The Choice Of Sheathing For Mineral Insulated Thermocouples

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INTRODUCTION

The mineral-insulated integrally metal-sheathed (MIMS) form of thermocouple consists of matched thermocouple wires surrounded by insulating material (typically MgO) compacted by rolling, drawing or swaging until the sheath is reduced in diameter. The advantages of MIMS thermocouples are:

- Chemical isolation of wires from the surrounding atmosphere.
- Shielding of thermoelements from sources of electrical interference.
- Protection of the wires and insulation from damage due to shock.
- Flexibility of the final assembly allowing bending.

For two decades, people have credited MIMS construction with a greater capability than deserved. Quite frequently, this form has shown less stability, less durability and lower temperature limits than corresponding unsheathed elements. The nickel bearing MIMS thermocouples used above 400°C (750°F) are especially vulnerable to calibration instability and shortened lifetime - factors which bear heavily on thermocouple use and selection.

HYSTERESIS

Thermoelectric hysteresis is one contributor toward calibration instability. Hysteresis is a form of short-range order/disorder phenomenon occurring between 200 and 600°C (peaking at ≈ 400°C) for Ni-Cr alloys such as Type K. It is evidenced by a calibration change of several degrees as the thermocouple temperature is cycled within this temperature band. Type N thermocouples exhibit hysteresis of up to 5°C when heated and cooled between 200 and 1000°C (peaking around 750°C). At 900°C hysteresis is 2 to 3°C. If the type K thermocouple, for example, will be used below 500°C, hysteresis can be reduced by annealing overnight at 450°C.

OXIDATION

Another phenomenon affecting calibration is oxidation. Ni-Cr-Al alloys (*e.g.*, Chromel*) have limited life in air above 500°C because of oxidation. A special form of oxidation is so-called “green rot” which is preferential oxidation of Cr in atmospheres with low oxygen content (*e.g.*, sheaths in which the volume of air is limited and stagnant). Nicrosil resists oxidation up to about 1,250°C (2,300°F) and does not exhibit green rot.

Several new sheath materials called “Nicrobell” (**) consist of Nicrosil with 1.5% or 3.0% niobium. Nicrobell “A” is particularly formulated to be resistant to oxidation. Another new oxidation resistant sheath material called Nicrosil + (***) consists of Nicrosil plus 0.15% magnesium. It is reported (ref. 4) to exhibit less spalling and probably have a longer life than some Nicrobell version(s) tested.

Nicrosil, itself, does not have satisfactory resistance to reducing atmospheres, such as encountered in most combustion or many heat treating processes. Other adaptations of Nicrosil for use as sheath material (such as Nicrobells B, C and D) can be expected to deal with typical nonoxidizing atmospheres.

CONTAMINATION

A third influence on calibration stability is contamination. The idea behind the mineral-insulated, integrally designed, metal-sheathed thermocouple is that the uniform compression of finely divided mineral oxides (typically MgO) insulation surrounding the wires and filling the sheath would seal the internal volume, thereby eliminating contamination. The volume of the insulation compressed by swaging, rolling or drawing is on the order of 85% of solid material. This is useful, permitting the tubing to be bent and also permitting the manufacture of smaller diameter assemblies. It does, however, permit the intrusion of gas such as water vapor or air. It also permits vapor diffusion of elements composing the wires or sheath. Bentley and Morgan determined that the vapor-phase diffusion of Mn (manganese) through the MgO insulation has the greatest influence on thermocouple decalibration.

METAL FATIGUE

Metal fatigue is another cause of shortened thermocouple life. Differing temperature coefficients of linear expansion between sheaths and wires causes strain during heating or cooling. These strains result in eventual fracture due to metal fatigue. On heating to 900°C, the thermal expansion of Nisil differs from SS 304 by 0.4% of length. Nicrosil has only 0.05% difference in thermal expansion compared to Nisil (the leg most likely to fracture). A sheath of Nicrosil, Nicrosil + or Niobell would therefore induce less metal fatigue in either leg of the Type N thermocouple than would stainless steel.

COMPOSITION

Composition changes in SS sheathed couples are generally greater than in Inconel (****) sheathed couples. In tests performed by Anderson, *et al.*, the KN leg showed an increase in chromium but a decrease in aluminum. These changes in composition contributed the major portion of the resulting change in calibration of the thermocouple.

Most stainless steels have from 1 to 2% of manganese. Type 304 has ≈ 2% manganese. Others have manganese concentrations varying from 1% to 10%. Inconel has up to 1% Mn. As a rule of thumb, each 1% of Mn in the sheath material contributes -10°C calibration shift for 1,000 hours at 1,100°C. According to Bentley, at 1,200°C, Type N in a 3 mm diameter SS sheath drifted -24°C in 1,000 hours.

HUMIDITY

There is a multiple effect of water vapor within the sheath. It is rapidly absorbed in the MgO, reducing the insulation resistance. Humidity intrusion can ruin a MIMS thermocouple assembly in as short a time as a few minutes. In lesser amounts, it destroys a protective oxide coating on Nickel-Chromium alloys, subjecting them to more rapid deterioration. The changes due to water

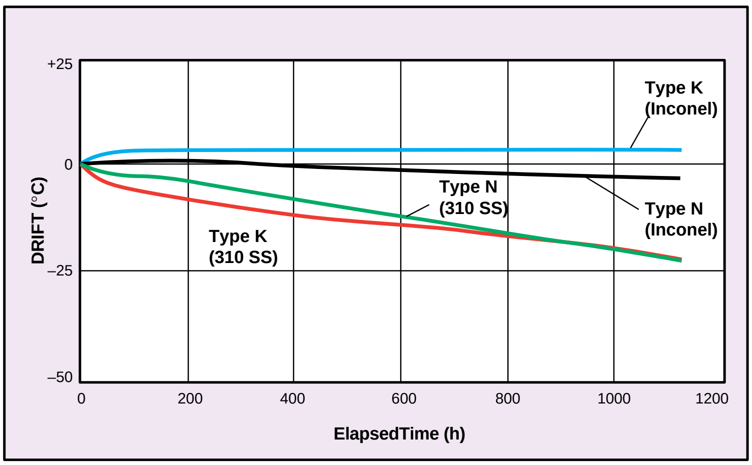

Figure 1. Drift of 3 mm diameter stainless steel sheathed and Inconel 600 sheathed type K and Nicrosil vs. Nisil thermocouples in 1200°C in vacuum. The dips in the drift curve are the result of the "in-place inhomogeneity test" where the samples were extracted from the furnace by 5 cm.

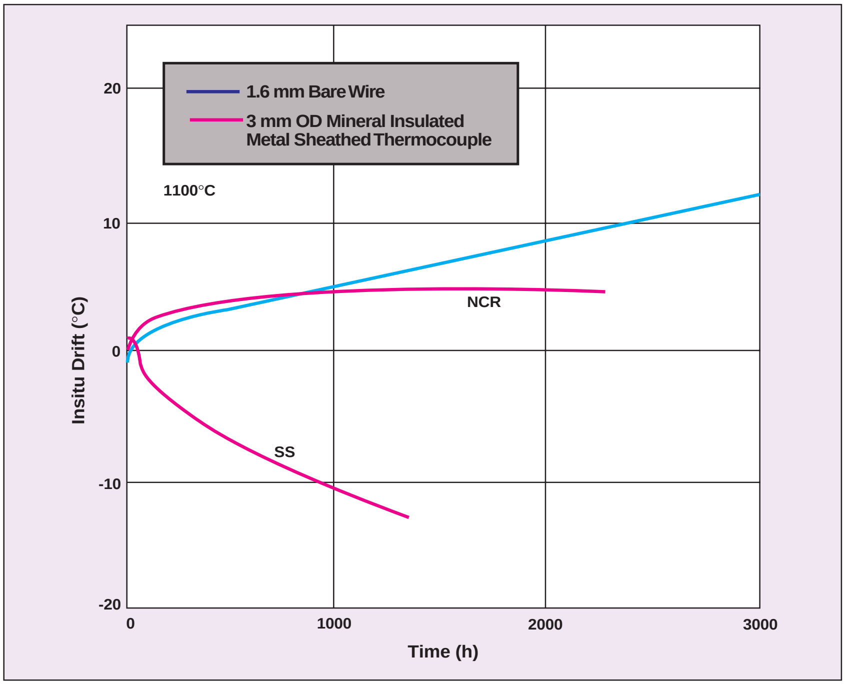

Figure 2. The insitu drift in type N thermocouples with tips held at 1100°C. Curves refer to mineral insulated metal sheathed thermocouples with 3mm OD sheaths of 310 stainless steel (SS) or Nicrosil (NCR) and 1.6mm bare wire thermocouples in air. The range in drift for the latter is also indicated.

vapor can be sufficiently severe as to make affected couples useless by reducing insulation resistance. This reduced resistance can result in misleading temperature readings, premature failure or even erroneous readings after open circuiting.

Water vapor can be introduced during thermocouple fabrication or repair, or even by changes in atmospheric pressure during air shipment or during long periods of storage (*e.g.*, six months) at construction sites. Care must be taken of hermetic seals during shipment and installation.

RECOMMENDATIONS

Although not mentioned above , there is some relationship between the diameter of these thermocouple materials and stability and longevity at elevated temperatures. The surface of the brickwork on which electrical heaters are supported becomes conductive at elevated temperatures. This leads to flow of electrical currents through thermocouple sheaths to ground, perhaps through the measuring instrument.

The temptation to use the finest sheathed thermocouples (as fine as 1 mm) should be resisted for higher temperature or corrosive industrial environments.

Stainless steel is a poorer sheath for mineral-insulated, metal-sheathed thermocouples than either Inconel 600 or modified Nicrosil when used with Ni-Cr thermocouples such as Type K or Type N. The modified Nicrosil sheathed thermocouples offer improved oxidation resistance up to 1,100°C (1,200 to 1,250°C for Type N), reduced failures due to differential thermal expansion, improved ductility and the elimination of the drift problems caused by the vapor diffusion of manganese from stainless steels or Inconel.

Considering the current state of supply of the newer materials, one could well choose a low manganese (0.3% or less) Inconel sheathed Type K MIMS thermocouple until such time as modified Nicrosil sheathed Type K or N and appropriate supporting data become readily available.

(*) CHROMEL is a trademark of the Hoskins Manufacturing Co.
(**) NICROBELL is a trademark of NICROBELL Pty. Ltd. NICROBELL sheath alloys are patented in a number of countries including the USA
(***) NICROSIL + is a trademark of Pyrotenax Australia Pty. Ltd.
(****) INCONEL is a trademark of the International Nickel Co.

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Z

Material Selection Guide

This chart is a guide to selection of thermocouple sheath and thermowell materials according to process fluid. It includes factors such as catalytic reaction, contamination and electrolysis. However, there are many instances where factors other than these must be considered. It is recommended that such special applications be submitted to OMEGA ENGINEERING for recommendations.

These recommendations are only guides based on the most economical material selection. OMEGA ENGINEERING cannot be held responsible if these recommendations are not satisfactory for specific applications.

SUBSTANCE	CONDITIONS	RECOMMENDED METAL
Acetate Solvents	Crude or Pure	Monel or Nickel
Acetic Acid	10% - 70°F	304 Stainless Steel
" "	50% - 70°F	304 Stainless Steel
" "	50% - 212°F	316 Stainless Steel
" "	99% - 70°F	430 Stainless Steel
" "	99% - 212°F	430 Stainless Steel
Acetic Anhydride		Monel
Acetone	212°F	304 Stainless Steel
Acetylene		304, Monel, Nickel
Alcohol Ethyl	70°F	304 Stainless Steel
" "	212°F	304 Stainless Steel
Alcohol Methyl	70°F	304 Stainless Steel
" "	212°F	304 Stainless Steel
Aluminum	Molten	Cast iron
Aluminum Acetate	Saturated	304 Stainless Steel
Aluminum Sulphate	10% - 70°F	304 Stainless Steel
" "	Saturated 70°F	304 Stainless Steel
" "	10% - 212°F	316 Stainless Steel
" "	Saturated 212°F	316 Stainless Steel
Ammonia	All concentrations 70°F	304 Stainless Steel
Ammonium Chloride	All concentrations 212°F	316 Stainless Steel
Ammonium Nitrate	All concentrations 70°F	304 Stainless Steel
" "	All concentrations 212°F	304 Stainless Steel
Ammonium Sulphate	5% - 70°F	304 Stainless Steel
" "	10% - 212°F	316 Stainless Steel
" "	Saturated 212°F	316 Stainless Steel
Aniline	All concentrations 70°F	304 Stainless Steel
Amylacetate		Monel
Asphalt		Steel (C1018) Phosphor Bronze, Monel, Nickel
Barium Carbonate	70°F	304 Stainless Steel
Barium Chloride	5% - 70°F	Monel
" "	Saturated 70°F	Monel
" "	Aqueous - Hot	316 Stainless Steel
Barium Hydroxide		Steel (C1018)
Barium Sulphite		Nichrome
Benzaldehyde		Steel (C1018)
Benzene	70°F	304 Stainless Steel
Benzine		Steel (C1018), Monel, Inconel
Benzol	Hot	304 Stainless Steel
Boracic Acid	5% Hot or Cold	304 Stainless Steel
Bromine	70°F	Tantalum
Butadiene		Brass, 304
Butane	70°F	304 Stainless Steel
Butylacetate		Monel
Butyl Alcohol		Copper
Butylenes		Steel (C1018), Phosphor Bronze
Butyric Acid	5% - 70°F	304 Stainless Steel
" "	5% - 150°F	304 Stainless Steel
Calcium Bisulfite	70°F	316 Stainless Steel
Calcium Chlorate	Dilute 70°F	304 Stainless Steel
" "	Dilute 150°F	304 Stainless Steel
Calcium Hydroxide	10% - 212°F	304 Stainless Steel
" "	20% - 212°F	304 Stainless Steel
" "	50% - 212°F	317 Stainless Steel
Carbolic Acid	All 212°F	316 Stainless Steel
Carbon Dioxide	Dry	Steel (C1018), Monel
" "	Wet	Aluminum,Monel,Nickel
Carbon Tetrachloride	10% - 70°F	Monel
Chlorex Caustic		316SS, 317SS
Chlorine Gas	Dry 70°F	317 Stainless Steel
" "	Moist 70°F	Hastelloy C
" "	Moist 212°F	Hastelloy C
Chromic Acid	5% - 70°F	304 Stainless Steel
" "	10% - 212°F	316 Stainless Steel
" "	50% - 212°F	316 Stainless Steel
Citric Acid	15% - 70°F	304 Stainless Steel
" "	15% - 212°F	316 Stainless Steel
" "	Concentrated 212°F	317 Stainless Steel
Coal Tar	Hot	304 Stainless Steel
Coke Oven Gas		Aluminum
Copper Nitrate		304, 316
Copper Sulphate		304, 316
Core Oils		316 Stainless Steel
Cottonseed Oil		Steel (C1018), Monel, Nickel
Creosols		304 Stainless Steel
Creosote Crude		Steel (C 1018), Monel, Nickel
Cyanogen Gas		304 Stainless Steel
Dowtherm		Steel (C1018)
Epsom Salt	Hot and Cold	304 Stainless Steel
Ether	70°F	304 Stainless Steel
Ethyl Acetate		Monel
Ethyl Chloride	70°F	304 Stainless Steel
Ethylene Glycol		Steel (C1018)
Ethyl Sulphate	70°F	Monel
Ferric Chloride	1% - 70°F	316 Stainless Steel
" "	5% - 70°F	Tantalum
" "	5% - Boiling	Tantalum
Ferric Sulphate	5% - 70°F	304 Stainless Steel
Ferrous Sulphate	Dilute 70°F	304 Stainless Steel
Formaldehyde		304 Stainless Steel
Freon		Steel (C1018)
Formic Acid	5% - 70°F	316 Stainless Steel
" "	5% - 150°F	316 Stainless Steel
Gallic Acid	5% - 70°F	Monel
" "	5% - 150°F	Monel
Gasoline	70°F	304 Stainless Steel
Glucose	70°F	304 Stainless Steel
Glycerine	70°F	304 Stainless Steel
Glycerol		304 Stainless Steel
Heat Treating		446 Stainless Steel
Hydrobromic Acid	48% - 212°F	Hastelloy B
Hydrochloric Acid	1% - 70°F	Hastelloy C
" "	1% - 212°F	Hastelloy B
" "	5% - 70°F	Hastelloy C
" "	5% - 212°F	Hastelloy B
" "	25% - 70°F	Hastelloy B
" "	25% - 212°F	Hastelloy B
Hydrocyanic Acid		316 Stainless Steel
Hydrofluoric Acid		Hastelloy C
Hydrogen Peroxide	70°F	316 Stainless Steel
" "	212°F	316 Stainless Steel
Hydrogen Sulphide	Wet and dry	316 Stainless Steel
Iodine	70°F	Tantalum
Kerosene	70°F	304 Stainless Steel
Lactic Acid	5% - 70°F	304 Stainless Steel
" "	5% - 150°F	316 Stainless Steel
" "	10% - 212°F	Tantalum
Lacquer	70°F	316 Stainless Steel
Latex		Steel (C1018)
Lime Sulphur		Steel (C1018), 304, Monel
Linseed Oil	70°F	304 Stainless Steel
Magnesium Chloride	5% - 70°F	Monel
" "	5% - 212°F	Nickel
Magnesium Sulphate	Cold and Hot	Monel
Malic Acid	Cold and Hot	316 Stainless Steel
Mercury		Steel (C1018) , 304, Monel
Methane	70°F	Steel (1020)
Milk		304, Nickel
Mixed Acids (Sulphuric and Nitric - all temp. and %)		Carpenter #20
Molasses		Steel (C1018), 304, Monel, Nickel
Muriatic Acid	70°F	Tantalum
Nap	70°F	304 Stainless Steel
Natural Gas	70°F	304 Stainless Steel
Neon	70°F	304 Stainless Steel
Nickel Chloride	70°F	304 Stainless Steel
Nickel Sulphate	Hot and Cold	304 Stainless Steel
Nitric Acid	5% - 70°F	304 Stainless Steel
" "	20% - 70°F	304 Stainless Steel
" "	50% - 70°F	304 Stainless Steel
" "	50% - 212°F	304 Stainless Steel
" "	65% - 212°F	316 Stainless Steel
" "	Concentrated - 70°F	304 Stainless Steel
" "	Concentrated - 212°F	Tantalum
Nitrobenzene	70°F	304 Stainless Steel
Nitrous Acid		304 Stainless Steel
Oleic Acid	70°F	316 Stainless Steel
Oleum	70°F	316 Stainless Steel
Oxalic Acid	5% - Hot and Cold	304 Stainless Steel
" "	10% - 212°F	Monel
Oxygen	70°F	Steel (C1018)
"	Liquid	304 Stainless Steel
Palmitic Acid		316 Stainless Steel
Petroleum Ether		
Phenol		304 Stainless Steel
Pentane		304 Stainless Steel
Phosphoric Acid	1% - 70°F	304 Stainless Steel
" "	5% - 70°F	304 Stainless Steel
" "	10% - 70°F	316 Stainless Steel
" "	10% - 212°F	Hastelloy C
" "	30% - 70°F	Hastelloy B
Picric Acid	70°F	304 Stainless Steel
Potassium Bromide	70°F	316 Stainless Steel
Potassium Carbonate	1% - 70°F	304 Stainless Steel
Potassium Chlorate	70°F	304 Stainless Steel
Potassium Chloride	5% - 70°*F	304 Stainless Steel
" "	5% - 212°F	304 Stainless Steel
Potassium Hydroxide	5% - 70°F	304 Stainless Steel
" "	25% - 212°F	304 Stainless Steel
" "	50% - 212°F	316 Stainless Steel
Potassium Nitrate	5% - 70°F	304 Stainless Steel
" "	5% - 212°F	304 Stainless Steel
Potassium Permanganate	5% - 70°F	304 Stainless Steel
Potassium Sulphate	5% - 70°F	304 Stainless Steel
" "	5% - 212°F	304 Stainless Steel
Potassium Sulphide	70°F	304 Stainless Steel
Propane		304 Stainless Steel
Pyrogallic Acid		304 Stainless Steel
Quinine Bisulphate	Dry	316 Stainless Steel
Quinine Sulphate	Dry	304 Stainless Steel
Resin		304 Stainless Steel
Rosin	Molten	304 Stainless Steel
Sea Water		Monel
Salommoniac		Monel
Salicylic Acid		Nickel
Shellac		304 Stainless Steel
Soap	70°F	304 Stainless Steel
Sodium Bicarbonate	All concentrations 70°F	304 Stainless Steel
" "	5% - 150°F	304 Stainless Steel
Sodium Bisulphate		Monel
Sodium Carbonate	5% - 70°F	304 Stainless Steel
" "	5% - 150°F	304 Stainless Steel
Sodium Chloride	5% - 70°F	316 Stainless Steel
" "	5% - 150°F	316 Stainless Steel
" "	Saturated - 70°F	316 Stainless Steel
" "	Saturated - 212°F	316 Stainless Steel
Sodium Fluoride	5% - 70°F	Monel
Sodium Hydroxide		304 Stainless Steel
Sodium Hypochlorite	5% still	316 Stainless Steel
Sodium Nitrate	Fused	317 Stainless Steel
Sodium Peroxide		304 Stainless Steel
Sodium Phosphate		Steel (C1018)
Sodium Silicate		Steel (C1018)
Sodium Sulphate	70°F	304 Stainless Steel
Sodium Sulphide	70°F	316 Stainless Steel
Sodium Sulphite	150°F	304 Stainless Steel
Steam		304 Stainless Steel
Stearic Acid		304 Stainless Steel
Sulphur Dioxide	Moist Gas - 70°F	316 Stainless Steel
" "	Gas - 575°F	304 Stainless Steel
Sulphur	Dry - Molten	304 Stainless Steel
"	Wet	316 Stainless Steel
Sulphuric Acid	5% - 70°F	Carp. 20, Hastelloy B
" "	5% - 212°F	Carp. 20, Hastelloy B
" "	10% - 70°F	Carp. 20, Hastelloy B
" "	10% - 212°F	Carp. 20, Hastelloy B
" "	50% - 70°F	Carp. 20, Hastelloy B
" "	50% - 212°F	Carp. 20, Hastelloy B
" "	90% - 70°F	Carp. 20, Hastelloy B
" "	90% - 212°F	Hastelloy D
Tannic Acid	70°F	304 Stainless Steel
Tar		Steel (C1018), 304, Monel, Nickel
Tartaric Acid	70°F	304 Stainless Steel
" "	150°F	316 Stainless Steel
Tin	Molten	Cast Iron
Tolvene		Aluminum, Phosphor Bronze, Monel
Trichloroethylene		Steel (C1018)
Turpentine		304 Stainless Steel
Varnish		304 Stainless Steel
Vegetable Oils		Steel (C1018), 304, Monel
Vinegar		304 Stainless Steel
Water	Fresh	Copper, Steel (C1018), Monel
"	Salt	Aluminum
Whiskey, Wine		304, Nickel
Xylene		Copper
Zinc	Molten	Cast Iron
Zinc Chloride		Monel
Zinc Sulphate	5% - 70°F	304 Stainless Steel
" "	Saturated - 70°F	304 Stainless Steel
" "	25% - 212°F	304 Stainless Steel