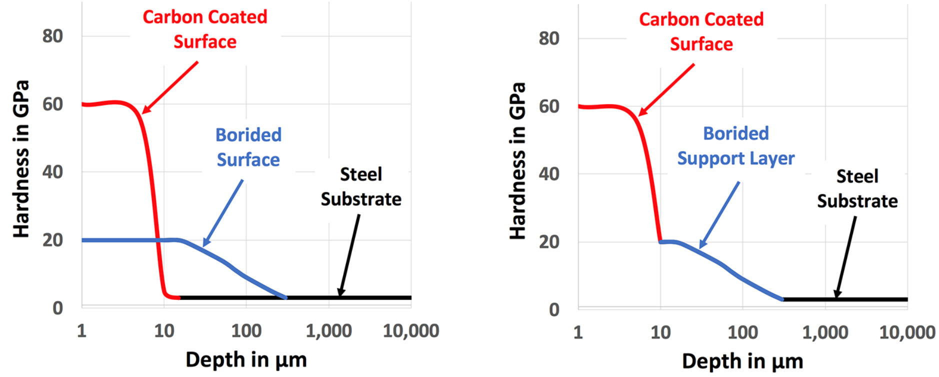

Hardness as a function of layer depth for conventional carbon-coated and borided surfaces (left), as well as the proposed hybrid boride-carbon coated surface (right). *Photo credit Michigan State University (MSU).*

Boride-carbon hybrid technology to produce ultra-wear and corrosion resistant surfaces for applications in harsh conditions

Developing a boride-carbon duplex layer hybrid surface treatment that reduces friction, wear, and corrosion for mechanical assemblies in harsh conditions

Engineered surfaces play a crucial role in tribological systems to enable new products and manufacturing processes that can endure harsh service conditions such as high impact and contact loads, highly abrasive wear, extreme temperatures, and corrosive environments. Because of their frictional loss reduction capabilities, engineered surfaces are instrumental to improving durability and energy efficiency in these products and processes. Despite numerous technological advances in surface treatment technologies, engineered surface coatings are subjected to increasingly harsher conditions, particularly in industries that suffer from abrasive, adhesive, corrosive and fatigue wear, and frictional efficiency losses. Improving traditional borided surfaces will help to increase surface hardness, wear resistance, and friction reduction for industrial manufacturing tooling and tribological components in mechanical assemblies.

This project will develop a hybrid duplex layer surface treatment by combining ultrafast boriding technology with next-generation superhard carbon coatings. The ultrafast large-scale boriding process works by forming a thick, hard, uniform boride layer throughout the surface-near region of a metal substrate (e.g. steel alloys) within less than 30 minutes of treatment time. This boride layer will be applied to lab-scale workpieces made from ferrous or high-temperature non-ferrous alloys tested in this project. The superhard carbon top layer coating, which is fabricated from tetrahedrally bonded amorphous carbon (ta-C), will then be applied to the borided surface. This ta-C coating is applied with a low temperature high power density carbon evaporation process, which enables the carbon coating to form on the borided surface with strong adhesion. This additional ta-C layer increases the surface hardness and lowers friction on all ferrous and non-ferrous alloy surfaces.

Benefits for Our Industry and Our Nation

The proposed carbon-boride hybrid duplex layer coating under development can reduce friction, wear, and corrosion for mechanical assemblies in harsh service conditions. Compared to baseline boriding, this hybrid surface engineering technology combines the advantages of a novel ultrafast boriding process with the next generation of superhard carbon coatings. Using state-of-the-art carbon-boride coatings is expected to have numerous benefits for cross-cutting industries with harsh operating conditions, including:

- Unprecedented combination of wear and corrosion resistance, low frictional losses and affordability for treated parts so that it can be utilized in many applications.
- Higher efficiency and improved durability for novel mechanical systems to meet the challenges posed by increasingly harsher operating conditions across industries.

Applications in Our Nation's Industry

The proposed hybrid coating technology will have a variety of benefits to multiple cross-cutting industries. Target markets include cross-cutting industries requiring improved wear resistance, corrosion resistance, fatigue strength and lower friction in tools and mechanical assemblies. This has particularly high importance in very harsh operating conditions to enable game-changing levels of durability and efficiency in transportation, renewable power generation and energy efficient manufacturing.

Project Description

The project objective is to develop a commercially viable carbon-boride duplex layer coating for tribological mechanical components in harsh conditions. The materials in the coating are expected to outperform parts that were conventionally treated with either only boriding or only carbon coatings, and certainly those that were untreated. The project outcomes address supply chain steps: (a) laboratory-scale verification of coating performance specifications; and (b) identification of requirements for real-world applications in harsh service environments. The technology is projected to be commercially viable based on feedback from service providers and end-users.

Barriers

- Surface treatment specifications may vary by end-user application (e.g. transmission gear may require different layer thickness than an engine part).
- Unpredictable coating delamination is a critical risk. The top carbon layers could delaminate at the interface to the borided substrate. However, the borided layer cannot delaminate.
- Random coating failure can be very expensive. For duplex coating treatment in critical applications, working with the end-users to develop concepts for failure prediction as well as quality control procedures is needed.

Pathways

The project is structured to address the key barriers and minimize risk for DOE. The ultimate goal is to develop novel ultra-wear and corrosion resistant surfaces for tools and components of mechanical assemblies in harsh environments.

The first project pathway will demonstrate the technical performance of the duplex treatment. This validation will create stable and adhering duplex layer boride-carbon structures on metal substrates to meet specific performance targets for adhesion, wear rate, friction coefficient, corrosion resistance and fatigue strength. This will be developed on test samples with simple geometries (e.g., flat disks, cylindrical rods).

The second pathway will determine the commercialization path. This will be accomplished by identifying and specifying the requirements for real-world applications in harsh service environments and provide a cost-benefit analysis using realistic input data. In addition, this information will help to develop a cost-benefit model for end-users.

Milestones

This 18 months project began in May 2018.

- Develop boriding and carbon deposition conditions so that the carbon coatings adhere strongly to the borided layer (2018).
- Demonstrate the performance benefits of the duplex structure over coatings (Adhesion class: HF1, wear rate: 10-9 mm3/Nm, coefficient of friction: <0.1, corrosion resistance: > 3h in 15% HCl at room temperature, fatigue strength increase: >30%) (2019).
- Identify relevant applications that could benefit from the hybrid technology, and develop a cost-benefit model that will help potential end-users to evaluate the technology for their applications (2019).

Technology Transition

Michigan State University is partnering with the Fraunhofer USA Inc. and Argonne National Laboratory (ANL) for the fabrication and testing of this carbon-boride hybrid surface treatment. Following successful development, this solution could be available in short order. This technology would be utilized as a surface treatment and offered by heat treatment and coating service providers to manufacturing industries such as makers of automotive powertrain components. These providers act as distribution channels for this type of product offering because some of them are already licensees of technologies utilized in the project (particularly ANL's ultrafast boriding technology). In addition, these providers can establish high throughput professional surface treatment services to mitigate perceived barriers by end-users. Depending on costs, reliability, and internal knowhow, end-users could also decide to have in-house treatment capabilities.

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