Metal-embedding method helps tiny sensors function in extreme environments

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University of Wisconsin-Madison mechanical engineers have developed a method for fabricating "packages" of tiny sensors that measure temperature more accurately than bulk thermocouples. Inserted unobtrusively in critical locations, these metal-embedded micro-thin film thermocouples could more effectively monitor conditions and diagnose problems during manufacturing processes such as injection-molding or die-casting.

Monitoring and controlling temperature is critical to a variety of applications, including manufacturing, automotive, aeronautics and aerospace. Sensors detect and solve problems that occur in these environments, resulting in less damage to tools, down time for machine maintenance and repair, energy consumption and product waste, says Xiaochun Li, an assistant professor of mechanical engineering.

In the United States, for example, continuous casting produces more than 100 million tons of steel each year, and many of the problems that occur during this process arise during the initial solidification at the meniscus, or the interface between the top surface of steel and the mold, he says. Higher and more variable meniscus heat flux leads to more defects, while thermal stress could lead to cracks in the mold surface at the meniscus.

"Direct measurement of temperature and strain in the mold coating layer would greatly improve our understanding of factors that control mold life," says Li. "Even a modest production improvement — for example,

$10 per ton — can save $1 billion per year."

Li is one of four authors of a paper in the May Journal of Micromechanics and Microengineering that describes how they fabricated an array of metal-embedded micro thin film sensors — a process that protects the sensors from oxidation, chemical corrosion, wear, contamination and other factors.

Currently, in a manufacturing environment most temperature sensors are bulk thermocouples that occupy a large volume in a tool or machine. They are attached either to the surface of components, where they might be far from where the machine meets the product (to avoid interfering with machine operation), or destructively inserted into critical locations, making it difficult to gather accurate temperature measurements across those locations.

In addition, the conventional thermocouples have crude junction definition and respond slowly to changing temperatures, says Li.

Recent technological advances have made micro thin film thermocouples, with thicknesses on the order of 100 nanometers, a better alternative to much larger bulk thermocouples.

"Owing to their small sizes, distributed micro thin film sensors could be incorporated into manufacturing tooling systems, particularly dies, molds and inserts for die casting; and stamping, forging and injection molding, without interfering with normal operations," says Li. "Their small size also enables these sensors to respond to changes much quicker than ordinary macro sensors."

Most of these sensors, however, are fabricated onto substrates and are directly exposed to extreme conditions, such as prolonged high temperatures, that can cause them to fail prematurely.

To protect the sensors, yet maintain their small size and sensitivity, Li and graduate students Xugang Zhang and Hongseok Choi and postdoctoral researcher Arindom Datta developed a method to embed them in nickel. Initially, the group's research centered on identifying the best dielectric materials — alumina and silicon nitride — to isolate the sensor layers from the metal substrate and embedding. After the researchers fabricated the sensor array, they etched away the silicon substrate, transferred the array to an electroplated nickel wafer and added nickel "caps."

The resulting metal-embedded sensors could be applied as unit or laser-cut out of the metal wafer for individual use. And because of their small size, they can be embedded without impairing the structural integrity of tooling.

"If these micro sensors can be embedded at critical locations not accessible to ordinary sensors," says Li, "tremendous benefits can be achieved since both the spatial and temporal resolution of in-process sensing systems can be improved significantly, adding advanced intelligence to the tooling to enable real-time monitoring and control."

He says researchers could apply the technique in other areas. "Our embedding method can potentially be used to package any kind of micro or nano devices for harsh environment applications," he says.

Source: University of Wisconsin