Base metal thermocouples drift rate dependence from thermoelement diameter.

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Abstract. Temperature measurements are one of the key factors in many industrial applications that directly affect the quality, effectiveness and safety of manufacturing processes. In many industrial applications these temperature measurements are realized by thermocouples. Accuracy of thermocouples directly affects the quality of the final product of manufacturing and their durability determines the safety margins required. One of the significant effects that affect the precision of the thermocouples is short and long term stability of their voltage output. This stability issue occurs in every type of thermocouples and is caused by multiple factors. In general these factors affect the Seebeck coefficient which is a material constant, which determines the level of generated voltage when exposed to a temperature gradient. Changes of this constant result in the change of the thermocouples voltage output thus indicated temperature which can result in production quality issues, safety and health hazards. These alternations can be caused by physical and chemical changes within the thermocouple lead material. Modification of this material constant can be of temporary nature or permanent. This paper concentrates on the permanent , or irreversible changes of the Seebeck coefficient that occur in commonly used swaged MIMS Type N thermocouples. These permanent changes can be seen as systematic change of the EMF of the thermocouple when it is exposed to a high temperature over a period of time. This change of EMF by time is commonly known as the drift of the thermocouple. This work deals with the time instability of thermocouples EMF at temperatures above 1200 °C. Instability of the output voltage was taken into relation with the lead diameter of the tested thermocouples. This paper concentrates in detail on the change of voltage output of thermocouples of different diameters which were tested at high temperatures for the overall period of more than 210 hours. The gather data from this testing was used to establish the relation between the level of EMF drift and the lead diameter of the thermocouple thermoelements. Furthermore this data was also used to create a drift function which mathematically expresses the dependency between the drift rate and the diameter of the thermocouple leads.

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1. Introduction

Measurements of temperature have a great importance in wide range of industrial applications. As temperature affects the quality, safety and effectives of many of these applications, a great effort has been made to enhance the precision and reliability of temperature measuring sensors. One of the main types of temperature sensors that are used in industry are thermoelectric sensors, more commonly known as thermocouples. These sensors play a irreplaceable role in high temperature industrial measurements. Their robust construction, ability to withstand high temperatures and harsh conditions had made them popular among many users. These active temperature sensors are used for monitoring and control of many industrial processes. As a widely used type of temperature sensor, there are still effects which occur in thermocouples under various conditions that need further investigation. This process of testing and investigation is necessary to understand the behaviour under boundary condition. Although base metal thermocouples have been used in a wide variety of industrial applications for a long period of time there are still cases in which these sensors accuracy is affected. Accuracy of thermocouples directly affects the quality of the final product of manufacturing and their durability determines the safety margins required. To efficiently reduce the effects, that result in lower levels of precision it is necessary to explore various influences that can cause measurement errors and investigate possibilities of their reduction or removal.

2. Long term stability of thermocouples

Short and long term stability of thermocouples voltage output is one of the substantial effects that affect the precision and reliability of these sensors. This stability change is caused in general by the change of the Seebeck coefficient which is a material constant. This coefficient determines the level of generated voltage when exposed to a temperature gradient. It is unique for each type of material and combination of materials. Changes of this constant result in the change of the thermocouples voltage output thus indicated temperature which can result in production quality issues, safety and health hazards. These alternations can be caused by physical and chemical changes within the thermocouple lead material and they occur in every thermocouple type. Modification of this material constant can be of temporary or permanent nature. The reversible changes in Mineral Insulated Metal Sheathed thermocouples (MIMS) happen most commonly by the annealing process which happens at temperatures above 600°C and by hysteresis effect which occurs at temperatures to 1000 °C [1, 4, 5]. Irreversible changes happen at temperatures above 600 °C for the bare wire thermocouple configuration and at 1000 °C for the MIMS configuration [1, 4, 5]. These changes happen due to chemical contamination and cause a degradation of electro motive force (EMF). In this paper we are going to concentrate on the permanent , or irreversible changes of the Seebeck coefficient that occur in commercially used MIMS Type N thermocouples. Type N thermocouples leads are made with metal alloy consisting of 14.4% chromium, 1.4% silicon, 0.1% magnesium which is used for one branch of the thermocouple and another alloy consisting of 95,6% nickel, 4.4% silicon is used for the other branch. These permanent changes can be seen as systematic change of the EMF of the thermocouple when it is exposed to a high temperature over a period of time. This change of EMF by time is commonly known as the drift of the thermocouple. The presented work deals with the drift occurring in base metal Type N thermocouples in MIMS configurations which were exposed to temperatures over 1200 °C over a period of time exceeding 210 hours. Thermocouples with different diameters were used to be able to determine the relationship between the level of drift and the thermoelement diameter.

2.1. Cause of instability of nickel based thermocouples

The stability of voltage output of thermocouples as mentioned earlier is one of the significant issues that occur in each type of thermocouples. This study is going to deal with the chemical induced changes thus the permanent change in Seebeck coefficient. These permanent changes arise in nickel based thermocouples (type N and K) at temperatures above 600°C. An increasing voltage output can be seen when thermocouples without a protective sheathing are exposed to these temperatures. This positive drift can be seen in nickel based thermocouples with metal sheathing and mineral insulation (MIMS) but only at temperatures between 600°C to 900°C. By higher temperatures a significant and constant voltage drop occurs. This behaviour was described in various publication [1, 2, 3] with the same results for type N and type K thermocouples. The mentioned publications describe the process of drift by the migration of particles between the thermocouple thermoelements and the mineral isolation material and the metal sheath. The main source of contamination according to publications [1, 2] is considered manganese (Mn) as the main element that causes drift. This elements can be found in the sheathing material of the thermocouple and at temperatures over 1100°C it contaminates the thermocouple thermoelements affecting the Seebeck coefficient. The publications [1, 2] also points out that the concentration of manganese in the sheathing material also determine the level of the drift. For instance when a Inconel 600 which has a 1% concentration of manganese was used as sheathing material the voltage output drop wasn't so high as when a AISI 310 material with 2% manganese concentration was used. Publications [4, 5] show a decrees of indicated temperature of type N and K MIMS thermocouples with a 3mm outer diameter. At temperature of 1100°C the measured temperature difference form the initial state was 10°C and at temperature of 1200°C the drop was 24°C. These results were obtained after a 1000 hour testing cycle.

Several publications deals with the thermocouple drift and time stability in which they point out that a considerable degree of long term stability of nickel based thermocouples is an issue that needs further investigation. In this presented paper we are going to deal with this drift problematic but in a relation to the diameter of the thermocouple thermoelements wires.

3. Measuring setup

The drift of the voltage output and diameter relationship was measured on type N thermocouples in MIMS configuration. The sheath material for the tested thermocouples was made of Inconel 600 and with mineral insulation inside the sheath. Eight thermocouples of the highest precision class for the mentioned type were tested. The outer diameters together with the corresponding wire diameter are presented in Table 1. One pair of the same thermocouple diameter and type from the same manufacturer was tested to avoid possible error caused by the manufacturing process. Furthermore two runs of the drift testing were planned to proof the repeatable behaviour of drift for individual diameter of sensors.

Table 1. Outer and lead diameters of tested type N thermocouples.

Outer diemeter of Type N thermocouples (mm)	Thermo element wire diameter (mm)
0.5	0.085
1.0	0.140
1.5	0.280
2.5	0.340

The temperature stability and homogeneity of the testing furnace was determined by initial furnace homogeneity scans with a calibrated noble metal type R thermocouple. After establishing the temperature profile the ideal depth for the thermocouples was determined and was set for 550mm (position of the tip of sensor from the opening of the furnace). Temperature time stability was also determined with the same type R thermocouple. The resulting stability over a 5 hour test was not more than ± 0.06 °C which was considered as sufficient for our study. Furthermore to be confident about the furnaces temperature stability a calibrated type R thermocouple was used to monitor the temperature inside the furnace. All the initial tests were done at work temperature of 1200°C which was the later used testing temperature as well. The temperature stability of the reference point is also of great importance because it determines the voltage output of the thermocouple and its temperature instability would result in the voltage output instability of the thermocouple which would make the drift detection difficult. This reference point temperature stability was ensured by a dry block cell with a high long term stability of ± 0.010 °C. The uncertainty budget of the experiment taking into account uncertainties of each element used in the experiment can be found in the Table 2

Table 2. Uncertainty budget of the experiment taking into account uncertainties of each element used in the experiment. The uncertainty values of each source are presented in °C.

Source of uncertainty	Values (°C), where k = 2
Furnace stability	0.03
Type N thermocouple	1.1
Type R thermocouple	0.3
Reference point stability	0.005
Multimeter	0.0045

To be able to determine the level of drift from the thermoelements diameter the thermocouples had to be exposed to an identical temperature conditions. This was ensured by putting all the tested sensors to a narrow ceramic tube which ensured that the temperature conditions would be sufficient for our measurement.

After setting up the measuring equipment and the initial testing phase the first batch of thermocouples was exposed to a temperature of 1200°C for a time period of more than 80 hours. The second run of tests was done on the second batch of thermocouples at temperatures of 1250 °C for a time period of more than 210 hours. The thermocouples were tested from their original state without applying any annealing process. The results of this continuous testing are presented in the following part of the paper.

4. Measuring results

The data presented was recorded using an automatic recording system which consisted of a switch system, multimeter device and PC with recording software. The recording interval of all the sensors voltage output was set for one minute. By this quick and automatic recording we ensured the comparability of the data from each sensor due to virtually identical data record time. The recorded data has a certain level of noise which was compensated using mathematical filtration methods. After this initial filtration an average value vas calculated for each five hour sections to make the interpretation of the drift level clearer. The results of the measurements that were obtained at temperature of 1200 °C are presented in Figure 1 and the results measured at 1250 °C are presented in Figure 2. The figures shows the voltage output difference of type N thermocouples of different diameters from the initial state of the voltage value.

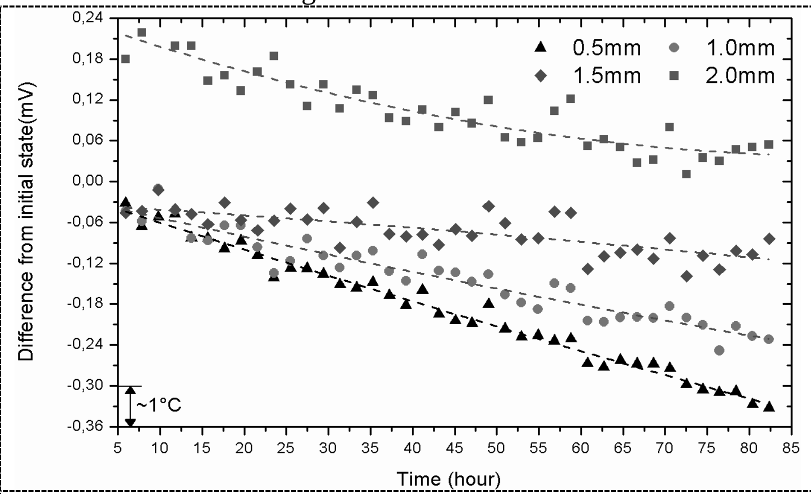

Figure 1. Voltage output difference form initial state for type N

thermocouples of different diameters (measured at 1200°C).

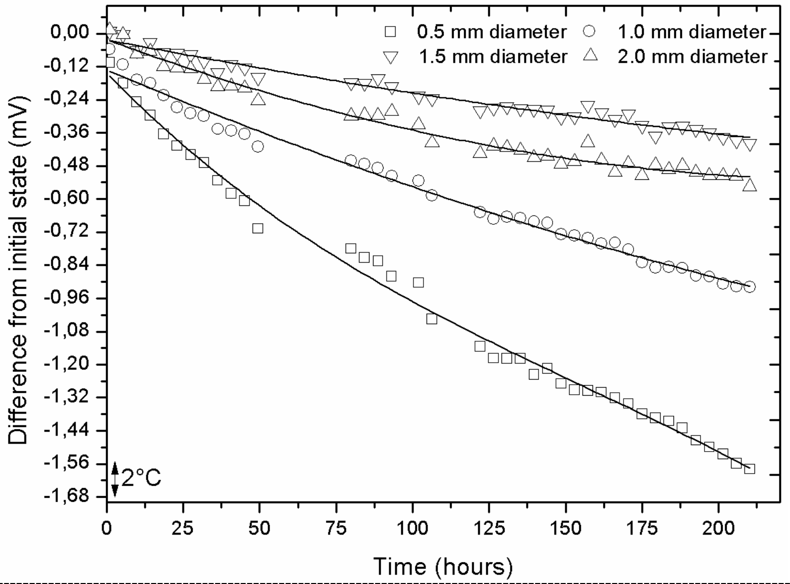

Figure 2. Voltage output difference form initial state for type N thermocouples of different diameters (measured at 1250°C).

As we can see from the Figure 1 a decrees of the voltage output is visible. The highest level of voltage decrees was noticeable on the smaller thermoelement diameters. This highest level of decrees can be seen on the thermocouple with the smallest outer diameter of 0.5mm. These result were the same for the measurements performed by the temperatures of 1200 °C and 1250 °C. The level of decrees was 5 °C from the initial state after 84 hour (at 1200 °C) and for the same diameter at 1250 °C the difference from the initial state after 214 hours was 25 °C. Other diameters of thermocouples show a different maximum level of decrees and their values are presented in Table 3. As can also be seen there is a difference between drift rates at different temperatures. The higher temperature resulted in a more rapid drift as can also be seen in Figures 1 and 2. The results have confirmed that the exposure of nickel based thermocouples to high temperatures causes a drop of voltage with time. These results have also proven that the levels of voltage output decrease and thermocouple thermoelements diameter size are related.

Table 3. Maximum temperature difference from the initial state for various thermoelement diameters at 1200°C and 1250°C.

Thermo element wire diameter (mm)	Temperature difference from the initial state after 84 hours at 1200 °C (°C)	Temperature difference from the initial state after 214 hours at 1250 °C (°C)
0.085	- 5	- 25
0.140	- 3	- 14
0.280	- 2	- 7
0.340	- 4	- 8

Values of temperature decrees and the corresponding wire diameters have been used to establish a drift function for the type N thermocouples in MIMS configuration. These functions can be seen in Figure 3 and Figure 4 and they express the dependence of average temperature decrees by one hour and the thermoelement diameter when thermocouples are exposed to a temperature of 1200 °C and 1250 °C. As can be seen from the there figures the smaller thermoelement diameters show a higher level of average °C/hour decrease than the larger diameters. This is not the case for the 0.340mm thermoelement where an anomaly occurs that need to be further examined and analysed.

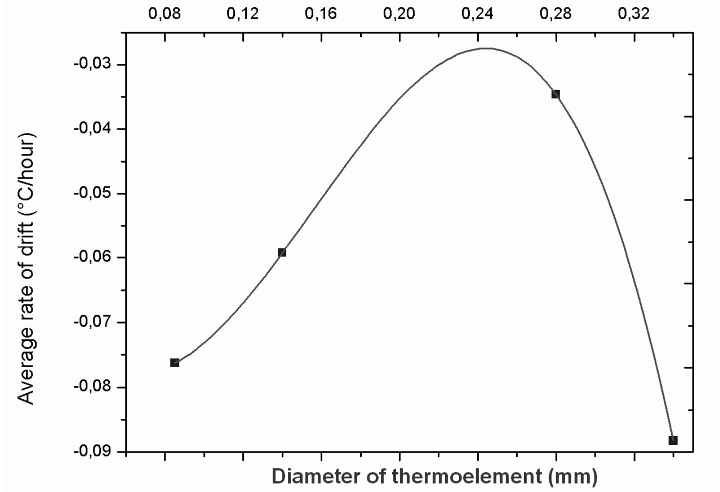

Figure 3. Function of type N thermocouple thermoelements diameter and an average temperature decrees in temperature from the initial state after one hour (measured at 1200°C).

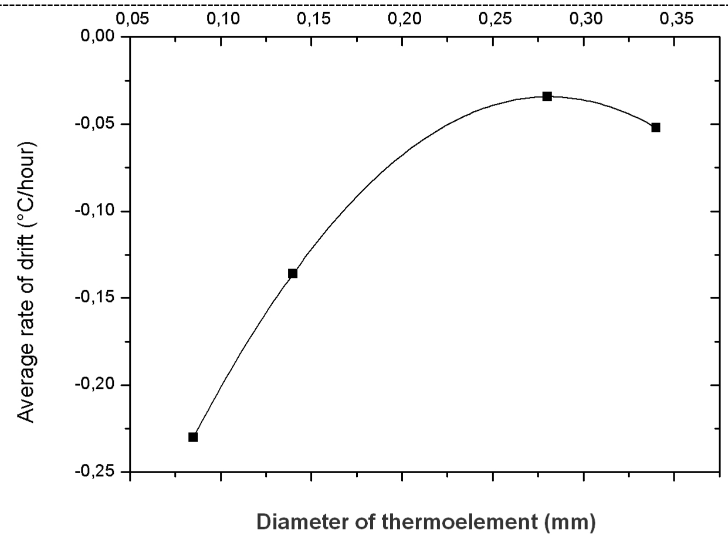

Figure 4. Function of type N thermocouple thermoelements diameter and an average temperature decrees in temperature from the initial state after one hour (measured at 1250°C).

5. Conclusion

The measured data show a clear relationship between the level of voltage output decrease and the thermocouple thermoelements diameter. This drift behaviour was observed at temperatures above 1200 °C. The sources form which this conclusion was determined can be seen in Figure 3 and 4. These figures show the different trends of voltage decrease and average °C/hour drop for different thermoelements diameters. This behaviour of nickel based thermocouples in NIMS configuration agrees with the publications [1, 2, 3] in terms of general drift behavior. The publications describe the cause of the drift as a chemical contamination of the thermoelement material by manganese (Mn) which can be found in the sheath material of the thermocouple. According to the publications the contamination process starts to occur at temperatures above 1000°C. By analysing the previously made studies in this field we have come to the conclusion that the levels of drift for different thermoelement diameters rely from the amount of material that is contaminated. Smaller diameters are therefore naturally doped faster by the Mn than the larger diameter thermoelements.

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