the three specimens, this was evident by the temperature profile shown in figure 3 and the thermal resistivity calculation shown in table 2. Further research shows that stainless steel is commonly used in food processing ovens and conveyors that are exposed to high heat [4]. Thermal resistance of materials is important to electrical components, so the components do not overheat and fail.

Overall, it was learned that steel has the most resistivity to heat and aluminum the least resistive, this observation was also confirmed multiple times in figures 2-4 and experimentally confirmed as well. Research was done to confirm the experimental data and the applications of the different specimen materials. This experiment was a good way to showcase thermal conductivity/resistivity through different materials.

References

1. https://www.qats.com/cms/category/heat-sink-material/
2. https://moodlecourses2122.wolfware.ncsu.edu/mod/resource/view.php?id=1729
3. https://www.clintonaluminum.com/how-hot-is-too-hot-for-aluminum/
4. https://thermtest.com/thermal-conductivity-of-steel
5. https://en.wikipedia.org/wiki/Thermal_conductivity
6. https://en.wikipedia.org/wiki/Thermal_resistance

Appendix A: Data Collection Sheet With Calculations and Notes

Specimen	Diameter (m)	Length (m)	Area (m^2)
1	0.025	0.03	0.000490625
2	0.025	0.03	0.000490625
3	0.01311	0.03	0.00013492

Specimen 2			
Profile	Temperature ©	X (mm)	T
T1	50	0	50
T2	48.1	14.97	48.1
T3	46.5	30.06	46.5
T4	45.26	40.28	45.258408
T5	25.104856	70.28	25.104856
T6	24.2	80.5	24.2
T7	22.8	95.59	22.8
T8	21.5	110.56	21.5
Voltage	9		
Current	0.85		
Power	7.65		
Specimen 1			
Profile	Temperature ©	X (mm)	T
T1	34.8	0	34.8
T2	32.6	14.97	32.6
T3	30.6	30.06	30.6
T4	29.136884	40.28	29.136884
T5	26.997608	70.28	26.997608
T6	25.8	80.5	25.8
T7	23.6	95.59	23.6
T8	22	110.56	22
Voltage	9		
Current	0.85		
Specimen 3			
Profile	Temperature ©	X (mm)	T
T1	43.5	0	43.5
T2	42.3	14.97	42.3
T3	39.6	30.06	39.6
T4	38.5	40.28	38.519656
T5	23.33	70.28	24.28138
T6	23.5	80.5	23.5
T7	22.8	95.59	22.8
T8	21.5	110.56	21.5
Voltage	9		
Current	0.85		

Appendix B: Hand Calculations

$$K = \frac{qL}{A(T_{hot} - T_{cold})}$$

Specimen 2: $q = 9V \cdot 0.85A = 7.65\,W$

$L = 0.03\,m$

$A = \pi(0.025/2)^2 = 0.00049\,m^2$

$\Delta T = T_3 - T_6 = 46.5 - 24.2 = 22.3$

$$K = \frac{7.65\,W \cdot 0.03\,m}{0.00049\,m^2 \cdot 22.3^\circ} = 21\,\frac{W}{m\text{-}K}$$

Specimen 1: $q = 7.65\,W$

$L = 0.03\,m$

$A = 0.00049\,m^2$

$\Delta T = 30.6 - 25.8\,^\circ C = 4.8$

$K = 97.58\,\frac{W}{m\text{-}K}$

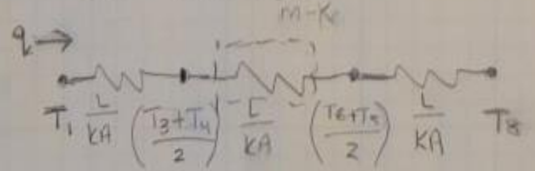
Specimen 3: $q = 7.65\,W$

$L = 0.03\,m$

$A = 0.00013$

$\Delta T = 39.6 - 23.5 = 16.1$

$K = 109.65\,\frac{W}{m\text{-}K}$



$$R_2 = \frac{L_1}{k_1 A_1} \rightarrow \frac{0.03\,m}{\left(22.21\,\frac{W}{m\text{-}K}\right)\cdot(4.9\cdot 10^{-4}\,m^2)} = 2.75\,\frac{K}{W}$$

$$R_1 = \frac{0.03\,m}{\left(218.65\,\frac{W}{m\text{-}K}\right)\cdot(4.9\cdot 10^{-4}\,m^2)} = 0.28\,\frac{K}{W}$$

$$R_3 = \frac{0.03\,m}{\left(119\,\frac{W}{m\text{-}K}\right)\cdot(0.000134\,m^2)} = 1.88\,\frac{K}{W}$$

Equipment

Equipment Used**:**
HT 11 Linear Heat Conduction Unit
Thermocouples
Stainless Steel Specimen
Aluminum Specimen
Brass Specimen