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Short Communication

The sky is falling: Chemical characterization and corrosion evaluation of deposition produced during the static testing of solid rocket motors

William J. Doucette [a,*], Laurie S. McNeill [a], Scout Mendenhall [b], Paul V. Hancock [c], Jason E. Wells [c], Kevin J. Thackeray [c], David P. Gosen [d]

[a] Utah Water Research Laboratory, Utah State University, 8200 Old Main Hill, Logan UT 84322, USA
[b] Molzen-Corbin, 2701 Miles Road SE, Albuquerque, NM 87106, USA
[c] ATK Launch Systems, 9160 North Highway 83, Corinne, UT 84307, USA
[d] Univar, 17425 NE Union Hill Rd, Redmond WA 98052, USA

HIGHLIGHTS

- ► Static tests of rocket motors result in deposition of entrained soil and fuel combustion products over large areas
- ► Chloride is the main combustion product generated from the ammonium perchlorate–aluminum based propellant.
- ► Steel coupons exposed to test fire soil (TFS) deposition had higher corrosion rates than paired non-exposed coupons.
- ► Sites receiving more TFS deposition had higher corrosion rates.

GRAPHICAL ABSTRACT

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ABSTRACT

Static tests of horizontally restrained rocket motors at the ATK facility in Promontory UT, USA result in the deposition of entrained soil and fuel combustion products, referred to as Test Fire Soil (TFS), over areas as large as 30–50 mile^2 (80–130 km^2) and at distances up to 10–12 miles (16–20 km) from the test site. Chloride is the main combustion product generated from the ammonium perchlorate–aluminum based composite propellant. Deposition sampling/characterization and a 6-month field corrosivity study using mild steel coupons were conducted in conjunction with the February 25th 2010 FSM-17 static test. The TFS deposition rates at the three study sites ranged from 1 to 5 g/min/m^2. TFS contained significantly more chloride than the surface soil collected from the test site. The TFS collected during two subsequent tests had similarly elevated chloride, suggesting that the results obtained in this study are applicable to other tests assuming that the rocket fuel composition remains similar. The field-deployed coupons exposed to the TFS had higher corrosion rates (3.6–5.0 mpy) than paired non-exposed coupons (1.6–1.8 mpy). Corrosion rates for all coupons

* Corresponding author. Tel.: +1 435 797 3178; fax: +1 435 797 3663.
E-mail address: william.doucette@usu.edu (W.J. Doucette).

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decreased over time, but coupons exposed to the TFS always had a higher rate than the non-exposed. Differences in corrosion rates between the three study sites were also observed, with sites receiving more TFS deposition having higher corrosion rates.

1. Introduction

As part of a multi-year program designed to evaluate and improve the performance and safety of reusable solid rocket motors (RSRMs), static ground tests are conducted at the Alliant Techsystems (ATK) Promontory, Utah facility. During static tests, the heavily instrumented RSRMs, containing an ammonium perchlorate–aluminum based composite propellant, are horizontally restrained and ignited while data on performance are collected. During a typical 2-minute test, a high-temperature cloud of combustion products and an estimated 1.5 million kg of entrained soil are generated. This combustion cloud typically reaches heights of 10,000–15,000 ft above ground surface.

As the cloud cools, the deposition material, referred to as Test Fire Soil (TFS), drops on the surrounding area (usually at a 10–20° angle that extends out to 10–12 miles) that includes rangeland, farmland, low-density residential housing and several wildlife management areas. Due to its exposure to elevated temperatures (combustion gas temperatures approach 6000 °F) and combustion products (largely aluminum oxide and hydrogen chloride [Dreschel and Hall, 1990]), the composition of the Test Fire Soil (TFS) is expected to be different from the native soil.

The monitoring conducted during several past Space Shuttle launches and vertically restrained static rocket motor tests having similar fuel composition provides some pertinent information on the potential constituents and impact of the deposition material generated during the static tests. The typical RSRM used in the Space Shuttle program contained over 500,000 kg of a composite propellant comprised of an ammonium perchlorate oxidizer (70%), an aluminum powder fuel (16%), a polybutadiene–acrylic acid–acrylonitrile terpolymer (PBAN) binder (12%), an epoxy curing agent (2%), and a catalyst of iron oxide powder (0.1%) (Dreschel and Hall, 1990). The main exhaust products were aluminum oxide Al_2O_3 (30%), carbon monoxide CO (23%), hydrogen chloride HCl (22%), water (10%), and nitrogen (8%) (Dreschel and Hall, 1990). Hydrochloric acid is formed when the HCl gas dissolves in the water produced during combustion and the existing atmospheric water vapor (humidity). From the bulk deposition collectors used during three shuttle launches at the Kennedy Space Center in Florida USA, Dreschel and Hall (1990) estimated HCl and Al_2O_3 depositions to range from 0 to 127 g/m^2 and 0 to 246 g/m^2, respectively. The deposition was highly influenced by wind speed and direction and led to short-term decreases in soil and water pH surrounding the Kennedy Space Center after shuttle launches. At a NASA test facility in Mississippi, Nowak and Friend (2006) observed that soil pH was decreased by vertically restrained static rocket tests, but only temporarily because alkalinity in the soil neutralized the acid.

In contrast to the Space Shuttle launches and vertically restrained static tests, the plumes generated from the horizontally restrained static tests in Northern Utah contain large quantities of soil. For very large rocket motors, horizontal mounting is easier and provides better access to the motor. Safety considerations and space limitations required placing the large motor static test sites close to a small mountain range that makes up the eastern boundary of the facility. The rising grade behind the test facility creates a point where the high thrust exhaust entrains large amounts of soil and rock.

By using aircraft to make real time measurements, Cofer et al. (1993) found that the number of large diameter particles (>5 um) in the Utah site's static test exhaust cloud was greater than that of a shuttle launch and most of the large material was composed of soil debris. They also found that although the peak atmospheric HCl concentrations during a static test in Utah were slightly greater than that observed during a shuttle launch in Florida (50 ppm_v vs. 35 ppm_v), the HCl concentrations decreased from the peak much more rapidly at the Utah site. We speculate that the relatively alkaline soil (pH 8, 30% carbonate content) entrained in the combustion cloud neutralized some of the HCl.

Questions regarding the composition and potential corrosivity of the TFS generated during static rocket testing prompted this investigation. The deposition material (TFS) was collected during the February 2010 FSM-17 static test and analyzed for chloride and other major anions and metals. This material was also compared to the TFS collected during several other static tests in order to evaluate compositional variability. To assess the potential corrosivity of the TFS under environmental conditions and compare it to other locations, fifteen, pre-weighed, standard mild carbon steel specimen coupons were mounted on tripod stands, 15 min before the February 2010 static test at the three sites within the projected deposition plume (exposed). After the deposition was visually observed to have stopped, a second panel of 15 coupons was mounted next to the exposed panel (non-exposed). Triplicate coupons were collected from each set at five times over a six-month exposure period and were cleaned to remove the corrosion byproducts. Corrosion rates, determined from weight loss measurements, were compared to those obtained from non-exposed samples and to literature values.

2. Experimental

The FSM-17 static rocket motor test started at 11:50 am MST on February 25, 2010. Sky conditions were mostly cloudy with a light morning fog dissipating by the time of the test. Winds above 10,000 ft mean sea level (MSL) were out of the northwest at 10 m/s. Temperatures at 10,000 and 20,000 ft MSL were −10 and −20 °C, respectively. Weather conditions were monitored by ATK meteorologists and used to make pre-test plume path predictions and select three sites for the collection of deposition material and the initiation of a six-month corrosion monitoring experiment (Fig. 1). Sites were located at approximately 41°N 112°W with elevations ranging from 1327 to 1448 m. All three sites did receive TFS deposition, although snow cover and atmospheric conditions likely limited soil entrainment based on visual and radar comparisons with previous static tests.

2.1. Deposition material (TFS) collection

Polyethylene tarps (3 m^2), placed on the ground at each of the three locations just before the start of the static motor test, were used to collect TFS for the post-test characterization of inorganic materials (major anions and metals). Universal pH paper test strips placed on the tarps were used to provide a rough estimate of pH since the amount of wet deposition collected was insufficient for the use of a standard pH probe and meter. After the deposition stopped, the collected material was transferred from the tarp into a labeled HDPE bucket by using a nylon scraper. The buckets were sealed and transported to the Utah Water Research Laboratory (UWRL, Logan UT, USA) where the material was allowed to air dry for two days. After drying, the material was weighed and transferred to HDPE plastic containers pending characterization. Large stainless steel bowls (12 in. diameter) were used to collect TFS for organic material characterization but insufficient material prevented the analysis. Soil cores (10 cm × 2.5 cm diameter) were also collected at the test site by using a hand driven ASM soil corer (American Fork, ID, USA) and divided into four 2.5 cm sections prior to the analysis. However, since no trends in metals or major ion concentrations were observed with depth, the results for the soil cores are presented as the average and standard deviation for all four sections.