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A Study of the Engraving of the M855 5.56-mm Projectile

by Joseph South, Aristedes Yiournas, Jordan Wagner, John Brown, and Robert Kaste

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Weapons and Materials Research Directorate, ARL

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14. ABSTRACT

The interaction between a small-caliber projectile and its weapon system cannot be readily measured during the launch event. The forces and resulting deformations on the projectile due to engraving are small and localized compared to the ballistic pressure. Consequently, the interaction is inferred from the condition of the projectile after it has exited the barrel. A direct method of examining the engraving force and the resulting projectile deformation is through the use of rate-controlled push tests. This approach allows for the experimental assessment of the load vs. displacement behavior as the projectile engraves and allows for a before and after measurement of mass and diameter. This report employs both a push test methodology to evaluate low-rate dynamic engraving loads as well as a soft recovery approach to evaluate the effect of engraving on the M855 projectile as a function of propellant charge. The result of this combined approach is the ability to evaluate the projectile response to engraving over a range of loads and loading rates and to quantify the dimensional changes to the projectile. The understanding of the projectile-barrel interaction due to the engraving process allows projectile and weapon designers to tailor their approaches to increase projectile launch survivability and performance.

15. SUBJECT TERMS

engraving, soft recovery, push test, M855, 5.56 mm, small arms, projectile

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1. Introduction

Small-caliber projectiles, such as the M855 ball round, are some of the simplest munitions in the Army inventory. The M855 projectile (*1*) depicted in figure 1 is comprised of three components: a lead-antimony slug, a steel core penetrator, and a copper jacket; and is similar to the ammunition that has been used for the last century. The outer shape of the projectile generally can be described by three regions, the leading end or ogive, a main body, typically a cylindrical section, and the aft end which may include a chamfer, radius, or tapered section referred to as a boattail.

This ammunition is used in service and training for the M16A2/A3/A4, the M4, and the M249 weapons.

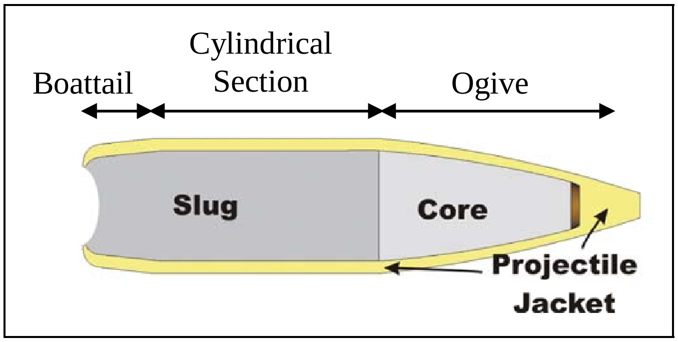

Figure 1. The M855 projectile.

Due to the size of the M855 projectile, the interaction between the projectile and the weapon system cannot be readily measured during the launch event using traditional techniques such as x-ray and shadowgraph as they do not provide the resolution required to examine the physical state of the projectile surface. In this report, the interaction is examined using both a push test methodology as well as a soft recovery approach. Together these two approaches evaluate the low rate dynamic engraving loads and the physical effect of engraving on the M855 projectile as a function of loading rate.

Push testing is an approach where an instrumented testing machine translating at a known displacement rate forces the projectile into and through the barrel. This approach controls the rate of engraving and provides the ability to obtain the load vs. time or displacement behavior. This data in turn allows for investigations of how the projectile responded to the engraving process. Variables such as rate, temperature, and barrel condition can be controlled and the dimensions of the projectile, before and after the test, can be measured. A unique benefit to this approach is the ability to measure the mass loss due to the engraving process.

Soft catching projectiles is an approach where the projectile is launched by traditional means and then captured as to minimize deformation. To do so the projectile must be decelerated below critical rates and the projectile must enter the capture media below a critical velocity. Projectiles can be soft caught in different media such as fabric, paper, water, or in this instance ballistic gelatin. Proper experimental design is required so that the resulting deformation of the projectile is due to launch and not the soft catch. The critical velocity is the velocity at impact, when the projectile begins to deform and/or fail within that particular media. Range can be simulated by either capturing the projectile fired at full charge into a target at a given distance from the muzzle or by launching the projectile utilizing varied charge weights.

This report will discuss the experimental setup and results between push testing and soft-recovered M855 projectiles. The experiments will evaluate the before and after condition of the projectile due to the applied physical loads or displacements. The goal of the research is to develop an understanding of the physics behind engraving and launch and what ramifications there are to the projectile and its components.

2. Experimental

2.1 Push Tests

The push testing was conducted at predetermined displacement rates. Those rates were 33, 99, 152, 203, 254, 304, and 355 mm/s. The experimental setup for this test is based on the research of White and Siewert (*2*) and Siewert (*3*). A picture of the testing fixture taken from White and Siewert is shown in figure 2. The test fixture consists of a steel mounting adaptor that had been modified to mate with the outer diameter of a M16A2 barrel and to be threaded onto a MTS hydraulic test frame. The adaptor features an inner sleeve that matched the outside diameter (OD) of a M16A2 barrel whose length has been reduced to 156 mm (6.125 in). The sleeve keeps the barrel vertical and in alignment with the MTS test frame. The end of the inner sleeve opens to a 0.950-in perpendicular cutout. This cutout allows for the pushed projectile to fall freely after exiting the barrel. The original fixture design of White and Siewert was modified to incorporate an exit for a strain gauge wiring harness. This modification was made by drilling a 12.4-mm hole from the OD of the adaptor thru to the inner sleeve at a distance of 1.875 in from the top face of the adaptor.

The shortened M16A2 barrel, shown in figure 3, has a total length of 156 mm (6.125 in) measured from the base of the barrel extension. Prior to sectioning, the barrel was measured with a star gauge by the U.S. Army Aberdeen Test Center (ATC) along the length and verified to be within the technical drawing package tolerances. Shown on the barrel is a strain gauge. The gauge is a MicroMeasurements EA-06-062TT-350 microstrain gauge. The gauge was mounted in the hoop direction and was centered 5.125 in from the end of the M16A2 barrel extension. The wiring harness for the gauge was threaded through the inner sleeve and out the 12.4-mm (0.5-in) hole.

Figure 2. Pictures of the 5.56-mm test fixture.

Figure 3. Section of a M16A2 barrel used for push testing.

Projectiles were pushed thru the M16A2 barrel section using a precision ground drill blank rod. The diameter on the rod was 5.5 mm (0.2165 in) and the available push length was 159 mm (6.25 in). The rod was swaged into a threaded adaptor that mated with the MTS test frame. This adaptor kept the rod inline with the centerline of the M16A2 barrel section. Figure 4 presents an image of the push rod, push-rod adaptor, and the barrel section.

Figure 4. Image of the push rod, rod adaptor, and the sectioned M16A2 barrel.

The push tests were conducted at the seven predetermined constant displacement rates. The M855 projectiles were procured from standard production lots from Lake City Army Ammunition Plant. A minimum of 13 projectiles were pushed at each displacement rate. The diameter of the projectiles was measured prior to testing. The diameter measurements were taken along the cylindrical section of the M855 using a Scherr-Tumico 1-in micrometer with a precision of 0.0001 in. The mass of the projectiles before and after the push test were measured using a Mettler AT201 digital scale that was mounted onto a granite table.

Prior to and between each test, the barrel section was cleaned with Copper Solvent IV* from Pro-Shot Products using a Kleen-Bore† universal rifle, handgun, and shotgun cleaning kit and bore brushes. At the start of a test, a bullet was placed into the barrel so that it made contact with the forcing cone. Then the barrel and fixture on the actuator were raised up so that the push rod was just above the bullet. The crosshead was paused for a few seconds, and then the actuator moved down at the specified rate, pushing the bullet through the entire length of the barrel section.

During each test the load, crosshead displacement, time and hoop strain on the strain gauge were captured. The diameter of the pushed projectile was measured by taking the average of the three groove pair marks on the projectile. Previous research has shown that the M855 projectile does not always make contact with the M16A2 barrel along the groove section (*4, 5*). Diameters were measured along the projectile cylindrical section using a pair of digital calipers with a precision of 0.0001 in at the three groove pairs, and the average was reported.

2.2 Soft Recovery

To simulate displacement rates that exceed the MTS frame capability, M855 projectiles were fired at varying charge weights. This significantly reduces the logistical burden on recovery because a much shorter range is needed to produce velocities low enough to ensure that the projectile is not damaged on impact. Correspondingly fewer projectiles and shots are required to hit the target. Projectiles were launched using the standard propellant, WC844, and projectile of the M855 cartridge. The projectile, cartridge case, and propellant were the standard combat issue M855 system produced by Lake City Army Ammunition Plant. The maximum displacement rate, at the muzzle, vs. propellant charge establishment was derived using interior ballistic modeling. Figure 5 shows a plot of the displacement rate, at the muzzle, of the M855 projectile fired from the M16A2 a varying charge weights. The plot shows that the charge loads resulted in a wide range of anticipated muzzle displacement rates. The rates expected by the charge weight are significantly greater than the maximum displacement rate of 350 mm/s achievable by the MTS test frame.

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*Copper Solvent IV is a registered trademark of Pro-Shot Products, Taylorville, IL.

†Kleen-Bore is a registered trademark of Kleen-Bore, Inc., Jacksonville, FL.

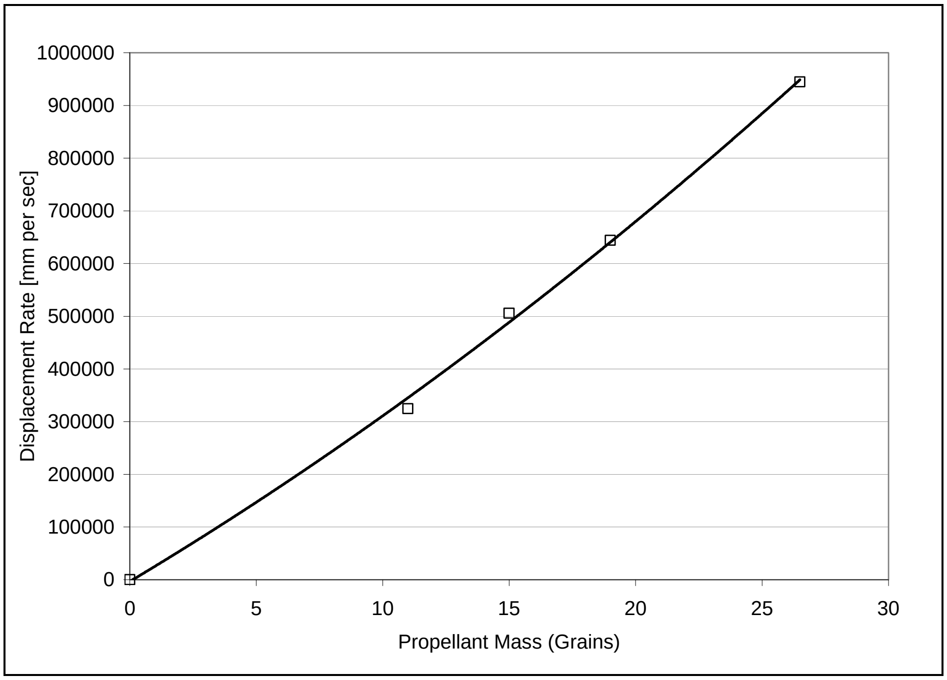

Figure 5. Plot of the displacement rate, at the muzzle, vs. propellant mass for WC844 and the M855 cartridge/projectile fired from an M16A2.

The soft-recovery testing was conducted according to the method outlined by South et al. (*5*). The testing was conducted at both the Bldg. 390, indoor Range 159 and the outdoor M-Range located at Aberdeen Proving Ground, MD. The charge weights investigated were 8, 12, 16, 20, 24, and 27 gr. Charge weights were measured using a RCBS Model 505 reloading scale. This scale features magnetic dampening, large black-on-white graduations for fast recognition, three poise beam measures to ±0.1 gr, and 511-gr capacity. Testing for charge weights up to 20 gr was conducted in Bldg. 390, Range 159. The 24- and 27-gr tests were conducted at M-Range. For each charge weight, 12 projectiles were loaded by hand using a Lyman Comet reloading press into standard primed M855 cartridges and the M855 projectiles were inserted. All projectiles in this study were shot from a new M16A2 rifle. Prior to testing, the rifle was measured with a star gauge by the ATC along the length and verified to be within the technical drawing package tolerances. The targets consisted of 20% ballistic gelatin blocks. Each gelatin block measured 8 × 8 × 18 in. A 20% gelatin block is made from 8 lb of Knox brand gelatin powder and 32 lb of water.

Experiments for charge weight ranging from 8 to 20 gr were conducted in Bldg. 390, Range 159. For these tests, one gelatin block was placed ~5 m from the muzzle of the M16A2, and M855 projectiles were launched into the block. After each firing, the projectiles were recovered from the gelatin via forceps. For the 20-gr charge weight, two gelatin blocks were stacked end to end without any air gap. This was necessary to fully capture the projectile. This setup could not capture projectiles fired with more than 20 gr of propellant without damaging the projectile. All firing was conducted from a hard recoilless mount.

Experiments for charge weights of 24 gr and greater were conducted at M-Range. The experiment consisted of firing projectiles into a target array placed at 550 m from the muzzle. The target consisted of nine 20% ballistic gelatin blocks. Each gelatin block measured 8 × 8 × 18 in and they were stacked three high and three across, representing a target size of 24 × 24 in. All firing was conducted from a shouldered firing position. Again, the projectiles were recovered from the gelatin via forceps.

The projectiles were cleaned at each range with a soft cloth in order to remove excess gelatin. Prior to any analysis, the projectiles underwent a series of immersion cleanings. The projectiles were cleaned in a Branson 1200 ultrasound by immersion for three minutes in acetone followed by immersion for 3 min in methanol. After the immersion baths, the recovered projectiles were wiped with a clean cloth and allowed to fully dry. The mass of the soft recovered projectiles was measured using a Mettler AT201 digital scale that was mounted onto a granite table. Diameters were measured along the recovered projectile cylindrical section using a Scherr-Tumico micrometer with a precision of 0.0001 in at the three groove pairs, and the average was reported.

3. Results

3.1 Push Tests – Load

The resulting load vs. displacement profiles for the seven different displacement rates are shown as figures 6–12. The different colors in the plots refer are the results of the individual test at that specific displacement rate. There is a fair amount of variability within the load profiles for a given displacement rate. In general, all of the profiles have an initial ramp up in load as the projectile begins to engrave, some distance of push where the engraved projectile is translated thru the barrel. The load eventually falls to zero as the projectile is pushed completely through the sectioned M16A2 barrel. The load profiles for the different tests have two distinct peaks. The first peak is just as the projectile engraves and the second is right before the projectile exits the barrel section.

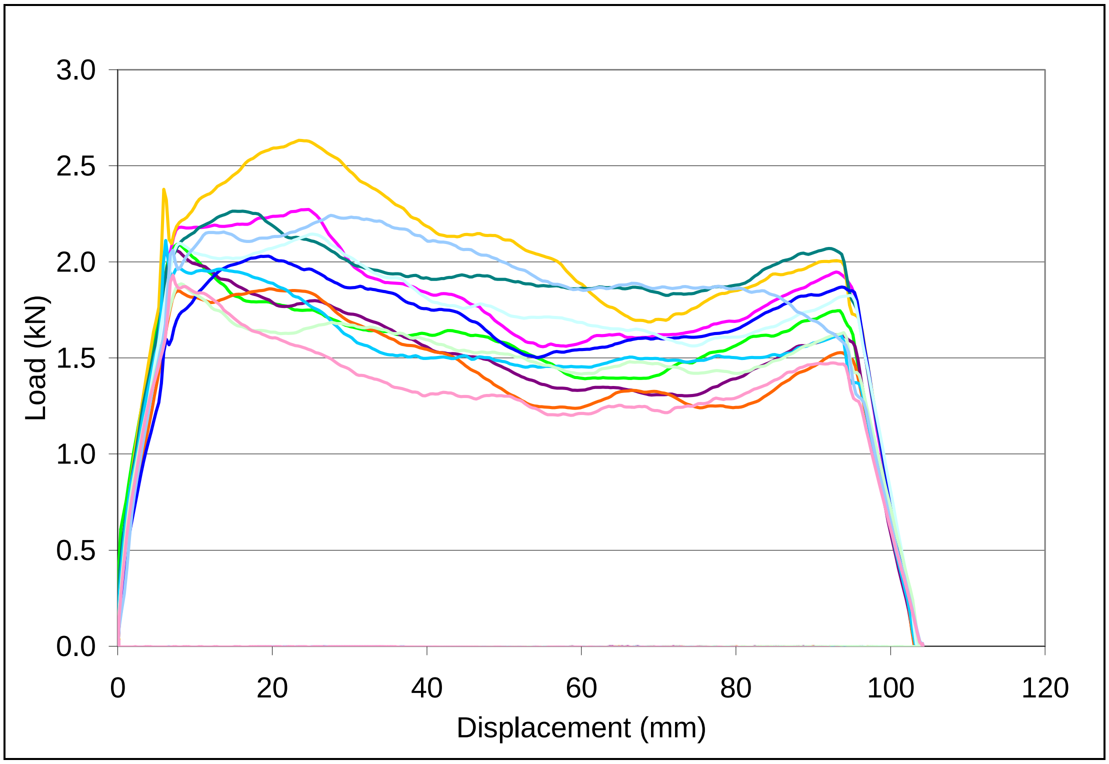

Figure 6. Load vs. displacement for 33-mm/s displacement rate.

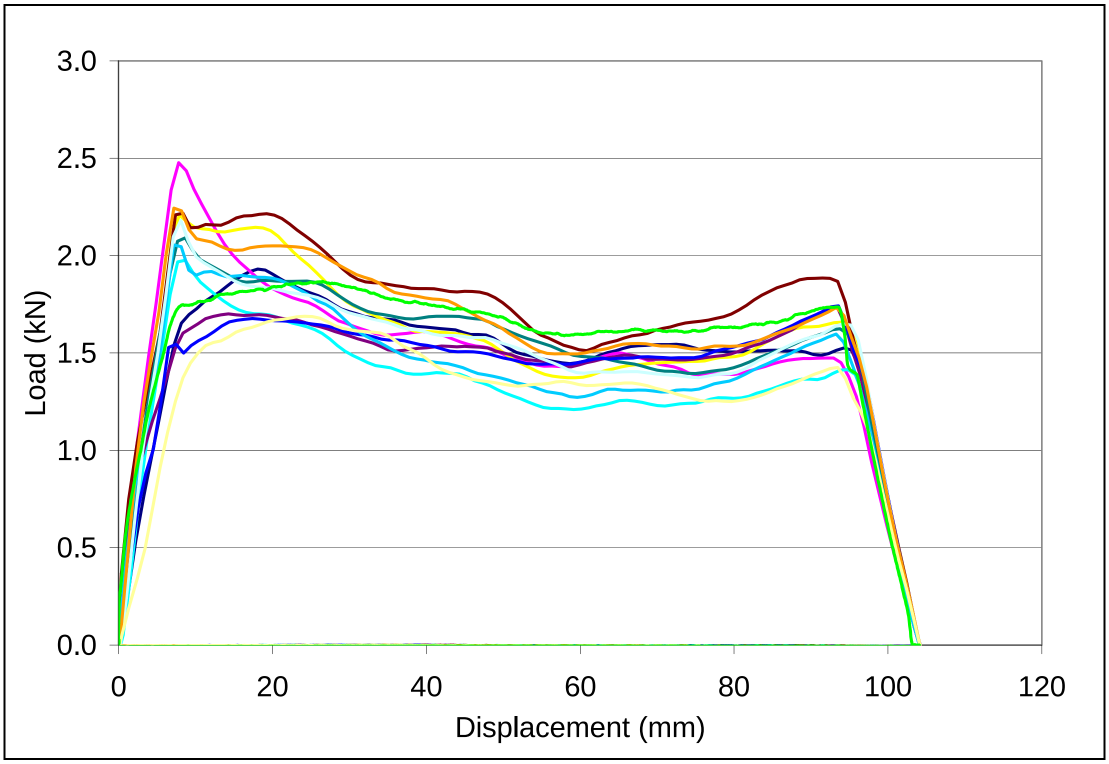

Figure 7. Load vs. displacement for 99-mm/s displacement rate.

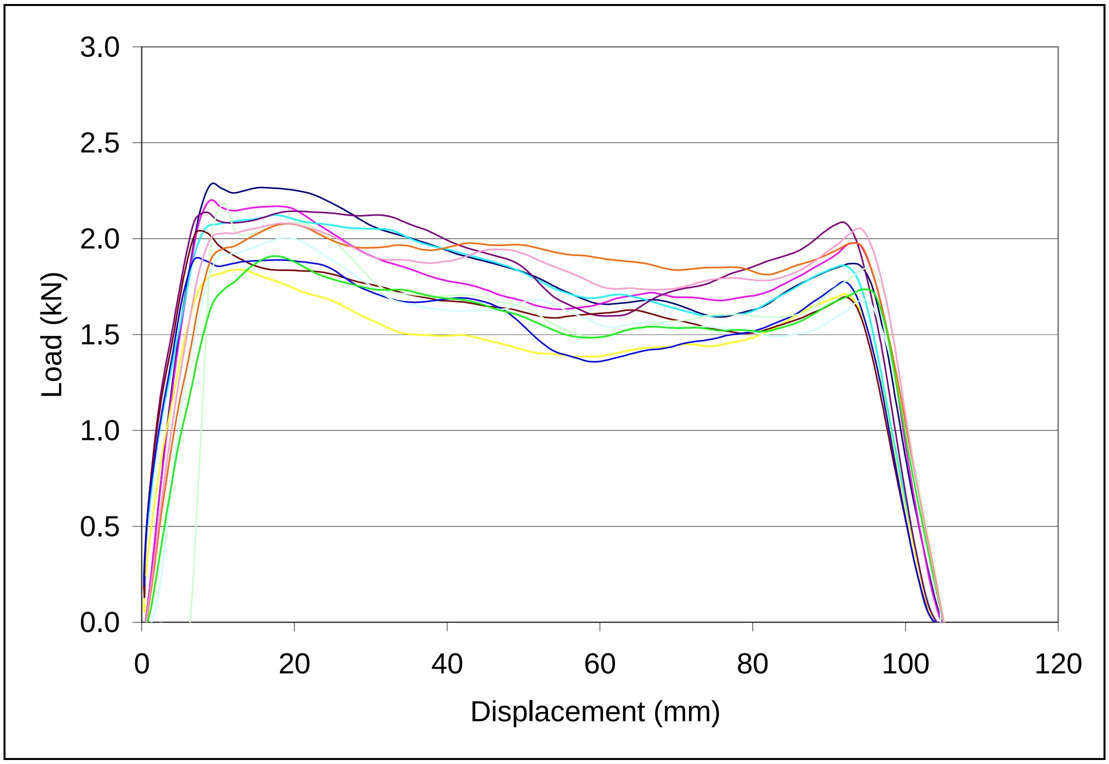

Figure 8. Load vs. displacement for 152-mm/s displacement rate.

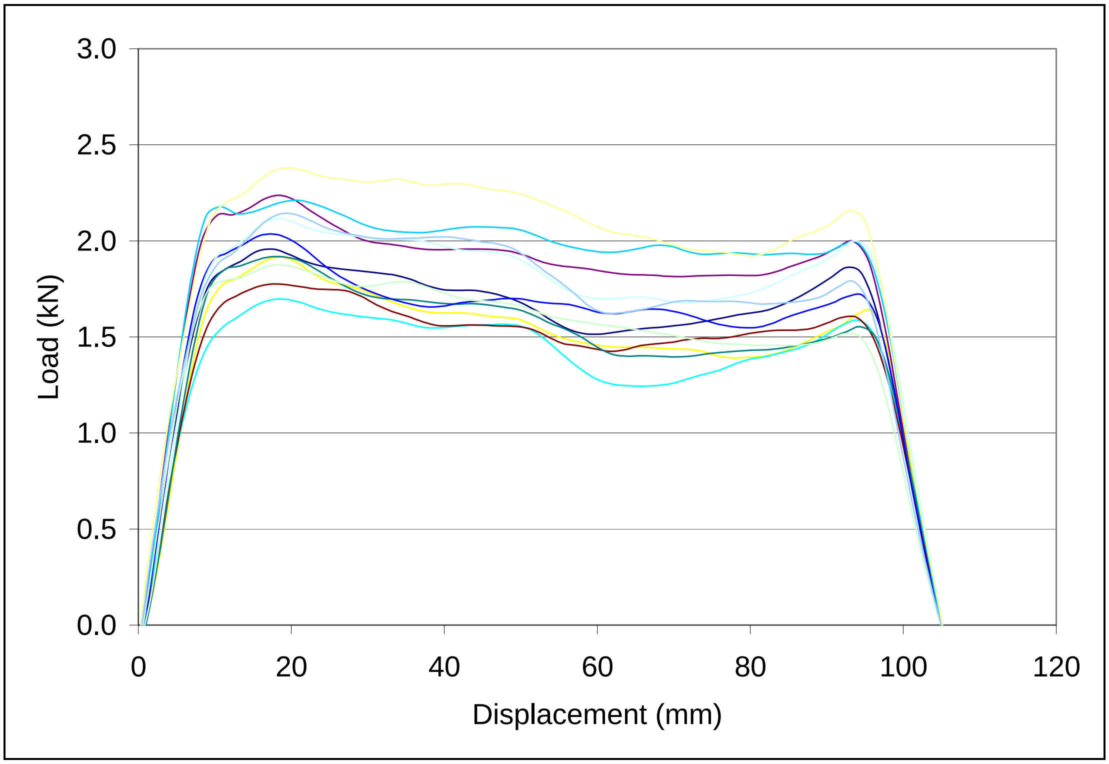

Figure 9. Load vs. displacement for 203-mm/s displacement rate.

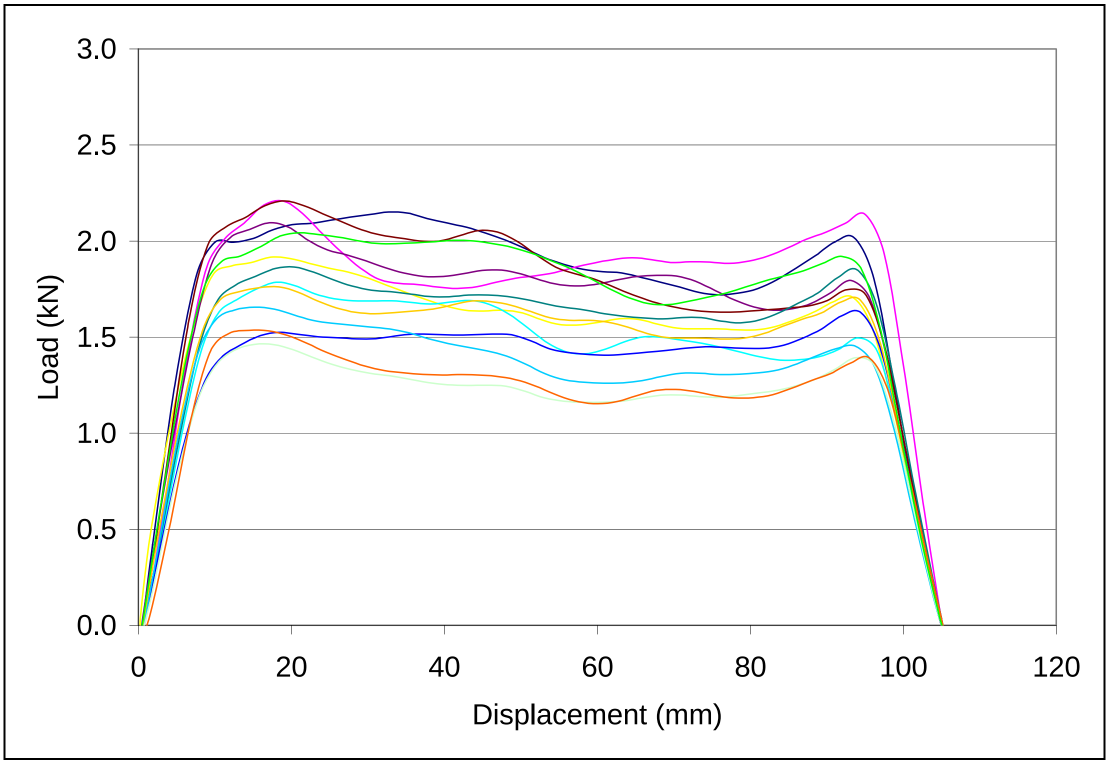

Figure 10. Load vs. displacement for 254-mm/s displacement rate.

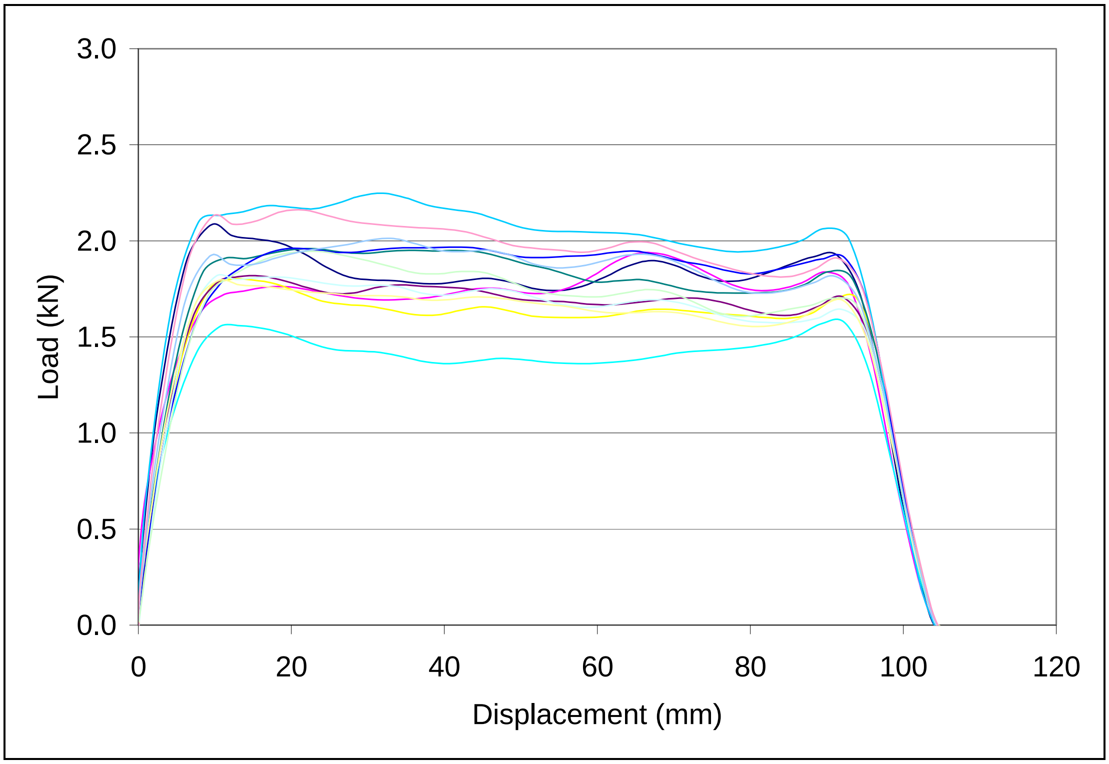

Figure 11. Load vs. displacement for 304-mm/s displacement rate.

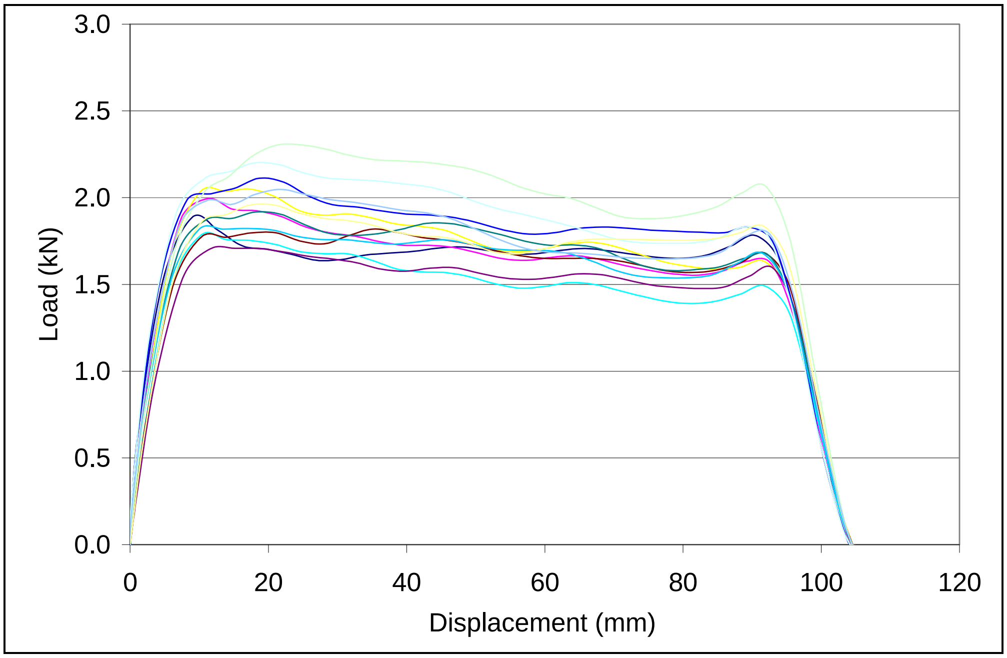

Figure 12. Load vs. displacement for 355-mm/s displacement rate.

A reduced version of the data in figures 6–12 is presented in figures 13 and 14. The average initial maximum load vs. displacement rate is presented in figure 13. There appears to be a slight reduction in this initial maximum load with increasing rate. The error bars in the plot show one standard deviation. Figure 14 shows a plot of the average second maximum load vs. displacement rate. There appears to be no distinct trend of the second maximum load with rate.

3.2 Push Tests – Hoop Strain

Figure 15 is a plot of the maximum hoop strain measured by the strain gauge on the OD of the sectioned barrel. The data shows an increase in the hoop strain with increasing testing rate. This data indicates that the projectile is responding differently as a function of rate and the resulting response is manifested thru the barrel to the strain gauge.

3.3 Push Tests – Projectile Diameter

The average projectile diameter before and after being pushed is presented in figure 16. The data shows that the measured average diameter before engraving was ~5.688 mm. This data is very close to the historical average produced at LCAAP of 5.69 mm (*6*). This value is the mean value on the M855 Technical Drawing Package (*1*). The before data measured only the 150 mm/s rate and above. The decision to measure the diameters before push testing was not made until after testing had begun. Figure 16 shows a decrease in the projectile diameter with increasing push rate. There appears to be a substantial decrease in the diameter at the higher rates. However, given how the data was collected, it is uncertain whether the decrease is due to the permanent deformation of the projectile jacket or due to the loss of jacket material.

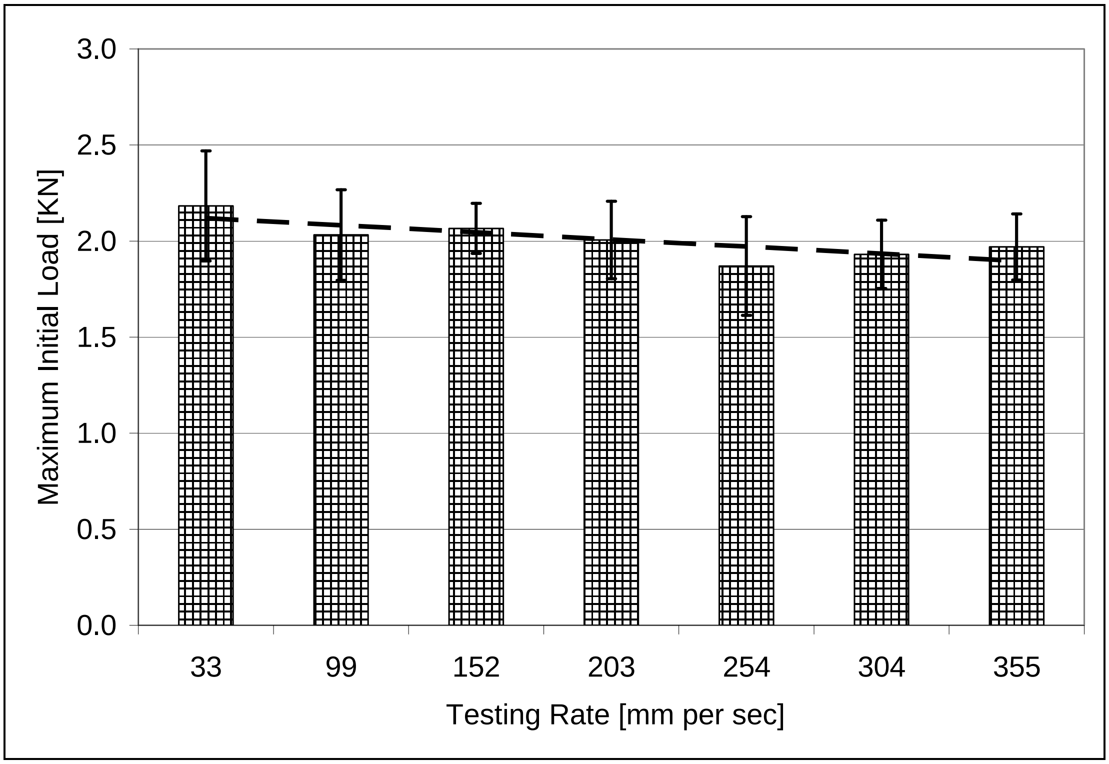

Figure 13. Plot of the average maximum initial load vs. displacement rate.

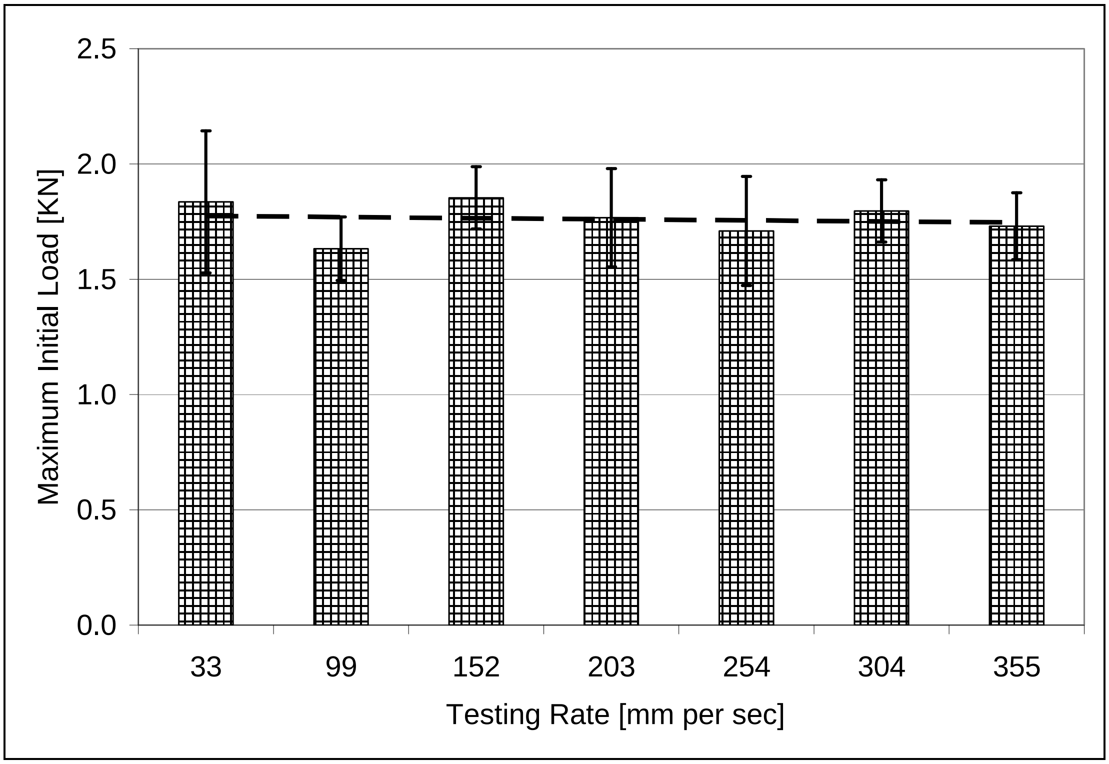

Figure 14. Plot of the average second maximum load vs. displacement rate.

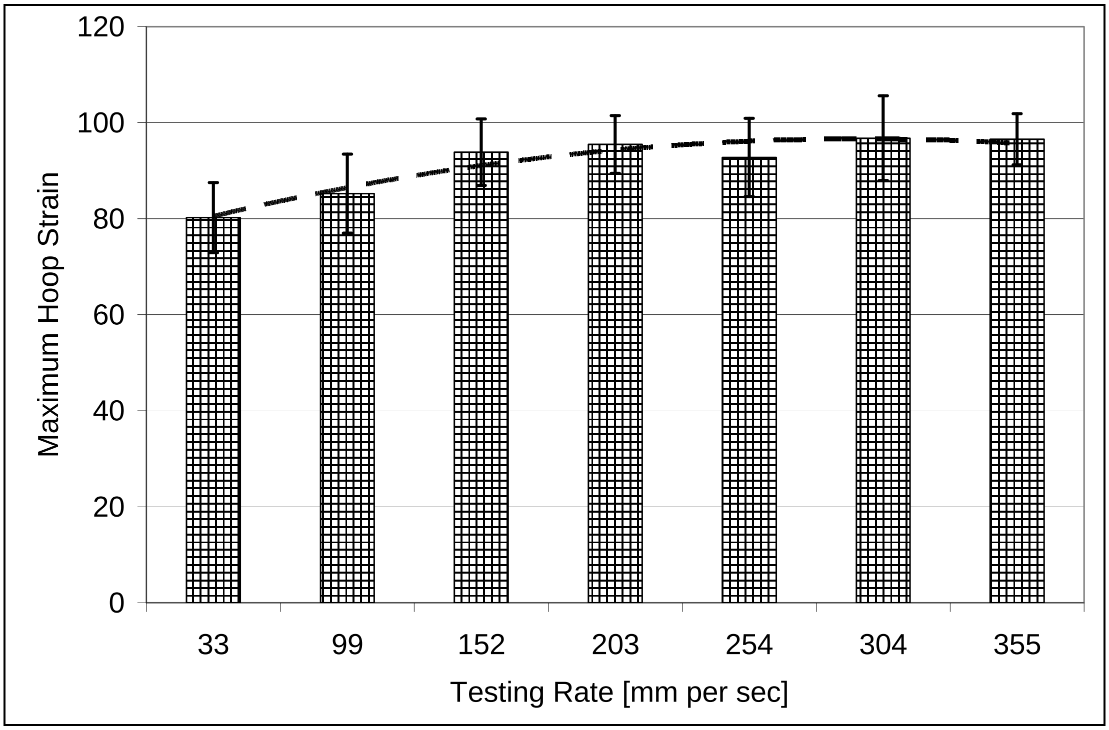

Figure 15. Plot of the maximum hoop strain on the OD of the barrel vs. displacement rate.

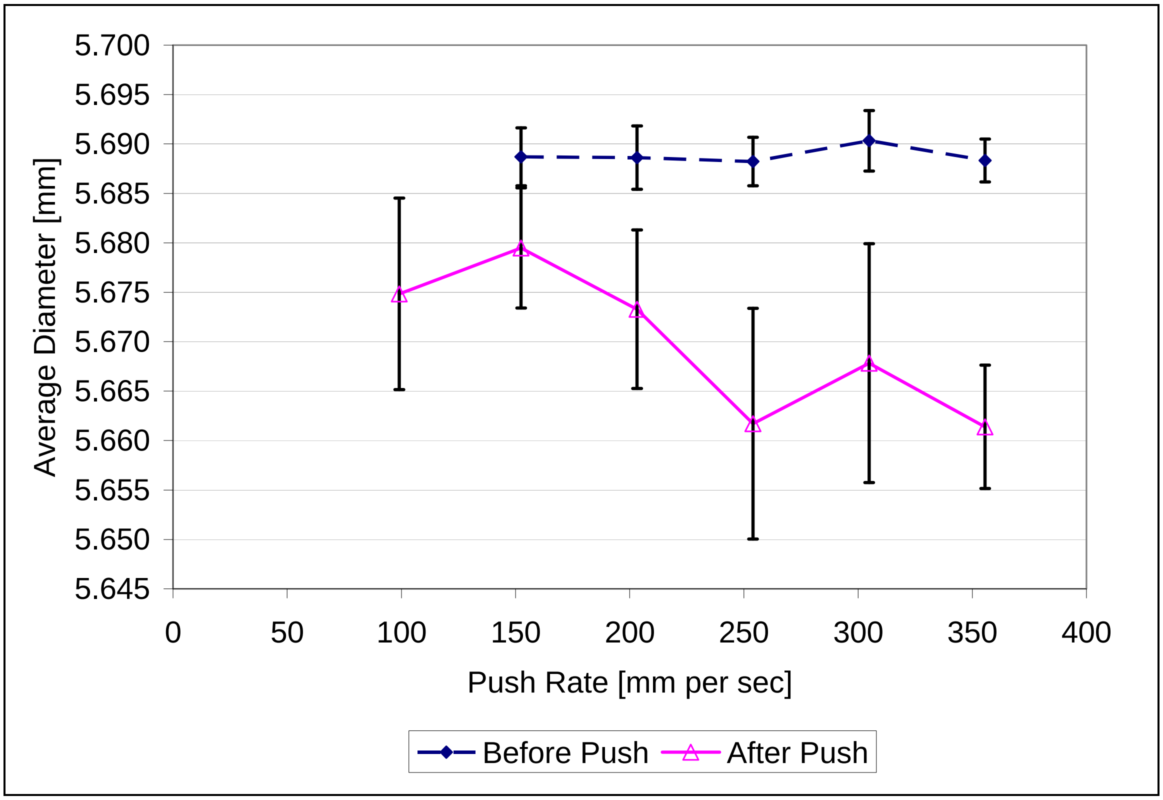

Figure 16. Plot of the average diameter before and after the push test.

3.4 Push Tests – Projectile Mass Loss

The mass loss of the projectiles was determined by weighing the projectiles before and after pushing. The results of the measurements are show in figure 17. The figure shows that the mass loss does not vary with displacement rate. In general, the mass loss is very low with an average loss of 0.15 mg. On average, the total mass loss is less than four thousandths of 1%.

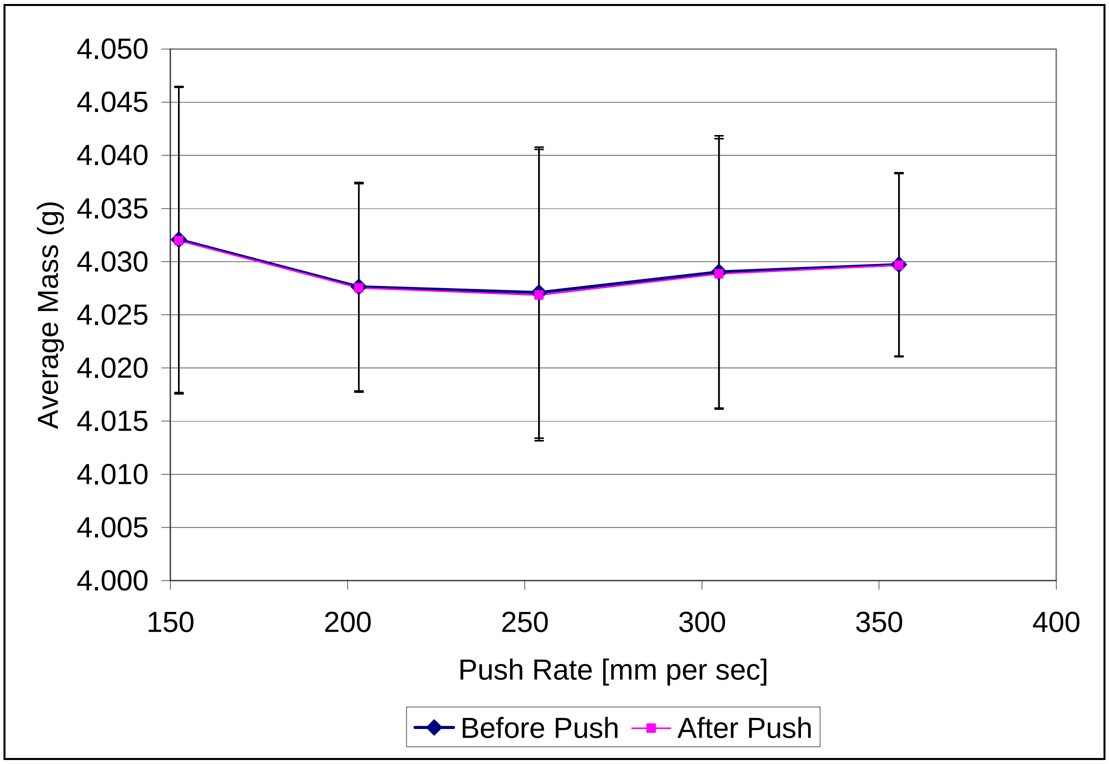

Figure 17. Plot of the average mass loss vs. push rate.

3.5 Soft Recovery – Projectile Diameter

The average diameter of the projectile after firing and soft recovery vs. charge weight is presented in figure 18. The plot shows a decrease in the average diameter with lower charge weights but an increase in the diameter back to the nominal diameter of 5.690 mm at the higher charge loads.

3.6 Soft Recovery – Projectile Mass Loss

The mass of the projectiles after soft recovery is shown in figure 19. The final mass is fairly consistent across the different charge weights. There is a reduction in the final mass for the 20-gr charge weight; however, the standard deviation for this data set is the largest of all six charge weights. Given the low sample size, it appears that the average is skewed by one or two points. The average across all charge weights is 4.023 g.

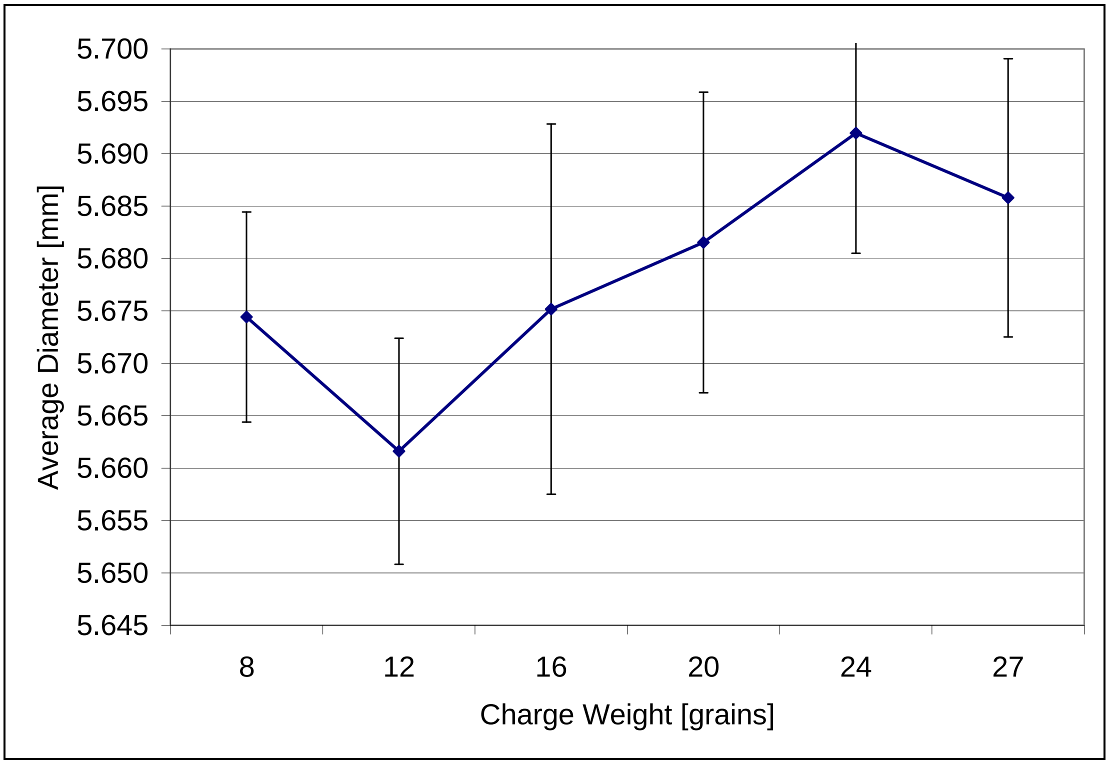

Figure 18. Plot of the average diameter vs. the charge weight for soft recovered projectiles.

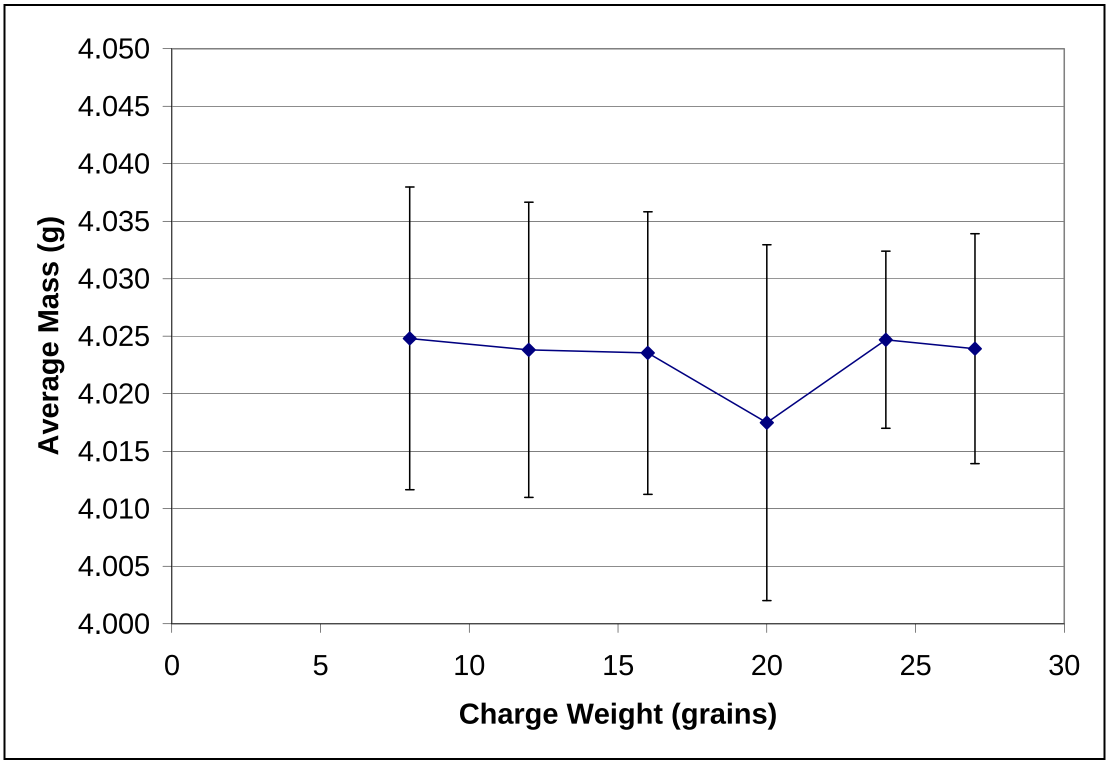

Figure 19. Plot of the average mass after soft recover vs. charge weight.

4. Discussion

4.1 Push Tests

The results of the push tests revealed contradictory data. The load vs. displacement profiles did not drastically change with respect to displacement rate. It was expected that there would be a stronger correlation of peak load with the displacement rate due to strain rate effects. White and Siewert (*2*) found an increase of 60% to 200% in the average pressure, or engraving load, as a function of displacement rate. Their data was limited only to two rates—33 and 99 mm/s. Comparing the data of figures 6 and 7 at the 50-mm displacement locations shows a decrease in the average loads from 1.62 to 1.51 kN, or 7%. These two data sets are within one standard deviation of one another. In general, the experimental load data does not show a strong correlation with rate over the seven displacement rates.

The maximum hoop strain shown in figure 15 shows an increasing response by the projectile. Previous research by South et al. (*4*, *5*) and South and Newill (*7*) has shown the response of the M855 due to the applied pressures during launch. Due to an applied load, the M855 projectile lead base core is driven into the inelastic state. This, in turn, supports the projectile jacket during the engraving and launch process. The increase in hoop strain may be due to the increasing rate forcing the lead core inelastic and thus supporting the jacket. The result would be a greater force being exerted by the jacket onto the barrel. The increase in the hoop strain is the expansion of the barrel under the applied force of the bullet.

Given that the increase in the hoop strain is due to a greater force exerted by the projectile, it is possible that the projectile diameter would be deformed more at the higher rates. Figure 16 shows a decrease in the projectile diameter with increasing displacement rate. This reduction in diameter may be due to a higher amount of compression of the jacket as the projectile is forced into the barrel. The maximum hoop strain is the same for the 304 and the 350 mm. At these rates, the mass loss is less than the 250 mm/s rate, but the average diameter continues to decrease. It is possible that there is a change in mechanism at these higher rates that results in deformation to the projectile. More experimentation is required to evaluate this.

The final mass of the projectile due to the push test shown in figure 17 shows a minimum at 250 mm/s. The mass loss at the higher rates of 304 and 350 mm/s starts to decrease. Figure 20 presents the relation between the average mass loss and the maximum initial load. The plot shows a trend where mass loss increases with decreasing maximum initial load. Specifically, the maximum mass loss was achieved on those tests that showed the lowest average maximum load. This data implies that mass loss was occurring as the projectile traveled down the barrel away from the forcing cone. The increase in the mass loss at the 254 mm/s rate correlated to a slight reduction in the hoop strain at that rate, as shown in figure 15.

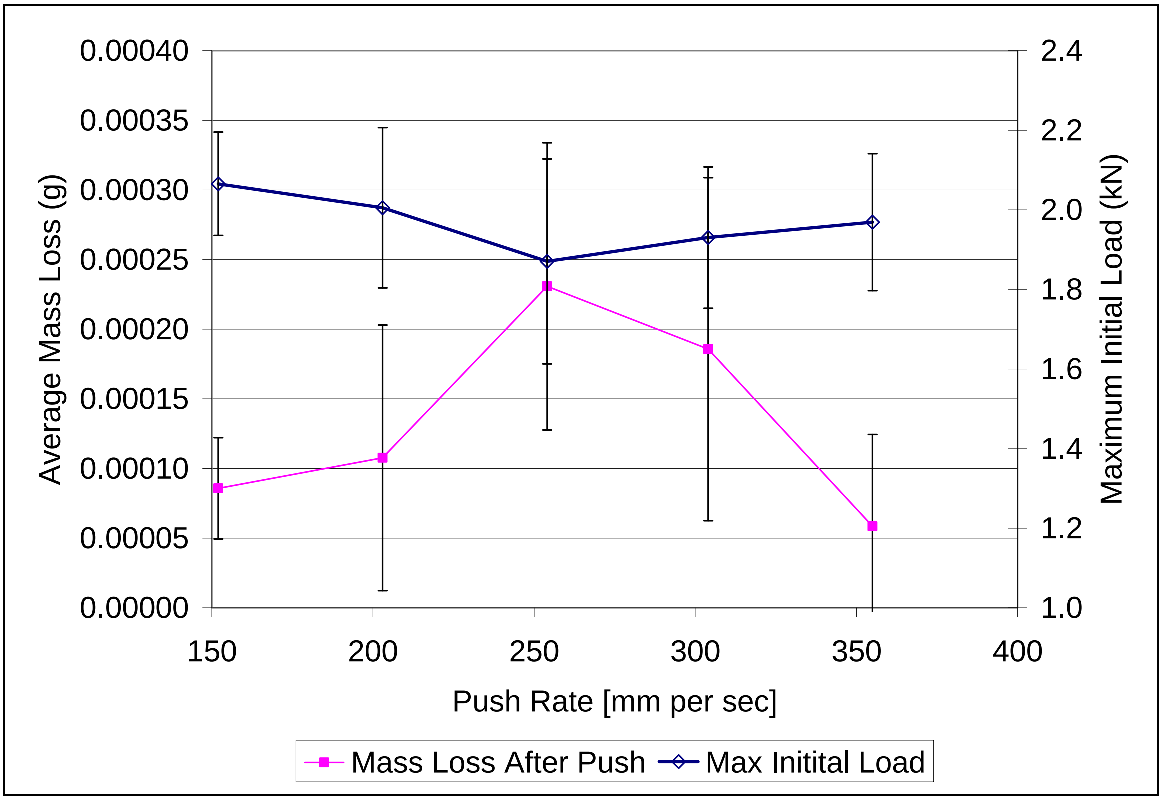

Figure 20. Plot showing the relation between the average mass loss and maximum initial load vs. push rate.

4.2 Soft Recovery

The results of the soft recovery tests contrast those of the push tests. The projectile diameters and weights after soft recovery were measured. Figure 18 shows an increase in the projectile diameter with increased charge weight. However, the variability within the data at a given charge weight can be very large. The data in figure 18 shows a distinct increase in projectile diameter with increased charge weight, but the diameter at 24 gr is slightly higher than the nominal TDP dimension. The mass of the projectiles after soft recovery is somewhat lower than the values from the push test. The average from the soft recovery was 4.023 g, while that of the push tests was 4.029 g. The distance the projectiles traveled through the bore in the firing tests was substantially greater than in the push tests. Given the scatter within the data, the mass difference is not significant.

It appears that the 100 mm of travel during the push test reproduced the same amount of projectile mass loss as ballistically firing the M855 projectile. Unfortunately, it is not possible to determine where along the barrel the mass loss occurred. During the cleaning of the barrel between each push test, copper deposits were found at the forcing cone and further down the barrel. The barrel was not cleaned during the firing testing. While it is likely that the projectile mass loss was due to the interaction with the forcing cone, it cannot be determined if that material remained on the forcing cone or was transferred further down the barrel. The load vs. displacement plots of figures 6–12 do not show any load spikes further down the barrel to indicate a build up and release of material. Additional testing is required to further quantify these results.

5. Conclusions

In this research, two methodologies were used to evaluate the effect of engraving on the M855 projectile over a range of rates. The results showed that for quasistatic rates up to 355 mm/s there is little change in the maximum force required to engrave the projectile. However, once a projectile was engraved, the force that the projectile imparted to the barrel and the resulting barrel expansion increased with increasing rate. Pushed projectiles showed a decrease in diameter due to engraving. The mass loss due to the engraving was extremely small, on the order of 0.0037% or 0.15 mg. The diameters of soft-recovered projectiles were found to vary with charge weight. Final diameters of soft-recovered projectiles were found to be approximately the same for those engraved using the push test. It appears that the mass loss of the projectile occurs during the first 100 mm of projectile travel; however, it is uncertain what the distribution of this mass loss is over the distance.

This data gathered is limited by the number of rifle barrels that were examined. Additional experiments should be conducted that expand both the number of barrels examined and the number of samples per barrel.

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