Railgun Materials Science

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Introduction: NRL has initiated a program in electromagnetic (EM) launcher technology focusing on railgun materials science issues. A railgun consists of a power supply that drives current through a pair of conductors or rails to accelerate a projectile to high velocity. The rails and their insulators are contained in a barrel mounted on a platform. The platform must house the power supplies, controls, and projectile loader for the EM Gun (EMG). The conditions within the barrel for high-velocity launch of a multi-kilogram projectile are extreme. They can reach 10,000 atmospheres pressures, megampere currents, and tens of kilo gees acceleration. The barrel must withstand these conditions for up to several rounds per minute for thousands of shots without failure or significant degradation. These parameters are well beyond the state of the art in materials science. NRL scientists are studying the rail, armature, sliding interface, and insulators under these conditions. Initial results from moderate power railguns have shown problems due to rail surface erosion, alloying of materials, arc formation, and localized heating effects. The NRL program is focused on understanding the conditions within the barrel and developing techniques to mitigate damage. A consortium of pulsed power and materials scientists from the Plasma Physics, Materials Science and Technology, and Chemistry Divisions are conducting the research.

Electric Launchers and the Navy: Electric launch offers significant advantages over chemical propellant launch. Conventional guns are limited to velocities comparable to the sound speed of the propellants in the barrel, which limits their effective range to less than 20 nmi. They also require handling of large quantities of energetic materials (propellant and explosive payload) both in the supply chain and on-board ship. This impacts the ship design and the number of shells that can be stored in the ship's explosives magazine. An EMG offers the potential to launch projectiles at higher velocity, which translates into short delivery time and ranges up to 200 nmi, and to use shipboard electric generating capability to launch rather than chemical propellants. The projectile would also be a kinetic energy round with little or no explosives, which simplifies both the supply chain and the magazine requirements. The NRL program is designed to address the barrel materials issues associated with this gun.

Railgun Technology: A railgun consists of parallel conducting rails connected by a sliding contact called an armature. The launch package, consisting of the armature and payload, is initially pressed between the rails at the breech end. When current is driven through the rails and armature, as shown in Fig. 7, the armature is accelerated by the magnetic field. The accelerating force is proportional to the square of the current driven in the system. This allows one to control the acceleration by programming the current waveform. The launch velocity is limited by the electrical power available, barrel geometry, and the materials properties of the barrel and armature.

NRL is focusing on the barrel materials science issues associated with the Navy railgun. A new railgun Materials Testing Facility (MTF) is being built to allow barrel research at the appropriate power levels. The lab will contain a 6-m long railgun powered by an 11-MJ capacitive energy store using solid-state opening and closing switches. Up to 2 MA of current will be available to launch 1-kg projectiles to greater than 2 km/s velocities. The containment is designed for maximum diagnostic access, rapid turnaround, and easy reconfiguration. NRL has an extremely wide range of bulk and surface materials diagnostics for application to the problem.

Barrel Materials Analysis: Prior to the operation of the MTF railgun NRL scientists have been analyzing rail materials generated by Navy tests at the Institute for Advanced Technology (IAT) located at the University of Texas at Austin.[1] Figure 7 represents a simplified schematic of the rails and armature used for these

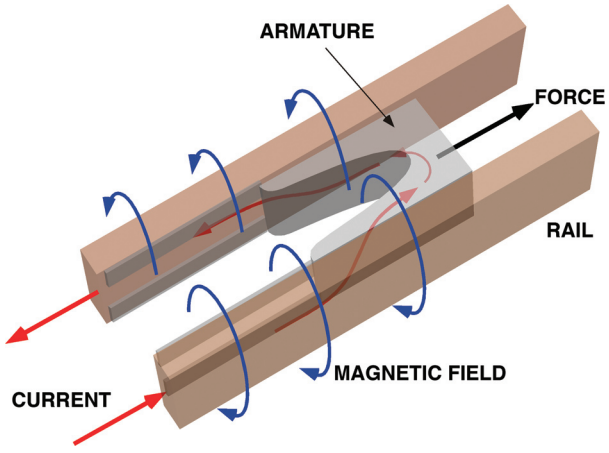

FIGURE 7
Sketch of railgun geometry. Current is driven through one rail, across the armature, and back through the other rail. The magnetic field drives the armature along the rails.

tests. The launcher has a 3.5-m long square bore with 40-mm-wide rails separated by epoxy-glass laminated insulators. The armature was made of aluminum alloy with a polycarbonate bore rider in front to keep it aligned with the rails. The 500 g package was launched at greater than 2 km/s velocity with 1 MA peak, 6-ms-long current pulse generated by a 10-MJ capacitor bank. NRL has been analyzing single and multiple shot rails from the tests, evaluating rail damage, developing empirical scaling relationships, and trying to understand the launch physics. Figures 8 and 9 contain examples of some of the post-shot analysis of a 20-shot rail. The pictures in both figures come from the vicinity of 40 cm from the start point in the railgun. The current at the time the armature passed this location was approximately 1 MA and the velocity was 1 km/s.

Figure 8(a) shows the rail top surface. The gray colored material is aluminum that has melted off the sliding armature. The three boxes (Fig. 8(b)) show increasing magnification scanning electron microscope (SEM) photographs of the aluminum deposit at one edge. The images at 200-, 30-, and 10-µm scales show the top surface of a thin aluminum layer on the copper rail. Figure 8(c) shows the spectrum generated by Energy Dispersive Spectrocopy (EDS) from near one of the 5-µm sized voids in the aluminum. EDS allows one to determine the atomic constituents near the surface of the material. The spectrum shows a large peak where aluminum is expected. Likewise there are peaks from zinc, copper, oxygen, and carbon.

Figure 9(a) shows a scan from a stylus profilometer of the surface at the 39-cm location. The scan shows that the surface has been eroded by approximately 150 µm near the edge of the rail and to a lesser depth on the other side. In between there appears to be a deposit, found to be a mixture of aluminum and copper, of 200 to 250-µm thickness. Figure 9(b) shows a high-resolution image of the edge of the rail near the 40-cm location approximately where the rectangle in Fig. 8(a) is located. The erosion of the copper near the edge is clearly visible. Figure 9(c) shows SEMs of the ~15 to 20 µm thick edge inside of the groove region. There is evidence of copper dendrites forming near the interface and copper-aluminum crystal formation within the deposit. In the thick deposit region, layers of aluminum were clearly visible in the SEM photographs, showing that the thickness grew from shot to shot. In addition, there have been a variety of X-ray diffraction, X-ray fluorescence, surface stress, material hardness, and other diagnostics applied to the surfaces and cross sections of these rails. From the different diagnostics, a picture of the rail-armature interface under high-power conditions during the acceleration process is being developed.

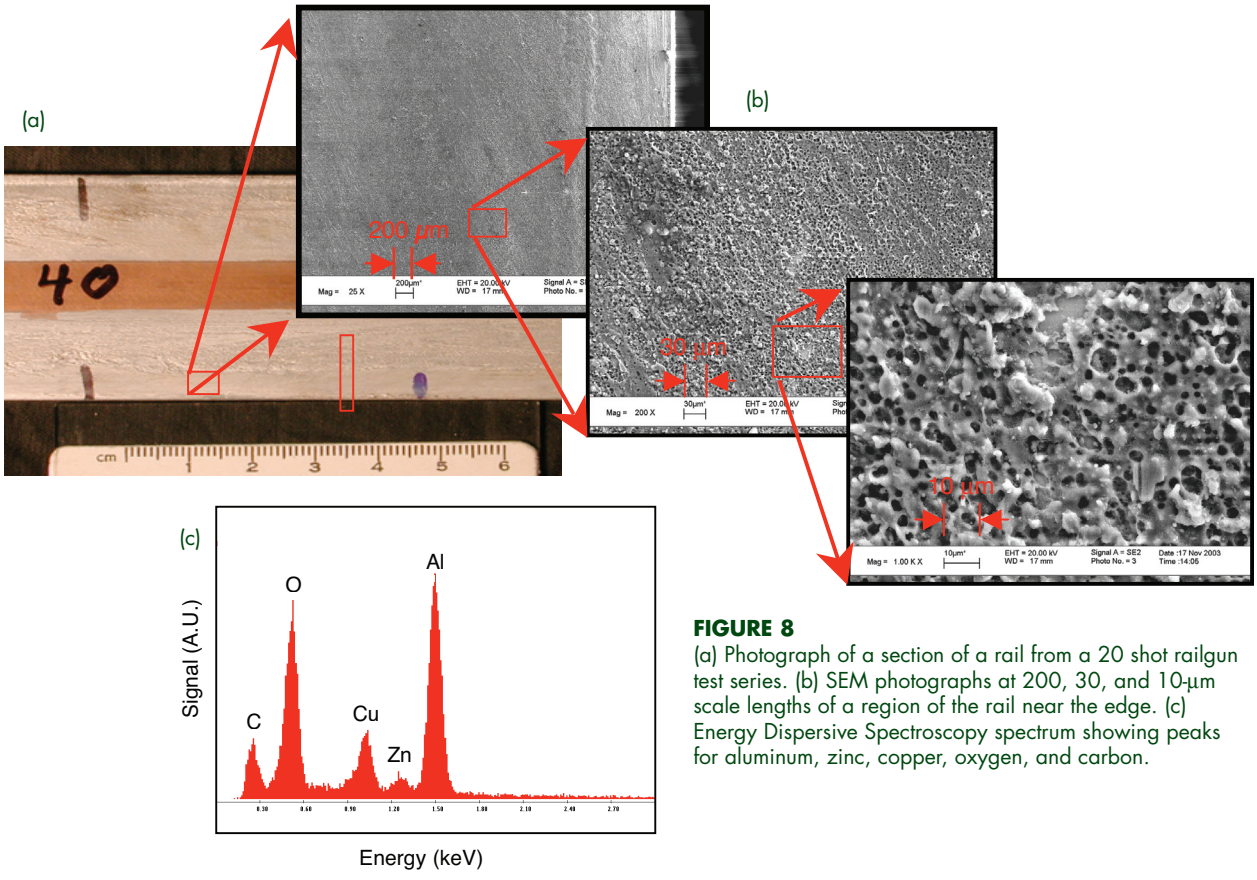

FIGURE 8
(a) Photograph of a section of a rail from a 20 shot railgun test series. (b) SEM photographs at 200, 30, and 10-µm scale lengths of a region of the rail near the edge. (c) Energy Dispersive Spectroscopy spectrum showing peaks for aluminum, zinc, copper, oxygen, and carbon.

Conclusion: The development of an EMG for a future Navy platform will be a significant accomplishment. The new NRL facility will provide a testbed to explore the technology at high power. The preliminary work on analysis of rails from other laboratories has both demonstrated the capabilities of the NRL materials analysis and illustrated the effects of a high power launch. NRL hopes to understand and solve some of these problems over the next few years.

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Reference

[1] R.A. Meger, K. Cooper, H. Jones, J. Neri, S. Qadri, I.L. Singer, J. Sprague, and K.J. Wahl, "Analysis of Rail Surfaces from a Multishot Railgun," *IEEE Trans. on Magnetics* **41**(1), pp. 211-213 (2005). ★

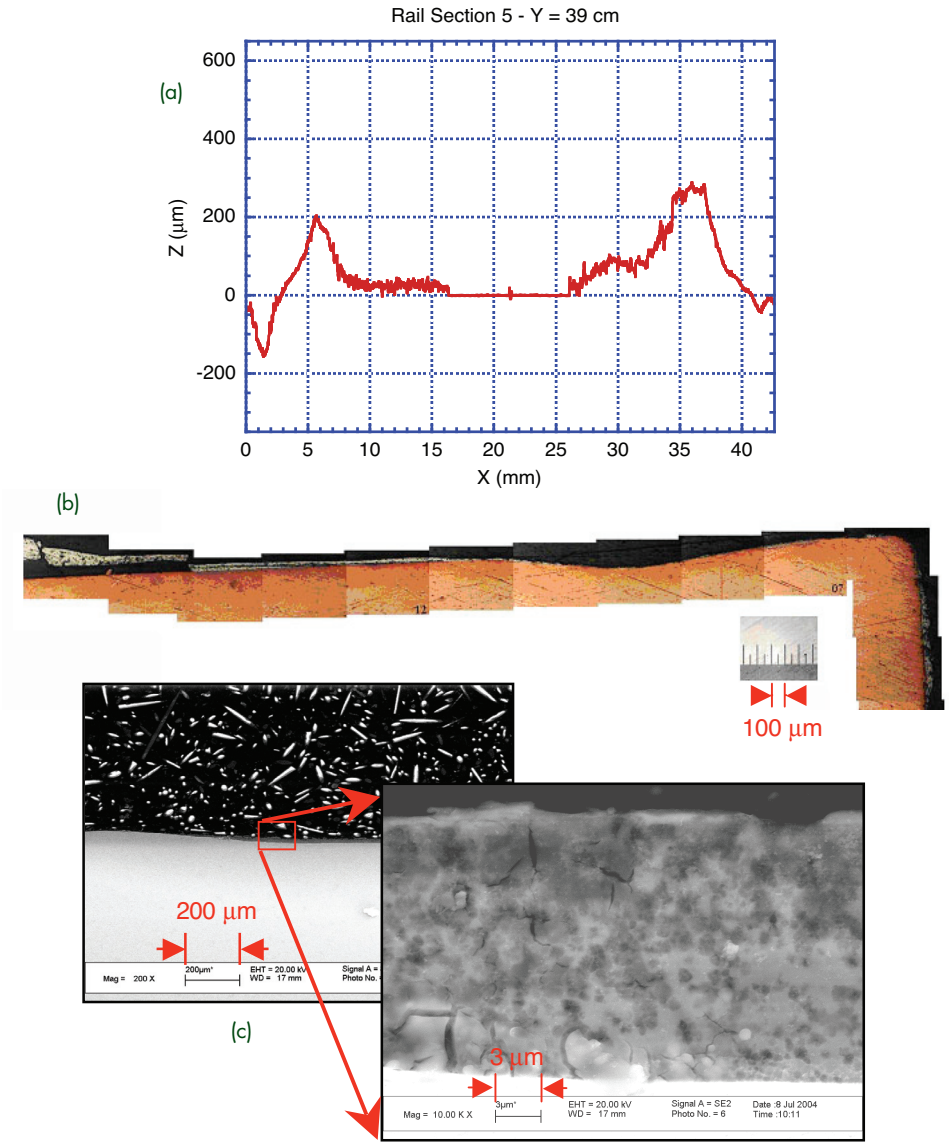

FIGURE 9
(a) A scan from a stylus profilometer at the 39 cm location on the rail section shown in Fig. 8(a). (b) A montage of high-resolution photographs of the cross section near the edge of rail segment in Fig. 8(a). (c) SEM photographs of the deposit on the copper rail in the vicinity of the groove on the edge of the rail.