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Bullet on bullet fragmentation profile in soils

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ABSTRACT

Lead–antimony alloy slugs encased in a brass jackets are common small arms caliber ammunition used for training and target practice. When small caliber ammunition is fired at testing and training ranges, these metals—some of which are toxic—are introduced into the environment. Research was conducted on the effects of bullet on bullet impacts and the resulting bullet fragmentation. The extent of bullet fragmentation, among other factors, affects the formation of mobile metal species from small arms firing ranges. Bullet on bullet impact can increase the surface area to mass ratio of the bullet metal alloys in the soil. The solubility of a metal is typically associated with the specific corrosion rate in the berm environment which is dependent on the surface area of the fragments. The purpose of the study was to analyze the bullet on bullet impact effects in six soil types. Changes in the metal distribution as a result of bullet impact was evaluated through sieve analysis and changes in the particle size distribution. The bullet on bullet impact observed in this study demonstrated a significant and observable shift in the fragmentation profiles for the lead, antimony, and copper in soils after shooting an average of 1050 tungsten-nylon bullets into the legacy lead soils. This study provides new information to assist with determining the potential environmental fate, transport, and environmental availability associated with constant bullet on bullet impact at testing and training ranges.

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1. Introduction

The 5.56 mm (0.223 cal) cartridge contains a bullet that is commonly compose of a lead–antimony (Pb–Sb) alloy slug with a carbon steel (Fe–C) penetrator encased in a brass jacket [copper–zinc alloy (Cu–Zn)] that is used in the M-16 rifle. The use of the Pb–Sb bullet at small arms firing ranges (SAFRs) for training and target practice introduces these metals into the SAFR berm soil as whole bullets and bullet fragments. A report by the Interstate Technology Regulatory Council (ITRC) estimated that more than 96% of the lead present at small arms firing ranges (SAFRs) is in the form of intact bullets or bullet fragments (ITRC, 2003). Griggs et al. (2010) reported that bullet fragmentation patterns in soil are different when bullets are fired at a close distance (i.e. 25 m) as opposed to when bullets are fired at a further distance (i.e. 95 m); this is based on a decrease in the bullet terminal velocity as the bullet travels further from the muzzle of the rifle (HQDA, 2008).

The kinetic energy of the bullet leaving a rifle is based on the average muzzle velocity of the rifle; the M-16 rifle has an average muzzle velocity of 945 m/s with a kinetic energy of approximately 1797 KJ (HQDA, 2008). The mass of a typical 5.56 mm bullet or projectile is 4 g or 61.8 grains (DAC, 2005). After traveling 25 m, with an adjusted bullet velocity of approximately 918 m/s the kinetic energy is approximately 1685 KJ (HQDA, 2008). The soil type has also been shown to influence the fragmentation pattern and metal distribution in the soil profile (Griggs et al., 2010). The bullet penetration into soil depends on several factors such as velocity and bullet characteristics; since the 5.56 mm bullet is a high velocity bullet it tends to tumble and disintegrate soon after impact (HQDA, 2008). It has been shown that larger percentages of the average mass of metal particulates passed through a 1.68 mm sieve for rocky and sandy soils than percentages for softer, less compressible soils (Griggs et al., 2010).

The terminal ballistics of a bullet is when a bullet comes in contact with its target and in this study with the soil, bullets, or bullet fragments in the soil. Soil particle size separation by wet sieve analysis demonstrated that <1.8% of the total amount of Pb

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introduced by bullets was present in the <0.45 micron (soluble) size fraction (Griggs et al., 2010). Bullets and bullet fragments can corrode to form soluble metals and metal salts that can potentially sorb to soil particles (Lin et al., 1995; Murray et al., 1997; USEPA, 2001). The migration of metals (e.g. Pb, Sb, and Cu) from SAFRs through surface water transport has been observed in numerous studies (Heier et al., 2009; Johnson et al., 2005; Martin et al., 2013).

As bullet and bullet fragments are introduced into SAFR berm soils the increased use of SAFRs for training and target practice will generate more bullet fragments over time, but the bullet on bullet fragmentation profile rate of change has not been well studied. The objective of this study was to observe the bullet on bullet impact fragmentation of small arms legacy lead (i.e. Pb–Sb) bullets in several soil types and determine if there was a change in the metal distribution in the soil through the act of firing non Pb–Sb bullets or tungsten-nylon (W-nylon) bullets into six legacy lead soils.

2. Materials and methods

2.1. Soil characterization

Six uncontaminated soils (i.e. soils into which no bullets had been fired) were selected as representative of what can be typically found in SAFR berm backstop material. The following notation was used to identify these six soils: Muck = M, Loess = L, Clay = C, Sandy Clay = SC, Sand = S, and Glacial Till = GT. Soil type classification was based on the U.S. Army Engineer Soil Classification system, ASTM D2487-11 (ASTM, 2011), see supplementary data Table S1. Peaty, high organic carbon content is the Muck soil classified as MH. The Loess soil, classified as ML, is a light wind deposited silty soil. The loamy soil was classified as CL and called Clay. The Sandy Clay is a lateritic, iron-rich quartzose soil and the Sand is primarily quartzose; both are classified as SM. The rocky, saline soil with some organic content is the Glacial Till also classified as SM. A soil mixing process provided consistently homogenized samples through the use of rakes, shovels, and a tiller used to mix and fold the soils in a 3 m × 3 m polyethylene container. The soils were then sieved to remove particles greater than 25.4 mm and stored in tared, lined 55-gallon drums until needed.

2.2. Sample prep

The mass of soil in the lined 55-gallon drums was from 123.6 to 236.9 kg (Table 1). Small grab samples were removed from each drum, placed in a tarred container, and dried in the oven at 104 ± 1 °C for 24 h to determine the soil moisture content. The resulting percent soil moisture content was used to determine the dry weight of the soil in each barrel. To simulate soils from SAFRs which contain Pb–Sb bullets, legacy lead (LL) range material or bullets and bullet fragments from actual firing ranges were introduced into the six clean soils. The legacy lead material, consisting of Pb–Sb alloy and Cu–Zn jacketed bullets and bullet fragments, were physically separated from small arms firing range soil as discrete particles in two size categories: 1) small – as < 3.35 mm and 2) large – from 6.7 mm to 3.35 mm. Determination of the amount of legacy lead to be added to each barrel was based on the total dry weight of the soil. Two percent of the dry weight soil mass of legacy lead was added to each of soils in the 55-gallon drums. The legacy lead was added in two size fractions, small and large: 71.6% of the mass required to bring the legacy lead to 2% dry weight was added in the form of the small size category; 28.4% of the mass required to bring the legacy lead to 2% dry weight was added in the form of the large size category. Once the legacy lead was added, the drums were sealed and placed on a barrel roller for 24 h to thoroughly mix the legacy lead into the soil; now referred to as legacy lead soil.

Table 1
Legacy lead soil type and number of tungsten-nylon bullets fired into each mass of soil.

Soil type	Notation	Soil mass (kg)	Number of W-Nylon rounds fired	Distance to catch box (m)
Muck (M)	M-LL/W25	158.7	792	25
Loess (L)	L-LL/W25	205.8	1027	25
Clay (C)	C-LL/W25	218.8	1091	25
Sandy Clay (SC)	SC-LL/W25	228.8	1142	25
Sand (S)	S-LL/W25	236.9	1182	25
Glacial Till (GT)	GT-LL/W25	123.6	1066	25

Legacy lead soils were fired on with W-nylon 5.56-mm bullets to produce legacy lead post fired soils. The W-nylon bullets provide a different bullet slug metal source so that the pre Pb–Sb alloy metal fragmentation could be compared to the post Pb and Sb fragmentation profile without the introduction of additional Pb and Sb into the legacy lead soils. Firing into the legacy lead soil continued until the W-nylon bullet fragments accounted for 2% of the soil in the catch box or approximately 20,000 ppm W in the soil (Table 1). Shooting was stopped after every 90 rounds to reshape the catch box soil. The notation used to identify these soils is by soil type (or 'Soil Type'-LL) followed by a slash and the bullet type (i.e. W) and firing distance in meters (i.e. 25) (e.g. M-LL/W25).

Each of the post-firing soils was placed into a 3 m × 3 m polyethylene container and a series of splitting and recombining homogenization steps was performed as was previously mentioned. Once the soil was homogenized, the container was divided into nine subsections and 0.6–0.8 L discrete samples were removed from each of the nine subsections and used for metal analysis. Additional composite subsamples were removed for soil classification, soil composition, particle size analysis, and mineral identification through X-Ray Diffraction (XRD) techniques.

2.3. Soil analysis

The U.S. Environmental Protection Agency (USEPA) considers metal concentrations in soils to be the concentration obtained following a total digestion of the soil fraction that passes through a 1.7 mm sieve. This is a result of the often particulate nature of metal contamination, and avoids the digestion of large metallic particles like intact bullets and large bullet fragments. In this study, analysis of samples less than 1.7 mm were used to determine metal concentrations in pre- and post-fired soils. The particle size of each soil sample was determined by wet sieving followed by drying and weighing. Pre- and post-fired results were compared. The concentration of metals in each of the size fractions was determined by grinding, digesting, and analyzing the resultant soil digest for the metals of interest (i.e. Pb, Sb, and Cu). Tests were also done to determine the concentrations of soluble metal species in the samples.

A Perkin–Elmer Optima 4300 Dual View (DV) Inductively Coupled Plasma (ICP) Atomic Emission Spectroscopy (AES) was used to analyze samples for metals following EPA Method 200.7 (USEPA, 1994). The instrument detection limit (IDL) for aqueous samples was 0.01–0.05 mg/L, metal dependent. Soil samples were digested following EPA Method 3051A and analyzed using the Perkin–Elmer Optima 4300 Dual View ICP-AES with a minimum detection level (MDL) from 0.6 to 5 mg/kg, metal dependent. Statistical analysis was performed using SigmaPlot™ 12.5 with an alpha value of 0.05.

Geochemical characteristics of each soil with regard to mineral species present were determined by XRD. To determine the type of

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