New optical method pinpoints weak spots in jet engine thermal coatings

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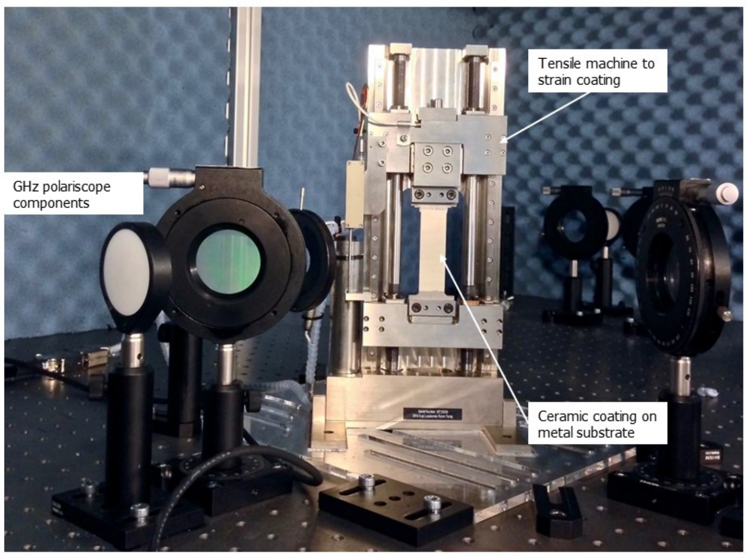

Researchers used a tensile machine to pull a metal specimen with a ceramic thermal barrier coating sprayed on its surface. With a polariscope, they could measure changes in refractive index resulting from this applied strain. Some of the components of the GHz polariscope are seen on either side of the tensile machine. Credit: Peter J. Schemmel, Heriot-Watt University

Researchers have demonstrated, for the first time, that an optical analysis method can reveal weak areas in ceramic thermal barrier coatings that protect jet engine turbines from high temperatures and wear. The technique could be used to predict how long coatings would last on an airplane and might eventually lead to new thermal barrier coatings, making engines more efficient and cutting both the cost and pollution of air travel.

The lifetime of a thermal barrier coating used on airplane turbine blades can range widely from as little as 1,000 hours up to 10,000 hours at full turbine thrust, even when the coating is applied in the exact same way. Because the lifetime is unpredictable and failure during flight could be catastrophic, turbine blades are scheduled for replacement based on the shortest estimated lifetime.

"Our strain-measurement technique can analyze the coatings immediately after manufacturing and work to identify the turbine blades that would last the longest in the airplane," said leader of the research team, Andrew J. Moore, of Heriot-Watt University, UK. "Ultimately, we want to develop an imaging device that would show the strain distribution in the coating of an entire turbine blade, information that would be used to decide if that turbine blade would go into service."

In The Optical Society journal *Optics Express*, the researchers demonstrated that changes in refractive index, a measure of how fast light travels through a material, could be observed when a piece of metal coated with a ceramic thermal barrier coating was pulled in a controlled manner. Moore's research team is collaborating with Rolls-Royce, a leading manufacturer of jet engines.

"If we can correlate how the strain distribution is related to the coating's lifetime, then we could determine which coatings will fail first and shouldn't be put into an aircraft and which ones will last much longer," said Moore. "This would increase the time between services significantly, which would bring huge savings."

The new technique could also be used to predict the lifetimes of coatings developed to be more reliable or tolerate higher temperatures, which allows engines to run more efficiently. It might also find use in automotive and nuclear power applications where ceramics are also used as thermal barriers.

Seeing through opaque materials

Using gigahertz (GHz) illumination was key to the new technique because these wavelengths can travel though some opaque materials, such as ceramics, allowing analysis from within the material. Visible wavelengths, on the other hand, can only be used for surface analysis of opaque materials.

The researchers tested their technique with pieces of metal sprayed with the same ceramic coatings used on Rolls Royce turbine blades. They put the pieces into a tensile machine that applied strain by slowly pulling the metal. Researchers then applied GHz illumination (280-380 GHz) during the process, which traveled through the ceramic coating and bounced off the metal beneath. The reflected light was then measured using a polariscope to determine how the refractive index of the ceramic changed with the applied strain. Although the team's current optical setup only acquires point-based measurements, the researchers say the technique could be used with an imaging setup to analyze an entire blade .

"With the GHz illumination we were able to see changes in the refractive index with applied strain," said Moore. "This shows that our approach could be applied for quality assurance in the future."

The researchers recently started experimenting with using higher frequency illumination in the terahertz (THz) range, which could improve the technique's spatial resolution. In collaboration with

Cranfield University, UK, they are also using their technique to make strain measurements of ceramic-coated metal samples that undergo accelerated aging. "We will be looking to see when the coatings fail and then correlating that with GHz and THz measurements we took prior to the aging process," said Moore. "This is a step toward using our technique to identify which coatings fail first."

More information: Peter Schemmel et al, Measurement of direct strain optic coefficient of YSZ thermal barrier coatings at GHz frequencies, *Optics Express* (2017). DOI: 10.1364/OE.25.019968

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