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Improved Inorganic Coatings For Gun Table Launchers

Dario A. Emeric, George D. Farmer,
and Howard E. Horner

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Preface

The mission of the U.S. Army Research Laboratory, Materials Directorate (ARL-MD) is to serve as the Army's principal executor of materials research and development, to provide advanced, improved materials options for Army systems developers and soldier support. Based on the above, it was decided to investigate the state of the materials technology relative to the fast degradation and wear of inorganic coatings and refractory coatings during the testing of the electric guns and, if possible, to find materials and/or coatings that can withstand the high temperatures and pressures produced or encountered during the firing or operation of the electric guns.

Introduction

Conventional gun barrels are highly optimized designs. The M1A1 gun tube weighs approximately 1180 kg and has a length of 5.3 meters. This corresponds to a mass-to-length ratio of about 223 kg/m for a maximum muzzle energy of 9 MJ. Conventional gun barrels have a service life of 500 to 1000 rounds depending upon the propellant and projectile used. These gun barrels can be fired at a rate ranging from 5 to 12 rounds per minute [1].

Excellent adhesion is a primary requirement of any coating deposition technique. Since parts' geometry is complex, the deposition process must possess good throwing power. Porosity is undesirable, therefore, the coating thickness should be such to ensure a total barrier or its density should closely approach that of the substrate. Several coatings and combinations thereof have been used or tested for protection of gun barrels. The coatings are selected for their environmental durability (resistance to erosion, corrosion, etc.) and compatibility with the propellants [2].

Electric guns have severe corrosion and erosion problems due to the high temperature and pressures produced by the plasma and hyper-velocities during the operation of the gun-tube launchers. The mechanisms of corrosion and erosion in gun-tube launchers are very complex. The overcoming of erosion and corrosion has become very important since they will determine the service life of the electric guns. In addition, it will be subject to ambient temperature corrosion because of the collection of combustion products and condensate in the cracks and crevices produced by the use of the gun.

Objective

It was decided to investigate the reason for the fast degradation and wear of inorganic coatings and refractory coatings associated with the electric guns and, if possible, to find materials and/or coatings that can withstand the high temperatures and pressures produced or encountered during the firing or operation of the electric guns.

Gun Barrels

Conventional gun barrels are highly optimized designs. The M1A1 gun tube weighs approximately 1180 kg and has a length of 5.3 meters. This corresponds to a mass-to-length ratio of about 223 kg/m for a maximum muzzle energy of 9 MJ. Conventional gun barrels have a service life of 500 to 1000 rounds depending on the propellant and projectile used. These gun barrels can be fired at a rate ranging from 5 to 12 rounds per minute [1].

Plating or Coating of Gun Barrels

Excellent adhesion is a primary requirement of any deposition technique. Since parts' geometry is complex, the deposition process must possess good throwing power. Porosity is undesirable, therefore, the coating thickness should be such to ensure a total barrier or its density should closely approach that of the substrate. Several coatings have been used or tested for protection of gun barrels: aqueous and nonaqueous deposition of low and high contractile chromium, refractory metals, and ceramics.

Coating processes to be used are: plating, the fused salt method, and the physical/chemical vapor deposition method. Other processes are: thermal spraying, ion plating, and implantation [2]. The ceramic surfaces of high temperature, vapor-phase synthesis processed materials provide both wear and corrosion resistance protecting the interior of the host material. The materials have relatively high thermal conductivities and, unlike conventional oxide ceramics, are not particularly susceptible to thermal shock. Some of these coatings are: tantalum plus 10% tungsten (3040°C) and hafnium carbide plus tantalum carbide (3900°C) [3]. Another method being considered is inserting plated liners in the gun barrels. The only drawback here is that the liner may not be able to be removed from the gun [2]. The coatings are selected for their environmental durability (resistance to erosion, corrosion, etc.) and compatibility with the propellants.

Electric Guns

Electric guns have severe corrosion and erosion problems due to the high temperature and pressures produced by the plasma and gun hyper-velocities. The mechanisms of corrosion and erosion in gun-tube launchers are very complex. The overcoming of erosion and corrosion has become very important since they will determine the service life (conventional guns have a service life of 500 to 1000 rounds depending upon the propellant and projectile used) of the electric guns. The guns will be subject to the chemical reaction of the hot gases produced by the combustion of the propellant and to the abrasive action of the unburned propellant and debris. In addition, it will be subject to ambient temperature corrosion because of the collection of combustion products and condensate in the cracks and crevices produced by the use of the gun [4]. Materials and coatings will be needed that can resist or withstand the above mentioned conditions.

Liquid Propellant

There are several liquid propellant formulations being tested, such as XM46 and XM86. The combustion products are mainly water (71%), nitrogen (16.6%), carbon dioxide (12.4%), and other compounds (0.1%) [2]. This should reduce muzzle blast and flash, but it will make the gun subject to ambient temperature corrosion because of the collection of combustion products and condensate in the cracks and crevices produced by the use of the gun. Materials and coatings are needed to resist in-bore aerodynamic heating. The materials and coatings used in the system must be compatible with the liquid propellant being tested because their incompatibility would be detrimental [2]. The erosion and/or corrosion of unprotected metal and incompatible coatings that are in contact with the propellant may affect the stability, performance, and function of the system. The seals (elastomeric and metal-to-metal) are wearing out at a fast rate giving rise to safety-related problems, degradation of performance, and malfunctions. Artillery will be the main user of the liquid propellant system with the system expected to be fielded in the year 2006. It is designed to be a 55-ton, self-propelled 155 mm howitzer. It will feature automated handling and firing of projectiles to achieve a very high maximum rate of fire; 12 or more rounds per minute compared to 4 rounds per minute for existing howitzers. Conventional tank guns can fire at a rate ranging from 5 to 12 rounds per minute [1].

Electromagnetic

The electromagnetic gun (the standard configuration of the electromagnetic gun consists of two parallel copper rails that act as both conductor and barrel) or a variation called a railgun (electromagnetic coils at fixed distances that fire the projectile according to the magnetic field provided by the coils) should reach a projectile velocity of six km/sec with a minimum ablation (ablation limits repetitive firing, decreases velocity, and may cause plasma armature separation and restrike) of the propulsion system, and to be able to fire multiple shots (active cooling of the system is needed for multiple shots) [4]. In a railgun, the projectile is forced ahead of the rapidly moving plasma (10,000°C to 50,000°C) arc at greater velocities (greater than 4 km/sec) than conventional explosive-driven guns. The Air Force [5] found that graphite-coated copper rails provide the lowest ablation of any practical rail material for all rail guns except those with extremely high injection velocities. The performance of plasma armature is strongly degraded by bore ablation effects at velocities greater than 5 km/s. Hot-pressed boron nitride surfaced insulators appear to provide the best combined ablation, electrical, and structural performance. Conventional plasma spraying and chemical vapor deposition were found to be poor rail coating processes. Problems were associated primarily with coating porosity and poor coating-to-substrate bond strength. Tungsten carbide and tungsten/copper mixtures were found to be poor rail coating materials. Coating bond strengths were poor, and theory indicates that their ablation performance is inferior relative to pure tungsten [4]. In summary, barrel erosion has been one of the greatest drawbacks to the electromagnetic launcher (EML) development. They have demonstrated a life of 20 to 50 rounds (conventional guns have a service life to 500 to 1000 rounds depending upon the propellant and projectile used) before refurbishment or replacement is required; therefore, materials and coatings are needed that can withstand the operating environment (plasma and nonplasma). The materials also have to withstand in-bore and aerodynamic heating.

Electrothermal-Chemical

The Army is working mostly in the laboratory on 30 mm guns and the Navy is working on 60, 105, and 160 mm guns [6]. The world's first rapid-fire 60 mm electrothermal gun was delivered to the Navy in June 1993 [7]. It will be able to repetitively fire smart projectiles weighing more than 6 lbs. at a muzzle velocity greater than 4000 feet per second. The gun has a firing rate of four rounds per minute with a burst size of 10 rounds (conventional tank guns can fire at a rate ranging from 5 to 12 rounds per minute). The Navy is combining the electrothermal gun with concurrently developed small-caliber smart munitions. Any electronic components of smart munitions fired by the gun would have to withstand accelerations between 30,000 and 45,000 times normal gravity. The projectile mass will be in the range of 1.7 to 3.5 kilograms. The guided projectile will have a minimum range of 2500 feet, the safe-kill is closer to 3500 feet. The system consists of a pyrotechnic igniter, gas transfer tubing, and the control valve section. The gas generator is a dual grain solid propellant housed in the projectile's aeroshell. The grain materials are an ammonium perchlorate oxidizer with a carboxyl-terminated polybutadiene fuel. The demonstration sabot design uses 7075-T6 aluminum (subject to stress corrosion cracking), but a graphite epoxy will be used in the production tactical version [7]. One of the material's problems encountered is the erosion of the electrodes (tungsten/copper) by the plasma produced during the operation of the electrothermal-chemical (ETC) guns. In addition, nonconductive ablative materials are also needed [6].

Ram Accelerator Gun

The ram accelerator gun, a nonelectromagnetic gun system, is now being built by the Air Force [5], as well as the Army [8]. The Air Force's version is a tube with vents (for the venting of the 105 mm howitzer gases) and intake valves for the various combustible gases. The energy content of each section will be determined by the type of fuel and oxidizer used; therefore, the velocity of the projectile will be proportional to the type and blend of combustible fuel used. The initial acceleration of the projectile will be provided by a 105 mm howitzer. The Army's version of 120 mm tank guns and the accelerator consists of two or more joined gun barrels. These guns could be used to launch projectiles at a great distance with supersonic speed. Also, it could be used for testing full-scale penetrators against future armor at hypersonic velocities.

Conclusions

In order to find out about materials and/or coatings problems associated with hypervelocity guns, the authors visited experts on the subject at several military installations, conducted several literature searches, and reviewed literature on the subject. Based on the above, it has been concluded that there are materials and coatings problems that will have to be solved if the electric guns are going to become part of the military arsenal. The concept scientist and/or engineer will try to prove the feasibility of the concept on paper. Once the feasibility of the concept has been proven, the concept is passed on to the developer. The developer makes the concept operational, with the materials and coatings commercially available, however, presently commercially available materials and/or coatings cannot withstand the operating environments for the extended periods of field operation; therefore, the electric guns prototypes do not meet the desired performance and the reliability requirement to have it in the field.

It is the authors' opinion that it is necessary for all the technical parties involved in the project to work in closer coordination from the concept stage, development, and fielding of the electric gun in order to develop materials to meet the desired field requirements. Extensive research and development efforts will be needed to develop materials that meet the desired performance requirements for the new generation of gun-tube launchers.

After an extensive search for literature and personal communication with experts on the subject, the authors are not aware of any coatings or materials that will minimize the materials problems sufficiently to meet present field operational requirements (see the Recommendation Section). Many contractors and military agencies are already working on the technologies to minimize the erosion and corrosion problems and to improve the performance of the existing materials being used in the electric guns prototypes.

Recommendations

Several material candidates or processes that may warrant further investigation or evaluation for potential applications in the gun-tube launchers are listed below:

- Diamond-like nanocomposites: The Air Force has awarded a contract to Advanced Refractory Technologies, Inc. of Buffalo, NY to evaluate diamond-like atomic-scale composite coatings for protection of insulators from high energy plasma. Those coatings are said to offer high temperature performance, ablation resistance, low coefficient of friction, and excellent adhesion [9].
- Platinum-modified aluminide coatings: The Naval Surface Warfare Center, Carderock Division in Annapolis, MD has evaluated three variations of a platinum-modified aluminide coating intended for use on gas turbine components for their hot corrosion resistance [10].
- Chemical vapor deposition (CVD) diamond-like: Norton Diamond Film of Northboro, MA uses proprietary CVD processes with DC arc-jet engine and microwave systems. Thick and thin diamond-like films with features characteristic of natural diamond can be produced. One application of the CVD diamond-like coating is in the cutting tools because of its hardness, wear resistance, and low coefficient of friction [11].
- Recent advances in high velocity oxyfuel (HVOF) thermal spray equipment and coating compositions: the HVOF thermal spray process can spray various carbides and noncarbide materials onto many substrates. It produces a coating which has greater thickness, stronger bonds, higher hardness, and durability than with other thermal spray technique such as plasma arc [12].
- Nanoparticles such as the ceramic titanium boride: Nanoparticles (particles 1/1000 of a micron) used as the basis of a new composite material could be as much as 1000% stronger and more resistant to fracture than traditional materials. Work on this material is being conducted by materials researchers at Washington University in Missouri [13].

One item that may be of interest was the launcher designed by the engineers at Southwest Research Institute. It propels bullet-sized aluminum particles at speeds up to 11.2 km/sec to stimulate space collisions. This project was funded by the National Aeronautics and Space Administration. The launching technique uses a detonator, a conical-shaped charge, and an inhibitor made from a dense material. It has applications for a hypervelocity launcher [14].

Sandia National Labs has a hypervelocity launcher that can accelerate a 1/4-in.-diameter plate of metal to 15.8 km/sec, also to simulate space collisions [15].

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