U.S. DEPARTMENT OF
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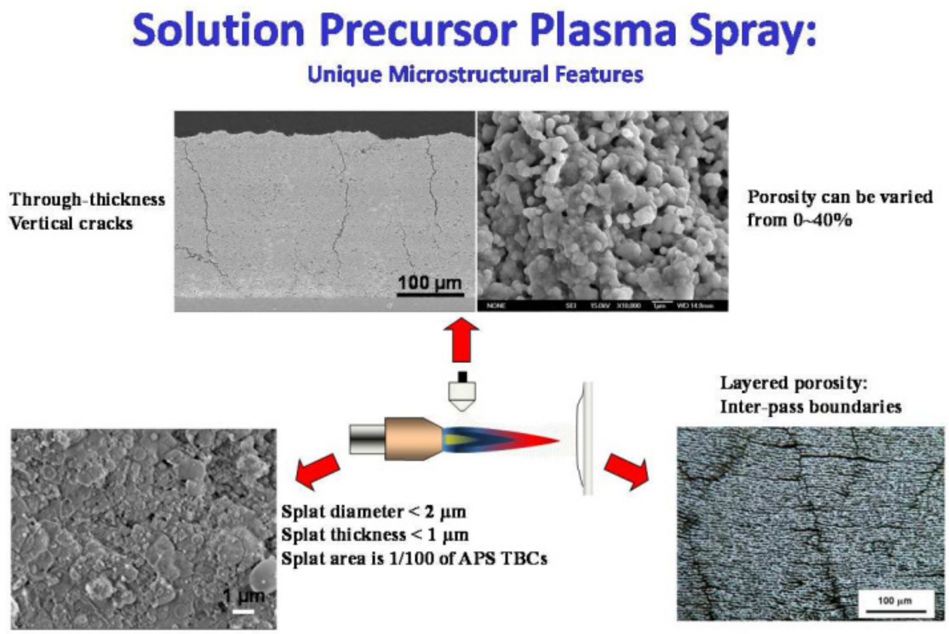
Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

Ultra-High Temperature Thermal Barrier Coating Development and Validation



The Solution Precursor Plasma Spray (SPPS) process can produce a coating with vertical cracking for strain tolerance, tailored porosity, and inter-pass boundaries to reduce thermal conductivity. *Photo credit Solution Spray Technologies LLC (SST)*

Industrial turbines and engines have an extensive impact on manufacturing and electrical power generation in the United States. Improving engine and turbine efficiency, durability, and commercial competitiveness remains a vital priority in these industries. These improvements have been extensively researched by developing thermal barrier coating (TBC) technologies in commercial-scale engines and turbines. Current TBCs are fabricated from yttria stabilized zirconia (YSZ). Despite significant TBC technology advances, turbines and engines are being introduced to harsher environmental conditions such as higher temperatures. These higher temperatures can cause adverse phase changes in conventional YSZ TBCs. Improving or replacing these TBCs will help increase turbine and engine performance, as well as reduce emissions.

This project will develop a new, higher temperature coating material to replace YSZ TBCs. The new coating is fabricated from yttrium aluminum garnet (YAG) material via the Solution Precursor Plasma Spray (SPPS) process. First, the project will seek to optimize the SPPS process tailored to the YAG TBC properties and specific applications. The YAG TBC will be deposited onto conventional turbine and engine components (particularly combustion liners and fuel nozzle injectors), and then tested for improved performance compared to conventional YSZ TBCs. The YAG TBC will then be scaled to a full-scale development engine and deposited onto turbine outer air seals (tipshoes) for rig testing. After verifying TBC performance, this technology seeks to be commercialized.

Benefits for Our Industry and Our Nation

The YAG TBC under development will allow future engine designs that can operate at a higher firing temperature and with a reduced amount of wasteful cooling air while replacing conventional YSZ TBCs. YAG also has a 25% lower density than YSZ, which reduces engine weight, as well as centrifugal loads on coated rotating parts. Using state-of-the-art YAG TBCs are expected to have numerous benefits for industrial turbines and engines, including:

- Improved power performance and engine efficiency compared to YSZ TBCs in existing engine models (e.g. improvement of 0.47% in power and 0.13% in engine efficiency for combustion liners, improvement of 0.7% in power and 0.1% in engine efficiency for tipshoes)
- Increased engine durability (and improved commercial competitiveness), which can concurrently reduce the cost and environmental impact

Applications in Our Nation's Industry

This YAG TBC is expected to have significantly improved properties over conventional YSZ TBCs. This enables the YAG TBC to be applied to numerous engine components, including fuel nozzle injector tips, combustion liners, clamp rings, and sliding rings, as well as turbine blades, stators, and outer air seals. These TBCs will allow for these devices to be used with higher temperature capabilities while maintaining durability and resisting corrosion. This technology is expected to replace conventional YSZ TBCs used in these devices.

Project Description

The project objective is to develop, and demonstrate the properties of a new YAG TBC manufactured via a novel SPPS process. These graded porosity TBCs will be developed to optimize key engine performance parameters depending on the application. The project outcomes involve depositing the YAG TBC onto fuel nozzle injectors and combustion liners for rig testing, and then testing the optimal porosity grading in a full-scale development engine. The full-scale development engine should validate improved system performance parameters (e.g. furnace cycling durability, thermal conductivity, temperature capability) compared to the YSZ TBC baseline.

Barriers

- YAG coatings fabricated from conventional air plasma spray (APS) tend to form an undesirable amorphous phase material in the plasma spray of powders, which leads to poor thermal cyclic performance.
- YAG has a relatively low thermal expansion coefficient that yields larger stress due to thermal expansion mismatch with the substrate.

Pathways

The project is structured to address the key barriers and minimize risk for DOE. The ultimate goal is to fabricate and demonstrate a SPPS YAG TBC with graded porosity on full-scale engine components that can be subsequently commercialized. Developing these coatings with graded porosity coatings optimizes durability, thermal conductivity, erosion resistance and abradability depending on the application.

The first project pathway will validate the feasibility and efficiency of the SPPS process for fabricating the YAG TBC. This validation will adapt and optimize the key parameters for applying the coating with a high enthalpy Sinplex plasma gun. This will involve developing the processing parameters, and then applying and optimizing the coating process on fuel nozzle injectors.

The second pathway will involve rig testing the YAG TBCs on full-scale fuel nozzle injectors and combustion liners. These rig tests will validate the YAG TBC advantages over the YSZ TBC baseline. These tests will demonstrate the enhanced performance parameters for these coatings.

The third pathway will validate the abradability, durability, thermal conductivity, and erosion resistance benefits of the graded porosity YAG TBCs. This will be verified by applying the coating to full-scale tipshoes. The optimal porosity grading for applying the coatings on these tipshoes will be determined via rub rig tests. These tests will be conducted in a full-scale development engine.

Milestones

This three year project began in May 2018.

- Successful demonstration of SPPS YAG TBCs with graded porosity that exceed 50 cycles of 10 hour duration at 1150°C and possess a projected thermal conductivity lower than 0.8 W/m-K at 1300°C (2019)
- Demonstrate a graded porosity YAG TBC on an air seal that has a projected thermal conductivity of less than 0.7 W/m-K at 1300°C (2020)
- Validate that the YAG backside temperature is at least 30% lower compared to the baseline YSZ backside temperature from the engine test (2021)

Technology Transition

Solar Turbines is partnering with Solution Spray Technologies (STT) for the manufacturing and testing of these graded porosity YAG TBCs. Following successful development, this TBC is expected to target power generation, combined heat and power (CHP), and oil and gas markets. Using its existing proven distribution channels, Solar will be able to sell this technology directly to prospective customers. These customers, which include hospitals, universities, utilities, and oil and gas companies, have previously formed alliances with Solar as part of their commercialization risk management strategy. Solar Turbines will then develop a product development and commercialization plan based on cost benefit analyses after successful engine test completion. Solar Turbines will also execute an agreement with SST to commercialize this technology in accordance with any data dissemination and intellectual property considerations.

Project Partners

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