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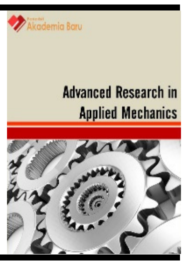

Effect of surface imperfections on the thermocouple performance

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ABSTRACT

Thermocouple is one of the most widely used temperature sensor in engineering. Besides practical, thermocouple also has very wide range of sizes and applications. Nevertheless, particular study on the thermocouple performance especially in terms of imperfections due to mechanical defect were never conducted. This is important since mechanical surface defect i.e. wear and crack can be frequently happened in practice. This study, therefore, investigate the effect of mechanical surface defects on the thermocouple performance during calibration. Eight samples of thermocouple with various wear and crack have been fabricated and tested in a calibration apparatus following NIST 250-25 standard with temperature variation from 75ºC, 100ºC, 125ºC and 150ºC. It is found that each type of mechanical surface imperfections (wear& crack) on the probes gives different effect to the performance with a different pattern as well. The uniformity of the heat to the sensor surface plays as the major cause to the performance.

1. Introduction

Thermocouple have been widely used to measure temperature in many applications. As one of the simplest measuring apparatus, thermocouple offers many advantages to users like fast response, quick procedure and robust reading. Not only in mechanical, thermocouple is also famous in the electrical and chemical industry especially those that need robust temperature control. In order to

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maintain the quality of thermocouple, calibration should be conducted in a certain period of time according to the regular standard. Problem that have been raising is the deterioration of the thermocouple along the time due to defects. In practice, mechanical impact almost happens every day and cannot be simply avoided i.e. during measurement or handling process. This, in turn, gives significant defects to the thermocouple micro- or even macroscopically. The defect can often reduce and even in some cases ruin the performance of the thermocouple. Eventually, high error occasionally obtained during calibration. This is a serious problem to be solved since calibration, as parts of maintenance, deals much with financial issue and the key of good measurements [1-2].

Researchers as well as industry have been trying to improve calibration process involving the evaluation on how important the calibration is, what kind of factors that can considerably affect calibration, also the attempt to improve the calibration itself. Larson *et al*. [3] reports that calibration error can create severe impact to the throughout system since calibration is a fundamental procedure before measurements. Accordingly, Numajiri *et al*. [4] evaluate the uncertainty of the freezing point for thermocouple calibration and investigate its causes. This is also prove that calibration, whatever the temperature range, is very important. The uncertainty in the thermocouple calibration should also be reduced in order to increase the calibration quality. Moric *et al*. [5] found that rousting the high temperature fixed points, the calibration quality can be increased [5]. Beside above researches, several research have also been conducted to improve thermocouple calibration involving addition of palladium [6] and also cobalt-carbon [7] into the thermocouple material. The addition is found to be significantly increasing the calibration quality. However, the effect of such mechanical defects as mentioned above on the thermocouple calibration performance have apparently not been investigated at all.

In accordance to that issue, this paper therefore investigates the effect of mechanical defect i.e. wear and crack on the thermocouple performance during calibration. Wear and cracks are the most common defect that occasionally happens in practice. This can also purposely give more actual thermocouple performance in practice and also provide valuable information to diagnose thermocouple error in the future.

2. Methodology
2.1 Thermocouple Sample Preparation

Commercial thermocouple type K was chosen to be investigated in this paper. This is due to the wide and flexible range of usage of the thermocouple K in practice. The technical specification for the thermocouple is shown in detail in Table 1. It is important to note that the allowable standard tolerance is around 0.75%.

Table 1
Technical specifications of the thermocouple K

Technical Specifications of Themocouple K	
Temperature range	0 to 1260^0 C
Standard tolerances	±2.2 or 0.75%
Upper temperature limits	1260^0 C

While Figure 1 shows the failure simulation i.e. wear and crack defect on the thermocouple surface. To clearly observe the effect from defects, the failure was varied from 20 to 80% as given in Table 2. This failure percentage describes the ratio of defects over normal thermocouple contact area. For instance, 20% means one fifth of the thermocouple contact area are fully defects. Same goes to 40, 60 and 80% respectively.

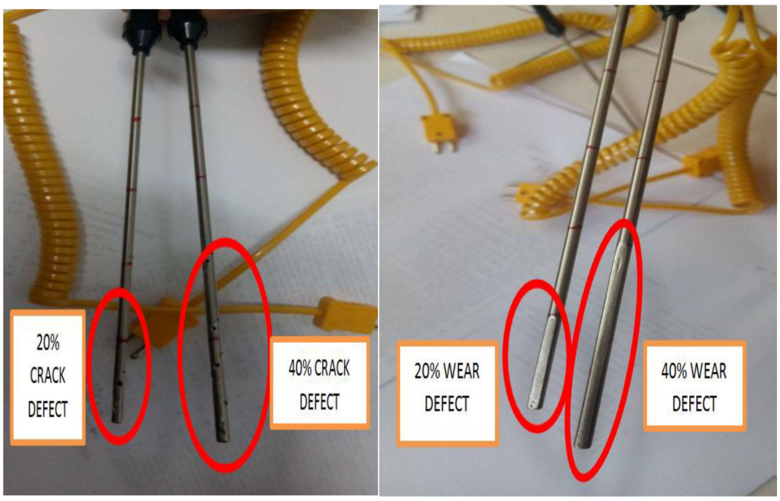

Fig. 1. Defects on the Thermocouple Sample

Table 2
Failure percentage of the samples

Samples	Failure Criteria	
	Crack	Wear
A	20%	20%
B	40%	40%
C	60%	60%
D	80%	80%

2.2 Experimental Procedure

The experimental procedure was conducted following NIST 250-25 Standard where one thermocouple standard is used to be compared with the thermocouple under test (DUT). The standard thermocouple and the DUT thermocouple as seen in Figure 3 were put in the calibration well.

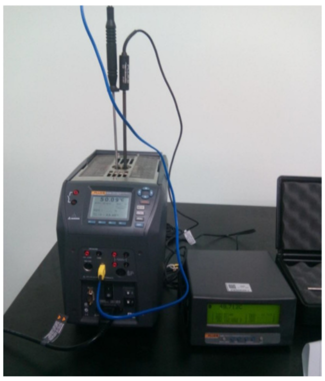

Fig. 3. Calibration Procedure according to NIST 250-35 Standard

The temperature used here were varied from 750 to 1500 Celsius. The result from tested thermocouple were then compared to the standard to find the error percentage as a representative for the performance. The error were calculated using Equation 1.

$$\%\ \text{Error} = \left|\frac{Data_{meas.} - Data_{Standard}}{Data_{Standard}}\right| x100\% \quad (1)$$

3. Results and Discussion

3.1 Effect of Crack on the Thermocouple Performance

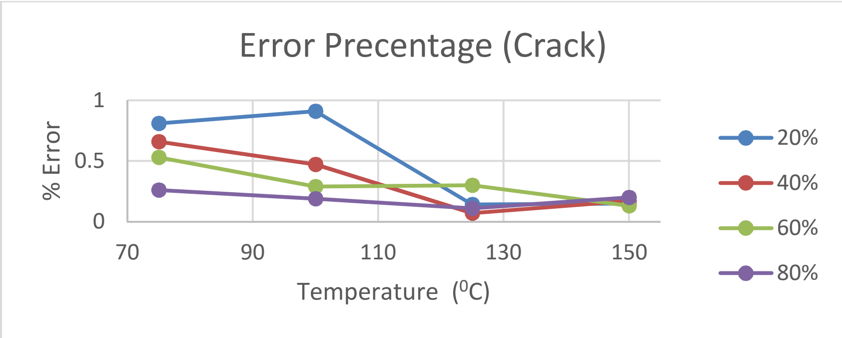

Fig. 3. Effect of crack on the performance

The effect of crack is depicted in Figure 3. Generally, as the temperature increases, the error percentage decreases. At 750 C, the error value is shown by roughly 0.8% while data 1500 C only has 0.2% error. This is due to the effective working temperature working of the type K thermocouple. Usually, thermocouple type K works well in the temperature higher than 1000 C. This is also confirms the result from Numajiri *et al*. [4] that low temperature give more uncertainty to the thermocouple performance.

Meanwhile, the new phenomena from this result is the decrement of error as the defect increases. This phenomena can be seen by comparing result from 20% with 80% defect where 80% defect failure is considerably lower than 20% defect. This is due to the surface uniformity on the thermocouple contact area. In the 20% failure only one fifth of the thermocouple surface introduced by the cracks. This apparently creates uneven reading due to uneven surface condition. The heat cannot be evenly absorbed on the surface since the defect creates heat resistance to the metal. Only normal surface can transmit the heat properly to the metal. Consequently, overall result (after averaging) is uneven as well. This creates large errors.

3.2 Effect of Wear on the Thermocouple Performance

Similar to the results of cracks, the effect of wear on the thermocouple performance also has similar pattern. As the temperature increases, the error decreases due to the effective working temperature of the type K thermocouple. Similar phenomena with Numajiri *et al*. [4] can also be seen in the result. At low temperature, the uncertainty is considerably higher than the result of cracks. One can note that this is due to the wear area on the surface is wider than from cracks.

While the increment of wear percentage does not give any recognizable pattern. It tends to give arbitrary results rather than pattern. Thermocouple with 80% wear give the highest error at 1000 C and conversely the lowest at 750 and 1500 C. Meanwhile, thermocouple with 20% wear gives almost constant error value from 0.3 to 0.55% if the temperature is increased.

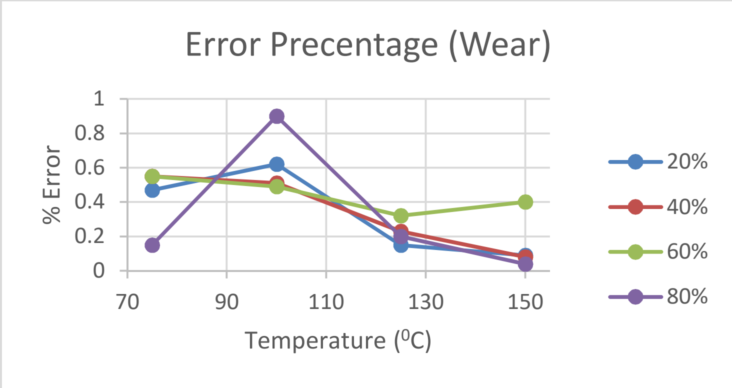

Fig. 4. Effect of wear on the performance

4. Conclusion

The effect of mechanical surface imperfections on the thermocouple performance has been studied experimentally. It is found that such imperfections only give slight reduction on the performance shown by low error obtained. However, if the ratio of defect is increased, the error apparently decreases due to the uniformity of the surface. Low defect ratio makes measurement reading becomes bias because the difference between normal surface area and imperfect surface area is drastically large. The overall average reading then become large as well and eventually increase the error. Therefore, the conclusion that can be made is thermocouple surface uniformity with respect to heat transfer uniformity to the thermocouple surface plays as the major factor to the thermocouple performance.

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References

[1] Hayder, G. and Puniyarasen, P., "Identification of astes from biodiesel production process." *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 3, no.1 (2016): 21 – 29.

[2] Idris, J., and A. Al-Bakooshb. "Application of Non-Destructive Testing Techniques for the Assessment of Casting of AA5083 Alloy." (2014).

[3] Larson, Miller, Nadeau, and Edwin Roedder. "Two sources of error in low temperature inclusion homogenization termination, and corrections on published temperatures for the east tennessee and laisvall deposits." *Economic Geology*, vol. 1 (1973): 113-116.

[4] Numajiri, Haruhiko, Hideki Ogura, Masaya Izuchi, and Masaru Arai. "Uncertainty evaluation on the freezing point of silver for thermocouple calibration." In *SICE 2002. Proceedings of the 41st SICE Annual Conference*, vol. 2, pp. 1037-1040. IEEE, 2002.

[5] Morice, R., Edler, F., Pearce, J., Machin, G., Fisher, J., and Flitz, J. R. "High-temperature fixed point facilities for improved thermocouple calibration." *International Journal Thermophysics*, vol. 29, no. 1 (2008): 231-240.

[6] Ogura, H., M. Izuchi, and M. Arai. "Evaluation of cobalt–carbon and palladium–carbon eutectic point cells for thermocouple calibration." *International Journal of Thermophysics* 29, no. 1 (2008): 210-221.

[7] Edler, F., R. Morice, H. Ogura, and J. Pearce. "Investigation of Co–C cells to improve thermocouple calibration." *Metrologia* 47, no. 1 (2010): 90.