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Innovative boron nitride-doped propellants

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Abstract

The U.S. military has a need for more powerful propellants with balanced/stoichiometric amounts of fuel and oxidants. However, balanced and more powerful propellants lead to accelerated gun barrel erosion and markedly shortened useful barrel life. Boron nitride (BN) is an interesting potential additive for propellants that could reduce gun wear effects in advanced propellants (US patent pending 2015-026P). Hexagonal boron nitride is a good lubricant that can provide wear resistance and lower flame temperatures for gun barrels. Further, boron can dope steel, which drastically improves its strength and wear resistance, and can block the formation of softer carbides. A scalable synthesis method for producing boron nitride nano-particles that can be readily dispersed into propellants has been developed. Even dispersion of the nano-particles in a double-base propellant has been demonstrated using a solvent-based processing approach. Stability of a composite propellant with the BN additive was verified. In this paper, results from propellant testing of boron nitride nano-composite propellants are presented, including closed bomb and wear and erosion testing. Detailed characterization of the erosion tester substrates before and after firing was obtained by electron microscopy, inductively coupled plasma and x-ray photoelectron spectroscopy. This promising boron nitride additive shows the ability to improve gun wear and erosion resistance without any destabilizing effects to the propellant. Potential applications could include less erosive propellants in propellant ammunition for large, medium and small diameter fire arms.
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Keywords: Nano-boron nitride; Additive; Lubricant; Gun barrel; Wear and erosion; Gun propellant

1. Introduction

The U.S. military has a need for more powerful propellants with balanced/stoichiometric amounts of fuel and oxidants to provide an advantage to its warfighters. The useful life of each gun is limited either by the effects of barrel erosion on its performance or metal fatigue. The enlargement of the origin of rifling or the down bore area can affect ammunition performance resulting in range and accuracy loss, fuze malfunctions, excessive torsional impulse and excessive muzzle flash and blast overpressure. With increased demands for guns that fire faster, farther, and more accurately, barrel erosion has worsened and become a major limitation in developing better guns [1–3]. For example, with advanced propellants 155 mm artillery barrels may only survive a couple hundred rounds before they must be replaced at a cost of over $70,000 [4].

Many low vulnerability (LOVA) propellant formulations contain RDX, and it has been convincingly shown by several investigators that RDX is highly chemically erosive. New, experimental low-erosivity LOVA propellants have been produced by reducing RDX content and introducing nitrogen-rich energetic binder or filler compounds. The resulting propellant combustion gases, rich in nitrogen, act to re-nitride bore surfaces during firing and inhibit erosive surface reactions. The result is increased bore hardness, increased resistance to melting, and reduced chemical erosion. The lowered hydrogen concentration in the combustion gas of some of these propellants may also reduce hydrogen-assisted cracking of the bore

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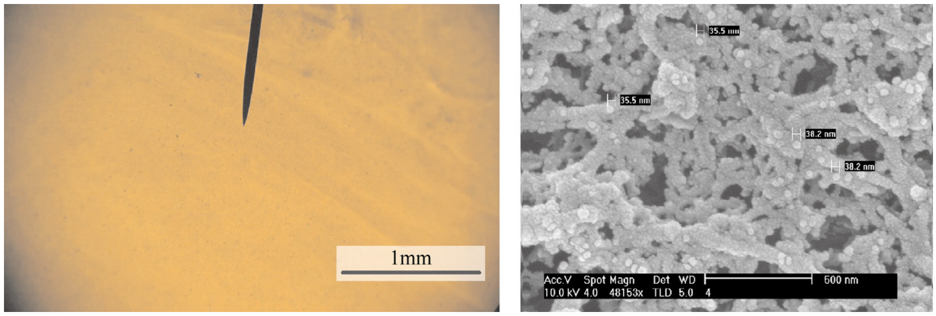

Fig. 1. SEM image of double base powder and amorphous BN (1:1 by weight) dispersed with acetone/ethanol using a sonic horn, and deposited onto a glass slide (48,000× magnification).

surface. Of the high-nitrogen propellants under development, the majority possess impetus and flame temperatures lower than RDX: a compromise between performance, sensitiveness and erosivity must be reached in these cases.

Significant effort has recently been directed at understanding the erosion mechanisms for barrels coated with protective refractory metals. The most plausible mechanism is that micro-cracks in the coatings, present from the time of manufacture, propagate due to pressure and thermal stress cycling and eventually reach the gun steel substrate. Through numerical modeling and analysis of eroded barrels, a number of investigators have shown that once cracks reach the substrate, chemical erosion, gas wash, and high interfacial temperatures cause pitting of the substrate and eventually undermine the coating. Segments of coating are subsequently removed by the flow or engagement with the projectile, and at this point the erosion rate of coated barrels may exceed that of steel barrels. A number of ways to mitigate this erosion pathway have been suggested, including development of better coating techniques to avoid the initial micro-cracks, pre-nitriding the gun steel before coating to slow down substrate erosion, introducing a protective interlayer, and controlled barrel storage and post-firing treatment to prevent oxidation of exposed substrate. Modeling and experiments have additionally shown that, with the notable exception of chromium, the erosion resistance of refractory metal coatings varies among different propellant gas chemistry environments. Ceramic additives to the propellant can theoretically reduce barrel deterioration by coating the inside of barrels, but implementation of composite propellants with conventional ceramics (i.e. alumina) has not resulted in improved wear resistance to date. Due to challenges with dispersing the particles in the propellant, and due to abrasion from incomplete sublimation, propellant and ceramic composites that produce regenerative wear-resistant coatings have not been demonstrated. Due to very good wear characteristics and thermal resistance, ceramic barrel liners have been identified as a promising technology for some time. However, the susceptibility of ceramics to fracture, driven by stress induced by the different thermal expansion properties of steel and ceramics, has prevented their widespread use.

The currently fielded 155 mm artillery propelling charge, M232/M232A1, has exhibited spiral wear and erosion problems. This was due to either the wear reducing liner, containing titanium dioxide, talc and wax, or other contributing factors. This resulted from the propellant chemistry and interaction of the combustion products within the gun tube wall. Modeling and simulation studies performed by Dr Samuel Sopok from Benet Labs have determined that the reaction of titanium dioxide with the talc and wax produced a residue that was hard to remove [5]. This product was an abrasive residue (number 80 ceramic grit) that built up in the gun barrel. This caused a spiral rifling imbalance and accelerated gun barrel erosion which markedly shortened gun barrel life. Boron nitride is an interesting potential additive to propellants that could reduce gun wear effects in advanced propellants. It has the properties of providing metal coating/lubricating, and steel hardening properties and nitrogen cooling effects.

On the other hand, boron nitride (in the form of crystalline hexagonal BN or amorphous BN) has interesting properties for a propellant additive (US patent pending). BN can form a lubricating coating on barrel walls. BN coated ammunition is currently used commercially for small arms to lubricate barrels and ammunition [2]. Further, boron can be used to dope steel, which drastically improves its strength and wear resistance. Boron-doped steel is used to reduce wear in numerous industrial applications and is typically produced by annealing steel that has been packed in boron oxide [6–12]. In this paper, we explore a new concept where BN is used as a propellant additive that can regeneratively coat and harden steel barrels. The BN is in the form of a nano-particle that can be evenly dispersed in the propellant without negative impact on its performance. Dispersion studies were performed to determine how easily the amorphous BN nano-particles could be dispersed in propellants. Scanning electron microscope (SEM) image of the BN in a commercial off-the-shelf double base propellant (1:1 by weight) dispersed with acetone/alcohol is shown in Fig. 1. The BN nano-particles were evenly dispersed and measured 38 nm on average.

Further, the production of the nano-scale boron nitride is economical. An economic model was constructed to project the cost of producing BN nano-particles from raw materials at the anticipated commercial scale (50,000 kg/yr). Based on this analysis, the projected cost of BN at the 50,000 kg/yr scale was found to be $91.15 per kg. This cost is reasonable because we use such a small percentage in the propellant formulation.