2015 Insensitive Munitions & Energetic Materials Technology Symposium
Rome, Italy 18-21 May 2015

Fragment Impact Gun Testing Technology and Issues

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The STANAG 4496 Ed. 1 Fragment Impact, Munitions Test Procedure, specifies a standard test of 2530±90 m/s, an alternate test of 1830±60 m/s and a standard fragment (projectile) geometry. The standard can be challenging to achieve and has several loosely defined and undefined characteristics that can affect the test item response. In particular fragment velocity variation, projectile tilt upon impact and aim point variation and are commonly observed challenges. Achieving 2530 m/s consistently and cost effectively can be challenging. Additionally, there are some efforts where over testing to higher velocities are viewed as desirable. The aim point of impact of the fragment is chosen with the objective of obtaining the most violent reaction: one test is conducted with impact in the center of the largest presented area of energetic material and a second in the most shock sensitive region. No tolerance for aim point is specified, although it is known that aim point variation can be a source for IM response variation. Fragment tilt on impact is also known to be a possible source for response variation and it is common to observe fragment tilts of 30˚ or even higher. The standard fragment is specified to be fabricated from mild, carbon steel with a Brinell Hardness (HB) less than 270. In the U.S., the fragment is often fabricated using ASTM1018 steel which has a significant margin for mechanical properties that lay within the specification. These, as well as other gun testing issues, have significant implications to resulting IM response.

INTRODUCTION

In the U.S., Insensitive Munitions (IM) fragment impact testing is commonly conducted as specified in MIL-STD-2105D and is completed as per NATO STANAG 4496. Figure 1 shows a typical test setup used for fragment impact testing. Normally, the test item is essentially placed as close to the gun as possible without causing damage to the gun. This is done in order to reduce impact variability. Typical distance from the gun is 20 to 30 feet. STANAG 4496 Ed. 1 specifies a standard test of 2530±90 m/s, an alternate test of 1830±60 m/s and a standard fragment (projectile) geometry. The standard can be challenging to achieve and has several loosely defined and undefined characteristics that can affect the test item response. In particular fragment velocity variation, projectile tilt upon impact and aim point variation and are commonly observed challenges.

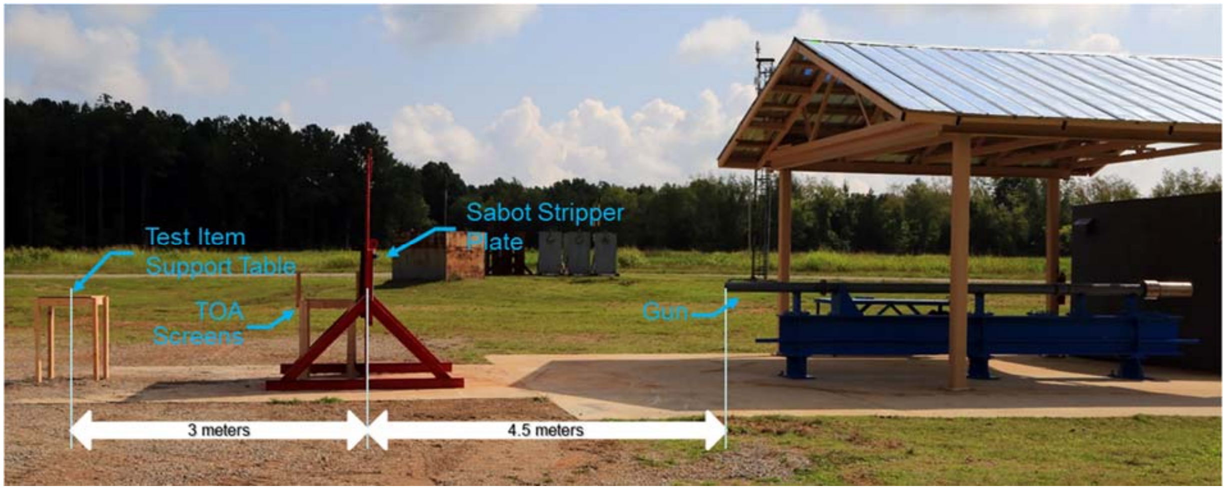

Figure 1. Typical test setup used for fragment impact testing (US Army Redstone Test Center).

PROJECTILE VELOCITY CHALLENGES

Achieving a velocity of 1830 m/s is well within the capability of a broad number of gun systems that are cost effectively available. Achieving 2530 m/s consistently and cost effectively can be more challenging. In the U.S., it is fairly common practice to use a smooth bore 40mm powder gun with a sabot in order to meet the velocity requirement. Such guns are available commercially, with many obtained from Physics Applications, Inc. (PAI). Figure 2 shows typical 40mm laboratory guns used for fragment impact testing. As the high velocity testing tends to produce significant barrel erosion, it common for these powder guns to incorporate a replaceable barrel section, known as the wear section. The wear section is connected to the gun breach and is replaced when significant wear is observed, typically between 150 to 300 shots. As the gun barrel wear produces an increasing barrel diameter over time, this growth must be compensated in order to maintain the projectile velocity, as well as to maintain projectile velocity consistency from shot to shot. Figure 3 shows some typical sabot constructions. The actual sabot design tends to be similar at different test facilities, but varies in geometry details and material. In order to compensate for the barrel wear, two approaches are commonly used: piecemeal sabot diameter to the measured bore and addition of material (tape) to a nominal diameter sabot for improved fit. Normal practice is to clean and shoot the gun before commencing testing and then to empirically determine the required charge load to achieve a desired velocity. During IM engineering development testing, it is often desirable to test at the high end of the specification in a tight velocity grouping targeting 2620 m/s. Consistently achieving a tight velocity grouping at 2620 m/s using single stage powder guns has proven to be challenging. Finally, variation in gun powder and ignition can have detri4mental effects on projectile velocity variation.

Figure 2 shows typical 40mm laboratory guns used for fragment impact testing.

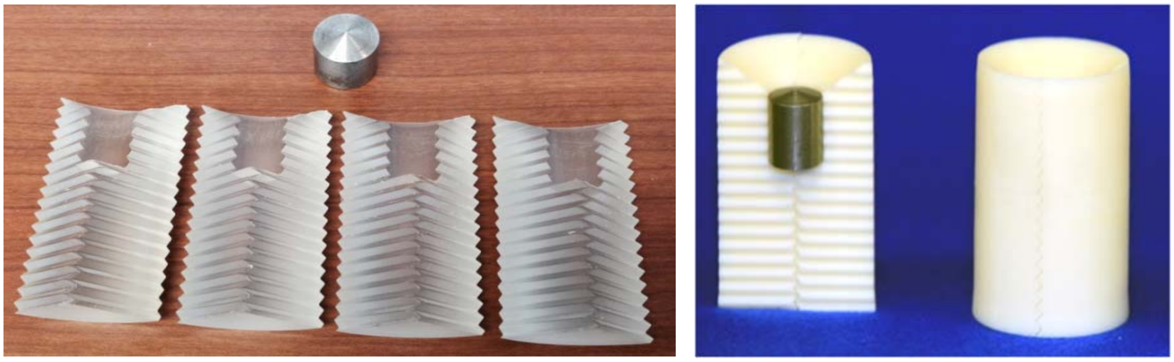

Figure 3 shows some typical sabot constructions (left: US Army ARDEC, right: GD-OTS).

There are some efforts where over testing to higher velocities are viewed as desirable during IM mitigation development with the view that having a velocity margin will provide some assurance of consistent mitigation at the standard velocity. This means that even higher test velocities must be consistently achieved with a target of 3048 m/s being used for some testing. It has proven to be difficult to achieve such high velocities with a single stage powder gun. As a result, two stage light gas guns have been used for such testing. A test standard where the requirement necessitates a two stage gas gun is not viewed as an affordable standard practice. Figure 4 presensts a picture of a two stage light gas gun used at AFRL Eglin AFB for fragment impact testing.

Figure 4. Two stage light gas gun used at AFRL Eglin AFB for fragment impact testing

Fragment velocities are measured using either make/break screens or high speed framing photographic techniques. Make or break screens are normally setup in a frame and the projectile velocity is calculated based on screen signal times and the distance between two screens. Figure 5 shows typical make and break screens. Error in velocity calculations can occur due to screen measurement error, movement of the screens before testing, fragment rotation during flight and potential screen triggering due to high velocity debris or preceding air shock. With a typical screen displacement of distance of 60cm, a 5 mm error would account for a 0.8% velocity calculation error, or about 20 m/s at a velocity of 2530 m/s. Velocity measurements from high speed framing images have the advantage of being able to measure the fragment velocity very close to impact. However, image blur and fragment rotation are potential sources of velocity measurement error. Figure 7 presents fragment high speed framing images. For high speed imaging measurements, a 0.7 μs exposure results in 1.8 mm of motion blur at 2530 m/s. This motion blur is observed on all images. To try to mitigate this effect, velocity measurements can be taken from the four corners of the projectile and then average them. It is common to see a standard deviation of 16 m/s in these calculations. Fragment drag is also a potential source of error. Using traditional drag formulation with an initial fragment velocity of 2530 m/s, the fragment is calculated to lose between 11 and 19 m/s per meter of travel when using drag coefficients of 0.87 (sphere) and 1.4 (spinning cube). Using a typical distance of 2.5 m from the velocity screens to the test item, associated velocity decreases would be 27.5 and 47.7 m/s respectively. Figure 6 presents a graph of velocity vs. distance for drag calculations using a 1.4 drag coefficient.

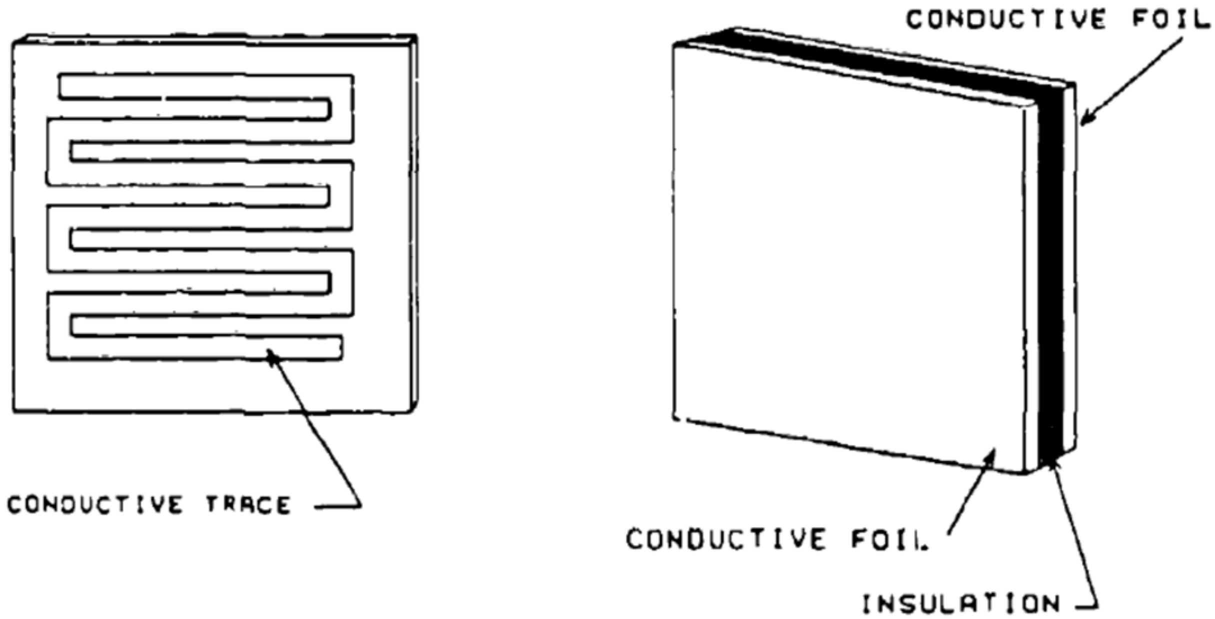

Figure 5. Typical break (left) and make (right) screen constructions.

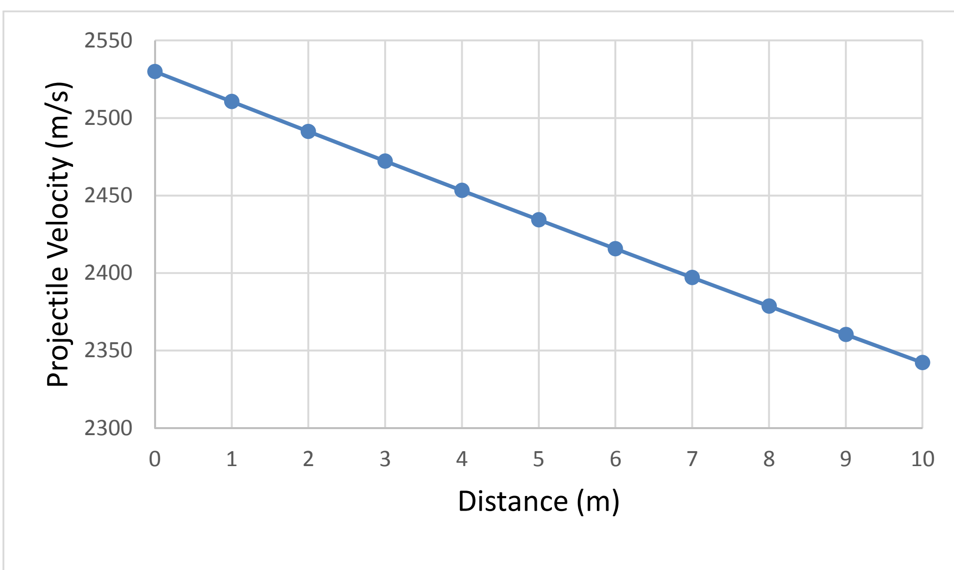

Figure 6. Projectile velocity vs. distance for the standard fragment from air drag calculations (drag coefficient of 1.4).

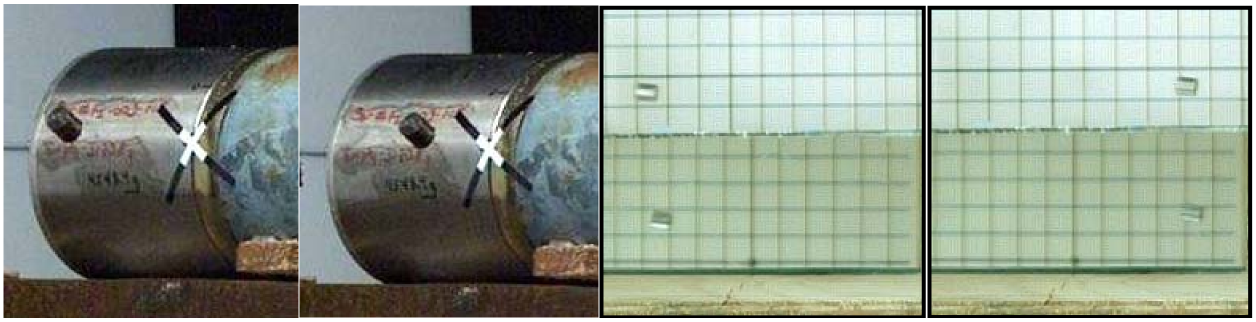

Figure 7. Fragment high speed framing images (left: AFRL Eglin, right: GD-OTS).

PROJECTILE TILT CHALLENGES

Fragment tilt on impact is known to be a possible source for response variation. As the standard fragment has a conical face with a full angle of 120˚, the initial shock imparted into the test item upon impact can vary significantly with fragment tilt. It is common to observe fragment tilts of 30˚ or even higher. There is no specification for acceptable fragment tilt in STANAG 4496 Ed. 1. The fragment tilt can be difficult to measure, is normally not reported and often there is no supporting photography or other data to assess fragment tilt. The STANAG 4496 Ed. 1 standard fragment is aerodynamically unstable, as it has a center of pressure (CP) in front of its center of gravity (CG) and is normally tested without spin stabilization. As a result, fragment tilt to some degree is a given. However, the rate of induced fragment tilt is highly dependent on the initial torque applied to the fragment. This is likely the cause for the large variation of observed fragment tilt. This initial torque has a number of potential sources including projectile balloting, gun exit dynamics and sabot non-uniform opening. Projectile balloting is known to occur when poor gas sealing by the sabot occurs during launch. Gun supports that allow gun dynamic harmonics associated with natural frequencies is also known to be associated with balloting and non-symmetric gun exit dynamics. Non-uniform sabot separation has been observed through non-uniform sabot impact patterns on the sabot stripper plate, as well as high speed photography. In typical sabot designs, the fragment is supported on the rear face by the split sabot geometry as seen in Figure 3. When the sabot is opened from the aerodynamic forces, the sabot supporting surface has a high potential for providing some torque forces to the fragment rear surface during sabot separation. The fragment high speed framing images from Figure 7 clearly show fragment tilt. These images also illustrate the difficulties in measuring fragment tilt due to image resolution and motion blur.

PROJECTILE AIM POINT CHALLENGES

STANAG 4496 Ed. 1 specifies that the aim point of impact of the fragment is chosen with the objective of obtaining the most violent reaction: one test is conducted with impact in the center of the largest presented area of energetic material and a second in the most shock sensitive region. No tolerance for impact point error is specified in STANAG 4496 Ed. 1. It is known that impact point variation can be a source for IM response variation for a number of reasons including induced shock strength, line of shot line components and produced venting area. For smaller munitions, such as medium caliber munitions, this can be very demanding. As a result, very tight impact point precision is often desired, but can be very difficult to achieve. It is very common to see impact point errors at 30 ft of 6mm and not uncommon to see 12mm errors. Occasionally, there are errors of 25mm or more. Some potential sources for impact location errors are projectile drift and aim point error. Projectile drift can be induced by a number of potential sources including projectile balloting, gun exit dynamics, non-stable aerodynamics, non-uniform sabot separation and wind. Projectile balloting and gun exit dynamics were somewhat previously discussed. As already mentioned, the STANAG 4496 Ed. 1 standard fragment is fundamentally aerodynamically unstable. The air drag on an aerodynamically unstable item is non-uniform and can therefore cause trajectory curvature. Although the drag forces are relatively small, they are not insignificant as evidenced by the calculated induced velocity reductions. Non-uniform sabot separation has been observed through non-uniform sabot impact patterns on the sabot stripper plate, as well as high speed photography. In typical sabot designs, the fragment is supported on the rear face by the split sabot geometry as seen in Figure 3. When the sabot is opened from the aerodynamic forces, the sabot supporting surface has a high potential for providing some torque forces to the fragment rear surface during sabot separation. Most test facilities have made various sabot modifications and material selection for improved sabot performance. Finally, wind has the potential for causing drift. STANAG 4496 Ed. 1 specifies that the wind speed and direction should be recorded. It would be rare to be performing tests in winds above 10 mph (4.5 m/s), which is only 0.18% of the 2350 m/s fragment velocity specification. Even in strong winds of 30 mph (13.4 m/s), the wind velocity is only 0.53% of 2350 m/s. The short firing distance and fact that most test areas are somewhat sheltered virtually eliminates cross wind as a significant source for impact point error. The method for obtaining the aim point can induce errors as well. A common method of obtaining the aim point is through the use of a laser bore scope. The apparatus typically consists of a small laser precision mounted into a cylindrical rod with an outside diameter made to fit snugly inside the bore at the barrel exit. Figure 8 presents photographs of laser bore scopes. Optical bore scope are also sometimes used. Both types of bore scope have the potential for aim point errors due to fit issues with the barrel bore. It is a common practice to rotate the bore scope in the barrel to project a circle on the target, with the assumed aim point as the center of the circle. Most test facilities have implemented high precision barrel fits with long inside barrel cylinders in order to achieve improved laser aim point alignment.

Figure 8. Typical laser bore sights.

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FRAGMENT MATERIAL PROPERTY CHALLENGES

Another potential source for IM response variation could be variation in the standard fragment material. The fragment is specified to be fabricated from mild, carbon steel with a Brinell Hardness (HB) less than 270.   In the U.S., the fragment is often fabricated using ASTM1018 steel which has a significant margin for mechanical properties that lies within the STANAG specification. As the fragment commonly breaks up during impact, the mechanical properties variation could be causing fragment break up variation and subsequent IM response variation. This would be particularly applicable to IM mitigation associated with packaging and launch containers.

CONCLUSIONS

In general, all of the surveyed U.S. fragment impact testing facilities meet the STANAG 4496 Ed. 1 Fragment Impact, Munitions Test Procedure requirements. However, improved test precision is often desired in order to reduce IM response variations. A survey of fragment impact testing in the U.S. has identified potential sources of gun testing variations in projectile velocity, projectile tilt, projectile aim point and projectile material properties. Methods to reduce testing variation and associated variation in test response should result in a lower number of required tests and a reduction in overall testing costs. Based on this limited analysis, it appears that there are some cost effective measures, as well as a need for further investigation. Some potential cost effective measures include investigating improved sabot designs and materials, assuring good sabot to barrel fits, closely controlling ignition and propellants, accounting for projectile drag, improved precision velocity measurements, and high precision aiming hardware and procedures. Longer term methods to address testing variation includes potential gun designs to reduce detrimental gun wear and dynamics. Finally, a review of STANAG 4496 Ed. 1 may be warranted, with the intent of improving the test procedure with an objective of practically improving the test precision and resulting test result variation, while maintaining consistent with realistic fragment threats. Areas of concern include the projectile shape, projectile aerodynamics, projectile impact tilt, aim point tolerance and the standard fragment material specification.

ACKNOWLEDGEMENTS

The authors would like to thank the following individuals and organizations for their participation in the Fragment Impact Gun Testing Coordination Meeting held 7 August, Naval Postgraduate School and for the use of figure materials: Jerry G. Webb, US Army Redstone Test Center; Dave Houchins, Naval Surface Warfare Center, Dahlgren Division; Koby Kennison, SAIC/Air Force Research Laboratory Eglin AFB; and David Hunter, General Dynamics – Ordnance and Tactical Systems.

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