U.S. Army Development of Active Smart Coatings™ System for Military Vehicles

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ABSTRACT

The goal of the U.S. Army Smart Coatings™ Materiel Program is to conduct research designed to lead to the development of coating systems for Army materiel incorporating unique properties such as self repair, selective removal, corrosion resistance, sensing, ability to modify coatings' physical properties, colorizing, and alerting logistics staff when tanks or weaponry require more extensive repair. A partnership between the U.S. Army Corrosion Office at Picatinny, NJ, along with researchers from several universities, will develop the next generation of Smart Coatings™ materiel via novel technologies such as nanotechnology, Micro-electromechanical Systems (MEMS), flexible electronics, meta-materials, and the like.

Keywords: Smart Coatings™, Army, nanotechnology, sensors, coatings, films, materiel

INTRODUCTION & PROGRAM DRIVERS

The Army is transforming itself into a lighter yet more lethal "objective force", all while fighting a war in Afghanistan and Iraq. The Army's Future Combat System is the heart of the Objective Force. Its new platforms must be deployable, be 70% lighter and 50% smaller than current armored combat systems, while maintaining equivalent lethality and survivability. To meet the lighter yet more lethal requirements of the Future Combat Systems, our scientists and engineers need to capitalize on new technologies and breakthroughs in the scientific arena for its materiel. "Materiel" refers to the equipment, apparatus, and supplies of a military force or other organizations.

The coatings we apply to our tanks, our helicopters, and other weapon systems, need to better protect its structures and its crew since design margins are significantly tighter resulting in much less room for error for these lighter vehicles. Today's coatings protect surfaces from a variety of factors including chemical agents or oxidative effects but are not capable of self-correcting or alerting the user if anomalies exist within the coating or substrate. The single functionality of the coating is also easily defeated through chipping and cracking.

The ability of the DOD to respond rapidly to national security can be adversely affected by corrosion. The effects of corrosion are becoming more prominent as the acquisition of new equipment is slowing down and as the service of aging systems and equipment is becoming increasingly relied upon. A considerable portion of the cost of corrosion is attributed to ground vehicles, including tank systems, fighting vehicle systems, fire support systems, high mobility multipurpose wheeled vehicles and light armored vehicles.

Corrosion is the #1 cost driver in life cycle costs for the Department of Defense (DOD). The General Accounting Office (GAO) estimates that the total cost for DOD corrosion related problems alone is $20 billion per year, $4 billion of which is related to painting and de-painting operations and $1.2 billion related to helicopters[1].

Not only is this a financial burden, it also costs valuable time. For example, maintenance personnel in Hawaii perform bi-weekly inspections for corrosion under floorboards on Chinook Helicopters. This inspection includes three man days to remove floor boards, two man days of inspection, and then three man days to replace floorboards. This is mandatory every 15 days! Along with these helicopter problems are wheeled vehicle problems. Seventeen percent of Army trucks in Hawaii are not mission-capable. Furthermore, the availability of HMMWV, "HumVees", is greatly decreased and many are scrapped after five years.

Another example of vehicle corrosion is on the fuel version of the heavy expanded mobility tactical truck (HEMTT). The truck's tanks are only filled half way due to the unknown load capacity caused by corrosion and degradation of the supports on the vehicle. This leads to the trucks, and therefore their crew, to make twice as many trips to complete their mission. This is extremely dangerous since the exposure time these crews and vehicles see doubles which in effect doubles the risk of being attacked. This risk is also inherited by the convoys, such as soldier transports and tanks, which depend on this fuel. This has become evident during numerous attacks noted in Baghdad and elsewhere.

The scariest impact of corrosion is related to safety. The U.S. Army had forty-six mishaps, thirteen serious injuries, and nine fatalities directly related to corrosion between 1989-2000. This does not include all the indirect impacts or figures beyond 2000. Now that we are at War there is a far greater impact of corrosion on safety[2].

The U.S. Army Corrosion Office at Picatinny, NJ is addressing these serious issues by developing coatings capable of collecting, analyzing, managing and adapting to data from the environment in real-time. For example, a tank with this Smart Coatings™ System will be corrosion resistant and consist of embedded flexible sensors capable of 1) collecting data from the current surroundings such as temperature, pressure, humidity, wind, visual, and chemical/biological weapons detection; 2) processing and managing data; 3) utilizing artificial neural networks and data fusion techniques for "thinking" autonomously; and 4) transmitting data real-time to onboard and/ or monitoring sites. If an anomaly such as a scratch or degradation from corrosion is detected within the coating, the embedded sensors will analyze the data and initiate a response. The response may result in the coating self-healing if a crack exists or the smart coatings™ color patterns may change via electroluminescence and/or electrochromics to visually display corroded areas on the tank, if desired. This display will replace the "red-lining" of the vehicles for maintenance and instead result in cost and time efficient spot treatment.

DISCUSSION

A vast array of novel technologies has been introduced over the past few years. Advancements in nano-technologies, MEMS, polymers, composites, flexible electronics, and numerous other areas allow the Department of Defense to improve and create faster, lighter, and more lethal systems.

The U.S. Army is attempting to take these technologies and implement them into an active coatings system though the Smart Coatings™ Materiel Program, thus creating the next generation of coating systems. These technologies give one the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization and yield advanced materials that will allow for longer service life and lower failure rates.

Nanostructured materials yield extraordinary differences in rates and control of chemical reactions, electrical conductivity, magnetic properties, thermal conductivity, strength, and fire safety. The small size allows for numerous systems and functions to be incorporated together and embedded into materials such as metals, polymers, paints/films, composites, etc.

The U.S. Army Corrosion Office has assembled a team including university support from the New Jersey Institute of Technology (NJIT), NJ, Clemson University, SC, University of New Hampshire, NH, Wake Forest University, NC, University of Massachusetts, MA, Northeastern University, MA as well as other military and industry representatives. This team is developing multilayered, modular active coatings with numerous functionalities such as self-repair, visual display, artificial intelligence, self-management, sensing package, and corrosion inhibitors, that can be customized as needed. An illustration of the Smart Coatings™ System is depicted in Figure 1.

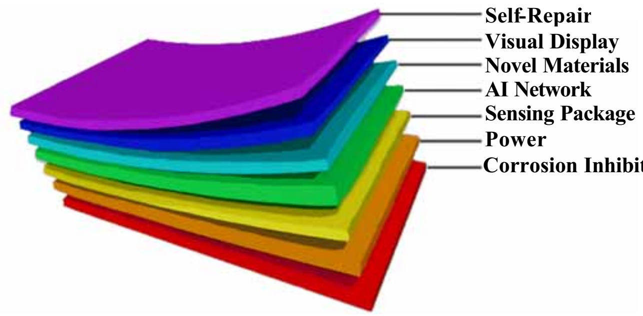

Figure 1: Potential Smart Coatings™ System Structure (PATENT PENDING U.S. Army & NJIT)

To date, several working prototype modules have been developed under this program. Some of the key areas of research within the modules include color modifying coatings, flexible electronics, wireless sensor packages, nanotube development, intelligent nano-clays, alternative fuel/power sources, de-painting/self-repair, material modification, and other military capabilities.

Color modification methods include using electrochromics, electroluminescence, intelligent clays (i-clays), single and multi-wall carbon nanotubes, and chemical additives to control and adapt color change capabilities on demand.

The Smart Coatings™ Materiel Program is also developing flexible electronic capabilities for sensing, communication, data collection/storage, and power alternatives. Flexible electronics have been developed at NJIT that demonstrate the capabilities of several different types of the flexible sensors, some of which can detect strain in the material, scratches on the surface, corrosion, pressure, flow, and temperature change.

Numerous tasks are currently working with nanotubes including their functionalization, development, and production. Single-walled carbon nanotubes (SWCNT) are being implemented into coatings and inks to initiate self-healing, active switching, sensing, color modification, and other functionalities. Work is also being performed to develop cost effect methods of development and scale-up of SWCNT production. Nanotubes are also being utilized for power/fuel cells development and electroluminescence. For example, the use of p-n junction SWCNT coatings as photovoltaic modules with the bottom layer functioning as a proton exchange membrane (PEM) fuel cell will provide power for active coatings capabilities while electroluminescence serve as a modifiable display.

Solubility and polymer wrapping of SWCNTs have given us the ability to functionalize these tubes. Beyond that, we are developing chemistries that enable the production of single-walled nanotubes with precise but tunable dimensions (properties).

The creation and development of intelligent nanoclays (i-clays) to detect corrosion & chem/bio agents via color changes or luminescent properties within the Smart Coatings™ System is also underway. These i-clays can be incorporated into inks, paints, composites, etc. to add functionalities to current coatings on Army materiel, as well as for the Smart Coatings™ System.

Self-repair and de-painting research is on going using micro-encapsulation techniques, nano particles, micro-etching, and MEMS. These technologies are being developed into a micro distribution systems mimicking the body's vascular and healing capabilities.

These technologies, tasks and modules are designed to be integrated into Smart Coatings™ Systems with desired functionalities. The ability to have an active, adaptive coatings system that acts more like a living entity than a typical paint job allows the coating to be utilized on both current and future weapon systems, for military and civilian applications

Major advances in the Smart Coatings™ program thus far include the development of military grade active sensing packages to detect damage (corrosion, substrate integrity, etc) and environmental conditions (i.e. radiation, chemicals, temperature, gases, strain, etc).

Several of these modules have been incorporated into a first level, "proof-of-concept," prototype that was successfully demonstrated at the U.S. Army Corrosion Summit 2005 in Clearwater Beach, FL. The prototype demonstrates the ability to sense a change in the environment, analyze the change, and alert the user of the anomaly through color changes on the substrate. Figure 2 illustrates a schematic of the prototype Smart Coatings™ System.

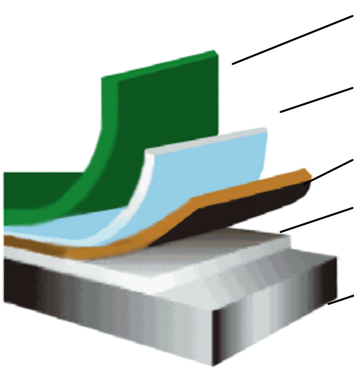

Figure 2: Schematic of Smart Coatings™ Prototype

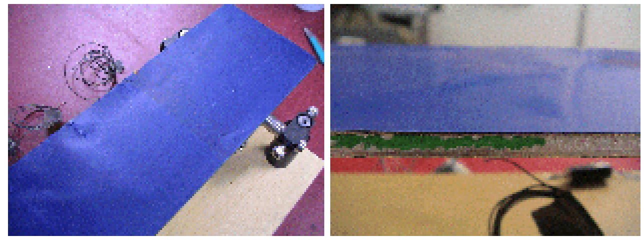

Figure 3: Smart Coatings™ Prototype Photos

The Army Corrosion Office, along with the New Jersey Institute of Technology, has developed this demonstrable Smart Coatings™ prototype on steel beams modeling that of the supports in the HEMTT truck and Chinook Helicopter (Figure 3). The embedded electronics can sense changes to the beam in real-time and alert the user of anomalies such as damage, corrosion, cracks, etc. The data can be collected and saved or used as an early warning system giving real-time status of the supports. This can be done through a visual display on the beam or the information can be transmitted to the cockpit and/or control center wirelessly.

This technology can be used to resolve the problem of half filling the HEMTT fuel tanks since the structural integrity and safe load capacity can be known instantly. In the case of helicopter support beams, the data can be transmitted remotely so the number of visual inspections can be greatly reduced saving time and money.

Current and future efforts under this program include more advanced sensor packages collecting real-time data of operational environments and conditions, as well as the integration and powering of these sensing packages into a multi-layered Smart Coatings™ system capable of "thinking and reacting" autonomously.

Along with this work, a hybrid photovoltaic power source is currently being developed as well as adding other functionalities into the Smart Coatings™ System. These advancements will allow the actions to be repeatable so that the coating will resemble a living entity that has the capacity for self-sustainment.

The transition plan for this program involves performing mechanical properties & material performance testing on Smart Coatings™ materiel as well as determining material composition. Scale-up processes for field testing on current Army materiel is planned for FY06. The resulting Smart Coatings™ Systems will then be transitioned to and tested on the Future Combat System (FCS). This complete system will be in the form of paint able to be brushed on, sprayed, vapor deposited, etc. and monitor remotely on board or at monitoring sites.

CONCLUSIONS

The need to protect our current and future military assets is obvious. It is in the Department of Defense's best interest to use the latest technologies to advance these assets. The current and future advances made in nanotechnology and MEMS is leading to the development of novel materials and systems that ultimately will allow the military to advance into the twenty-first century and beyond.

Corrosion, material degradation, and coatings failure is a serious cost to our military. Current coatings on military systems are not capable of self-sustainment, or alerting the user of potential anomalies that can cost the DOD billions of dollars per year as well as the loss of equipment, and even lives.

The Smart Coatings™ Materiel Program is attempting to assist with this dilemma by integration state–of-the-art technology into and on military systems. Through its research and development the program will 1) develop a novel multi-functional coating system for enhanced protection of tactical equipment; 2) decrease life-cycle costs while increasing readiness i.e. reducing equipment down time; 3) reduce the logistics burden of the Soldier; 4) control materiel signature & footprint via masking techniques; 5) reduce the potential hazards associated with current painting/de-painting operations.
6) correspond with Army's Transformation Strategy to help safeguard our national and international interests.

This program will integrate sensor technologies into an active sensor package capable of real-time analysis and reactions for Smart Coatings™. This Army Transformation will result in new and modernized weapons systems fielded globally capable of meeting challenges in materials and corrosion through the use of new technologies.

REFERENCES

[1] *Cost of Corrosion Report to Congress Jan 02:* National Association of Corrosion Engineers (NACE) 2002.

[2] Research performed on the *Technology Demonstration for the Prevention of Material Degradation Program,* U.S. Army Corrosion Office, U.S. Army ARDEC-RDECO, Picatinny, NJ.

[3] Research performed on the *Smart Coatings™ Materiel Program,* U.S. Army Corrosion Office, U.S. Army ARDEC-RDECO, Picatinny, NJ.