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Impact-disrupted gunshot residue: A sub-micron analysis using a novel collection protocol

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ABSTRACT

The analysis of gunshot residue (GSR) has played an integral role within the legal system in relation to shooting cases. With a characteristic elemental composition of lead, antimony, barium, and a typically discriminative spheroidal morphology, the presence and distribution of GSR can aid in firearm investigations. In this experiment, three shots of low velocity rim-fire ammunition were fired over polished silicon collection substrates placed at six intervals over a 100 cm range. The samples were analysed using a Field Emission Gun Scanning Electron Microscope (FEG-SEM) in conjunction with an *X-flash* Energy Dispersive X-ray (EDX) detector, allowing for GSR particle analyses of composition and structure at the sub-micron level. The results of this experiment indicate that although classic spheroidal particles are present consistently throughout the entire range of samples their sizes vary significantly, and at certain distances from the firearm particles with an irregular morphology were discerned, forming “impact-disrupted” GSR particles, henceforth colloquially referred to as “splats”. Upon further analysis, trends with regards to the formation of these splat particles were distinguished. An increase in splat frequency was observed starting at 10 cm from the firearm, with 147 mm^{-2} splat density, reaching a maximal flux at 40 cm (451 mm^{-2}), followed by a gradual decrease to the maximum range sampled. Moreover, the structural morphology of the splats changes throughout the sampling range. At the distances closest to the firearm, molten-looking particles were formed, demonstrating the metallic residues were in a liquid state when their flight path was disrupted. However, at increased distances-primarily where the discharge plume was at maximum dispersion and moving away from the firearm, the residues have had time to cool in-fight resulting in semi-congealed and solid particles that subsequently disrupted upon impact, forming more structured as well as disaggregated splats. The relative compositions of the characteristic elements that are present in GSR also change in the different splat morphologies sampled, which may contribute to the particles' physical structures. Two distinct populations of splats were also observed: circular and elongated, which suggest the residues hit the substrate at different angles. The difference in the splat impact angle can be ascribed to the position of the residues within the firearm discharge plume; particles get caught up in the vortex that is created by the discharge gases behind the projectile as it leaves the barrel, thereby affecting their directionality and flight time. This reasoning could also justify the existence of both spheroidal and splat particles at certain distances. The novel sampling and analytical techniques used in this experiment have provided previously unknown information in relation to GSR structure and formation which could have greater implications to its current analysis amongst laboratories and law enforcement agencies worldwide.

1. Introduction

When a cartridge-based weapon is fired, both gaseous and solid residues consisting of organic and inorganic particles from the ammunition are produced and expelled from the barrel [1–3]. Once these residues are in flight they cool very rapidly producing GSR, which is identified by its characteristic inorganic elemental composition of lead, antimony and barium [4]. The analysis of GSR provides important evidence in firearms incidents, making the quality of its analysis crucial. Therefore, it was established that SEM-EDX analysis was the ideal technique to do so due to its non-destructive ability to analyse samples and being able to provide

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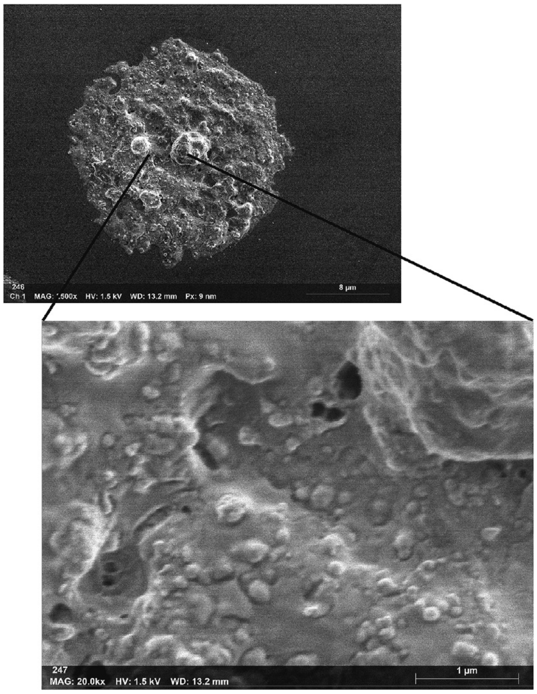

Fig. 1. FEG-SEM image of impact-disrupted GSR showing the imaging capabilities of a cold field emission SEM. Scale on zoomed in image: 1 μm *HV 1.5 kV.*

morphological and elemental composition data in a short amount of time [5,6]. Although GSR has a characteristic elemental composition, the origin of those particles cannot be concluded based on that alone. It has been acknowledged that to establish a particle is in fact GSR, the compositional data must be coupled with a characteristic spheroidal morphology to distinguish it from environmental aggregates such as residue from fireworks or vehicle brake pads [7–11]. In this experiment, the morphology and elemental composition of rimfire ammunition GSR is examined. Although the concept of coalescence of molten droplets to form GSR is not unknown [12] the novel sampling and analytical techniques used in this experiment demonstrate that particles may not always have sufficient time to cool into spheroidal residues, in particular at low velocities.

2. Materials and method

2.1. Experimental setup

In this experiment, six silicon collection substrates sized approximately 15 mm × 20 mm were set up perpendicular to the firearm and 7 cm below the firing line at bench level. The collection substrates were kept upright and in place with the use of plastic spine bars that were fixed onto the bench, allowing the substrates to be at a consistent height and perpendicular to the firearm for maximum residue collection. Prior to the experiment, these silicon substrates were cleaned for 5min in an ultrasonic bath using HPLC

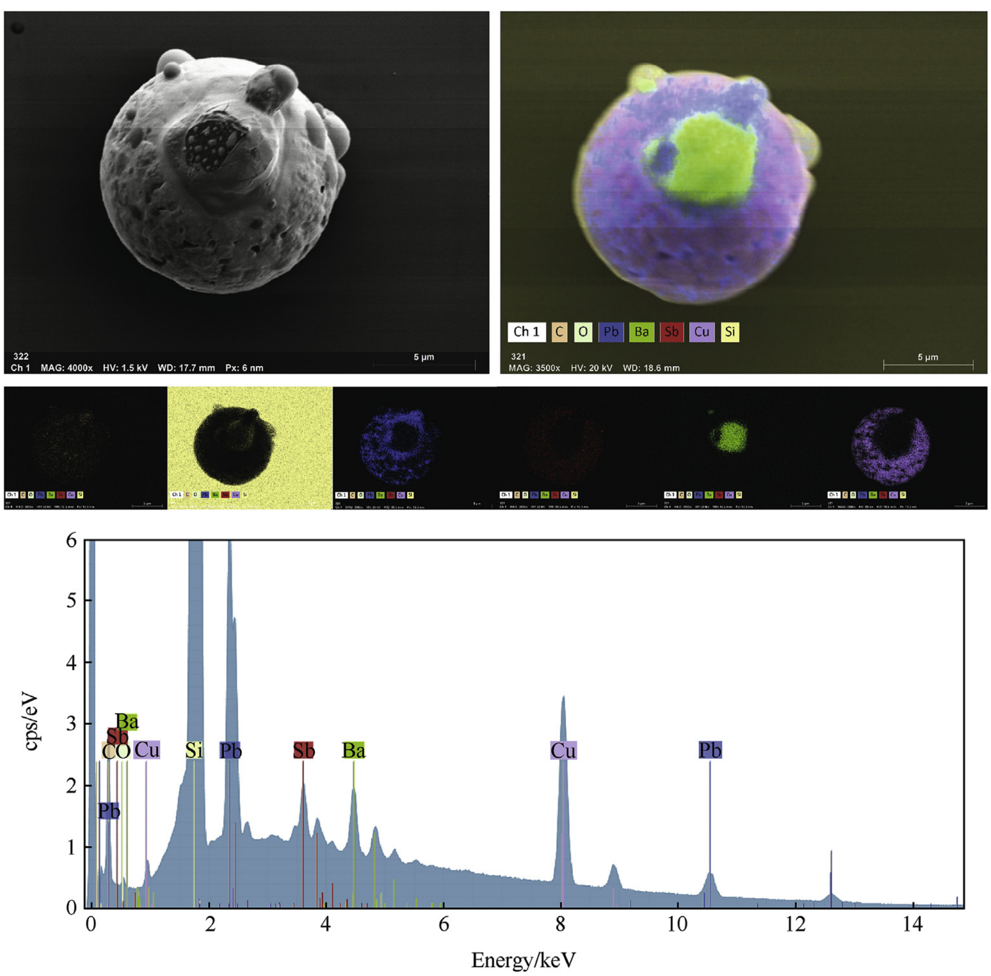

Fig. 2. FEG-SEM/EDX image of a characteristic spherical GSR showing sub-micron elemental distribution using the Bruker *X-flash* 5060f flat quad EDX detector. Image: *HV 1.5 kV.*, Elemental maps: *HV 20 kV.*