TITLE: **NANOSCALE REINFORCED, POLYMER DERIVED CERAMIC MATRIX COATINGS**
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DOE AWARD NO.: DE-FG26-05NT42528
PERFORMANCE PERIOD: APRIL 2007 TO MARCH 2008
DATE: APRIL 21, 2008

I. Objectives

The goal of this project is to explore and develop a novel class of nanoscale reinforced ceramic coatings for high temperature (600-1000 ^{0}C) corrosion protection of metallic components in a coal-fired environment. It is focused on developing coatings that are easy to process and low cost. The approach is to use high-yield preceramic polymers loaded with nano-size fillers. The complex interplay of the particles in the polymer, their role in controlling shrinkage and phase evolution during thermal treatment, resulting densification and microstructural evolution, mechanical properties and effectiveness as corrosion protection coatings will be investigated.

II. Accomplishments to Date

In the first eighteen months of the project (up to the last reporting period), based on extensive literature review and preliminary studies, two polymeric systems and a variety of potential fillers were identified. A new dip coating system using a universal mechanical testing machine was installed and used to make the coatings. Based on extensive and detailed processing studies, the most attractive fillers were identified. In addition, a detailed scientific investigation of the effect of slurry rheology and processing parameters on coating quality was conducted.

The main accomplishments this year have been:

- Optimization of the processing parameters for coatings with different fillers. Particular emphasis has been $TiSi_2$ and $ZrSi_2$ fillers.
- Development of process parameters to make coatings of different thicknesses
- Effect of thermal treatment on the coating microstructure and nature of the interface between the coating and substrate

A detailed investigation of effect of process parameters on the resultant coating has been conducted. In particular we developed formulations to make stable slurries of controlled rheology with different filler systems. These slurries are optimized for the dip coating process.

Using these optimized slurries, the rest of the process parameters have been investigated to make coatings. Although all the filler systems have been investigated the specific focus has been on the silicide systems (of titanium and zirconium) due to their desired performance characteristics.

We have developed a comprehensive theoretical framework to obtain coatings of controlled thickness. This is based on a modification of the classical Landau-Levich formulation for Newtonian viscous slurries. The modification that we have developed accounts for the true, shear thinning behavior of the slurries. This approach is leading to a better prediction of the effect of slurry rheology and process parameters (e.g. withdrawal speed during dip coating) on the green coating thickness. Further using detailed information about the shrinkage of the polymer during pyrolysis, a model has also been developed to predict the final fired thickness from the green thickness. These two models together provide a comprehensive way to predict and control the final fired coating thickness by controlling the slurry rheology and dip coating process parameters. This model would be generally applicable not only to these kinds of coatings but a broad range of slurry-based coatings.

Finally, the effect of the pyrolysis temperature on the coating microstructure has been investigated in detail. Particular emphasis has been on the nature of the interface between the substrate and the coating. It has been shown that there is an optimum, intermediate pyrolysis temperature for the highest quality interface. At lower temperatures, there is insufficient inter-diffusion between the coating and the substrate and at higher temperatures, the interface layer is too thick and debonds from the substrate.

III. Future Work

We have completed the selection of the material systems and the processing of the coatings (Tasks I and II in the proposed research). In remaining time, work will focus on completion of Task III and further refinement of the general model that for predicting the final thickness of coatings.

IV. Publications and Patents

- J.D. Torrey and R. K. Bordia, "Processing of Polymer-Derived Ceramic Composite Coatings on Steel", *J. Am. Ceram. Soc.*, **91** [1], 41-45 (2008).

V. Presentation, Awards Received and Student Supported Under this Grant

- Kaishi Wang, Rajendra K. Bordia**,** "Nanoscale Reinforced Polymer Derived Ceramic Matrix Coatings**",** Presented at 31st International Cocoa Beach Conference & Exposition on Advanced Ceramics and Composites, January 21-26, 2007, Daytona Beach, Florida
- R.K.Bordia. "Polymer Derived Nanoscale Ceramic Composites", nine invited presentations and seminars at various institutions in the US, India and Japan in 2007 and 2008.
- Humboldt Research Award for Senior Scientist to Rajendra Bordia from the Alexander von Humboldt Foundation of Germany.
- Mr. Kaishi Wang is a third year Ph.D. student in the Department of Materials Science and Engineering at the University of Washington. He is being supported on this project since December 15, 2005. He will work on this project for its entire duration as a part of his Ph.D. dissertation.