An experimental study on thermal conductivity of T2 copper with different surface roughness

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Abstract. Recent previous studies have shown that there is a correlation between heat conductivity and surface materials. In this project, the heat conductivity of 3 different samples of T2 copper with different surface roughness was studied. This was done by measuring the temperature of the samples at 9 different points using SOLTEQ Heat Conduction Study Bench (Model HE106). The surface roughness of the different samples was achieved using sandpaper and measured using the (SURFTEST SJ-410) where the different surface roughness was A: Ra=0.379µm, B: Ra=0.71µm, C:Ra=0.053µm. The sample was heated using a heater with 10W of power. From the collected data, it was observed that the specimen with the smoothest surface roughness has the best performing heat transfer with the specimen C that have the highest decreasing percentage temperature followed by specimen B and specimen A.

1. Introduction

The phenomenon of thermal conductivity has a significant importance in both simple and complex systems where it was shown that, in most applications like a microchip heat transfer, it is best to have an ideal heat transfer rate [1]. One factor that has been shown over the past several decades in several fields from synthetic design [2] to aviation design [3] is surface roughness. Surface roughness can be simply described as the unevenness in the surface of a given object [4]. In a previous study that studies the impact of surface roughness of aluminium alloy [5], it was pointed out the difficulties of thermal management.

Due to rapid advancement of technology, more and more devices that depends on electronic frameworks where thermal management is critical. Current engineering standard practice uses aluminium compound material for thermal management of electronic gears and structure configuration. However, the current practice has its limitations in terms of application since it was expressed that a better thermal conductivity material is needed that have higher contact pressure and thermal interface materials (TIM).

Past works have shown the relation between surface roughness and heat transfer where it was shown that the surface roughness effects the emissivity of the material due of the unevenness of the rougher surface [5].
However, the study is limited to radiant heat transfer but the effect of surface roughness on heat conduction is still limited in previous works. Therefore, the aim of this study is to investigate the effect of surface roughness on heat conductivity.

2. Methodology
This study uses a T2 copper as a test specimen. As seen in figure 1. The specimen that was used was a solid cylindrical that have a 30mm length and a 25mm diameter. The thermal properties and material properties of the different materials can be seen in table 1 and table 2.

| Material | Thermal Conductivity |
|----------|----------------------|
|          | W/m.K                | Btu/ft.h°F |
| C11000 (electrolytic tough pitch) | 388 | 224 |
| C17200 (beryllium-copper) | 105-130 | 60-75 |
| C26000 (cartridge brass) | 120 | 70 |
| C36000 (free-cutting brass) | 115 | 67 |
| C71500 copper-nickel, 30% | 29 | 16.8 |
| C93200 (bearing bronze) | 59 | 34 |

Table 2. Test specimen strength and mechanical properties.

| Specimen | Tensile strength (Rm/MPa) | Rockwell hardness (HRF) | Elongation (%) |
|----------|---------------------------|-------------------------|----------------|
| T2 Copper / C11000 | ≥ 295 | ≥ 65 | ≥ 3 |

Figure 1. Different surface roughness’s of specimens.

The surface roughness of the specimen was achieved using a BUEHLER Handimet Roll Grinder grinding machine with different grits to achieve different surface roughness. The surface roughness of the specimen was measured using a Mitutoyo surftest SJ-410 machine (Figure 2). The machine measures
and calculate the surface roughness using a probe where the average toughness, \( R_a \) calculate using arithmetic average (AA) where the total of the absolute values of all areas above and below the average line and then divided by the sampling length Figure 3. Higher AA value means a rougher surface.

![Figure 2](image1.png) **Figure 2.** Measuring the surface roughness with Mitutoyo surface test SJ-410.

![Figure 3](image2.png) **Figure 3.** Profile surface of arithmetic average (R_a).

The heat conductivity itself was measure using the SOTEQ Heat Conduction Study Bench (Model HE106) (figure 4) that can study two types of heat conduction for linear heat conduction it has a multi-section bar and for radial heat conduction it has a metal disk probe. This study uses linear heat conduction test module. In terms of providing heat for testing, the Study Bench has a digitally controlled heater with a selector switch and water-based cooling system.

This study uses Fourier’s Law of Heat Conduction as the base model (figure 5) for the linear conduction study where an electrical heater was used and a separate heat sink section to generate heat and the temperature was measured using sensors that are installed at 10mm intervals and the heat loss measured by the sensors are used to measure the heat conductivity. To reduce outside heat losses, heat resistant casing was used that have interchangeable center sections with attached casing pieces that fit with the heat input and heat sink sections. The sensors come with a miniature thermal couple plugs that is connected to a panel and a data acquisitions system and the temperature measurements are plotted in a computer.

The heat conductivity of the test sample is governed by the equation:

\[
Q = -kA \frac{dT}{dx}
\]

(1)

Where

- \( Q \) = rate of heat conduction in the x-direction
- \( k \) = thermal conductivity of the material
- \( A \) = cross-sectional area normal to the x-direction
- \( \frac{dT}{dx} \) = temperature gradient in the x-direction.

Also measured and recorded in this study is the temperature drop percentage between the heater surface and it is calculated using formula:

\[
Temperature drop percentages = \left( \frac{T_{n+1}}{T_n} - 1 \right) \times 100
\]

(2)
Where:

$T_{n=1}$ is the surface specimen surface temperature

$T_2$ is the temperature of the heater surface end where the heater is connected to the test specimen.

**Table 3.** Specimens configuration.

| Specimen | Grit used | Ra value (µm) |
|----------|-----------|---------------|
| Specimen A | 240       | 0.379         |
| Specimen B | 240, 320, 400, 600 | 0.071         |
| Specimen C | 240, 320, 400, 600, 1000, 1500, 2000 | 0.053         |

3. **Results and discussion**

Figure 6, 7, and 8 shows the temperature change in for all three specimens at different surface points. From the collected data, it is shown that the smoothest specimen, Specimen C has the largest percentage of temperature drop of -$51.65\%$ followed by Specimen B with -$49.82\%$ and specimen A at -$48.88\%$. This shows that smoother surface produces a better heat transfer while rougher surface produces worse heat transfer during contact with other metal. The better heat transfer is due better contact that allows for better heat transfer where the more surface contact area and allow for molecular interaction between two conducting elements. This also means that a rougher surface decreases the thermal efficiency due to the decrease in contact surface area between the heating element and the conducting element.
Figure 6. Graph temperature, $T$ vs distance, $x$ with $Ra = 0.379 \mu m$ at $10 W$.

Figure 7. Graph temperature, $T$ vs distance, $x$ with $Ra = 0.071 \mu m$ at $10 W$.

Figure 8. Graph temperature, $T$ vs distance, $x$ with $Ra = 0.053 \mu m$ at $10 W$. 
4. Conclusion
This study aims to test the thermal conductivity of different surface roughness. The result shows that the smoother the surface roughness the higher the percentage of temperature drop. This is due to the increase of surface contact with smoother surface roughness that allows for better heat transfer. This shows that among other parameters, surface roughness is a major contribution to heat transfer.

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