Anticorrosion coatings based on assemblies of superhydrophobic particles impregnated with conductive oil

Georgios Polyzos, Jaswinder Sharma, Ivan Vlassiouk

Energy & Transportation Science Division Oak Ridge National Laboratory, Oak Ridge TN 37831, USA

WP-2524-SEED

Abstract

- We developed low contact resistance passivate coatings for electrical system components. The coatings inhibited the build-up of resistive corrosion on electrical connector backshells as well as on steel components that are commonly used in electrical equipment.
- The developed coatings are based on assemblies of superhydrophobic diatomaceous earth (DE) and silica particles.
- To enhance the corrosion resistance and achieve low electrical resistance, exfoliated graphene sheets were dispersed in polydimethylsiloxane and the electrically conductive suspension was impregnated inside the porous patterns of the silica particles.
- The coatings can be applied to steel components, steel components coated with zinc-nickel and electrical connectors through an aerosol spray process.
- The developed coatings are inexpensive and scalable and can potentially be utilized to effectively protect critical infrastructure from corrosion. The developed coatings are compatible with coatings that are currently being used in electronic components (i.e. zinc-nickel).

Program Objective

The objective of this SEED project was to develop low resistance coatings that can eliminate the use of hexavalent chromium and cadmium. Such coatings can reduce the overall hazardous waste and the worker exposure to toxic materials. We investigated the corrosion resistance mechanism of multifunctional coatings based on superhydrophobic (SH) silica and graphene particles. The outer surface of the coating was nanostructured with low surface energy materials in order to become SH and repel water. The SH layer is an effective barrier against bulk water. However, SH surfaces alone cannot prevent water vapor condensation on a surface. The condensed vapors will ultimately penetrate through the coating layer and will initiate the build-up of corrosion. Moreover, SH coatings are porous and allow the oxygen permeation. In order to block the diffusion of water vapors and oxygen permeation, the bulk (volumetric) structure of the coating was filled with exfoliated graphene nanoplatelets (GnPs). The developed low-resistance coatings are compatible with zinc-nickel (ZnNi) and steel components. They can be applied on electrical connector backshells with ZnNi finish in order to impede the build-up of resistive corrosion and prolong the lifetime and performance of the connectors. The coatings can be applied using spray-coating techniques. The coated components were subjected to salt-fog testing according to ASTM B-117. In order to optimize the structure of the coatings particles with different sizes and geometries were utilized.

Proof-of-concept

- The synergistic effects of the water repellency, and moisture and oxygen barrier will result in an impermeable coating that will protect metal components from corrosion.

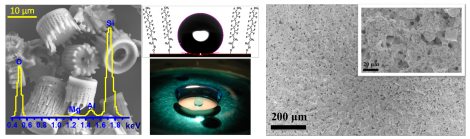
Metrics and criteria for success

- In order to demonstrate an improved technology, the coated components should demonstrate superior corrosion resistance compared to the respective steel and ZnNi components.

Success value

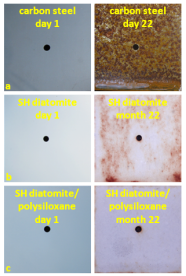
- The coatings should be corrosion-free for at least a three-fold longer testing time compared to the respective steel, and ZnNi components. This performance increase will result in coatings with corrosion resistance that is comparable to the corrosion resistance of hexavalent chromium and cadmium based coatings.

Background

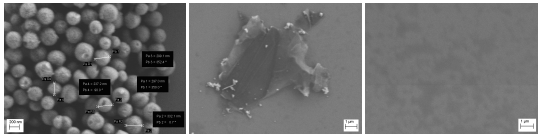


Superhydrophobic diatomaceous earth particles

Corrosion resistance tests on carbon steel plates exposed to weathering conditions. **(a)** The uncoated plate was entirely corroded in the first 22 days. **(b)** The coating based on assembled SHDE particles, provided limited corrosion protection. **(c)** The synergistic effect between the nanostructured SH surface and the water vapor barrier layer due to the impregnated polysiloxane oil resulted in corrosion-free plates over the 22 months of outdoor exposure.



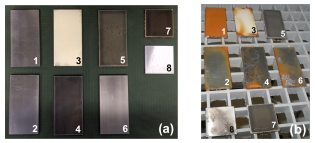
Materials and Methods



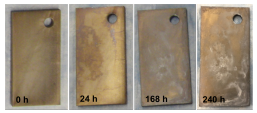
SEM images of porous silica particles of controlled size, aggregated graphene platelet, and exfoliated graphene nanoplatelets.

Results

Baseline samples

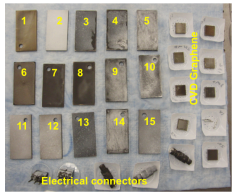


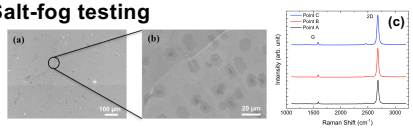
Steel (2x4 inch) and aluminum (1x1 inch) plates coated with polymer binders, SHDE and GnPs. (a) The plates before the salt-fog testing. (b) The plates after 72 h in the salt-fog chamber.



ZnNi plate before testing and after 24, 168, and 240 h in the salt-fog chamber

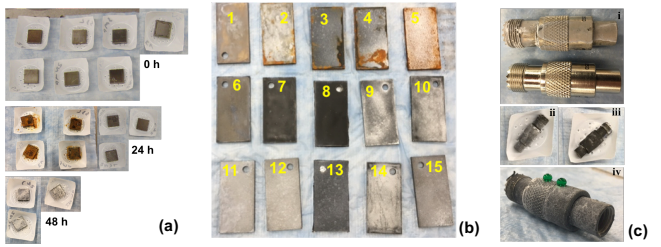
Salt-fog testing



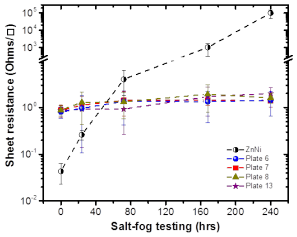


(a),(b) SEM images at low and high magnifications of graphene synthesized using chemical vapor deposition techniques. **(c)** Raman spectra at three different points of a graphene single layer.

Coated samples before the salt-fog testing. ZnNi plates (2x4 inch) and electrical connectors coated with different formulations of PDMS, GnPs and SH silica particles. Single layers of graphene crystals were deposited on top of ZnNi plates (1x1 inch).



(a) The CVD graphene samples. After 48 h of testing all samples were corroded. **(b)** Coated plates after 240 h of testing. Plates 6-15 have no sign of corrosion. Plates 6,7,8, and 13 are electrically conductive. Among all the developed formulations these are the best performing coatings. **(c) i)** Backshell electrical connectors before and after 240 h of testing. After 240 h of testing the uncoated connector is corroded and non-conductive. **ii, iii)** Coated backshell connectors after 240 h of testing. No sign of corrosion are observed. The white color is due to the silica component of the coating.



Sheet resistance values of the best performing coatings and of the ZnNi plate as a function of the salt-fog testing.

Future Work

1) Further decrease the sheet resistance of the coatings by exfoliating the GnPs in a conductive polymer matrix and by crosslinking the GnPs with the polymer matrix.
2) Study the galvanic mechanism between the graphene and the ZnNi layers.
3) Investigate mechanisms that can be utilized to mitigate the galvanic effect.
4) Study the abrasion and UV resistance of the coatings.

Conclusions

- The assemblies of GnPs, and SH silica particles demonstrated excellent corrosion resistance. The coatings based on spherical SH silica with 300 nm diameter were found to have the lowest sheet resistance (~ 1 Ω/sq) over the entire testing period (240 h).
- The sheet resistance of the pristine ZnNi plate started to increase within the first 24 h of testing.
- Our best performance coating demonstrated a ten-fold increase in the corrosion resistance compared to the ZnNi coating.
- The connectors were SH and corrosion free after 240 h of salt-fog testing.
- The developed coatings are inexpensive and can be applied on ZnNi coatings in order to extend their corrosion resistance and make it comparable to the corrosion resistance of coatings that are based on hexavalent chromium and cadmium.

Publications

Two journal article manuscripts are in preparation.

Acknowledgements: "This research was supported by the US Strategic Environmental Research and Development Program (SERDP) under contract WP-2524. The Oak Ridge National Laboratory is operated for the U.S. Department of Energy by UT-Battelle under Contract No. DE-AC05-00OR22725."