PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

ISSN 2081-5891 6, 4 (22), 2015, 19-30

Personal Armour Testing versus Small Arms Ammunition when the Test Standard Doesn't Fit

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Manuscript received May 28, 2014. Final manuscript received February 27, 2015

DOI: 10.5604/20815891.1185940

Abstract. Small arms ammunition which may impact personal armour and is deemed to be realistic as a threat by the user, may not always comply with armour test standards. In many cases there are good practical reasons why such realistic ammunition is not included in standards, including availability and variability. However, when using some test standards, approximate equivalents have been made between realistic ammunition and those levels available within the standards, for example, the use of 30.06 AP M2 as an alternative to 7.62 × 54R B32 API. Some weapon systems not represented within test standards, are not possible to be replaced by any test level listed in any test standard. For example the Heckler and Koch MP7 and FN P90, which are positioned in performance between handgun and rifle levels. Many armour specifiers and users will make minor modifications to levels in armour standards in order to allow the test method to be valid, but with slightly different ammunition types included within a specific level. For example NIJ 0101.06 Level III+ is often specified usually for materials-based reasons. Finally the paper will introduce how bullet surrogate projectiles may be an answer to some of the issues previously highlighted.
Keywords: mechanics, ammunition, armour, test standard

This paper is based on the work presented at the 10th International Armament Conference on „Scientific Aspects of Armament and Safety Technology", Ryn, Poland, September 15-18, 2014.

1. INTRODUCTION

In order to determine the efficacy of a personal armour system it must undergo some level of testing. As the primary aim of a personal armour system is to protect the wearer from impacting objects, it therefore seems sensible that the primary testing regime is that of the item's resistance to such impacting objects. Although impacting objects may be fragmentation, bullets, blades or even blunt objects, this paper focusses upon personal armour designed specifically for the defeat of small arms ammunition.

Some personal armour systems manufactured for the defeat of small arms ammunition are designed to meet the requirements of a specific theatre or operation and therefore potentially for a specific threat regime. However, it is much more common for the personal armour to be designed for a more generic threat regime.

If a personal armour is designed for the defeat of a specific threat regime, it then requires testing to confirm that it meets these relevant protection requirements. Therefore a test method or standard needs to be chosen which is relevant to the requirement for the protection. This decision regarding the test method or standard is often not as simple as it may initially seem. The conflict within the decision-making process is often due to a difference between the reality of the threat and what is available to use within the available test methods or standards.

1.1. Test Methods or Standards Available for Personal Armour versus Small Arms Ammunition

Unless the test method or standard is bespoke and hence is written specifically for a single personal armour or suite of armour systems, it will be one designed to be relevant for a potentially very wide range of personal armour systems. In most cases a widely used test method or standard has been written with a specific user or stakeholder community in mind. In fact it may well have been written by members or representatives of that stakeholder community. Probably the best known example of this is the NIJ-0101.0n series of test standards (for the purpose of this paper only the .04 and .06 versions will be considered). However, other test methods or standards are also available.

1.1.1. NIJ-0101.0n [1, 2]

The NIJ-0101.0n series of standards is one developed specifically for the US Law Enforcement community. The first version was released in March 1972 as NILECJ-0101.00.

Over the six versions of the standard since that time, the standard has always included a number of both low velocity and high velocity bullet levels. These have changed over the versions, and with the latest two versions the change in levels has made the utilisation for other stakeholder communities slightly more difficult to justify.

The NIJ-0101.0n standards have historically been used by stakeholders outside the originally intended US Law Enforcement one. One community that has used the NIJ-0101.0n standards extensively is the military one. For the military community the most common NIJ-0101.0n levels specified are levels IIIa, III and IV. Level IV refers to the 30.06 AP M2, which has been a level in the standard since the original NILECJ-0101.00. Level III was introduced in the NIJ-0101.01 version and consists of the M80 7.62 × 51 mm NATO ball. Level IIIa was introduced as the high handgun level in the NIJ-0101.02 and consisted of a .44 Magnum and a 9 mm FMJ. On many occasions this level has been specified by the military community, but only for the 9 mm FMJ. However, there was a change for the NIJ-0101.06 Level IIIa, which replaced the 9 mm FMJ with a .357 FMJ. This change reduces the relevance of this level of the NIJ standard for the military community, and it is for this reason that many military specifiers still refer to NIJ-0101.04.

1.1.2. HOSDB 2007 [3]

The HOSDB standard is the UK's equivalent to the NIJ-0101.0n. It was developed for the UK Police forces and has mainly been used for that specific user community only.

1.1.3. VPAM APR 2006 [4]

VPAM APR 2006 is a test standard produced by the VPAM association. The VPAM is an association of German-speaking test organisations, who have developed their own suite of test standards.

VPAM APR 2006 includes a very wide range of small arms ammunition with .22 LR at the lower end and 14.5 × 114 mm at the upper end. This standard also includes both Western and former Eastern Bloc ammunition types, thus allowing a greater potential for reality for the various user communities.

1.1.4. GOST R 50744-95 [5]

This standard is the Russian test standard for body armour. It includes levels which are probably considered to be realistic for Western nations. However, they are also levels which may be considered to incorporate a higher level of variability.

2. REALITY VERSUS THE TEST METHOD

Sometimes the reality of the situation for which the personal armour is required, is one which is difficult to reproduce with any available test method or standard. Some of these aspects include the test levels, behind armour blunt trauma and shot patterns.

2.1. Test Levels

The most obvious, and probably most critical, of these is that of ammunition chosen for the test levels. It is most common for the ammunition chosen for the test standard levels to be those originating within the country from which the test standard was authored. For example the ammunition types in the NIJ standards are of US manufacture, those in the HOSDB standard are easily available in the UK and those in the GOST standard are of Russian origin. The VPAM includes ammunition types from a number of different sources. However, it is possible that the more realistic threats to the end user may be from different sources. One way in which this issue has been addressed by some users will be discussed later.

2.2. Behind Armour Blunt Trauma (BABT)

Behind Armour Blunt Trauma is an injury caused to the body, when the armour has defeated the incoming projectile. For body armour covering the torso the injury can include bruising, rib fractures, lung injury and even commotio cordis (commotio cordis occurs when the heart is stopped, due to an impact to the chest. It occurs only in specific times during the cardiac cycle). For helmets the injuries could include skull fracture, diffuse axonial injury, or traumatic brain injury.

In body armour test standards BABT as such is not measured. However, in its place the back-face signature (BFS) caused by the deforming armour into a modelling clay is used. The allowable BFS is of a different threshold value within different standards. For example the NIJ standards specify a maximum BFS of 44 mm, the HOSDB 25 mm or 44 mm (for the HG1A level only), and the GOST 17 mm. The VPAM refers the test organisation to the specific product requirement in this matter.

Many people refer to the BFS as ‘the trauma’, but this is incorrect. The trauma is the injury and the BFS is the measurement method. There is very little evidence that the injury and the BFS can be correlated, and that which does exist is for very specific cases only, such as a .38 Special versus seven layers of Kevlar at an impact velocity of 244 m/s. This lack of correlation evidence was highlighted in a US OSC report in 1992 [6].

However, this limited data has somehow been sufficient for this BFS method to become incorporated into many body armour standards, since it was first included within NIJ-0101.01 in 1978. It is now very difficult to come to any agreement to move away from such a measurement, as this could be seen as lowering the standard and hence reducing the protection offered by the armour. In the UK a decision was made to change from the 44 mm limit of the NIJ to 25 mm, but the evidence for why this was done is largely lost in history. After many years of consideration, the UK Home Office is now relaxing some levels of BFS back to 44 mm.

These BFS levels have become accepted as being an important part of the test standard, even though there is very little evidence which connects the levels to injury. The question should also be asked as to which actual injuries are the BFS measurements actually related to. Considering body armour only bruising can be considered to be related to BFS, but this is a relatively minor injury. It was thought that rib fractures were also caused by displacement of the armour, but there is now emerging evidence that rib fractures may actually be a stress wave related injury [7]. The lung injury seen behind armour is similar to blast lung type injuries and hence is a stress wave induced injury and not displacement induced. Commotio cordis is also a stress wave induced injury.

Incorporation of these BFS levels in body armour test standards has led to body armour being designed to meet the BFS requirement over and above the ballistic requirement, which has ultimately led to less flexible armour systems. Less flexible armours are less comfortable and hence increase the burden on the wearer. Therefore it could be argued that body armour is made to be less comfortable by an aspect of the standard that only reduces what is actually a very minor injury.

An additional criticism which can be aimed at the BFS measurement methods is that they may be variable in their outcome. Figure 1 below shows more than 400 shots versus the same design of soft body armour using the same type of ammunition. The firings were all conducted using Roma Plastilina Number 1 over a test period of four years. The Plastilina was replaced at the recommended intervals within the relevant test standard.

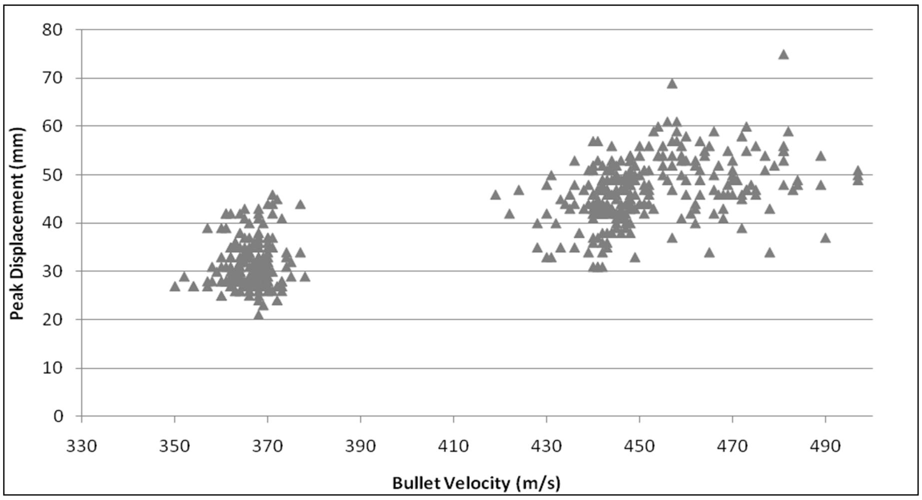

Fig. 1. Graph of Back-Face Signature versus Impact Bullet Velocity

Considering the bullet impacts at 365 m/s (HOSDB HG1) or 373 m/s (NIJ-0101.04 Level IIa), it is possible for the armour to either pass or fail the BFS requirement for both HG1 (25 mm) and NIJ-0101.04 Level IIa (44 mm). The particular armour is known to be consistent in its behaviour, as is the ammunition type. Therefore this would indicate there to be variability in the test method.

3. AMMUNITION EQUIVALENCE

If an ammunition type which is considered to be realistic is not included within a test method or standard, the armour specifier may determine that an ammunition type which is within a test standard, may be similar enough to the required threat to be used. One commonly assumed equivalence is between the 7.62 × 54R B32 API and the 30.06 AP M2. This may or may not be a sensible equivalence. Gotts et al [8] showed that versus an armoured steel target, most versions of the B32 API provide a higher performance than the 30.06 AP M2.

4. IN-BETWEEN THREATS

Unlike the previous case, in which an attempt is made to use an available or more realistic ammunition type to replace one in the test method or standard, there are cases where there is really no equivalent ammunition available. Two specific weapon systems which are not included in test methods or standards, but which could be an encountered threat, are the FN P90 and the H&K MP7.

These two weapons are designated as personal defence weapons by the manufacturers and as such they are expected to replace a pistol for those personnel who do not have the requirement for an assault rifle. These two weapon systems can be seen in Figure 2 and 3. Table 1 compares the P90 and the MP7.

Table 1. Comparison of P90 and MP7

Category	FN P90	H&K MP7
Calibre × length (mm)	5.7 × 28	4.6 × 30
Muzzle velocity (m/s)	715	725
Bullet mass (g)	2.02	1.6
Kinetic Energy at muzzle (J)	540	420

Fig. 2. H&K MP7

Fig. 3. FN P90

The design of these weapons and ammunition is such that they will defeat textile personal armour with ease, but will be defeated easily by ceramic plates.

The 540 J kinetic energy at the muzzle of the P90 is lower than the 713 J of a 9 mm FMJ at 398 m/s (NIJ-0101.06 Level II), but the effects versus textile body armour are much more serious. The kinetic energy density, however, for the P90 is 5.3 J/mm^2 compared to 2.8 J/mm^2 for the 9 mm. The kinetic energy density for the MP7 at muzzle velocity, for comparison is 6.3 J/mm^2. Comparison with a typical high velocity bullet type from a test standard could be the 7.62 × 51 mm M80 NATO ball as per NIJ-0101.06 Level III. This would have a kinetic energy at the muzzle of 3.44 kJ and a kinetic energy density of 18.8 J/mm^2. These comparisons, as well as those for the NIJ-0101.06 Level IIIa ammunition types, can be found in Table 2.

Table 2. Comparison of P90 and MP7 with Test Standard Ammunition Types

Ammunition Type	Test Standard / Level	Bullet Velocity (m/s)	Bullet Mass (g)	Kinetic Energy (J)	Kinetic Energy Density (J/mm^2)
9 mm FMJ	NIJ-0101.06 Level II	398	8.0	713	2.8
.357 SIG	NIJ-0101.06 Level IIIa	448	8.1	813	3.1
.44 Mag	NIJ-0101.06 Level IIIa	436	15.6	1,483	3.8
5.7 × 28 mm (P90)	None	715	2.0	540	5.3
4.6 × 30 mm (MP7)	None	725	1.6	420	6.3
7.62 × 51 mm NATO ball	NIJ-0101.06 Level III	847	9.6	3.444	18.8

These comparisons of kinetic energy and kinetic energy density for the different ammunition types show clearly that there is no sensible equivalence of ammunition within the NIJ-0101.06 standard. Other test standards include similar ammunition types in their levels to those found in the NIJ-0101.06. Even the VPAM APR 2006 with its 14 levels goes from their level 5 to level 6, which jump from a .357 (albeit one with a muzzle velocity of 580 m/s) to the 7.62 × 39 mm PS ball.

These weapons may well be used by police forces whose main protection is provided by textile body armour. This causes concerns, as the potential for fratricide now needs to be considered.

5. LOCAL AMENDMENTS TO TEST METHODS OR STANDARDS

Sometimes an armour specifier will realise that the threats, or more correctly the test levels, in the test standard are close to their requirement, but not quite what they need. It is then possible that the specifier will determine that the test standard may be used, but with some additional minor modification. A common example of this approach relates to NIJ-0101.04 or NIJ-0101.06 Level III. The level refers to a 7.62 × 51 mm NATO ball only. This is the lowest high velocity rifle test level within the NIJ standard.

In those cases where the rigid body amour plate is one with a ceramic strike-face the requirement to defeat the 7.62 × 51 mm NATO ball at muzzle velocity would also be expected to defeat 'lesser' threats such as the 7.62 × 39 mm PS ball or the 5.56 × 45 mm SS109. However, it is now easy to defeat the 7.62 × 51 mm NATO ball with a monolithic ultra-high molecular-weight polyethylene (UHMWPE) plate at a significant reduction in areal density. However, such a UHMWPE plate will not defeat either the 7.62 × 39 mm PS ball or the 5.56 × 45 mm SS109. Therefore the intelligent specifier who understands this limitation of monolithic UHMWPE will define an addition to the level in the NIJ and usually refer to it as NIJ Level III+, which of course does not really exist. This level III+ will include the PS ball and the SS109, thus forcing the manufacturers to offer a ceramic-faced plate or a very thick UHMWPE plate.

5.1. Ballistic Helmet Testing

Ballistic helmets are often specified to an NIJ standard. However the specification is often stated simply as 'NIJ Level IIIa'. It is rare that the specification includes which particular NIJ standard the specifier wants the helmet to be tested to. There is an NIJ standard for ballistic helmets NIJ-0106.01 [9]. However NIJ-0106.01 only consists of three levels, levels I, IIA and II, and so there is no level IIIa associated with an NIJ standard for helmets. When the specifier refers to NIJ Level IIIa they must therefore be referring to the body armour standard level, or possibly even NIJ-0108.01 [10] which is the NIJ standard for Ballistic Resistant Protective Materials. Most ballistic helmets are designed for the defeat of 9 mm FMJ ammunition only. Therefore with this intended protection level of 9 mm FMJ what are the options for which test standard are really suitable? NIJ-0101.06 is not an option as it no longer includes the 9 mm FMJ in level IIIa. The 9 mm FMJ can be found in level IIIa of NIJ-0101.04 and also in level IIIa of NIJ-0108.01. Therefore it could be either of these, but the specified velocity and tolerance are different. In NIJ-0101.04 the velocity for the level IIIa 9 mm FMJ is specified as 436 ± 9 m/s (427 to 445 m/s), while for the NIJ-0108.01 velocity is specified as 426 ± 15 m/s (411 to 441 m/s). If a standard is required which is not one originally written for the item being tested, it is critical that it is fully defined. It should be fully defined even if it is the relevant standard for the item being tested.

6. BULLET SURROGATES

In the vast majority of cases in which personal armour is tested versus a fragmentation threat, a surrogate approach is used.

The 'real' fragmentation is produced by some type of exploding munition, whether conventional or improvised. However it is not these 'real' devices, or even the fragments from them which are used for testing the personal armour. This is because the 'real' devices or fragments are not consistent from detonation to detonation. Therefore, in order to maintain consistency during the test process fragment simulating projectiles (FSPs) are used. These FSPs are delivered to the target by being controllably fired from a gun barrel, and not by being launched from an explosive munition. The most common FSP geometry is that of the chisel-nosed cylinder, which was developed at the end of the USA in the early 1940s [11]. The FSP cannot be considered to be a replicate of all, or even any, real fragments, but is instead used to allow for consistent and repeatable testing of armour materials and systems.

If there is a serious issue with both the availability and consistency of bullets in some types of small arms ammunition, used in either reality or in test methods and standards, might it be sensible to use bullet simulating surrogates (BSPs)?

This idea of bullet surrogates has been discussed quite a lot over the last decade, but it has really only been over the last two years that any serious development work has been conducted. Two European government organisations have independently started programmes of work in this area, and it is interesting to note that the approaches have been completely different.

The UK MOD's Defence Science and Technology Laboratory (DSTL) has considered a specific bullet type [12], which is one known to be an issue with both its availability (in the UK at least) and its variability – the 7.62 × 54R B32 API. The issue was highlighted by Gotts et al [8] at PASS 2010, a paper within which different sources of B32 API were compared by their V_{50} performance versus armoured steel targets. Their design is a near replica of the B32 manufactured in a way that is consistent for each projectile. The main difference to the original, however, is the non-inclusion of the incendiary component in either the nose or the tail of the projectile.

The alternative approach is that of the Royal Military Academy in Brussels [13]. Their approach is to produce a more generic projectile of a specific calibre, more in line with the thinking behind the FSP. The focus is on simplicity and hence repeatability of design.

7. SUMMARY

Small arms ammunition which may impact personal armour and is deemed to be realistic as a threat by the user, may not always comply with armour test standards. In many cases there are good practical reasons why such realistic ammunition is not included in standards, including availability and variability.

Where reality and the test methods do not line up it may be in the area of the test levels. Another complicating issue is that of BABT and the measurement of BFS.

However, when using some test standards, approximate equivalents have been made between realistic ammunition and those levels available within the standards, for example, the use of 30.06 AP M2 as an alternative to 7.62 × 54R B32 API.

Some weapon systems not represented within test standards, are not possible to be replaced by any test level listed in any test standard. For example the Heckler and Koch MP7 and FN P90, which are positioned in performance between handgun and rifle levels.

Many armour specifiers and users will make minor modifications to levels in armour standards in order to allow the test method to be valid, but with slightly different ammunition types included within a specific level. For example NIJ 0101.06 Level III+ is often specified usually for materials-based reasons. The use of test standards for ballistic helmets has caused some confusion, as specifiers use the NIJ standards, but not those designed for ballistic helmets.

Fragment simulating projectiles have been used since the 1940s. It may now be time to consider the use of bullet simulating projectiles and there are now two pieces of work being conducted in this area.

REFERENCES

[1] NIJ Standard-0101.04, *Ballistic Resistance of Body Armor NIJ Standard-0101.04*, US Dept of Justice, June 2001.

[2] NIJ Standard-0101.06, *Ballistic Resistance of Body Armor NIJ Standard-0101.06*, US Dept of Justice, July 2008.

[3] Croft J., Longhurs T.D., *HOSDB Body Armour Standards for UK Police (2007)*, *Part 2: Ballistic Resistance* Publication No 39/07/B, July 2007.

[4] VPAM APR 2006 (English), *General Basis for Ballistic Material, Construction and Product Testing*, May 2009.

[5] GOST R 50744-95, *Armour Clothing – Classification and General Technical Requirements*, GOST Standard, May 2003.

[6] *Police Body Armor Standards and Testing – Volume II: Appendices* OTA-ISC-535, Aug. 1992.

[7] Fenne P.M., Barnes-Warden J., Developing a test methodology to moderate levels of injury resulting from BABT, *Proceedings of PASS 2014*, Sep. 2014.

[8] Gotts P.L., Tawell M.G., Holden S.J., Variations in Ammunition Used for Testing Personal Armour, *Proceedings of PASS 2010*, Sep. 2010.

[9] NIJ Standard-0106.01, *NIJ Standard for Ballistic Helmets*, National Institute of Justice, Dec. 1981.

[10] NIJ Standard-0108.01, *Ballistic Resistant Protective Materials*, National Institute of Justice, Sep. 1985.

[11] Sullivan J.F., *Results of Programs on Development of Body Armour Undertaken at Watertown Arsenal during WWII*, Watertown Arsenal Report, Oct. 1945.

[12] Helliker M., Champion S., Helliker A., Ringrose T., The development of bullet surrogates for armour testing, *Proceedings of PASS 2014*, Sep. 2014.

[13] Coghe F., Puddu O., Pirlot M., On the introduction of a bullet simulating projectile: Experimental feasibility study, *Proceedings of PASS 2014*, Sep. 2014.