Active Coatings Technologies for Customized Military Coating Systems

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ABSTRACT

The main objective of the U.S. Army's Active Coatings Technologies Program (ACT) is to develop technologies that can be used in combination to tailor coatings for utilization on Army Materiel. ACT is divided into several thrusts, including the Smart Coatings™ Materiel Program, Novel Technology Development, as well as other advanced technologies areas. The goal of the ACT Program is to conduct research leading to the development of multiple coatings systems for use on various military platforms, 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 Arsenal, NJ along with researchers at several universities are developing active coatings systems via novel technologies such as nanotechnology, Micro-electromechanical Systems (MEMS), meta-materials, flexible electronics, electrochromics, electroluminescence, etc.

***Keywords*:** Active Coatings Technologies**,** Smart Coatings, Army, nanotechnology, sensors, MEMS

INTRODUCTION & PROGRAM DRIVERS

The Army is transforming 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, 70% lighter and 50% smaller than current armored combat systems, while maintaining equivalent lethality and survivability[1]. 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.

The coatings we apply to our tanks, helicopters, and other weapon systems need to better protect their structures and crew since design margins are significantly tighter resulting in much less room for error for these lighter vehicles.

The U.S. 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[2]. The coatings applied to weapon systems today lack the ability to self-correct when environmental conditions and circumstances change, nor do they have the ability to tell the user of potential anomalies such as corrosion, damage or adhesion problems.

A crucial 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[3].

The U.S. Army Corrosion Office at Picatinny Arsenal, NJ is addressing issues of military coatings systems by developing coatings capable of collecting, analyzing, managing and adapting to data from the environment in real-time. If an anomaly such as a scratch or degradation from corrosion is detected within the coating, 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 coating's color patterns may change via electroluminescence and/or electrochromics to visually display corroded areas on the tank, if desired.

There have been major advances in the Active Coatings Technologies program. These advances include researching into MEMS and Nano devices in order to create coating systems that will self correct and show where areas of weakness are. These devices will be crucial in this coating process; helping the Army move into the lighter realm. Self correcting coatings will significantly cut costly repairs. The research is ongoing and will continue looking at smaller electronics that will better help the Warfighter.

Current and future efforts under this program include the integration and powering of these sensing packages into a multi-layered Smart Coatings™ system capable of "thinking and reacting" autonomously. The resulting Smart Coating™ materiel will ultimately aid the Army/ Future Combat System and DOD by; 1) developing a novel multi-functional coating system for enhanced protection of tactical equipment; 2) decreasing life-cycle costs while increasing readiness i.e. reducing equipment down time; 3) reducing the logistics burden of the Soldier; 4) controlling materiel signature & footprint via masking techniques; and 5) reducing the potential hazards associated with current painting/de-painting operations.

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 Active Coatings Technologies Program, thus creating numerous technologies that can be combined to develop customizable coatings solutions to meet military user requirements. 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 Army Corrosion Office has assembled a team including university support from the New Jersey Institute of Technology (NJIT), Clemson University, University of New Hampshire, Pennsylvania State University, University of Massachusetts, South Carolina Research Authority, as well as other military and industry representatives. This team is developing multilayer, 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.

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.

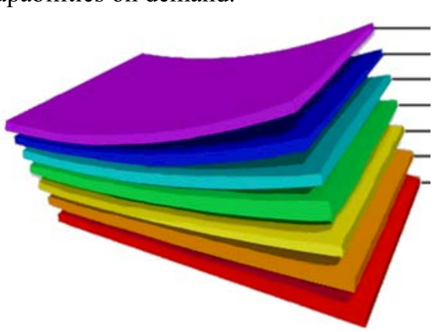

Figure 1: Smart Coatings™ System (PATENT App: 11/307611 02-14-06 U.S. Army & NJIT)

The 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 advanced Nanomaterials and their production. Nanotubes are also being utilized for power/fuel cells development and electroluminescence.
For example, photovoltaic power sources are currently being developed. One method includes the use of p-n junction SWCNT coatings as photovoltaic modules with the bottom layer functioning as a proton exchange membrane (PEM) fuel cell. This cell will provide power for active coatings capabilities while electroluminescence will serve as a modifiable display. Also, photovoltaic coatings have been developed that demonstrate solar cells functionalities as well as active display capabilities.

Solubility and polymer wrapping of SWCNTs have provided us the ability to functionalize these tubes. Beyond that, chemistries are being developed 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 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 and future coating systems.

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 customizable coating systems tailored with desired functionalities to meet user requirements. 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, military and civilian applications.

Major advances in the ACT 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).

The sensors and technologies developed under the program can be used with Army Materiel. A potential application is corrosion of the main support members of the Chinook Helicopter (Figure 2). The Chinook Helicopter has structural support members beneath floorboards that are susceptible to corrosion. Typically, bi-weekly inspections include 3 man days to remove floor boards, 2 man days of inspection, and 3 man days to replace floorboards. Utilizing the flexible sensor array and ribbon cables that are accessible in the cockpit or can transmit data wirelessly, technicians can utilize the sensors to determine the structural integrity of the support members without bi-weekly visible inspections. By enabling visible inspections to be conducted remotely, time and cost savings can be realized.

Another problem these technologies can help resolve exists on Heavy Expanded Tactical Truck (HEMTT). The fuel tanks on these trucks are only half filled since the structural integrity and safe load capacity of a given truck is not known due to material degradation. This means that twice the number of "runs' occur to deliver the required amount of fuel; costing valuable resources and time. Using the sensors contained in active coatings the safe load capacity can be known instantly. With both the Chinook and HEMTT, the data can be transmitted remotely so the number of visual inspections can be greatly reduced and conditioned based maintenance can be performed, saving time and money.

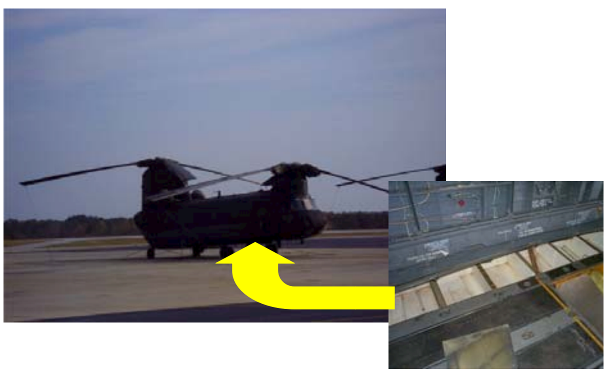

Figure 2: CH-47 Chinook Corrosion Under Floor Boards

Several of the technologies developed thus far have been incorporated into "proof-of-concept" prototypes. These prototypes were successfully demonstrated at the U.S. Army Corrosion Summit in 2005 & 2006. One prototype (Figure 4) 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 5 illustrates a schematic of that prototype system.

Another prototype (Figure 6) demonstrates a wireless version of the system in which the data is collected, wirelessly transmitted, and analyzed. The information can illustrate where and how structural changes, damage, material degradation, and material loss affect the integrity of beams, supports, and other structures (Figure 7).

Figure 3. Fuel version of HEMTT with corroded supports

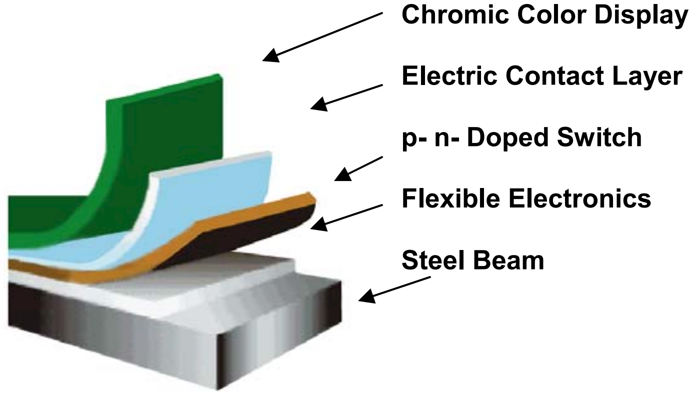

Figure 5: Schematic of Smart Coatings™ Prototype

The Army Corrosion Office, along with the New Jersey Institute of Technology, has developed these prototype systems modeling the supports in the HEMTT, Chinook and Blackhawk Helicopters (Figure 4). The embedded electronics can potentially sense changes in 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.

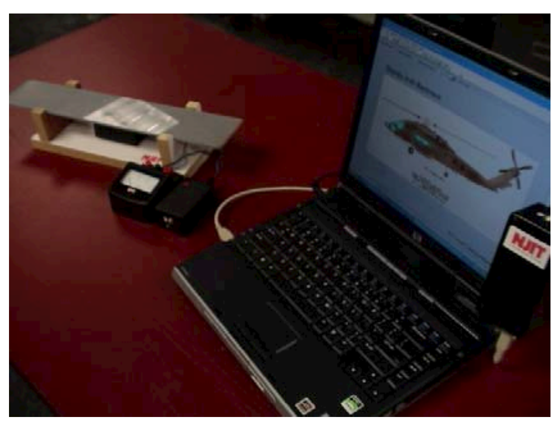

Figure 6: Wireless Sensor System with CPU interface

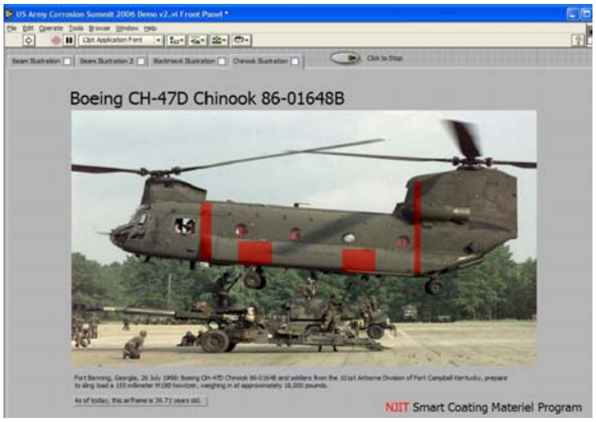

Figure 7: Display Illustration of Damage on CH-47D

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. 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 overall goal is to develop systems to be utilized on current military systems and to transition technologies to the Future Combat System (FCS).

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 the protection of these assets. The current and future advances made in nanotechnology and MEMS are 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 coating failures are a serious cost driver for 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 lives.

The Active Coatings Technologies Program, including the Smart Coatings™ Materiel Program, is helping to address this issue by integrating 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.; and

6) correspond with Army's Transformation Strategy to help safeguard our national and international interests.

The goal of this program is to develop those technologies needed to create active coating systems to aid in Army Transformation. This transformation will result in new and modernized weapons systems fielded globally that are capable of meeting current and potential challenges.

Active Coatings Systems will increase survivability & readiness while decreasing life-cycle costs, maintenance and potential hazards. The resulting systems will ultimately aid the Army/ Future Combat System and DOD in 1) developing a novel multi-functional coating system for enhanced protection of tactical equipment; 2) decreasing life-cycle costs while increasing readiness i.e. reducing equipment down time; 3) reducing the logistics burden of the Soldier; 4) color modification techniques; 5) reducing the potential hazards associated with current painting/de-painting operations.

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