Overview of the U.S. Army Technology Demonstration for Prevention of Material Degradation Program

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The U.S. Department of Defense has dealt with corrosion and material degradation issues on military vehicles, structures, and weapons systems for decades. Recent studies have reported costs of $20 billion per year to control metallic corrosion on military assets. To address the problem and the effects on military readiness, operator safety, and life cycle costs, the U.S. Army Corrosion Office enlisted Concurrent Technologies Corporation to execute the Technology Demonstration for Prevention of Material Degradation Program. This program includes the evaluation and demonstration of coating systems, advanced materials, improved maintenance processes, non-destructive testing, and an assessment of the effects of operating environments upon microdevice reliability. This paper presents an overview of the program and its findings to date.

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Introduction

Material degradation, particularly metallic corrosion, has a significant direct and indirect impact on the economy of the United States (U.S.). The results of a 2002 study indicate that metallic corrosion alone represents a $276 billion burden on the U.S. economy[1], which accounts for roughly 3.1% of the Gross Domestic Product (GDP). As many as 26 economic sectors, ranging from transportation, production, and manufacturing to utilities, were found to be facing significant costs due to corroding vehicles, components, and structures.

Within the Department of Defense (DoD), corrosion has a profound impact on the cost of ownership of military vehicles, weapon systems, support equipment, and infrastructure. The 2002 study found that the estimated direct cost of corrosion to the DoD is about $20 billion each year[1], which is roughly equivalent to $400 million per week. Of this total, approximately one third is generally considered avoidable, through the use of existing commercially available corrosion prevention or control techniques and technologies. It is recognized that corrosion-related indirect costs, such as safety and environmental expenses, could also be avoided by employing these technologies.

There are numerous examples available to illustrate the considerable impact of corrosion to the DoD. The U.S. Army spent between $2 billion and $2.5 billion in 1993 alone to mitigate corrosion on wheeled vehicles, including 5-ton trucks[2]. Corrosion was found to be so extensive on some of these trucks that total repair costs were greater than 65 percent of the average cost of a new vehicle. Corrosion also has a significant impact on the readiness, reliability, and operability of critical military assets. In 1996, corrosion was identified as the major reason why 17 percent of the Army's trucks located in Hawaii were Not Mission Capable (NMC)[2]. Some examples of corrosion on military trucks are presented in Figures 1 and 2.

Figure 1. Severe Corrosion on Undercarriage of Army Truck

Figure 2. Corrosion on Army Truck Door

The impacts of corrosion are not limited to the military ground vehicle community. A 2001 study concluded that maintenance of corrosion-related faults has degraded the readiness of all of the Army's force modernization helicopters[2]. More recently, the U.S. Army Aviation and Missile Command (AMCOM) reported in 2004 that "at least 90%" of the degradation of U.S. Army helicopters returning from Iraq and Afghanistan was related to airframe corrosion and engines damaged by ingestion of dust and sand. AMCOM has budgeted $1.6 billion to repair/address these problems[3]. Corrosion has also severely impaired the readiness and functionality of military armament. One study found that 30 to 40 percent of aborted missions for the 155 mm howitzer are the direct results of corrosion[2].

Safety concerns related to corrosion and degradation compound the cost and readiness issues. For example, as the components within a helicopter engine erode due to sand ingestion, the engine consumes more fuel and runs hotter, increasing the risk of in-flight failure[4]. One of the first fatalities of the Iraq war involved the crash of a Sea Knight that may have been caused by engine damage due to sand ingestion[5].

Damage to metallic components, however, represents just one (albeit significant) aspect of the overall material degradation challenge facing the DoD. Non-metallic materials are also employed in huge quantities on Army materiel, and these materials are subject to degradation through a variety of mechanisms. For example, both metallic and non-metallic materials employed in weapon systems and other assets have been eroded severely by the effects of airborne sand and dust particles while conducting operations in Iraq and Afghanistan. Organic-matrix composites (OMCs), often selected because of their light weight, high strength, and corrosion resistance, are subject to deterioration from exposure to ultraviolet (UV) radiation, water intrusion, and/or erosion. Critical microelectronic and micro-electromechanical systems

(MEMS) devices are subject to damage from moisture, vibration, and temperature extremes. Tent canvas and other cloths employed by the DoD are subject to mildew and rot in humid environments, particularly when placed in storage.

The Army TDPMD Program

In order to address the issues of corrosion and material degradation inherent in Army materiel, a scientific approach was necessary. The U.S. Army Technology Demonstration for Prevention of Material Degradation (TDPMD) Program provides an integrated approach to reducing the impact of corrosion and material degradation on Army assets. The TDPMD team is applying its expertise in science and engineering to the selection and implementation of the most appropriate approaches to reduce material degradation on Army materiel and assets, and consequently reduce life cycle operational costs. In addition, the TDPMD team is leveraging its experience from the U.S. Army Corrosion Measurement and Control (CM&C) Program, a program that was initiated in the fall of 2000. Team members include universities (Pennsylvania State University, the Ohio State University, and New Mexico State University), government entities (the Army Corrosion Office at Picatinny Arsenal, the Army Research Laboratory (ARL), and the Army Tank-automotive and Armaments Command (TACOM), among many others), and industry (Concurrent Technologies Corporation (*CTC*) and Hobe Corporation)

While the main thrust of the TDPMD Program is focused on technology transfer and validation, there are some research activities being conducted under the program as well. Program activities are grouped into six task areas, each broken down into subtasks. A brief high-level overview of the TDPMD activities is described below.

Demonstration of Technologies to Mitigate Material Degradation

This task is focused primarily on the evaluation and validation of advanced coating systems. Activities include an analysis of the chemical mechanisms of (sprayed-on) corrosion inhibitors, the extension of vehicle service life through the utilization of novel sacrificial metal coatings, an evaluation of conductive polymer coating technologies, evaluations of coatings for the prevention of canvas material degradation, and chromium-free coating systems.

Advanced materials are also being evaluated. These include composite materials and lightweight corrosion-resistant alloys.

In addition, modeling and simulation activities include the development and application of empirical corrosion modeling techniques.

Detection and Monitoring of Degradation

Activities under this task include the monitoring, via sensors, of the corrosion of vehicle structural components, as well as the application of a gas turbine engine contaminant ingestion sensor, the evaluation of nondestructive testing (NDT) technologies, and corrosion sensor testing and development.

The erosion of gas turbine engine components due to sand ingestion has received considerable attention in recent years[4-6]. Aircraft such as helicopters are continuously damaged and sometimes lost in theater due to engine component damage caused by sand ingestion. Under extreme conditions, engines can require a complete overhaul after only 50 hours on wing[5]. A severely eroded compressor component from a military helicopter engine, after only *80 hours* of operation, is presented in Figure 3.

Figure 3. Severe Erosion on Leading Edges of Blades on Engine Compressor Blisk (Photo courtesy of Naval Air Systems Command, Patuxent River, MD)

Ground vehicle engines suffer similar fates. The gas turbine engines employed on tanks in Iraq have been plagued by the need to continuously clean and service the complex filter systems[7]. Frequent clogging of inlet filters on helicopters has also led to increased maintenance[8]. The objective of the gas turbine engine contaminant ingestion sensor subtask is the demonstration of a sensor/detector that can measure the volume and type of contaminants ingested into a military gas turbine engine. If a relationship between measured contaminant ingestion and quantified component damage can be derived, this can be used to reduce the risk of in-use component failure and maximize the intervals between maintenance cycles.

MEMS Reliability Assessment

Included within the TDPMD Program framework is a series of subtasks related to the reliability of MEMS devices. Assured reliability following periods in storage is crucial for micro- and nano-electronics that are or will be used in U.S. Army applications, especially those involving safety-critical and mission-critical systems such as electronics employed in aircraft missiles and communications. The rapid advances in MEMS technology underscore the importance of defining the applications, failure modes, tests, standards, and modeling techniques for these devices.

Activities under this task include:

- Identification of existing and future MEMS applications.
- Search of existing data on MEMS failure modes and mechanisms.
- Environmental stress screening on procured MEMS devices.
- Review of existing data on test protocols and methodologies.
- MEMS reliability guideline development.
- Reliability modeling.

Component or System Repair and/or Maintenance Processes

This task includes the validation of corrosion protection technologies for hydraulic systems, an assessment of the effect of the environment on the application of corrosion preventive compounds (CPCs), and bioremediation technologies for waste CPCs.

Product Testing

This task involves joint test protocol (JTP) formulation and product testing. JTPs prescribe the initial testing for the evaluation of technologies (coatings, materials, surface treatments, etc.) for use on DoD vehicles and weapon systems. The product testing subtask enables the Corrosion Test Laboratory (CTL) at *CTC*'s Largo, Florida, facility to conduct mechanical, weathering, electrochemical, and corrosion testing on coatings, materials, sensors, CPCs, and other technologies that have been identified by the other TDPMD subtasks and the Army client. The CTL comprises five separate laboratories: sample preparation/storage laboratory, mechanical properties laboratory, electrochemical impedance spectroscopy (EIS) laboratory, accelerated weathering laboratory, and cyclic corrosion laboratory. The state-of-the-art equipment includes three 40 ft^3 cyclic corrosion chambers with capabilities of simulating over 50 different corrosive environments. One of these chambers, containing panels coated with the chemical agent resistant coating (CARC) that is used on military vehicles, is depicted in Figure 4.

Figure 4. Corrosion Chamber at CTC Largo CTL

Information Exchange

This final task includes maintenance and continuous upgrading of the Army Corrosion Website, the development of Web-based training, an assessment of the impact of the Iraq environment on Army materiel, and program outreach activities such as conducting the annual U.S. Army Corrosion Summit.

The Army Corrosion Website (www.armycorrosion.com) is accessible via the Internet, and is comprised of two sections: a public access section and a government-only, password-protected section. The public access section acts as a repository for Web-based training and relevant corrosion information and links. A sample of the training available on the public access section of the site is presented in Figure 5.

Figure 5. Screen Shot from Web-Based Basic Corrosion Control Course

The password-protected section contains more specific information that can be securely accessed by program managers, maintenance personnel, and other Government parties.

Initial Successes

Although the TDPMD Program has been enacted recently, several accomplishments have already been realized. Among the initial achievements:

- A more thorough understanding of the chemical mechanisms of sprayed-on corrosion inhibitors has been achieved.
- An assessment of advanced composite materials has identified specific applications to reduce weight and improve mobility of Army vehicles[9].
- NDT technologies are being considered in groundbreaking work to evaluate hidden damage to composite structures and corrosion under paint.
- Novel corrosion sensors for in-situ monitoring are under development.
- New advances in canvas material protection and bioremediation technologies for CPCs have been identified, with some candidates already showing promise for implementation.

- In partnership with New Mexico State University, in-situ sensors to monitor the effects of corrosion and applied stresses on the integrity of key military vehicle structural components are being evaluated.
- A portable corrosion control center (CCC) for the application of CPCs to Army vehicles has been developed and is being modified and implemented at Army installations.
- The Army Corrosion Website continues to provide corrosion training and information to military personnel around the globe, with future plans for the government section to act as a repository for corrosion data collected from the field.
- The assessment of the Iraq environment has yielded surprising results on the corrosive nature of a supposedly arid desert[10].

Summary

The TDPMD team is applying its expertise and experience in science and engineering to the selection and implementation of the most appropriate approaches for improving the control of material degradation on Army materiel and assets. It is anticipated that these efforts will lead to a significant reduction in life cycle operational costs, improved readiness and reliability, and enhanced performance and functionality for the warfighter.

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