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6. AUTHOR(S)

Patrick Boyle, Alexander Humphrey, and Michael Courtney

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

DFRL
U.S. Air Force Academy
2354 Fairchild Drive
USAF Academy, CO 80840

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Molybdenum disulfide (MS_2), tungsten disulfide (WS_2), hexagonal boron nitride (HBN), and Lubalox are common bullet coatings that purportedly reduce friction between the bullet and rifle barrel. Three different bullets, one a solid copper design, and two jacketed lead bullet designs, were tested in the 5.56 mm NATO rifle cartridge. After coating, these bullets were test fired through a chronograph with powder charges ranging from 0.52 grams to 0.91 grams. The energies of these bullets along with a control group of uncoated bullets were plotted against the powder charges. The work of friction for each combination was then determined as the vertical intercept obtained by least squares regression to a line. The different coating and bullet combinations produced changes in friction ranging from reductions in friction of 15% to increases in friction of 19%. Given the time and expense of coating bullets, the reduction in friction is not cost effective for most applications.

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Quantifying Friction Effects of Molybdenum Disulfide, Tungsten Disulfide, Hexagonal Boron Nitride, and Lubalox as Bullet Coatings

Patrick Boyle, Alexander Humphrey, and Michael Courtney
U.S. Air Force Academy, 2354 Fairchild Drive, USAF Academy, CO 80840
Michael_Courtney@alum.mit.edu

Abstract
Molybdenum disulfide (MS_2), tungsten disulfide (WS_2), hexagonal boron nitride (HBN), and Lubalox are common bullet coatings that purportedly reduce friction between the bullet and rifle barrel. Three different bullets, one a solid copper design, and two jacketed lead bullet designs, were tested in the 5.56 mm NATO rifle cartridge. After coating, these bullets were test fired through a chronograph with powder charges ranging from 0.52 grams to 0.91 grams. The energies of these bullets along with a control group of uncoated bullets were plotted against the powder charges. The work of friction for each combination was then determined as the vertical intercept obtained by least squares regression to a line. The different coating and bullet combinations produced changes in friction ranging from reductions in friction of 15% to increases in friction of 19%. Given the time and expense of coating bullets, the reduction in friction is not cost effective for most applications.

Introduction
High barrel friction reduces the muzzle velocity of bullets that is important in maintaining long range trajectories, reducing wind drift, penetrating barriers, and incapacitating targets. Friction also contributes to barrel heating and wear which degrade accuracy and reduce barrel life. A new method of measuring barrel friction has recently been developed for determining the average barrel friction over the length of a rifle barrel at ballistic velocities.[1] This method enables the first quantitative testing of various bullet coatings with purported friction reducing properties.

Molybdenum disulfide (MS_2), tungsten disulfide (WS_2), and hexagonal boron nitride (HBN) are powdered lubricants known to be effective in a variety of high-temperature and high-pressure applications.[2-4] However, the problem of reducing the force required to push a bullet through the bore of a rifle barrel has several relatively uncommon features including the need to engrave the rifle bullet to conform to the shape of the bore, the increase in the normal forces due to the obturation of the bullet under high accelerations, and the fouling of the surface with powder residues, primer residues, and bullet material which all invariably become mixed with applied lubricants.

Quantifying lubricant effectiveness is challenging due to difficulty quantifying the different forces when a bullet is being forced through a rifle bore.[1] One method to analyze the pressure curve that is created when shots are fired, but there are confounding factors including the mass of the powder, the spatial variation in pressure between the point of measurement and the base of the bullet, shot-to-shot variations in the pressure curve, gas blow by, and the strong dependence of most propellant burn rates on the pressure. A second method uses a guess of the friction as an input for numerical modeling and adjusts the guess until agreement is found with the measured pressure curve and velocity. Since the pressure curve and velocity might be subject to other factors, this method provides only an estimate. A third method is to measure the force required to push bullets through the bore with a rod at low speeds, 4 to 9 cm/s.[5] This method has the advantage of providing a complete force curve: the applied force at every position as the bullet moves down the barrel at constant velocity. However, it is not clear how well this might represent resistance forces in the barrel at the much higher velocities involved in firing or whether this method accurately simulates the effects of powder or copper fouling of the barrel.

In spite of the factors likely confounding the friction reducing effects of different coatings and the challenges quantifying claims of reduced friction, a number unsupported claims have been published regarding the ability of coatings to reduce bullet friction. The Martin patent [6] claimed increases of velocity of up to 5% with MS_2 and 10% with WS_2. This would require reductions of barrel friction of approximately 25% and 50%, respectively. The Martin patent also claims that these coatings eliminate copper fouling of the barrel. The Swedish ammunition company Norma Precision advertises friction reduction for their line of bullets coated with MS_2.[7] Several other bullet companies offer bullets coated with MS_2 also. Winchester offers bullets coated with a proprietary oxide coating using the trade name Lubalox. [8]

This paper presents quantitative determination of bullet friction of coated and uncoated bullets and compares them to assess whether these coatings are effective at reducing barrel friction for three different bullet designs.

Method

The process began with the coating of various 5.56 mm NATO bullets. The bullets were cleaned with stainless tumbling media in a rotary tumbler (StainlessTumblingMedia.com, Orem, UT). After drying, the cleaned bullets were separated into three groups and coated. Coatings were applied by impact plating as described in the Martin patent [6] using a rotary tumbler with small steel spheres and bullets in a glass jar. This process took 3 hours. After coating, the MS_2 coated bullets were waxed in accordance to the manufacturer's instructions (NECO, Benecia, CA).

The velocity of various bullets were measured with an optical chronograph (Millenium CED chronograph with accuracy estimated at 0.3%) as the powder charge of Alliant Blue Dot powder was varied in 0.13 g (2 grain) steps from 0.52 g (8.00 grains) up to 0.91 g (14.00 grains). All loads used Federal 205M primers. Five bullets were loaded for each combination of bullet type, coating, and powder charge. The resulting velocity was combined with bullet mass to compute muzzle energy in Joules. When the average energy for five shots was graphed as a function of the amount of powder in grams, the resulting graph illustrated a strong linear relationship with a coefficient of determination (R^2) above 0.999.

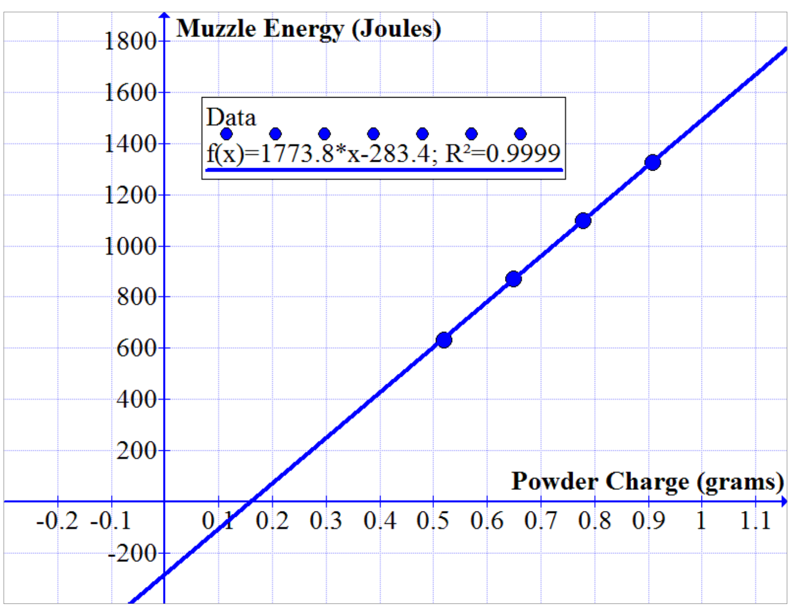

Figure 1: The linear relationship between the muzzle energy and powder charge of the 55 grain Nosler Ballistic Tip coated with HBN. The work done by friction acting on the bullet is -283.39 Joules with a correlation coefficient of 0.9999.

This relationship can be used to calculate the work done by friction on the bullet, which is the vertical intercept of the best-fit line. This is the energy lost to resistive forces in the barrel, which are collectively described as “friction” for the purposes of this method, although the relative contribution of engraving and friction forces are unknown. The average frictional force can then be calculated by taking the lost energy (vertical intercept) and dividing by the barrel length (0.57 meters for the Remington 700 used here).

The rifle barrel was carefully cleaned before shooting the uncoated bullets and also before shooting the bullets in any coating group. Six to ten shots were fired with each coating prior to data collection for that coating in order to condition the bore. The specific bullets tested were the 50 TTSX (Barnes Bullets, LLC, Mona, UT), 55 NBT (Nosler, Inc., Bend, OR), and 62 BFB (Berger Bullets, Fullerton, CA) which were coated with MS_2, WS_2, and HBN. The 55 NBT was also coated with a Lubalox coating by the manufacturer and is marketed by Winchester. Each type of bullet also fired uncoated to serve as a control. The 50 TTSX bullets are a solid copper. The 55 NBT bullets are a jacketed lead bullet with a plastic tip. The 62 BFB bullets are jacketed lead without a tip.

Results

For the powder and charge weights employed here, the relationship between muzzle energy and powder charge had a high linear correlation ($R^2 > 0.995$). The constant efficiency over a broad range of powder charges allows extrapolation back to the vertical intercept to provide a determination of the energy lost to barrel friction.

Bullet	Uncoated	HBN	WS2	MS2	Lubalox
50 TTSX	498(15)	495(20)	537(22)	509(7)	
55 NBT	332(5)	283(11)	355(12)	394(8)	345(20)
62 BFB	447(2)	393(25)	415(17)	384(18)	

Table 1: The work done by friction (in Joules) for each bullet and coating. The uncertainty is shown in parentheses.

Table 1 shows the relationship between the work done by friction in Joules and each coating for the 50 TTSX bullet. The HBN coating resulted in a small decrease in friction (less than 1%). The WS_2 and MS_2 resulted in 8% and 2% increases in work done by friction, respectively. Table 1 also shows the work done by friction for the 55 NBT with each coating. HBN reduced friction on the 55 NBT by 15%. The WS_2 and MS_2 resulted in 7% and 19% increases in work done by friction respectively. Lubalox increased the friction by 4%. Finally, Table 1 shows the work done by friction for each coating for the 62 BFB bullet. The HBN coating reduced friction by 12% for the 62 BFB. The WS_2 resulted in a 7% decrease in work done by friction. MS_2 reduced the work done by friction by the greatest margin by 14%.

Discussion

The results of this experiment provide quantitative method for measuring the average barrel friction of bullets in 5.56mm NATO with various bullet coatings. Our results indicate that the claims that bullet coatings reduce friction are not generally valid. Although Hexagonal Boron Nitride showed a decrease in work done by friction on all bullets tested, this decrease ranged from 15% in the 55 NBT to less than 1% reduction in the 50 TTSX. Considering that an increase of bullet velocity by 10% as claimed by Martin [6] would require over a 50% reduction in barrel friction, none of the coatings tested live up to claims of significant reductions in friction. The WS_2 coating varied from an increase in work done by friction by 8% to a reduction of 7%. The MS_2 coatings also varied from an increase in friction of 19% in the 55 NBT to a reduction of 14 % in the 62 BFB bullet. Even though the 62 BFB bullet shows reduction with all coatings (7% to 14% reduction in work done by friction) this is nowhere near the 50% reduction in work done by friction needed for a 10% increase in velocity. Thus, the use of coatings is largely ineffective considering the time and expenses associated with coating bullets.

It is not clear why lubricants which are effective in reducing friction in other high-pressure and high temperature applications are relatively ineffective in reducing friction between bullets and a rifle bore. It may be that the copper and/or powder fouling render the lubricants ineffective. It may be that most of the force that needs to be overcome in pushing a bullet through the barrel is engraving the rifling into the bullet. It may be that the coatings are ineffective at the ballistic velocities and the high normal forces between the bullet and barrel.

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Bibliography

[1] Boyle, P., Humphrey, A., Proctor, S., and Courtney, M. 2012. “Measuring Barrel Friction in the 5.56 mm NATO,” Technical Report No. ADA555779, Defense Technical Information Center, Fort Belvoir, VA.

[2] Winer, W. O., 1967. “Molybdenum Disulfide as a Lubricant: A Review of the Fundamental Knowledge,” Wear 10(6), pp. 422-452.

[3] Sliney, H.E., 1982. “Solid Lubricant Materials for High Temperatures – A Review,” Tribology International 15(5), pp. 303-315.

[4] Martin, J.M., Le Mogne, T., Chassagnette, C., and Gardos, M.N., 1992. “Friction of Hexagonal Boron Nitride in Various Environments,” Tribology Transactions 35(3), pp. 462-472.

[5] White, L. and Siewert, J., 2007. “Final Report of the Rifling Profile Push Test,” Technical Report No. ADA468801, Defense Technical Information Center, Fort Belvoir, VA.

[6] Martin M.D., 2000. “Method of Impact Plating a Bullet With a Powdered Lubricant,” US Patent 6036996.

[7] Norma, 2011. “Norma Diamond Line.” http://www.norma.cc/en/Products/Our-Brands/Norma-Diamond-Line/ Accessed 10 November 2011.

[8] Stock M.E., Eberhart G.T., 2007. "Upset Jacketed Bullets", US Patent 2007/0131131 A1.