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DRIFT OF NICKEL BASED MIMS THERMOCOUPLES AT TEMPERATURES ABOVE 1000°C: THE EFFECT OF THERMOCOUPLE DIAMETER

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Abstract – In this work the drift of type K and type N MIMS thermocouples has been studied as a function of the thermocouple outer diameter in the temperature range 1000-1300°C. It is shown that type K and type N MIMS thermocouples drift significantly above 1000°C, the drift being more pronounced for smaller diameters. The data presented in this paper allows to compare the performance of type K and type N thermocouples at high temperatures over a wide temperature range and at different diameters.

Keywords: thermocouple, drift, Type K, Type N, MIMS

1. INTRODUCTION

Nickel based thermocouples are the most commonly used temperature sensors in science and industry due to their high temperature capability and low cost.

At temperatures higher than 1000°C they undergo significant metallurgical degradations and, as a result, their signal departs from the temperature of the environment they are immersed in. This is called thermocouple drift: it can render thermocouple measurement unreliable, so shortening the life of the thermocouple.

In bare wire configuration the thermocouple wires, herein called thermoelements, are exposed to the gaseous atmosphere of the operating environment. The direct contact with an aggressive atmosphere can lead to significant drift. In air, for instance, oxidation of the wires occurs, producing a change in composition of the thermoelements, which results in thermocouple drift [1], the drift being more pronounced the higher the temperature and the smaller the thermoelement diameter. In order to limit drift, it is suggested to use larger thermoelements diameter at higher temperatures: the recommended maximum operating temperatures for 0.81 mm, 1.63 mm and 3.25 mm thermoelement diameter are 980°C, 1090°C and 1260°C respectively [2].

The Mineral Insulated Metal Sheathed (MIMS) configuration (Fig. 1) was introduced to overcome the limits of bare wire configuration: the sheath is made of materials which better withstand the oxidising or carburising operating environments compared to the alloys the thermoelements are made of. The recommended maximum operating temperatures reported above for bare wire thermocouples can be exceeded in MIMS configuration: once the thermoelements are protected by the sheath smaller thermoelement diameters can be used at the same temperature. The MIMS configuration results in a more reliable sensor, having longer life and higher temperature capability.

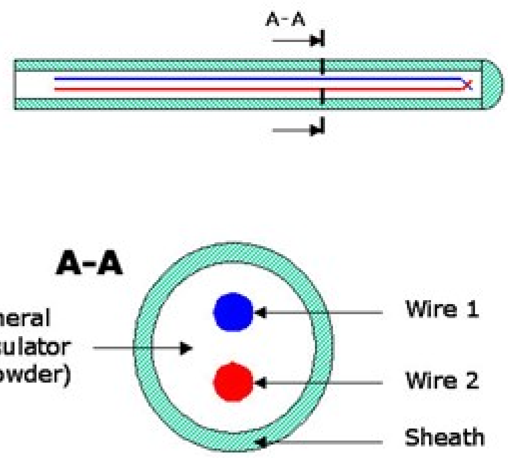

Fig. 1. MIMS configuration; schematic longitudinal and cross sections.

Demanding industrial applications generally prefer Nickel based MIMS thermocouples to Nickel based bare wire sensors. This is not only driven by the improved ruggedness of MIMS configuration, but also by the reduced diameter of the sensor.

The remote location of and limited access to some operating environments require the use of sensors having small diameters. For instance in gas turbines, the high pressure turbines are characterised by small size blades and vanes and access to those components or their gas path can require thermocouples having diameters as small as 1 mm.

The fast time response needed in some applications leads to the preferential selection of small diameter thermocouples. In gas turbines, for instance, fast time response is needed to follow the rapid transients between different steady states of the gas turbine operation.

Very limited information is available in the literature about the effect of diameter on drift of type K and type N MIMS thermocouples at temperatures above 1000°C [3,4,5,6,7]: the results on drift as a function of the diameter are limited to exposure at one single temperature, 1200°C [3,5,6] or 1100°C [4] or two close temperatures, 1200°C and 1250°C [7]. This paper aims at clarifying the role of diameter on the drift of Nickel based MIMS thermocouples: the drift results as a function of diameter are presented over a wide temperature range, from 1000°C to 1300°C. Type N thermoelements and two different type K thermoelements compositions have been studied.

2. INSTRUMENTATION

The instrumentation used for this investigation comprises:

- high temperature furnaces capable to reach temperatures as high as 1300°C. Both tubular furnaces and box furnaces modified to accommodate thermocouples were used for the investigation;
- dataloggers which continuously acquires data from the sensors;
- a PC controlling the datalogger through a software written in Labview and storing the acquired data on the hard drive.

During the drift test a type S thermocouple was used as a reference sensor measuring the real temperature of the furnace in close proximity of the type N or type K thermocouple junction end.

3. DRIFT TESTS

All the thermocouples tested in this work were sheathed in Inconel 600, the most common alloy for Nickel based MIMS thermocouples, whose nominal composition is reported in Table 1.

Isothermal drift tests have been undertaken on three different groups of sensors:

- Inconel 600 sheathed type N thermocouples,
- Inconel 600 sheathed type K thermocouples, having a negative thermoelement containing Mn and Al, herein called "type K composition 1" thermocouples,
- Inconel 600 sheathed type K thermocouples, having a negative thermoelement containing no Mn and no Al, herein called "type K composition 2" thermocouples.

Table 1. Nominal Inconel 600 composition.

Element	Content (wt.%)
C	0.15 max
S	0.015 max
Cr	14-17
Si	0.5 max
Cu	0.5 max
Fe	6-10
Mn	1 max
Ni	Balance

Table 2, Table 3 and Table 4 show the composition of positive and negative thermoelements for type N, type K composition 1 and type K composition 2 thermocouples respectively.

Table 2. Nominal compositions for positive (NP) and negative (NN) type N thermoelements.

Element	NP (wt%)	NN (wt%)
Cr	-	14.5
Si	4.2	1.4
Mg	0.1	0.1
Ni	Balance	Balance

Table 3. Compositions for positive (KP) and negative (KN) "type K composition 1" thermoelements.

Element	KP (wt.%)	KN (wt.%)
Al	-	1.73
Mn	-	1.58
Si	0.48	1.48
Co	-	0.64
Fe	0.45	0.13
C	-	0.02
Cr	9.61	-
Cu	0.04	-
Ni	Balance	Balance

Table 4. Compositions for positive (KP) and negative (KN) "type K composition 2" thermoelements.

Element	KP (wt%)	KN (wt%)
Cr	9.5	-
Si	0.5	2.5
Co	-	1.1
Cu	-	2.2
Fe	0.3	0.2
Mg	0.1	0.1
Ni	Balance	Balance

3.1. Type N thermocouples

Type N thermocouples having 3 mm, 2 mm and 1.5 mm outer diameters have been tested at four different temperatures:

- 1000°C up to 200 h,
- 1100°C up to 400 h,
- 1200°C up to 400 h,
- 1300°C up to 100 h.

Fig. 2 shows the results of the drift tests at 1000°C, 1100°C and 1200°C. Drift test results at 1300°C are shown in a separate figure (Fig. 3) for better visualization.

At each temperature the reduction in outer diameter results into a more pronounced drift having a negative value.

For 3 mm outer diameter thermocouples the drift is 0.4°C after 200 h at 1000°C, decreasing to -0.5°C after 200 h at 1100°C and -1.2°C after 400 h at 1100°C. A further increase in temperature to 1200°C results into -4.2°C drift after 200 h and -6°C after 400 h.

For 2 mm outer diameter thermocouples the drift is 0.2°C after 200 h at 1000°C, decreasing when exposed to 1100°C to -1°C after 200 h and -2°C after 400 h. When exposed at 1200°C drift is as high as -7.3°C after 200 h.

Thermocouples having 1.5 mm outer diameter experience a 0°C drift after 200 h at 1000°C. The drift decreases at 1100°C to -1.8°C after 200 h and -2.8°C after 400 h. At 1200°C -8°C drift and -13°C drift were measured after 200 h and 400 h respectively.

At 1000°C the drift is very limited and within 0.5°C for all the diameters. However, for all the diameters an increase in temperature leads to a more negative drift and in particular the higher the temperature the more negative the drift. Furthermore, while at 1000°C the drift rate is very low and positive and for this reason very limited drift is experienced, at temperatures higher than 1000°C, except during the first 25 h exposure at 1100°C for 3 mm and 2 mm outer diameter thermocouples, a significant negative drift rate is experienced, which produces an increasingly more pronounced drift at longer exposure time.

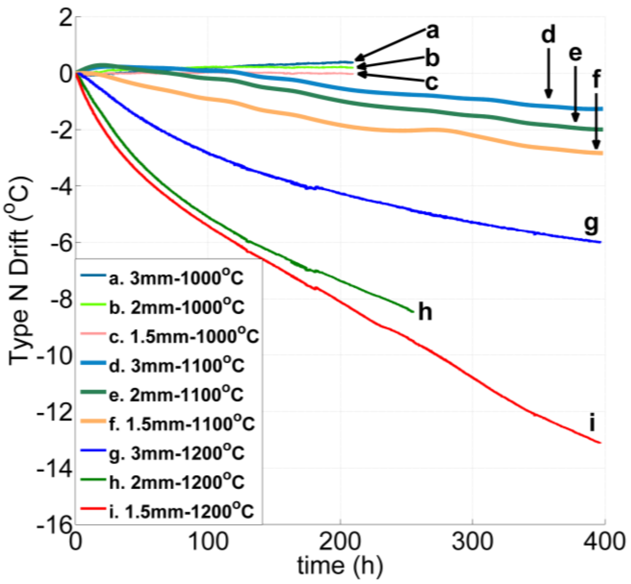

Fig. 2. Drift of Inconel 600 sheathed type N thermocouples having 3 mm, 2 mm and 1.5 mm outer diameters at 1000°C, 1100°C and 1200°C.

At 1300°C (Fig. 3) the 1.5 mm and 2 mm outer diameter type N thermocouples failed after about 30 h exposure, experiencing -18°C drift and -8°C drift respectively before failure. The 3 mm outer diameter type N conventional thermocouple experienced a drift as high as -14°C in about 100 h exposure.

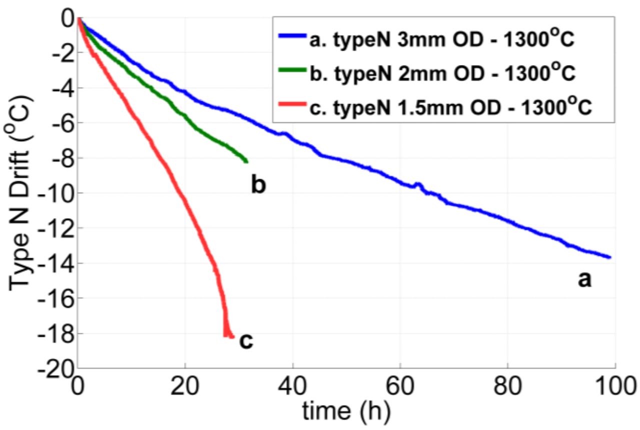

Fig. 3. Drift of Inconel 600 sheathed type N thermocouples having 3 mm, 2 mm and 1.5 mm outer diameters at 1300°C.

3.2. Type K composition 1 thermocouples

Type K composition 1 thermocouples having 3 mm, 2 mm and 1.5 mm outer diameters have been tested at four different temperatures:

- 1000°C up to 400 h,
- 1100°C up to 400 h,
- 1200°C up to 400 h,
- 1300°C up to 100 h.

Fig. 4 shows the drift tests results at 1000°C, 1100°C and 1200°C, while the results at 1300°C are shown in a separate figure (Fig. 5) for better visualization.

Thermocouples having 3 mm outer diameter experience at 1000°C drift equal to 0.8°C and 0.9°C after 200 h and 400 h respectively. At 1100°C their drift is -0.7°C after 200 h and -0.9°C after 400 h. Although their drift is characterised by very limited drift rate at 1000°C and 1100°C, when the temperature is increased to 1200°C a significant negative drift rate was measured: at 1200°C the drift is as high as -4.1°C after 200 h and -6.7°C after 400 h.

Thermocouples having 2 mm when exposed at 1000°C experience drift equal to 2.1°C and 2.4°C after 200 h and 400 h respectively. At 1100°C the drift is -0.2°C after 200 h and -0.6°C after 400 h. The drift rate is pronounced when the junction end is exposed at 1200°C: drift as high as -5.5°C and -8°C is experienced after 200 h and 400 h respectively.

At 1200°C thermocouples having 1.5 mm outer diameter experience the most pronounced of all the type K composition 1 thermocouples in Fig. 4: -6.7°C drift was measured after 200 h exposure increasing to -9°C after about 250 h when the thermocouple failed. At 1100°C less than -0.1°C drift is experienced after 200 h and a negative drift rate results into a drift equal to -0.8°C after 400 h. At 1000°C the plots of drift for 1.5 mm and 2 mm outer diameter thermocouples overlap almost perfectly.

In Fig. 4 the thermocouples can be distinguished in three separate groups based on the temperature their junction end has been exposed to:

- thermocouples with junction ends at 1000°C, herein called group 1,
- thermocouples with junction ends at 1100°C, herein called group 2,
- thermocouples with junction ends at 1200°C, herein called group 3.

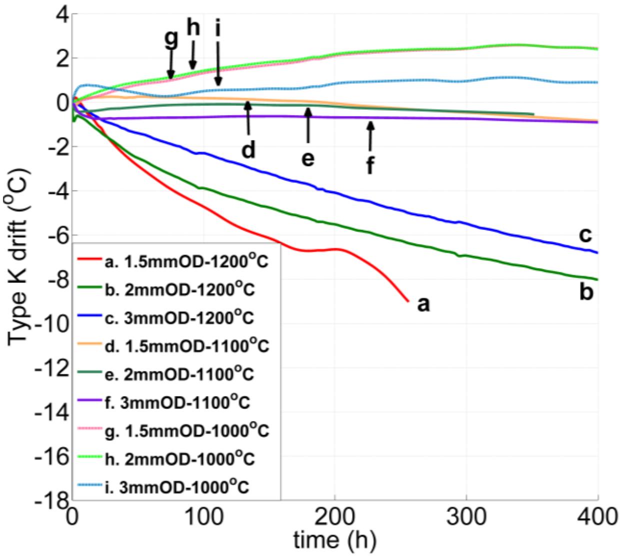

Fig. 4. Drift of Inconel 600 sheathed type K composition 1 thermocouples having 3 mm, 2 mm and 1.5 mm outer diameters at 1000°C, 1100°C and 1200°C.

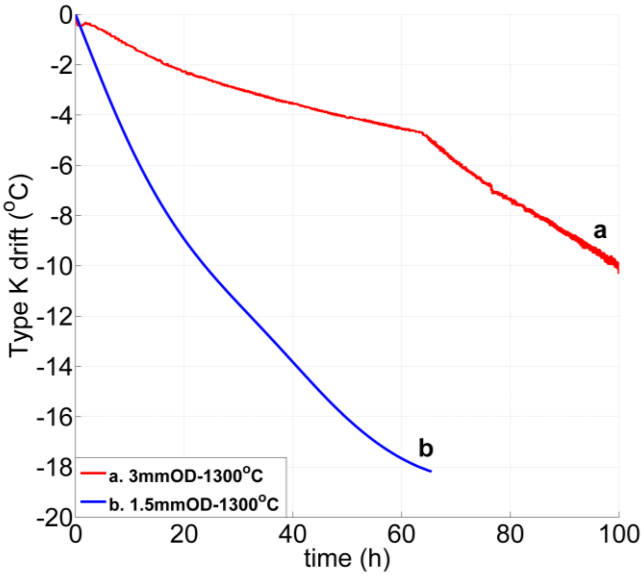

Fig. 5. Drift of Inconel 600 sheathed type K composition 1 thermocouples having 3 mm and 1.5mm outer diameters at 1300°C.

At exposure time longer than 20 h thermocouples of any diameter in group 2 have more negative drift than thermocouples of any diameter in group 1 and thermocouples of any diameter in group 3 have more negative drift than thermocouples of any diameter in group 2: temperature has a more marked influence on drift than outer diameter has.

Thermocouples with junction end exposed to 1000°C (group 1) have always positive drift between 0°C and 2.6°C and a positive drift rate except for the 3 mm outer diameter thermocouple between 10 h and 70 h of exposure.

Thermocouples that experienced 1100°C at the junction end (group 2) have drift always between -0.9°C and 0.8°C: for time longer than 100 h the drift rate is negative and increases in absolute value with decreasing outer diameter.

Thermocouples with junction end exposed to 1200°C (group 3) have always negative drift for time longer than 5 h, with more pronounced drift for smaller outer diameter thermocouples.

At 1300°C (Fig. 5) the 3 mm outer diameter thermocouple drifts up to -10°C in 100 h exposure. The 1.5 mm outer diameter thermocouple failed after 65 h exposure after experiencing more than -18°C drift. A very early failure of the 2 mm outer diameter thermocouple occurred at 1300°C: its drift is not plotted in Fig. 5.

3.3. Type K composition 2 thermocouples

Type K composition 2 thermocouples having 3.2 mm, 2.38 mm and 1.63 mm outer diameters have been tested at two different temperatures:

- 1100°C up to 400 h,
- 1200°C up to 400 h.

The drift tests results are reported in Fig. 6.

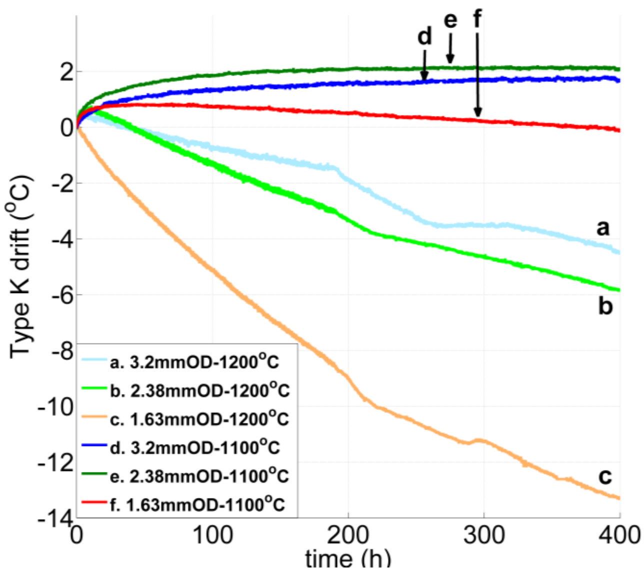

Fig. 6. Drift of Inconel 600 sheathed type K composition 2 thermocouples having 3.2 mm, 2.38 mm and 1.63 mm outer diameters at 1100°C and 1200°C.

For thermocouples exposed at 1100°C the measured drift is always between 0°C and 2.1°C, except for time longer than 385 h for the 1.63 mm outer diameter thermocouples, which experience a marginally negative drift up to the end of the test. At 1100°C the drift of 1.63 mm outer diameter thermocouples is characterised by a negative drift rate for time longer than 25 h: the measured drift is equal to 0.5°C after 200 h and -0.1°C after 400 h. Thermocouples having 3.2 mm and 2.38 mm outer diameters have always positive drift rates at 1100°C: their drift is respectively 1.6°C and 2.1°C after 200h, and 1.7°C and 2.1°C after 400 h.

At 1200°C the drift is always negative for all the outer diameters at time longer than 40 h. Except for the first 10 h, the drift rate is negative, leading to increasingly pronounced drift at longer exposure time for all the thermocouple diameters, and increases in absolute value with decreasing outer diameter. Drift is as high as -8.9°C after 200 h and -13.2°C after 400 h for the 1.63 mm outer diameter thermocouples, -3.3°C after 200 h and -5.8°C after 400 h for the 2.38 mm outer diameter thermocouples, -1.9°C after 200 h and -4.5°C after 400 h for the 3.2 mm outer diameter thermocouples.

3.4. Comparison between type N and type K thermocouples

A comparison between type K and type N thermocouples based on their performance in terms of drift is reported in Fig. 7, Fig. 8 and Fig. 9.

In Fig. 7 the drift of thermocouples having 3 mm or 3.2 mm outer diameter is plotted at 1000°C, 1100°C, 1200°C and 1300°C.

Type N and type K composition 1 thermocouples have very comparable drift at 1000°C (Fig. 7, a and b), 1100°C (Fig. 7, c and d) and 1200°C (Fig. 7, f and g), being their temperature readings at each temperature within about 1°C at any moment in time. At 1300°C type K composition 1 thermocouples outperform type N thermocouples, as they have lower drift rates and total drift (Fig. 7, i and l).

At 1100°C the drift of type K composition 2 and type N thermocouples have different sign, being always positive for the type K composition 2 thermocouples (Fig. 7, e) and negative for type N thermocouples at time longer than about 100 h (Fig. 7, c). The drift of type K composition 2 thermocouples reaches a plateau, whilst the type N thermocouples have a negative drift rate: this could suggest that at longer exposure time the drift experienced by the type N thermocouples could exceed in absolute value the drift of type K composition 2 thermocouples.

In Fig. 8 the drift of thermocouples having 2 mm or 2.38 mm outer diameter is plotted at 1000°C, 1100°C and 1200°C.

At 1200°C the 2 mm outer diameter type N thermocouples show a more pronounced drift than the type K composition 1 and composition 2 thermocouples (Fig. 8, f, g and h).

At 1100°C and time longer than 100 h the type K composition 1 thermocouples have a lower drift and in absolute value a lower drift rate compared to the type N thermocouples (Fig. 8, c and d). After 400 h the type K composition 2 (Fig. 8, e) and type N (Fig. 8, c) thermocouples have both, in absolute value, about 2°C drift. However, the drift of type K composition 2 thermocouples reaches a plateau while the type N thermocouples show a negative drift rate, suggesting that at longer exposure time the type N thermocouples could have more pronounced drift compared to the type K composition 2 thermocouples.

At 1000°C the type N thermocouples outperform the type K composition 1 thermocouples (Fig. 8, a and b).

Fig. 9 shows the drift of thermocouples having 1.5 mm or 1.63 mm outer diameter at 1000°C, 1100°C, 1200°C and 1300°C.

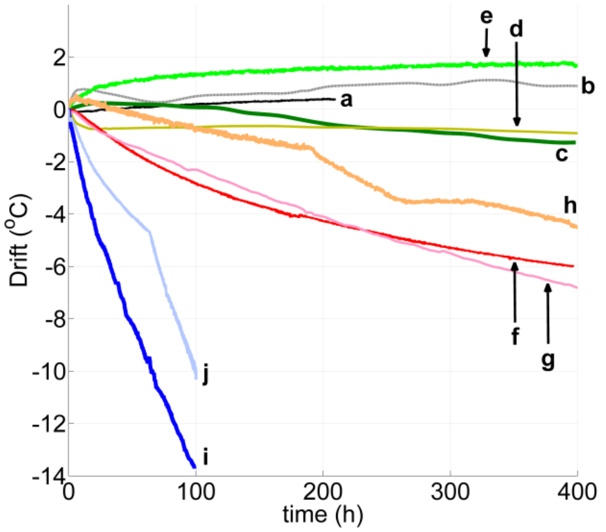

Fig. 7. Drift of Inconel 600 sheathed type K and type N thermocouples having 3 mm or 3.2 mm outer diameter at 1000°C, 1100°C, 1200°C and 1300°C; a. Type N-1000°C, b. Type K composition 1-1000°C, c. Type N-1100°C, d. Type K composition 1-1100°C, e. Type K composition 2-1100°C, f. Type N-1200°C, g. Type K composition 1-1200°C, h. Type K composition 2-1200°C, i. Type N-1300°C, j. Type K composition 1-1300°C.

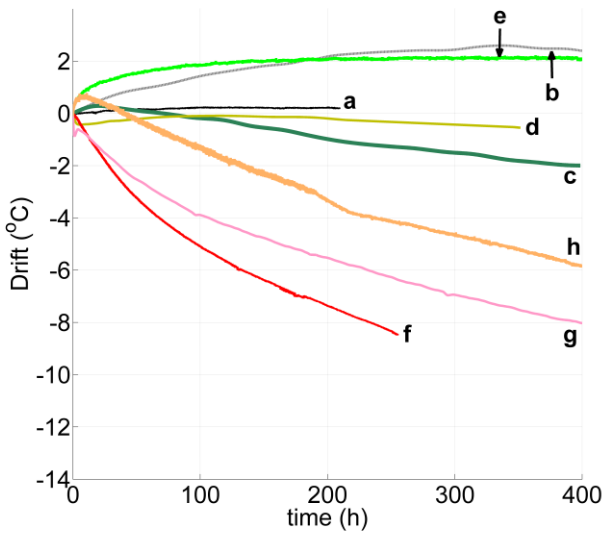

Fig. 8. Drift of Inconel 600 sheathed type K and type N thermocouples having 2 mm or 2.38 mm outer diameter at 1000°C, 1100°C and 1200°C; a. Type N-1000°C, b. Type K composition 1-1000°C, c. Type N-1100°C, d. Type K composition 1-1100°C, e. Type K composition 2-1100°C, f. Type N-1200°C, g. Type K composition 1-1200°C, h. Type K composition 2-1200°C.

At 1000°C the type N thermocouples outperform the type K composition 1 thermocouples (Fig. 9, a and b).

At 1100°C (Fig. 9, c, d and e) and 1300°C (Fig, 9, i and j) the type K thermocouples, both composition 1 and 2, drift much less than the type N thermocouples.

At 1200°C (Fig. 9, f, g and h) the type K thermocouples, both composition 1 and 2, experience comparable drift to the type N thermocouples, differing within about 1°C from the type N drift.

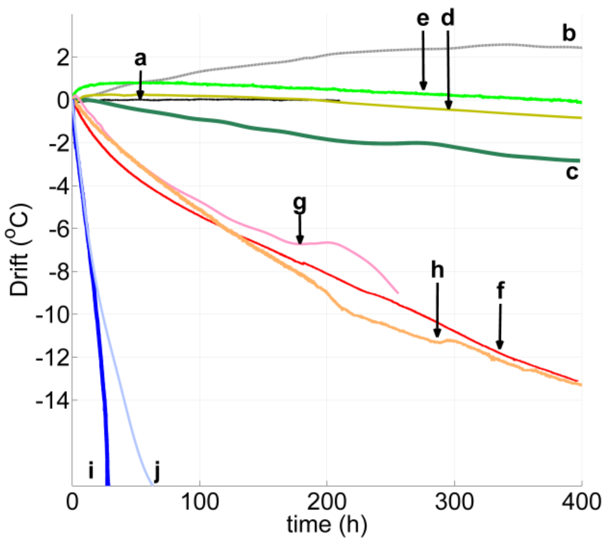

Fig. 9. Drift of Inconel 600 sheathed type K and type N thermocouples having 1.5 mm or 1.63 mm outer diameter at 1000°C, 1100°C, 1200°C and 1300°C; a. Type N-1000°C, b. Type K composition 1-1000°C, c. Type N-1100°C, d. Type K composition 1-1100°C, e. Type K composition 2-1100°C, f. Type N-1200°C, g. Type K composition 1-1200°C, h. Type K composition 2-1200°C, i. Type N-1300°C, j. Type K composition 1-1300°C.

3.5. Drift rates

Fig. 10 reports the average drift rate for type N and type K composition 1 thermocouples at 1000°C, 1100°C and 1200°C. At 1000°C the average drift rate is positive. A temperature increase to 1100°C results in a negative average drift rate. At 1200°C the drift rate is from 2 to 4 times larger than at 1100°C. Data in reference [7] for type N thermocouples having 0.5 mm, 1 mm and 1.5 mm outer diameters complement data in this work: at 1200°C a decrease in diameter results in more pronounced drift rates.

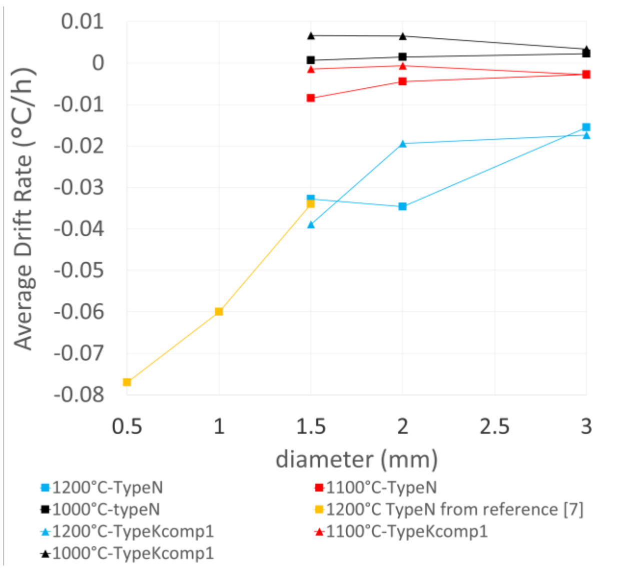

Fig. 10. Average drift rate of Inconel 600 sheathed type N and type K composition 1 thermocouples as a function of diameter at 1000°C, 1100°C and 1200°C.

4. CONCLUSIONS

Temperature measurements in industry often require the use of small diameter Nickel based thermocouples. In this work the isothermal drift of Inconel 600 sheathed MIMS type K thermocouples and Inconel 600 sheathed MIMS type N thermocouples has been investigated. Two different type K compositions have been studied. The tests have been undertaken in a wide temperature range, between 1000°C and 1300°C, as a function of the thermocouple diameter. At each temperature, for each kind of thermocouple, three sensors having different diameters have been tested. A larger coherent data set has been generated compared to the literature, where only sparse information on drift as a function of the diameter is available.

Above 1000°C significant drift can be experienced by Nickel based thermocouples. The drift is strongly affected by temperature and tends to be more pronounced at higher operating temperatures: at 1300°C drift as high as -18°C was measured in only 30 h exposure. Smaller diameter thermocouples experience larger drift rates than sensors having bigger outer diameters.

A comparison between type K and type N thermocouples reveals that in MIMS configuration above 1000°C type N thermocouples tend to experience drift comparable to or more pronounced than type K thermocouples. The opposite is known to occur for bare wire thermocouples [1].

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