

REPORT DOCUMENTATION PAGE				<i>Form Approved</i> <i>OMB No. 0704-0188</i>	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY)		2. REPORT TYPE		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)

Friction Effects of Lead-Based and Lead-Free Primers in 5.56mm NATO

Peter David Summer
U.S. Air Force Academy¹, 2354 Fairchild Drive, USAF Academy, CO 80840

Michael W. Courtney
BTG Research, PO Box 62541 Colorado Springs, CO 80920
Michael_Courtney@alum.mit.edu

Abstract

A possible dependence of barrel friction on primer type was discovered in a previous project. The purpose of the present study is to quantify friction effects of three different small rifle primers (one based on lead styphnate and two based on diazodinitrophenol, DDNP). When powder is carefully selected to have a near perfect linear response between muzzle energy and powder charge, the resulting vertical intercept of a best-fit line represents the mechanical work done pushing the bullet through the rifle bore or the energy lost to barrel friction. Thus the average frictional force is simply the energy lost to barrel friction divided by the barrel length. This method determined the energy lost to friction to be 376 ft lbs (+/- 35 ft lbs) when using the Russian made (Murom) DDNP based primer and a 62 grain jacketed lead match grade bullet (Berger Flat Base), which was significantly greater than the 330 ft lbs (+/- 2 ft lbs) lost to friction using a lead-based primer (Fed 205m primer, made by ATK) with the same bullet. The American made DDNP based primer (ATK) produced a measured 322 ft lbs (+/- 40 ft lbs) lost to friction. The large uncertainty in the friction determination with the ATK lead-free primer was caused by velocity variations and made its friction statistically indistinguishable from either the Murom lead-free primer or the Fed 205m lead-based primer. A table in the appendix summarizes bullet friction measurements to date for 13 different bullets under a variety of experimental conditions (twist rates, primer, bullet coating, etc.). Bullet friction measurements are included for the M193 and M855 bullets with and without the petroleum based sealant added between the bullet and cartridge case.

Introduction

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 (Boyle et al. 2012A). This method has been used to test purported friction reducing effects of various coatings, with the findings that most coatings do not offer any significant reductions in barrel friction (Boyle et al. 2012B). The original study employing this method (Boyle et al. 2012A) mentioned preliminary data showing an increase in barrel friction associated with lead-free primers based on diazodinitrophenol (DDNP). Previous work with DDNP primers has shown that primers based on this compound can show much greater shot-to-shot variations in performance than lead styphnate based primers, which in turn can be a source of delayed ignition and misfires (Courtney and Courtney 2011). A recounting of primer history in the US military shows a repeated pattern of premature adoption of new primer compounds to address a perceived performance need often leading to unintended consequences and field failures because the new compound was not sufficiently vetted prior to adopting for field use (Courtney and Courtney 2011).

Quantifying effects of barrel friction is important, because increased barrel friction can generate higher operating pressures and rob projectiles of energy needed to quickly incapacitate enemy combatants. Lower velocity projectiles will have more drop and wind drift with distance. It is also conceivable that the lead in lead styphnate based primers was inadvertently contributing to the lubrication and reliable operation of the AR based M-16 and M-4 based rifles fielded by various

¹ Distribution A. Approved for public release. Distribution unlimited. The views expressed in this article are those of the authors and not necessarily those of the U.S. Air Force Academy, the U.S. Air Force, The Department of Defense, or the U.S. Government.

branches of the military. If lead-based fouling combines with the applied lubricants in a synergistic manner to maintain feeding and functioning, then a change in primer type to remove the lead primer may have the consequence of reducing system reliability.

The purpose of the present study is to more carefully evaluate the dependence of barrel friction on primer type in 5.56 mm NATO for the available small primers. Most manufacturers of DDNP based primers do not sell their primers as components, but only sell DDNP based primers as components in their loaded lead-free ammunition. To the authors' knowledge, the only exceptions are the Russian made primers from the factory in Murom, which have been imported and marketed under the PMC, Wolf, and Tula brands. The authors contacted ATK, Winchester, and Remington to request component DDNP based primers for testing; however, none of these US manufacturers chose to provide component primers for testing. Knowing that ATK lead-free primers are used in Air Force training ammunition and are also being offered by ATK for field use by the US military, the authors acquired DDNP based primers from ATK by purchasing fully loaded lead-free ammunition.

Method

The method for determining barrel friction has been described previously (Boyle et al. 2012A, Boyle et al. 2012B). Bullet velocity is 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 2 grain steps from 8.00 grains up to 14.00 grains. All loads used 62 grain Berger Flat Base (BFB) bullets. A high quality match grade bullet with a thin, precision jacket, soft lead core, and tight weight tolerance was chosen rather than one of the military projectiles such as the M193 (55 grain full metal jacket) or the M855 (62 grain penetrator core). These military projectiles show larger variations in hardness, dimensional, and weight tolerances, likely leading to greater variations in barrel friction and muzzle velocity and potentially introducing confounding factors, when the experimental goal was to isolate the influence of primer type on barrel friction. For example, the M855 bullet averages 62.7 grains in weight with a standard deviation of 0.166 grains and an extreme spread (sample size of 50) of 0.640 grains (Magee et al. 2012). The 62 grain Berger Flat Base bullet averages 61.981 grains in weight with a standard deviation of 0.050 grains and an extreme spread (sample size of 100) of 0.293 grains (Magee et al. 2012).

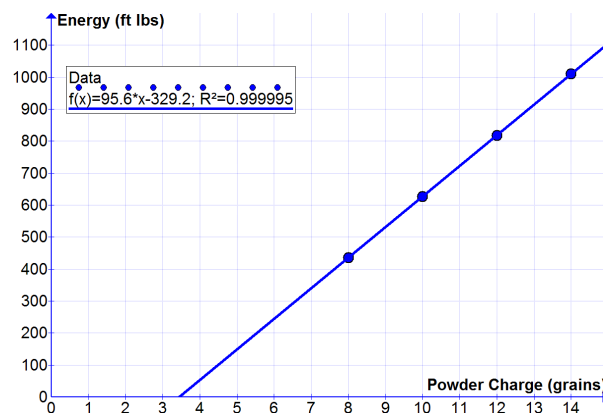


Figure 1: Muzzle energy vs. powder charge for 62 grain BFB bullet and Fed 205m primer, along with best fit line.

Five bullets were loaded for each combination of primer type. The resulting velocity was combined with bullet mass to compute muzzle energy. 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) consistently above 0.995, often higher. Figure 1 illustrates the analysis technique by graphing energy vs. powder charge for the Fed 205m (lead-based) primer and the 62 grain BFB bullet. A linear least squares fit returns the

slope and vertical intercept. The slope is the additional energy obtained for each additional grain of powder. The vertical intercept is negative and represents the mechanical work necessary to barely push the bullet out of the barrel. Thus, the vertical intercept is reasonably interpreted as the energy needed to overcome resistive forces in the barrel. The high linear correlation gives a high level of confidence that the muzzle energy is truly a linear function of powder charge for the choice of bullet and powder so that extrapolating back to the vertical intercept to determine the friction is valid. The error bars for the energy of each data point are not visible in the graph, because the uncertainty in energy is so small ($< 1\%$) due to the choice of bullet and careful attention to barrel cleaning and reloading procedures.

The unavailability of ATK primers as individual components made it necessary to purchase loaded ammunition to acquire ATK DDNP based primers. The purchased ammunition was Federal Premium Law Enforcement 5.56x45 mm 43 Grain Lite Open Tip Match Ballisticclean (part number BC556LTOM1). The experimenters faced a design choice between removing the live primers with a decapping pin to load in the same brass as the Murom DDNP and the Fed 205m primers, or simply removing the bullet and powder from the LC09 brass provided with the loaded ammunition. Because previous friction experiments have noted no dependence of friction measurements on the type of cartridge case (BTG Research, unpublished data) and we were concerned with the possibility of damaging live primers in the decapping process, the experimenters decided to shoot the ATK DDNP based primers in the original LC09 brass. After the bullet was pulled with a collet type puller, the factory ball powder was removed from the case, and the cases were loaded with the experimental powder charge of Alliant Blue Dot powder and a 62 grain Berger Flat Base bullet was carefully seated.

Results

This method determined the energy lost to friction to be 376 ft lbs (+/- 35 ft lbs) when using the Russian made (Murom) DDNP based primer and a 62 grain jacketed lead match grade bullet (BFB), which was significantly greater than the 330 ft lbs (+/- 2 ft lbs) lost to friction using a lead-based primer (ATK Fed 205m primer) with the same bullet. The American made DDNP based primer (ATK) produced a measured 322 ft lbs (+/- 40 ft lbs) lost to friction. The large uncertainty in the friction determination with the ATK lead-free primer was caused by velocity variations and made its friction statistically indistinguishable from either the Murom lead-free primer or the Fed 205m lead-based primer. These results are summarized in Figure 2.

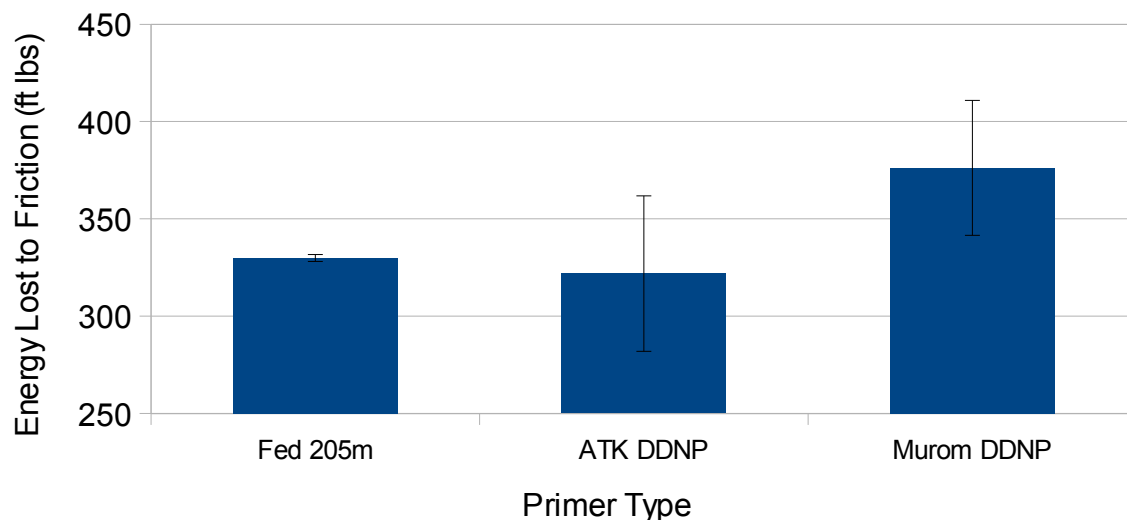


Figure 2: Energy lost to barrel friction for three primer types in 5.56 mm NATO using a jacketed lead match grade 62 grain bullet.

Discussion

The ATK DDNP based primer showed about the same friction as the ATK lead-based primer, but the uncertainty was much larger with the DDNP based primer due to greater variations in muzzle energy. The Murom DDNP based primer also showed much larger uncertainty in the energy lost to friction. Since the experimental method infers energy lost to friction from the muzzle energy at different powder charges, any load component (bullet or primer or coating) that increases variations in muzzle energy will also increase the uncertainty in friction determinations.

Table A1 in the Appendix shows that the lowest uncertainties in friction determinations tend to be when using a jacketed lead bullet with a Fed 205m lead-based primer. Bullets of different construction (lead-free) and DDNP based primers tend to result in larger uncertainties in friction. It is unclear whether this is attributable to larger shot-to-shot variations in barrel friction or if it might be due to larger variations in ignition and powder burn. An earlier study (Courtney and Courtney 2011) showed that DDNP based primers have greater variations in pressure than lead-based primers, and they can also result in significant delays in ignition. (No delays in ignition were noted in the present study, but Alliant Blue Dot, being a flake powder, is much easier to ignite than spherical powders most commonly used in military ammunition.)

Table A1 also shows an increase in friction using a DDNP based primer with the 62 grain ATK made M855 bullet. This bullet is loaded at the factory with a petroleum based sealant between the case mouth and the bearing surface of the bullet. Adding the sealant with a lead-based primer and switching to a DDNP based primer both seem to increase the friction, but the relatively large (21 to 25 ft lbs) uncertainties do not support this conclusion with certainty.

It is also notable that the manufacturer (ATK) of the US made DDNP based primer seems to be aware of environmental degradation even though the lead-free product is labeled “Premium” and marketed for law enforcement use. The package contains the following advisement, **“WARNING:** Extended storage at elevated temperature may degrade performance and result in misfires.”

Barrel friction is influenced by many different factors including bullet construction, barrel twist, primer type, bullet coating, and any sealant that may be used between the bullet bearing surface and the cartridge case. Consequently, changing any of these components may result in an unsafe increase in barrel pressure or a loss of muzzle energy. Thus, before fielding new ammunition with component changes, the full system should be fully tested and validated before adoption for field use. A prior report on DDNP based primers (Courtney and Courtney 2011) enumerated some test criteria for validation of lead-free primers:

1. Peak blast wave magnitude and consistency comparable with lead-based primers.
2. Misfire rates at or below those with lead-based primers.
3. Shelf-life and long term stability comparable with lead-based primers.
4. Muzzle velocity consistency and peak chamber pressure comparable with lead-based primers.
5. Ignition delay times comparable with lead-based primers.
6. Comparable accuracy with lead-based primers in both machine rests and hand-held testing.

In light of the results presented here and the known degradation of DDNP based primers in suboptimal storage conditions, we would add two more:

7. Comparable friction with lead-based primers.
8. Thorough performance testing after environmental conditioning over a wide range of storage temperature and humidity.

Appendix

Bullet					Friction		
Manufacturer	Style	Weight	Primer	Coating	Work	Uncertainty	Reference
		grains			ft lbs	ft lbs	
Berger	Flat Base (BFB)	62	Fed 205m	Bare	329.90	1.80	Present Study
Berger	Flat Base (BFB)	62	Fed 205m	HBN	289.51	18.79	Boyle et al. 2012B
Berger	Flat Base (BFB)	62	Fed 205m	WS2	305.83	12.44	Boyle et al. 2012B
Berger	Flat Base (BFB)	62	Fed 205m	MS2	283.08	13.63	Boyle et al. 2012B
Berger	Flat Base (BFB)	62	ATK DDNP	Bare	321.94	39.94	Present Study
Berger	Flat Base (BFB)	62	Murom DDNP	Bare	376.25	34.66	Present Study
Nosler	Ballistic Tip Lead Free	40	Fed 205m	Bare	214.86	13.82	Boyle et al. 2012A
Nosler	Ballistic Tip	55	Fed 205m	Bare	245.06	3.73	Boyle et al. 2012B
Nosler	Ballistic Tip	55	Fed 205m	HBN	208.69	7.81	Boyle et al. 2012B
Nosler	Ballistic Tip	55	Fed 205m	WS2	261.85	9.18	Boyle et al. 2012B
Nosler	Ballistic Tip	55	Fed 205m	MS2	290.61	5.78	Boyle et al. 2012B
Nosler	Ballistic Tip	55	Fed 205m	Lubalox	254.51	15.00	Boyle et al. 2012B
Hornady	VMAX	53	Fed 205m	Bare	234.46	7.24	Boyle et al. 2012A
Hornady	VMAX	60	Fed 205m	Bare	308.82	9.02	Boyle et al. 2012A
Hornady	Spire Point	55	Fed 205m	Bare	280.91	16.30	BTG Research
Sierra	BlitzKing	55	Fed 205m	Bare	323.98	14.50	BTG Research
Barnes	TSX	53	Fed 205m	Bare	744.16	15.33	BTG Research
Barnes	TTSX	50	Fed 205m	Bare	367.66	10.86	Boyle et al. 2012B
Barnes	TTSX	50	Fed 205m	HBN	365.01	14.47	Boyle et al. 2012B
Barnes	TTSX	50	Fed 205m	WS2	396.06	16.51	Boyle et al. 2012B
Barnes	TTSX	50	Fed 205m	MS2	375.75	5.47	Boyle et al. 2012B
Nosler	NCC	69	Murom DDNP	Bare	389.30	32.40	BTG Research
ATK	XM193	55	Fed 205m	Bare	291.78	18.59	BTG Research
ATK	XM193	55	Fed 205m	Sealant	290.27	3.72	BTG Research
ATK	M855	62	Fed 205m	Bare	318.17	10.57	BTG Research
ATK	M855	62	Fed 205m	Sealant	356.80	20.92	BTG Research
ATK	M855	62	Murom DDNP	Sealant	393.11	24.99	BTG Research
Berger *	Flat Base (BFB)	62	Murom DDNP	Bare	272.80	20.96	BTG Research
Berger *	Flat Base (BFB)	52	Murom DDNP	Bare	229.50	20.19	BTG Research

*Table A1: Energy lost to friction for 5.56 mm NATO bullets tested to date. Test rifle was a Remington 700 in 5.56mm NATO with a 1 in 12" twist. * designates a Savage 25 test rifle in .222 Remington with 1 in 14" twist.*

Table A1 compiles all the available friction measurements for 5.56 mm NATO bullets. It is notable that the petroleum based sealant used between the case mouth and the bullet increases the friction of the M855 bullet, but not the M193 bullet. This may be because the M855 bullet, containing the steel penetrator core, is a harder bullet, or it may be because there is a lot more sealant in the M855 loads, covering almost the entire bearing surface of the M855 bullet rather than a thin band as in the M193. This increase in friction suggests that it may be worthwhile to

develop a sealant that decreases rather than increases friction or to experiment with more precise ways of mating the case mouth and bullet to provide an effective moisture seal without significantly increasing barrel friction.

Acknowledgements

This research was funded by BTG Research (www.btgresearch.org) and the United States Air Force Academy. We appreciate the use of Dragonman's range for conducting the experiments. Additional experiments were conducted at the Colorado Rifle Club and at Louisiana Shooters Unlimited. Elya Courtney assisted with data collection for data attributed to BTG Research and Boyle et al. 2012A and Boyle et al. 2012B.

Bibliography

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

Boyle, P., Humphrey, A., and Courtney, M. 2012B. "Quantifying Friction Effects of Molybdenum Disulfide, Tungsten Disulfide, Hexagonal Boron Nitride, and Lubalox as Bullet Coatings," Technical Report No. ADA568594, Defense Technical Information Center, Fort Belvoir, VA.

Courtney, A. and Courtney, M. 2011. "Comparing Blast Pressure Variations of Lead Styphnate Based and Diazodinitrophenol Based Primers," The WSTIAC Journal. Volume 11. Number 2. http://wstiac.alionscience.com/pdf/WQV11N2_ART01.pdf

Magee, L., Oats, A., and Courtney, M. 2012. "*Comparing Measured Bullet Weight with Manufacturer Specifications.*" Technical Report No. ADA555976, Defense Technical Information Center, Fort Belvoir, VA.

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

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

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.

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.

Martin M.D., 2000. "Method of Impact Plating a Bullet With a Powdered Lubricant," US Patent 6036996.