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# Study of Temperature Measurement Accuracy by Using Different Mounting Adhesives

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***Abstract* – Thermal compounds are adhesive used to improve heat conduction between two surfaces. It can be used to secure a thermocouple to a surface which the temperature is being measured. This paper studies the temperature accuracy when using different types of thermal adhesives to secure thermocouples to a metal surface. An aluminum block attached to heater resistors was heated up by supplying varying power levels to create different temperatures. The measured temperature is compared to a reference thermocouple in the aluminum block to check the accuracy of each thermocouple when it is secured with different adhesives. It was found using the Loctite 3873 to secure a thermocouple to a metal surface will produce the most accurate temperature reading with an error below 2.6°C. This enables researchers to use the appropriate adhesive to obtain the most accurate results and also to know what are the errors contributed by different adhesives.**

***Keywords—Thermal compound, thermocouple adhesive, aluminum block, temperature***

## I. INTRODUCTION

Thermal measurement is an integral part of measuring thermal performance of products in test laboratories. The purpose is to determine if measured surface temperature on device under tests (DUTs) are within specified accuracy limits required in test laboratories [1]. Therefore, it is critical to ensure measured temperature is accurate. When measuring temperature on a surface, the thermocouple must make proper contact with the surface in order to obtain accurate measured temperature. Thermal adhesive/ compounds are used in order to improve contact and have stronger adherence between the thermocouple to the surface being measured, [2]. This method is commonly used by test laboratories [2, 3]. In this study, thermal adhesives were used to attach thermocouples on a heated an aluminum block to measure its surface temperature and compare it against the reference (true) value. These adhesives being studied are of the Loctite brand and polyimide tape is of the Kapton brand.

There are various choices of adhesives with varying specs that can be used for temperature measurement. In this study, the accuracy of the temperature measurement when using different adhesives for measuring temperature will be studied. Various thermocouples will measure temperature of an aluminum block while being attached using various adhesives. We compared the temperature measured using three different types of Loctite adhesives and a Kapton tape. Loctite is commonly used in the industry to adhere thermocouples to a surface for measurement [3 – 5]. Thermal adhesives are an alternative to soldering as an attachment method [5]. The Kapton (polyimide tape) measurement was added in because it is also a method used in the industry for attachment of a thermocouple to a surface for temperature measurement studies [2 – 5]. We set different supply voltages (5 V, 6 V, 7 V, 8 V. 9 V and 10 V) into the heater resistors to heat up the aluminum block to different temperatures. The measured temperature was recorded.

## II. SCOPE OF STUDY

This paper focuses on comparison of various thermal adhesives and Kapton tapes in securing a thermocouple for temperature measurement on an aluminum block.

### *A. Thermal Compound and Kapton Tape*

Different thermal adhesive and Kapton tape were used in this study to mount the thermocouple on an aluminum block. There are many types of thermal compound that can be found in industry, but in this study, we limit it to the Loctite 3873, Loctite 416, Loctite 480 and Kapton tape in this study on its effectiveness in measuring temperature accuracy on an aluminum block when using different mounting methods.

## III. TEST SETUP AND VERIFICATIONS

The temperature has been measured by using the concept of a custom built anodized aluminum block by Kanesalingam and Kung [6]. Anodized aluminum has a known thermal emissivity value which can be set in a thermal camera to



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accurately measure its surface temperature. The aluminum block is also attached with heater resistor inside it which serves as the reference temperature. To heat up the block, it is supplied with different voltage. There is also a reference inside the block that is able to measure the "True" values of the temperature.

Method by Kanesalingam and Kung [6] was used to verify the accuracy of the setup with the aluminum block. This was done so that the reference thermocouple inside the block can be compared against the thermocouple that is attached with different thermal adhesives measures.

*A. Attaching Thermocouple on Aluminum Block*

To perform the measurement, the thermocouples were attached on the block surface by using thermal compounds and Kapton tape mentioned in above section. A thermocouple was also placed inside the aluminum block to measure the temperature. This temperature will be a reference for measured temperature on the block surface. The thermal camera did not need to be used for this setup because the temperature of the reference (true) value of the aluminum block can be obtained by the thermocouple inside the block.

The thermocouple used in this study is Type J with thickness AWG 36. The thermocouple wire size was selected so that it is easily welded but not too large as to provide a cooling effect on the surface. Thermocouple wires are welded (as shown in Fig. 2) to ensure proper connection between both the ends to prevent inaccurate temperature readings. The welding melts both of the metal types of the thermocouple wire together without using any solder. The various thermocouples are then attached on the aluminum block surface by using Loctite 3873, Loctite 416, Loctite 480 and the Kapton tape. The temperature is then recorded by attaching the thermocouples to a temperature logger. The difference in thermal conductivity of the thermal compounds is shown in Table I.

Table I. TECHNICAL SPECS OF DIFFERENT THERMAL COMPOUNDS.
Source: Self compilation with datasheets from [7 – 9].

| Adhesive model | Thermal conductivity (W/(m·K)) |
|---|---|
| **Loctite 3873** | 1.25 (ISO 8302) |
| **Loctite 416** | 0.1 (ISO 8302) |
| **Loctite 480** | 0.1 (ISO 8302) |

Figure 1 shows the setup of the power supply to the heater resistors and the mounted thermocouple (with thermal adhesive) connected to a temperature logger. Thermocouple Type J was with an accuracy of ± 1.1°C.

The aluminum block upon which the thermocouples were attached to is shown in Fig. 3. Upon attachment to the thermocouple, the Loctite adhesives are cured using the relevant accelerator types. As for the Kapton tape, in order to work effectively, it requires sufficient placement area [5]. Thus, an area of 1 cm × 2 cm was used to stick the thermocouple on the aluminum block.

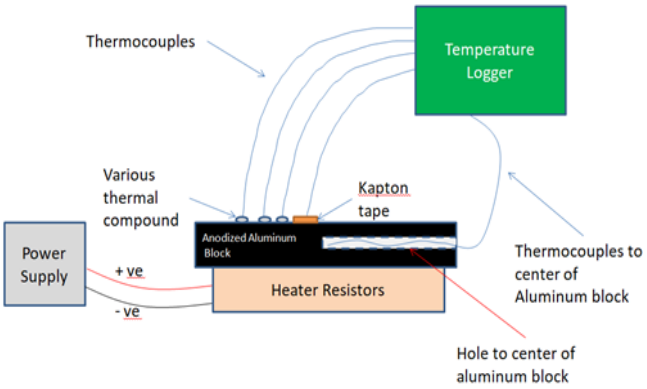


Fig. 1. Setup of experiment.

Fig. 2. Welded Type – J thermocouple.

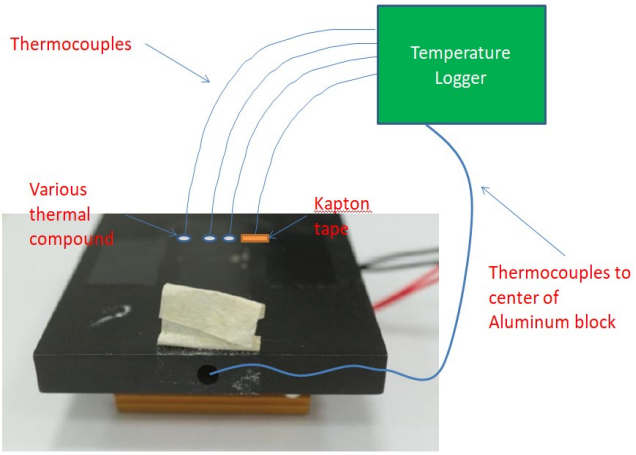


Fig. 3. Attachment method of thermocouple on aluminum block.


Fig. 4. Loctite 3873, Loctite 416, Loctite 480 and Kapton tape used in study.

## IV. TEST RESULTS

The results of the different compounds and Kapton tape for attachment of the thermocouples are shown in Table II. Loctite 3873 has the smallest error to the reference value among the 3 Loctite models and the Kapton tape that was evaluated in Fig. 4. Loctite 416 has acceptable accuracies for temperatures up to 57.4°C and increases in error in higher temperatures.

It is observed that the Kapton tape is unable to adhere to the aluminum surface at temperature of 79°C and above. Tape methods are the least reliable because the adhesive layer of the tapes can suffer from delaminating which can cause instability in measurements [3, 4].

The thermocouple adhered with a Kapton tape showed a maximum temperature difference of 6.1°C across the measured temperature range of 48.3°C to 69.2°C. The similar effect is observed in other studies as well [5].

## V. MEASUREMENT UNCERTAINTY

The thermocouple tolerance has been calculated and considered in measuring temperature in this study. Measurement uncertainty [10, 11] in the system (shown in Table III) comes from multiple sources. The uncertainty cause by the reference thermocouple comes from the temperature logger measurement accuracy of ± 0.67°C, thermocouple tolerance of ± 1.1°C and the temperature logger reference junction compensation accuracy of ± 0.5°C. All the same tolerance exist for the 4 other measurement thermocouples. Root Sum Square (RSS) was used to calculate the total uncertainty. The total uncertainty calculated assuming a 95 % Confidence Interval, is ± 2.21°C.

Table II. PERFORMANCE COMPARISON OF DIFFERENT THERMAL COMPOUNDS

| | | | Loctite 3873 | | Loctite 480 | | Loctite 416 | | Kapton Tape | |
|---|---|---|---|---|---|---|---|---|---|---|
| Power Supply setting (V) | Aluminum block Heater resistor values (ohms) | ***Reference Thermocouple at center of Aluminum block. $T_{HotPlate}$ | $T_{Loctite\ 3873}$ (°C) | Δ $T_{HotPlate}$ - $T_{loctite\ 3873}$ (°C) | $T_{Loctite\ 480}$ (°C) | Δ $T_{HotPlate}$ - $T_{loctite\ 480}$ (°C) | $T_{Loctite\ 416}$ (°C) | Δ $T_{HotPlate}$ - $T_{loctite\ 416}$ (°C) | $T_{Kapton\ Tape}$ (°C) | Δ $T_{HotPlate}$ - $T_{kapton\ tape}$ (°C) |
| 5V | 3.33 | 48.3 | 47.6 | 0.7 | 46.4 | 1.9 | 46.6 | 1.7 | 46.2 | 2.1 |
| 6V | | 57.2 | 56.4 | 0.8 | 54.8 | 2.4 | 55.1 | 2.1 | 51.4 | 5.8 |
| 7V | | 69.2 | 67.8 | 1.4 | 65.1 | 4.1 | 65.8 | 3.4 | 63.1 | 6.1 |
| 8V | | 81.5 | 79.7 | 1.8 | 76.3 | 5.2 | 77.3 | 4.2 | * | |
| 9V | | 93.3 | 91.3 | 2 | 86.7 | 6.6 | 88 | 5.3 | * | |
| 10V | | 110.2 | 107.6 | 2.6 | 98.4 | 11.8 | 104.1 | 6.1 | * | |
| **Min** | | | | 0.7 | | 1.9 | | 1.7 | | 2.1 |
| **Max**** | | | | 2.6 | | 11.8 | | 6.1 | | 6.1 |

*Kapton tape, for table 8V, 9V and 10V no measured temperature because the kapton tape could not ahere to the surface at 70 degree celcius and above.

**Larger the temperature difference (error), the larger the value from the actual value.

***Actual value of temperature of Aluminum block

Table III. MEASUREMENT UNCERTAINTY CALCULATION FOR THE THERMAL MEASUREMENT SETUP

| Symbol | Source of Uncertainty | Value | Unit | Distribution | Divisor | Uncertainty | Uncertainty $^2$ |
|---|---|---|---|---|---|---|---|
| Reference Thermocouple | DX2030 Reference junction compensation accuracy | 0.50 | ℃ | R | 1.73 | 0.29 | 0.08 |
| | DX2030 Measurement Accurarcy (digital display) @ 110°C | 0.67 | ℃ | R | 1.73 | 0.38 | 0.15 |
| | Thermocouple Tolerance °C @ 110°C | 1.10 | ℃ | R | 1.73 | 0.64 | 0.40 |
| Thermocouple mounted with compound or Kapton tape | DX2030 Reference junction compensation accuracy | 0.50 | ℃ | R | 1.73 | 0.29 | 0.08 |
| | DX2030 Measurement Accurarcy (digital display) @ 110°C | 0.67 | ℃ | R | 1.73 | 0.38 | 0.15 |
| | Thermocouple Tolerance °C @ 110°C | 1.10 | ℃ | R | 1.73 | 0.64 | 0.40 |
| Uncertainly due to mounting | Random Uncertainty. | 0.00 | ℃ | R | 1.73 | 0.00 | 0.00 |
| | **Root Sum Square (RSS)** | | | | | | **1.13** |
| **$U_{\_temperature}$ (°C)** | **Expanded Uncertainty (95% confident level, K=1.96)** | | | | | | **2.21** |

It is observed that the uncertainty of the measured temperature is small compared to the Max errors observed in the measurements. This indicates the temperature readings are "actual" values and not variations in the temperature caused by the uncertainty.

For simplicity, the uncertainty calculation above has neglected the uncertainty caused by the following:-

- thermocouple couple mounting/placement.
- thermal compound/Kapton tape effect (cooling) of mounting the thermocouples.
- random uncertainty (assumed to be zero).

For a measurement temperature range of below 81.5℃, using the Loctite 3783 adhesive provides the most accurate temperature reading as compared to other compounds/ methods of securing the thermocouple. Temperature reading is within the measurement uncertainty values. For higher temperatures, the error from the actual value increases to 2.6℃ but is still below the errors from the other adhesives.

## VI. CONCLUSION

In conclusion, when mounting a thermocouple on a metal block, attachment using a thermal adhesive is preferred than to that of a Kapton tape. This matches a previous study that mentions aluminum tape is preferred over polyimide (Kapton) tape where the former provides better accuracy and the latter has a downside of weak adhesion strength [5].

There is a difference in temperature accuracy when different types of adhesives are used to attach the thermocouple. The most preferred adhesive from the evaluation is the Loctite 3873 as it provides the closest temperature to the true value. This reason is possibly attributed to higher thermal conductivity of Loctite 3873 @ 1.25 W/(m.K) as compared to Loctite 416 and Loctite 480 which are only at 0.1 W/(m.K). With a lower thermal conductivity, the heat transfer from the aluminum surface to the thermocouple is not effective, thus causing a larger thermal resistance which subsequently causes a larger temperature drop. Researchers are also able to know what are the errors contributed by different types of adhesives and therefore select the most suitable adhesive for their application.

## VII. FUTURE WORK

For future work, it is proposed to repeat the study on different surfaces such as plastic and glass to see if similar effects can be observed. Also, the measurement uncertainty and repeatability of the measurement should be studied to observe if there are any repeatability errors. The study can also add in the aluminum tape so as to compare it to the accuracy to the Kapton tape in this setup.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] International Electrotechnical Commission, "CTL Instrument Accuracy Limits," *Int. Electrotech. Comm.*, 2019.
[2] International Electrotechnical Commission, "Laboratory Procedure for Acceptance, Preparation, Extension and Use of Thermocouples," *Int. Electrotech. Comm.*, 2019.
[3] A. Géczy, B. Kvanduk, B. Illés and G. Harsányi, "Comparative Study on Proper Thermocouple Attachment for Vapour Phase Soldering Profiling," *Solder. Surf. Mt. Technol.*, vol. 28, no. 1, pp. 7–12, 2016.
[4] A. Geczy, B. Kvanduk, B. Illes and Z. Illyefalvi-Vitez, "Thermocouple Attachment Methods for PCB Profiling During Vapour Phase Soldering," in *2012 IEEE 18th International Symposium for Design and Technology of Electronics Packages*, pp. 133–137, 2012.
[5] M. J. Wickham and C. P. Hunt, "Thermal Profiling of Electronic Assemblies," *Nat. Phys. Lab. Report*, MATC(A)50, 2001.
[6] J. Kanesalingam and F. Kung, "Using SMT Chip Resistors Beyond Their Rated Thermal Specification," in *2018 34th Thermal Measurement, Modeling & Management Symposium (SEMI-THERM)*, pp. 155-160, 2018.
[7] "LOCTITE® 3873," 2014. [Online]. Available: www.henkel.com/electronics.
[8] "LOCTITE® 480," 2017. [Online]. Available: www.henkel.com/industrial.
[9] "LOCTITE® 416," 2010. [Online]. Available: www.henkel.com/electronics.
[10] European Telecommunications Standards Institute, "Etsi tr 100 028-1," *Eur. Telecommun. Stand. Inst.*, vol. 1, pp. 1–285, 2001.
[11] European Telecommunications Standards Institute, "Etsi tr 100 028-2," *Eur. Telecommun. Stand. Inst.*, vol. 1, pp. 1–285, 2001.