GRAIN GROWTH IN TYPE K THERMOCOUPLES

By Howard Hilborn

Grain growth in metals is a well-documented phenomenon; however, its cause, effect and cure with respect to type K thermocouples seems little-known to most thermocouple users.

In all cases, grain growth is time and temperature dependent; most often, in fact, time at elevated temperatures is such an overriding factor that little else can be changed to generate a positive result.

However, some steps can be taken to solve the problem for temperatures normally seen by type K thermocouples. Exposure to temperatures above 1200°F for extended periods of time will cause extensive grain growth in a type K thermocouple when conventional sheath material is used. We have seen cases where the cross-section of the Alumel® wire was covered by two to three grains. When this occurs, the material can easily break at the grain boundary, resulting in thermocouple failure.

Test results indicate that failure rate is difficult to accurately predict. In one test case, for example, 10% of the samples failed in three months, 60% in six months, and 72% in 11 months of exposure to temperatures in the 2000°F to 2100°F range. All samples studied were ¼" O.D., 310 S/S sheathed type K single-element thermocouples, all were tested under identical conditions, and all exhibited extensive grain growth (two to five grains in cross-section). While those that failed did so at different times, some never failed at all, although they exhibited the same conditions as those that did fail. Though there has been some speculation as to why certain thermocouples did not fail (when for all practical purposes they should have), no definitive conclusions were reached; suffice it to say, they simply exceeded themselves. All of the failures took place in the Alumel® wire, as it is more subject to grain growth than the Chromel® wire.

The coefficient of expansion differential between the Alumel® wire and the sheath is the biggest controllable contributor to thermocouple failure from grain growth. In fact, if the coefficient of expansion of the sheath is identical to that of the thermocouple wire, grain growth is either drastically reduced or even completely eliminated. 310 S/S is commonly used as a thermocouple sheath at elevated temperatures, and it withstands the environment well; however, the expansion differential is extreme. Inconel® more closely approximates the coefficient of expansion of Alumel® and works well at high temperature as long as there is no sulphur in the process, as sulphur bearing atmospheres cause rapid failure of Inconel® due to a phenomenon known as "green rot".

In the past, the best choice of sheath material for minimizing grain growth was Inconel®; however, recent developments in sheath materials have given us new options. New duplex alloys will soon be commercially available that very closely match the coefficient of expansion of Alumel® and give superior resistance to temperatures as high as 2400°F. Preliminary tests of type K thermocouples with this sheath material have shown an increased resistance (by a factor of eight to 10 times) to grain growth of the Alumel® wire.

A typical application in which grain growth causes failures is in fired-process furnaces where, while the temperature being measured is the tubeskin temperature, the thermocouple is often exposed to process gas temperatures that far exceed those tubeskin temperatures. In such situations, proper routing can play a major role in extending thermocouple life. By keeping the thermocouple sheath in contact with the furnace tubes, the tubes are used as heat sink, thereby keeping the thermocouples much cooler than the surrounding gas temperatures. By using this method of thermocouple routing, life in excess of six years has been achieved in situations that would otherwise have seen failure in less than a year, in the majority of thermocouples.

The ultimate solution at this time is to convert to type N thermocouples and use the new duplex alloy sheath material when it becomes available. This combination has shown the ability not only to completely eliminate grain growth, but also has the interesting side effect of enhancing electromotive force (EMF) stability… but that's a subject best saved for another paper.

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