Contact Resistance Demonstration

Abstract

Contact resistance is the discontinuity of heat transfer between two separate solids. The smoother the two contact surfaces are, the less contact resistance will be and the greater the heat transfer. This is an important part of the heat conduction field. This paper deals with one very inexpensive way to study contact resistance and to teach students about heat transfer across two surfaces. Starting with a 1-inch diameter steel shaft, 21 inches long, 6 holes (1/8-inch diameter) were drilled to the center line. These holes housed K-type thermocouples. One end of the shaft was machined smooth while the other was cut with a torch and cleaned up with a grinder. It was irregular and bumpy which gave inconsistent contact. By using a hot plate (for cooking) along with a metal plate to supply the base heat, the shaft was placed in the vertical position with either the smooth or rough end against the plate. The shaft was held in place by a chemistry flask stand. Once the temperatures of the shaft stabilized, these temperatures and the temperature of the base plate were recorded. The shaft represents a round fin and the temperature dropped off according to the round fin formula. These temperatures were plotted and curve fit with a 4^{th} degree polynomial function. Using this equation, the fin distance was set to zero to find the fin temperature at the interface. The derivative of this equation at the fin length of zero, gave the slope of the line at the interface. This slope was used to find the heat transfer. With these values, the contact resistance was calculated. The shaft was flipped to the other end and the procedure was repeated. The rough end had a higher contact resistant and a higher base plate temperature. The smooth end, made better contact with the base plate and was more effective in transferring heat to the fin, thus lowering the base plate temperature.

Introduction

The study of contact resistance is important in many industries. CPU cement for instance helps hold microchips in place but also bridges the gap when contact resistance that might be present between the chip and the mother board. Marlow and Das outlined the effects of contact resistance and the factors affecting it on ohmic contacts to semiconductor devices.[1] This resistance was shown to be significant under certain conditions. Chang (et.al.) studied methods of measuring the ohmic or rectifying behavior of a metal-semiconductor barrier under operating conditions.[2] They calculated the contact resistance for several combinations.

Other parts that manufacturing dictates that they are made separately, may have to be attached (welded, bolted, etc.) to complete a heat transfer circuit. Care must be made to assure the mating parts have the lowest contact resistance possible.

This paper details a simple and inexpensive way to demonstrate the importance of understanding contact resistance for engineering students. It also incorporates an analytical method for helping the understanding of this phenomenon. This experiment was intended for student learning and not for scientific rigor. There are just too many variables that are not controllable in a classroom setting. The lecture on heat transfer can explain the concept, but a physical demonstration enhances learning objectives. Heat transfer lectures do not normally have associated laboratory classes. This experiment can easily be conducted in a class room without extensive laboratory equipment. This type of teaching method promoted active learning as the primary learning objective.[3] Allowing students to actually see a problem and then formulate a solution, enforces the concept through an active learning technique. [4]. Research has shown that this is a far superior method to learning than the traditional lecture-based class.

Background

Contact resistance exists when two separate solids come in contact with each other. Small micro bumps create cavities at the interface that give a lower heat transfer than does the areas where the solids are in contact. Figure 1 shows a representation of the contact surface between to solid parts [5].

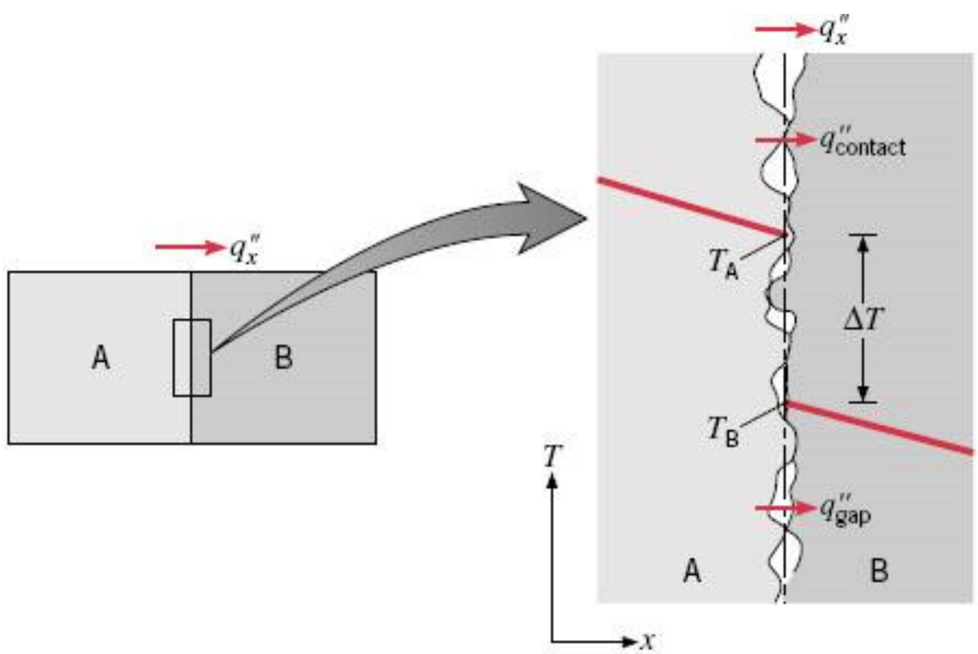

Figure 1 shows a representation of the contact surface between two solids, A and B.

In order to calculate the thermal contact resistance, several quantities must be found. Looking at equation 1, the resistance required both surface temperatures and the heat flux of the gap to be known.

$$R''_{t,c} = \frac{T_A - T_B}{q''_s} \qquad Eqn\ (1)$$

The experiment involved a long shaft that mimicked a round fin. The fin was long enough so that it approached an infinite fin problem. Once temperatures along the fin were recorded, the students had to manipulate the data to find the heat flux at the interface and the two temperatures.

Experimental Setup

This simple test setup was very inexpensive and easy to set up and conduct. The first piece required, was a heat source. A simple hot plate for cooking worked very well (see Figure 2).

Figure 2 shows the hot plate used for the heat source

On top of the hot plate, a flat metal plate was heated. This metal can be any type of metal but the greater the heat transfer coefficient, the more uniform the surface temperature will be. Figure 3 shows this setup.

The shaft used for the fin is a 1-inch CR-1020 shaft, 21 inches long. One end was machined smooth while the other end was rough cute (see Figure 4). The difference end conditions allow a comparison of different contact resistance conditions. The smooth end had less resistance and conducted heat from the plate to the fin more effectively, thus lowering the temperature of the flat plate.

Figure 3 shows the heating plate's position atop the hot plate.

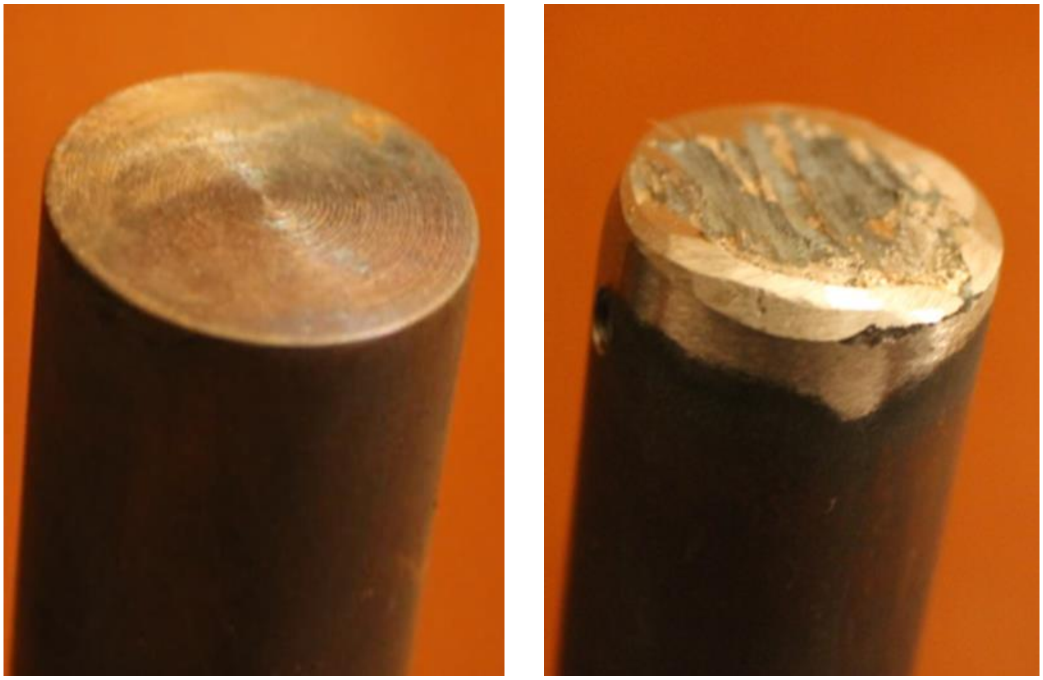

Figure 4 shows the end conditions of the shaft.

To measure the temperatures of the fin, six holes were drilled starting at ½ inches from one end and then every four inches after that. The last hole was ½ inches from the opposite end. These holes were 1/8 inches in diameter and ½ inch deep (to the centerline of the shaft). These holes can be seen in Figure 5. A K-type thermocouple was epoxied in each hole and attached to a reader.

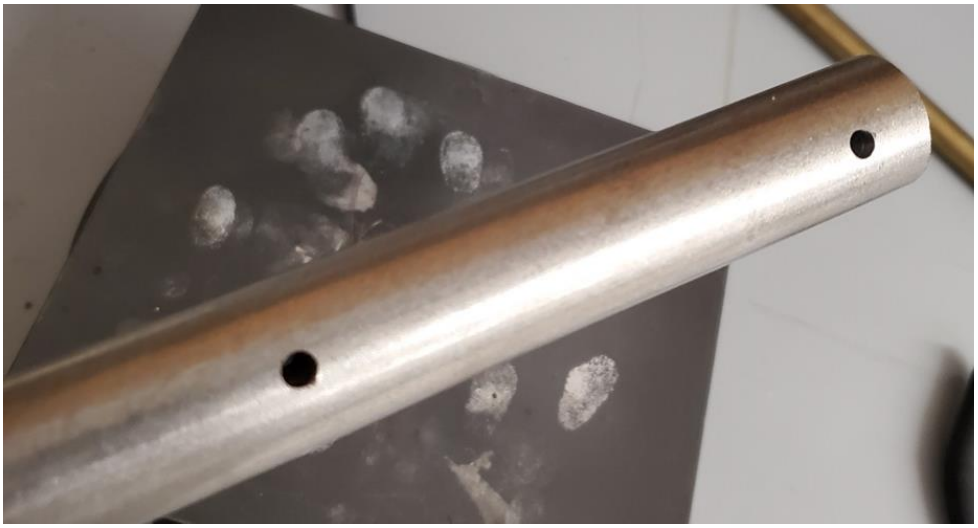

Figure 5 shows the location and orientation of the thermocouple seats.

The final assembly used a chemistry flask stand to hold the shaft in place, placing either end against the hot plate to allow for contact. The final assembly is shown in Figure 6. Once the data had been taken, the shaft was flipped so the opposite end makes contact with the hot plate and the temperatures were allowed to stabilize. This procedure showed a contact resistance difference between a smooth surface and a rough surface.

Figure 6 shows the final assembly

Student Deliverables

The first step was for the students to plot the data. Several different software packages are acceptable, but the following figure (Figure 7) was plotted in Excel.

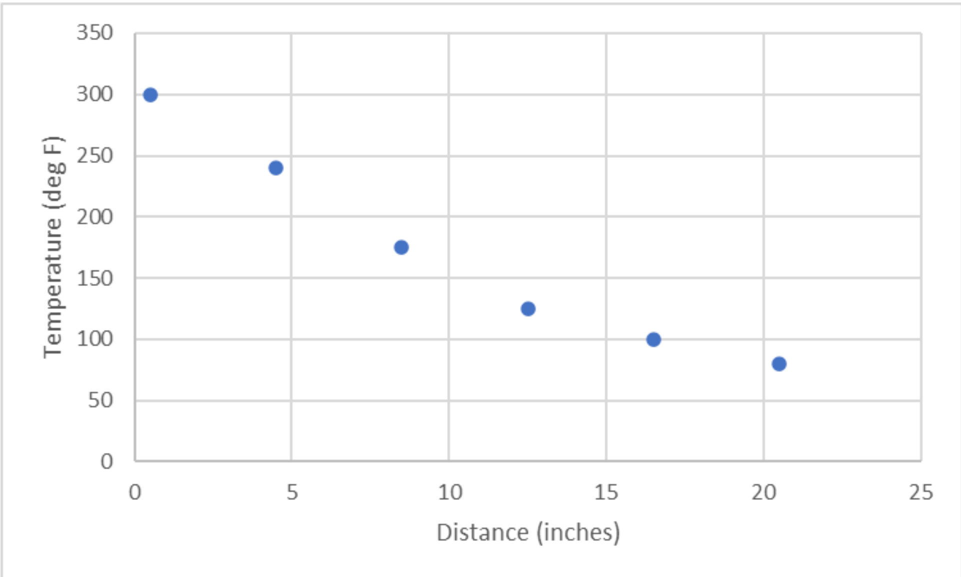

Figure 7 shows a representative data set for the experiment.

Manipulations of the graph was relatively simple. The plot was curve fit with a 4th degree polynomial, T(x). Also, the students recorded the base plate temperature (T_A). Now, the equation, T(x), was used to find the bottom fin temperature by setting the x distance to zero:

$$T_B = T(x)|_{x=0} \qquad Eqn\ 2$$

and the heat transfer across the gap (knowing the conductivity, k, of the metal shaft).

$$q''_x = -k \frac{dT}{dx}\bigg|_{x=0} \qquad Eqn\ 3$$

This gave all the information a student needed to find the contact resistance based on equation 1 and compare the contact resistance of a rough end to that of a smooth end. The contact resistance of the rough end was noticeably larger than the smooth end, and will depend of the degree of roughness of the shaft end.

Conclusions

The topic of contact resistance is very important for many industries including the microprocessor industry and heat exchanger design. This paper described a simple, and more importantly, inexpensive way to demonstrate the contact resistance of two different surface conditions. The student deliverables are fairly easy for students to calculate, but they require some equation manipulation and some thought. In addition to contact resistance, the opportunity arises for instruction on round, constant area fin heat transfer. The actual fin heat transfer equation can be used instead of a polynomial curve fit, but the math is considerably more complicated and the increased accuracy is negligible for this simple experiment. R-squared values of the curve fit for the data with a 4th degree polynomial was greater than 0.97. It is up to the instructor as to whether use the actual fin equation or curve fit. From experience, there were very little numerical difference in the contact resistance. In fact, many uncontrollable factors affect the accuracy in a classroom setting. This experiment was for demonstration purposes only and not for scientific discovery.

References

[1] Gregory S. Marlow, Mukunda B. Das, The effects of contact size and non-zero metal resistance on the determination of specific contact resistance, Solid-State Electronics, Volume 25, Issue 2, 1982, Pages 91-94,

[2] C.Y. Chang, Y.K. Fang, S.M. Sze, Specific contact resistance of metal-semiconductor barriers, Solid-State Electronics, Volume 14, Issue 7, 1971, Pages 541-550,

[3] Sarah E. Bonner (1999) Choosing Teaching Methods Based on Learning Objectives: An Integrative Framework. Issues in Accounting Education: February 1999, Vol. 14, No. 1, pp. 11-15.

[4] Diane F. Wood (2003) ABC of Learning and Teaching in Medicine: Problem Based Learning. Clinical Review, BMJ Publishing group, BMJ2003;326:328

[5] Incropera, DeWitt, Bergman and Lavine (2007) Introduction to Heat Transfer, John Wiley & Sons, Hoboken, NJ. pp. 101-102.