The effect of backing methods on the measured ballistic performance of armour materials

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Abstract. Backing materials are used during ballistic testing of armour materials to provide support and may additionally be used as an injury assessment method. For example, to record the back face deformation or assess penetrating injury risk from armour overmatch. Tests was conducted to investigate how different backing methods affected the measured ballistic performance of different protective materials. To characterise this potential effect, two ballistic materials/systems were chosen. The UK Tier 1 Pelvic Protection to represent a low Areal Density (AD) protection of 0.45 kg m^{-2} and a para-aramid woven pack, with total AD of 2.8 kg m^{-2} to represent a higher level of protection. A 20 shot V_{50} test was completed for each armour material on a selection of up to 14 different backing methods. These included Roma Plastilina® no. 1, 20% ballistic gelatin, foam based fragment packs, the AEP-2920 frame, the UK BABT rig (a silicone rubber based deforming element) and ex-vivo porcine tissue with armour overlaying the thorax and the thigh. The measured V_{50} performance on different backings was observed to vary from the baseline by up to -43% to +24%. Differences of -12% to +24% in the measured V_{50} performance were observed for backings that could be considered reasonable and/or common. Using a backing that does not sufficiently replicate an 'as worn' condition may result in Personal Protective Equipment that provides inappropriate protection: not protecting against the specified threat or producing unnecessary burden for the required protection, this therefore has implications for test methods and standards.

1. INTRODUCTION

1.1 Background

Backing materials are used during ballistic testing of armour materials to provide physical support. There are a variety of different backing methods in use across different nations, institutions and test specifications. Some of the backing methods enable additional measurements to be collected, for example to provide an assessment of the risk of penetrating injury during armour overmatch, or to record the back face deformation, which may be used as an additional pass/fail criterion or further analysed to provide an estimation of residual injury risk (e.g. with the UK Behind Armour Blunt Trauma (BABT) rig). Due to the differing requirements, it is not practical to enforce the use of a single backing method when assessing ballistic material performance. There is an embedded use of different backing methods across the ballistic material development and assessment community that complicates material performance comparisons, but provides comparison to legacy data.

It has previously been noted in the literature that conducting V_{50} testing (velocity at which the estimated probability of a complete penetration is 50%) of a given ballistic material using different backing materials can alter the measured performance [1-5]. Whilst this issue has been highlighted, there remains significant questions regarding which methods may be representative of 'as worn' performance or the degree to which methods may differ.

The focus of this paper is to investigate the influence on the measured V_{50} performance of an armour material on a selection of different backing methods and therefore, the resulting implications for choice of various test methods, comparison of results or considerations relating to optimisation of Personal Protective Equipment (PPE). The emphasis is on the potential changes to the measured ballistic response of an armour system, not the ability of a backing to assess any resultant injury in a person who may have been wearing the PPE when impacted. Two different soft armours designed for fragment protection were specifically considered.

The work described within this paper was instigated from the viewpoint of (injury) model development, which may be used in conjunction with an armour covering, not from a ballistic material characterisation or test standards position. This work supported the development of the TP5 fragment pack [1]. Therefore, the type of question being answered relates to providing the evidenced-based data to understand the caveats or limitations of the different backing methods on the resulting measured performance of the armour, given different test requirements.

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1.2 Test standards and backing methods

The main test standard applicable to military body armour (at least in the UK) is the NATO AEP-2920 [6]. AEP-2920 has different requirements for soft armour target retention and support, depending if the testing is for a V_{50} assessment, V_{proof} validation (velocity at which the probability of a complete penetration is lower than a specified value for a given confidence value), using Fragment Simulating Projectiles (FSPs) or bullets. These recommended backing methods cover the use of a frame (air backing), layered foam, Back Face Signature (BFS) materials (for example Roma Plastilina® no. 1 ballistic grade (RP1), but other BFS materials are allowed) and suggestions for use of instrumented BABT assessment models to measure the dynamic response of the backing material. This single standard alone covers a multitude of different backing conditions.

Of relevance to the testing and advice on PPE provided by Dstl, is that for police body armour, covered by the Home Office Centre for Applied Science and Technology (CAST) Body Armour Standard [7]. The backing material for the CAST standard uses RP1 for proof tests of unformed armour, which is similar in requirements to the National Institute of Justice (NIJ) Standard-0101.06 [8]. The CAST Body Armour Standard also uses Plastazote® LD29 foam as a backing for critical perforation analysis [7].

The above standards focus mainly on a BFS material (namely RP1) to generate a BFS measurement to act as a pass/fail criteria in the ballistic assessment, in addition to the armour complete or partial penetration response. Dstl uses the UK MOD thoracic BABT rig [9] (shortened to 'BABT rig' in the remainder of this document) for some of its PPE research activities, as a model to measure the dynamic response of the 'body' wall from a silicone rubber based deforming element. This is done both in an instrumented form to understand the BABT risk, typically for hard armour, as well as un-instrumented, as a 'standard' backing method for V_{50} type assessments of soft armour during research activities. A significant issue with the use of the BABT rig for V_{50} assessments is that the relatively expensive custom moulded silicone elements require frequent replacement, even when no BABT measures are required.

The BABT rig or BFS materials may be suitable when assessing a ballistic material or PPE in a ballistic range setting. When trying to understand a material or system performance in an arena style blast trial (for fragmentation), there are a long list of practical issues, making them no longer suitable as a backing. In these types of scenarios, often a backing is required that can indicate if, or how many, complete penetrations of the armour material occurred. Often, some way of estimating the resulting severity of the overmatch is required. For this type of requirement, layered fragment witness packs are typically used.

Layered foam packs [1; 10], strawboard [11] or metal spaced packs [12] are examples of the types of layered fragment witness packs used for an arena style blast trial for fragmentation [13], which may be covered by a ballistic material or armour system in order to assess its effectiveness.

For Dstl, the situation has arisen where a different backing may be required for a V_{proof} or V_{50} test, for military or police, bullet or fragment, if it is for acceptance or research and different again to what might be required for an arena blast trial. Therefore, an understanding of how all these different backing methods influence the measured ballistic performance, in addition to other methods that may be used for specialist requirements or by other institutions, is critical to select a suitable test method and to allow robust conclusions to be drawn on the armour material or system performance.

1.3 Previous research

In an effort to reduce the time taken to reset armours between tests, the use of a foam backing in place of the frame was implemented for FSP V_{50} testing of different body armour systems in Reference [4]. The results for a 3.8 kg m^{-2} AD system showed no apparent differences in the measured V_{50} between the chosen low-density foam and frame.

Differences in the measured V_{50} performance between RP1 and the frame have been highlighted previously [1], showing increases in measured performance of up to 13% depending on the frame clamping conditions. An average difference of +8% was observed on the frame compared to RP1 for 3 different armour materials, two para-aramids and one Ultra-High Molecular Weight Polyethylene (UHMWPE) of 3.3 kg m^{-2}.

Testing by Nguyen, *et. al.* [2] showed that the specific material type was a factor to determine if a simple frame provided a measured V_{50} performance higher or lower than on 20% gelatin at 10°C for lightweight ballistic materials. For a 190 g cm^{-2} Twaron® weave, the measured V_{50} performance was around 55% higher on gelatin than on the simple frame across a number of different test fragments. A 610 g cm^{-2} Dyneema® knit showed an average measured V_{50} performance around 10% lower on 20% gelatin than on the simple frame [2].

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Using 9 mm handgun rounds, References [5; 14] compared the V_{50} of a 3.5 kg m^{-2} soft armour system (Kevlar® 129) on RP1 and various foams (flat and curved). All the foams showed an increase in the measured V_{50} performance compared to the RP1, although the differences were not considered significant (maximum differences of around 5%).

1.4 Available backing materials and methods

In order to compare backings, the ideal would be to have a performance measure 'as worn' on a live person. Post Mortem Human Subjects (PMHS) or animals as a backing provide what is assessed to be the most realistic dynamic mechanical response, apart from a live person. Use of PMHS or live animals as backings for this work were not considered feasible due to ethical and practical limitations. The utility of different species of animal cadavers is debated for different applications within the wider wound ballistics literature. A goat thorax was selected as the baseline for comparison of methods in the 1970s to assess back face signature [15]. However, none of the armour backing materials/methods considered at that time matched the time-deformation response of the goat thorax [15].

The backing materials and methods selected for the current testing and reason for their use are summarised in Table 3.

Table 3. Summary of backing methods and reason for their selection

Backing	Reason(s) for inclusion
Ex-vivo porcine thorax	To give as close to 'as worn' conditions as possible. The porcine model (thorax) was previously chosen as a basis for UK BABT injury research as the mass and volume can be selected to match those of a human [16; 17]. Availability of fresh tissue from other ongoing trials, where it would otherwise have been disposed. Safety constraints concerning potential Transmissible Spongiform Encephalopathy (TSE) associated with goats and sheep from perforation of the head, spinal cord or abdomen [18][1].
Ex-vivo porcine thigh	To give as close to 'as worn' conditions as possible for items such as Pelvic Protection (PP) [19], designed to cover areas of the thigh.
Roma Plastilina® no. 1	A common backing material, specified in a number of standards[2].
Air backed frame	A common backing method, specified in AEP-2920.
ARTIC [20]	Development in the US of a ballistic-grade clay with predictable and controllable properties resulted in a material known as A Reusable, Temperature Insensitive Clay (ARTIC) [20]. This assessment supports the development and potential adoption of the backing method as an alternative to RP1.
UK BABT rig [9]	A common test method for armour research within Dstl.
20% gelatin at 10°C with a synthetic skin simulant [10]	Ballistic gelatin (20% concentration at 10°C) was used in early BABT research [21] and is a common model used for assessment of penetrating ballistic injury [10]. It may be convenient to use ballistic gelatin (or similar transparent gels) to assess injury risks from an overmatch of an armour system. Inclusion of the skin simulant layer was to help determine armour failure due to pencilling.
25% concentration SEBS [22; 23]	Poly(Styrene-b-Ethylene-co-Butylene-b-Styrene) triblock copolymer (SEBS) has been used as a ballistic [10; 23] and blunt [22; 24] assessment model, offering similar utility to gelatin without some of the practical limitations.
Strawboard, 3.8 mm thick, type D, 10 layer pack [11]	Used in UK for high velocity fragments or assessing injuries that could be lethal.
Metal spaced witness pack [12]	Legacy use in UK for high velocity fragments. The materials used were translated to the closest UK equivalent from the specification in Reference [12].

[1] Perforation of tissues within the head, spinal cord or abdomen may be unlikely when conducting shots against the thorax. However, as the testing was a V_{50} assessment, the trajectory and residual velocity of the shots that overmatched the armour could not be guaranteed.
[2] It is noted that the AEP-2920 and the CAST test standard specify the use of RP1 for bullets, but not FSPs.

MDFPIM V2.0 [10]	The Multiple Discrete Fragment Physical Injury Model (MDFPIM) V2.0 [10; 25] was developed by Dstl specifically for assessing risks from non-metallic fragments and low energy metal fragments[3]. The MDFPIM has been successfully used to compare effectiveness of different armour materials in buried Improvised Explosive Device (IED) arena trials and ballistic laboratory based multiple simultaneous fragment impacts.
TP5 fragment pack V1.0 [1]	A TTCP collaborative project was commissioned to develop a model to provide a backing that would provide representative boundary conditions to soft armour during ballistic impact testing, as well as additional metrics to correlate to injury risks in the event of an armour overmatch. Development of the model included matching blunt ballistic compliance to PMHS testing [1].
TP5 fragment pack V1.1 [1]	A variant of the TP5 pack with an updated skin material.
10 mm RHA	A 10mm thick Rolled Homologous Armour (RHA) plate was chosen to provide an indication of the result of using an extremely stiff backing material.

2. BALLISTIC TESTING

2.1 Backing materials preparation

For the ex-vivo porcine tissue, a single female large white pig was used, weighing approximately 60 kg. Shots were conducted on armour materials overlaying each rear thigh and on each side of the thorax. The shots for the thorax were completed randomly over ribs as well as the intercostal spaces. The testing started approximately 16 hours after the animal had been euthanized by a Schedule 1 method and was allowed to cool to room temperature (21±1°C) prior to testing.

For the purposes of the current testing, RP1 was used conforming to the CAST test standard [7], packed into trays of 420×350×100 mm and following the associated CAST ball drop calibration procedure[4]. If the required indentation depth was not achieved, the RP1 was reconditioned and re-tested. All shots were completed within 1 hour of calibration.

To facilitate direct comparison to RP1, ARTIC was packed into identical sized trays, and followed the identical calibration procedure (with the notable exception that all material was at room temperature, 21±1°C and not altered depending on the calibration result: it either passed and could be used, or failed and could not).

The 20% gelatin at 10°C was manufactured according to the 'Dstl 20% method', described in Appendix D.1 of Reference [10] and cast into blocks of 150×150×300 mm. Armour materials were held in contact with the skin simulant against one of the 150×300 mm gelatin faces. Impacts were completed within 30 minutes of removal of the gelatin from the conditioning cabinet.

The 25% SEBS by volume – mineral oil gel was made as follows:

- The required volume of mineral oil (Primol 352, an ExxonMobil product supplied by Univar) was heated to 100°C for 2 hours in metal trays.
- The SEBS powder (Kraton G1652, a Kraton Polymers product supplied by Univar), calculated to give 25% concentration by volume was gradually added whilst stirring continuously.
- The mixture was allowed to soak at 120°C for a minimum of 4 hours, with regular mixing (approximately 10 minute intervals).
- Once clear and free of bubbles, the mixture was transferred into glass moulds with internal dimensions 300×300×300 mm.
- Additional stirring was completed to release trapped bubbles introduced during the pour.
- The cabinet was programmed to gradually decrease in temperature (down to 20°C) over a period of approximately 24 hours.
- Once cool, the gel block was removed from the glass mould.

[3] The foam used in the MDFPIM has a density of 160±10 kg m^{-3}, compared to the foam as one of the backing options in AEP2920 at 40±5 kg m^{-3} and in the CAST Body Armour standard for critical perforation assessment at 29 kg m^{-3}.
[4] Three drops with a 63.5 mm steel sphere (1.043 kg), from a height of 2.00±0.02 m, 75 mm from an edge and 100 mm between indent centres. The mean depression depth of the three drops must lie between 19±2 mm with no single value outside of 19±3 mm.

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2.2 Ballistic testing method

To characterise the effect of backing methods on the measured ballistic performance of soft armour materials, two ballistic materials/systems were chosen: one to represent a low Areal Density (AD) protection and one high AD protection. The low AD system was the UK Tier 1 Pelvic Protection [19] (NATO Stock Number 8420-99-873-0158), a three layer system based on antimicrobial undershorts with increased protection to vulnerable areas provided by two layers of knitted silk, with total AD of 0.45 kg m^{-2}. The Tier 1 PP was assessed with a 6 mm glass sphere (conforming to Reference [26]) as a representative threat for that armour system. The higher AD system (chosen to be more representative of soft armour to protect against metallic munition fragments) was a 20 layer para-aramid Kevlar® 640G woven pack, with total AD of 2.8 kg m^{-2}. The 20 layer Kevlar® pack was assessed with the 1.1 g Chisel Nosed (CN) FSP (G5 from AEP-2920 [6]).

A V_{50} assessment was conducted using a minimum of 20 fair shots for the different material/projectile and backing combinations. Not all backings were evaluated with every ballistic material due to limitations on available resources. The V_{50}s were calculated using a probit model within the statistical program R [27; 28]. This also enabled the 95% confidence intervals on the measurement to be calculated.

Shot spacing against the 20 layer Kevlar® 640G 2.8 kg m^{-2} pack followed Annex G.1 in Reference [6]; 63.5 mm spacing, along a line offset by 11° to avoid impacting previously damaged yarns. Shots were a minimum of 50 mm from any edge. For the Tier 1 PP, shot spacing was 50 mm. In all cases shots were a minimum of 50 mm from any edge of the backing method/material. The same shot spacing was applied to the backing material as to the armour, to avoid pre-damaged areas of the backing.

Testing was completed over multiple phases to the same method above, but utilising different compressed gas propulsion systems (air and helium), but with the same barrels. In each phase, velocity measurement was conducted using calibrated and cross-validated equipment.

For the 6 mm glass spheres, a 6.05 mm calibre, 300 mm length smooth bore barrel was used. For the 1.1 g FSP, a 800 mm length rifled 7.62 mm barrel and sabot were used to ensure stable flight (<3° yaw as per AEP-2920 [6]). A sabot stripper was placed between the barrel and target for shots with the 1.1 g FSP.

2.3 Ballistic Testing Results

A total of 22 separate V_{50} determinations were conducted with the various backing and armour material combinations (total of 459 fair shots). For security classification purposes, the V_{50}s and differences are reported as normalised values.

The 20 layer Kevlar® 640G 2.8 kg m^{-2} pack could not be assessed on the porcine tissue. A common baseline backing was desired to enable simultaneous comparison across the different backings for both armour materials. The frame was not considered a suitable baseline as the objective was to show methods to best replicate the 'as worn' performance. RP1 was selected as the baseline due to the lack of suitable data for an 'as worn' condition on both materials, not because RP1 was assumed to represent 'as worn' performance. The comparison is shown in Figure 14 with backing materials ordered in terms of increasing absolute average difference.

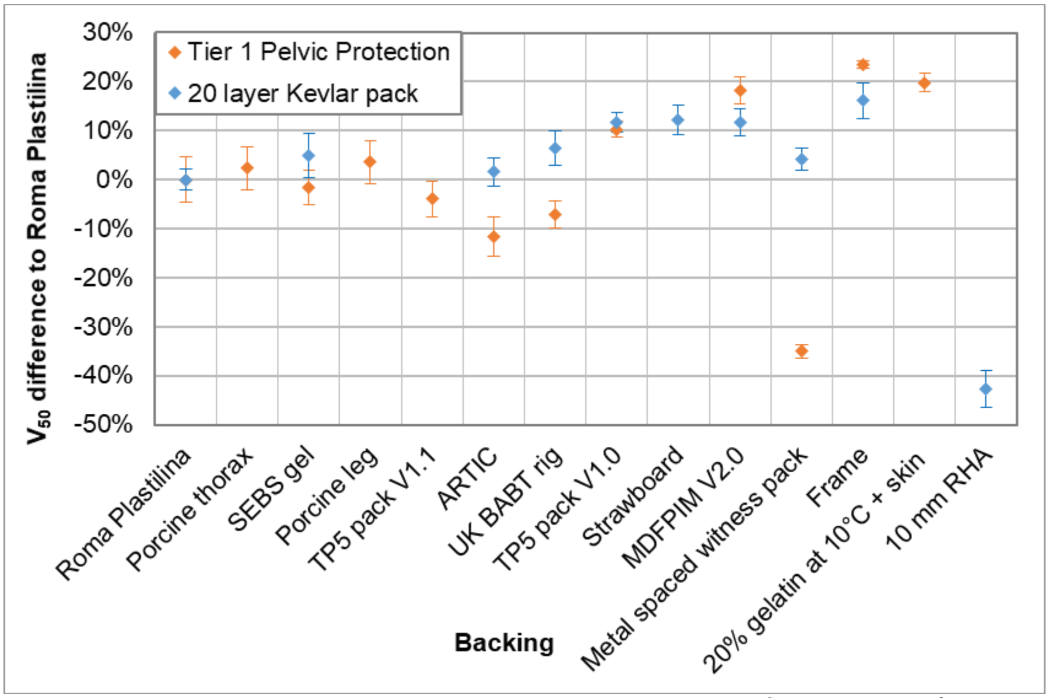

Figure 14. Measured V_{50} response of the Tier 1 PP and 20 layer Kevlar® 640G 2.8 kg m^{-2} pack, normalised to the response on a RP1, for different backing methods. Error bars show the 95% confidence interval.

3. DISCUSSION

3.1 Discussion of results

The 2.8 kg m^{-2} 20 layer Kevlar® pack showed differences in the measured V_{50} performance of up to 16% (+16/-0%) between common backing methods. The greatest differences observed were between the RP1 and the frame. The more flexible Tier 1 PP showed differences of -12% to +24% when compared relative to RP1, for backings that could be considered reasonable (all backings evaluated for the Tier 1 PP excluding the metal spaced witness pack), or -15% to +19% when the porcine thigh is used as the baseline. The difference in measured V_{50} performance between for the Tier 1 PP on RP1 and the frame was 24%.

A variation of 24% for the Tier 1 PP and 16% for the 20 layer Kevlar® pack between the measured V_{50} performance on RP1 and the frame is a much more significant source of 'error' in the armour system measured performance, than the ±2 m s^{-1} allowed for velocity system calibration within AEP-2920 [6] (around ±1% for the velocities used within this paper).

Using a stiffer backing, such as the metal spaced witness pack for the Tier 1 PP dramatically lowered the measured V_{50} response by 37% compared to the porcine thigh or by 35% when compared to RP1. The fact that the 2.8 kg m^{-2} 20 layer Kevlar® pack had a 4% increase in the measured V_{50} performance on the metal spaced witness pack compared to RP1 suggests a different loading condition between the rear face of the armour and front face of the backing compared to the Tier 1 PP. This highlights that the difference in the measured performance may not be consistent in sign or magnitude across different backings for different ballistic materials. This difference in sign in the measured V_{50} performance compared to RP1 was also observed when the UK BABT rig was used as a backing. However, in this instance, the magnitude of the difference was smaller (+6/-7%).

Of the 8 backing methods with measured V_{50} performance data for both the Tier 1 PP and Kevlar pack® (ignoring RP1 as it was used as the baseline), 2/7 backing methods showed the Tier 1 PP had a greater relative performance to the RP1 baseline than the Kevlar® pack. This showed the different backing methods did not consistently rank the materials based on the change in measured performance in the same order (to the same baseline).

Based on the data for the 2.8 kg m^{-2} 20 layer Kevlar® pack and Tier 1 PP: RP1, 25% SEBS gel, TP5 pack V1.0 and V1.1, ARTIC and the UK BABT rig are considered to give a reasonable

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representation of an 'as worn' condition. This was based on <10% difference to the porcine leg for the Tier 1 PP and RP1 for the 2.8 kg m^{-2} 20 layer Kevlar® pack. The suitability of these backings may change for different armour materials or threats, or if compared to a more realistic 'as worn' backing condition.

The fact that the measured V_{50} performance for the Tier 1 PP on the porcine thorax and thigh were not statistically significantly different at the 95% confidence level suggests that a single, suitable backing method is likely to be appropriate for assessment of PPE designed to protect the thorax or thigh, at least for lightweight protection systems.

It is considered that the effect of the backing on the measured V_{50} performance of an armour is a factor of the backing material properties (stiffness, rate sensitivity and boundary conditions[5]) and loading conditions from the armour (back face deformation size and shape, rate, etc.). The armour loading conditions will be dependent on the threat (size, mass, velocity, deformation or fragmentation, etc.) as well as the ballistic material type, properties and construction.

3.3 Consequence for testing

The AEP-2920 test method drives towards two separate assessments on different backings to characterise an amour system (for fragment protection) in order to satisfy V_{proof} and V_{50} requirements. However, these two separate assessments are not comparable and do not appear to be mutually supportive. The reason for the use of the frame in AEP-2920 is likely for practical reasons (re-usable with no material wastage, efficient and inexpensive). However, given that different material types/constructions appear to potentially behave differently when air backed to a more realistic 'as worn' backing (some increase significantly in measured performance whilst others decrease), the AEP-2920 frame may not even be suitable to rank material performance. This situation is likely to be compounded with new materials, constructions, composites, etc..

One of the remaining benefits of the frame is the ability to conduct residual velocity (V_r) measurements when the armour is overmatched. However, if the measured performance of the material is increased in the region of 20% on the frame compared to an 'as worn' condition, then residual velocity measurements are also likely to be unrealistic of an 'as worn' condition. Residual velocity measurements can be collected with the use of alternative backings (gels or layered fragment packs) that are likely to provide more accurate performance measures of the armour under test, both in terms of V_{50} and V_r metrics.

These issues underpin the need to follow good modelling practice (of which the use of a backing material or frame for a ballistic test is a model): a fitness for purpose assessment should be conducted each time, before the model is used. Because it has been done that way in the past is not justification to do so again. However, this fitness for purpose assessment may be simple if the test requirement issued to the institution conducting the testing specifies a certain backing or test standard, but may be more in depth if left open. It also suggests that the requirements manager / staff setting the requirement should be provided suitable technical advice in order to specify an appropriate backing or test standard for their given scenario and requirements.

3.4 Limitations and way forward

Porcine skin is known to overestimate the ballistic resistance of PMHS skin [10]. There is a risk that using the porcine thigh or thorax may underestimate the measured V_{50} performance of a realistic 'as worn' condition. Within practical and ethical limitations, the assumption was accepted that the porcine thigh or thorax provided the closest model to the 'as worn' condition.

A limitation of a number of the backings (including the frame) is an inability to assess (realistic) failure due to pencilling. If a backing is used that has a validated skin perforation response, i.e. the TP5 fragment pack V1.0 or V1.1 [1], MDFPIM V2.0 [10], 20% gelatin at 10°C with a synthetic skin simulant [10], or a suitable animal model [10], this failure mode could be assessed directly. This is likely to be more critical for thin, flexible or low AD materials.

Where the spaced metal witness packs have been used to support UK MOD body armour tests (for assessment of ballistic post barrier risk to allow direct comparison to legacy data), the potential effect on the measured armour performance was presumed from the outcomes of phase one of this testing. This provided sufficient understanding on potential affects to the measured armour response to suggest that an additional layer of 25 mm polystyrene be placed between the armour and front layer of the pack. Whilst this arrangement was not specifically assessed in terms of the result on the measured V_{50}, it was

[5] Boundary conditions were not specifically addressed here, but have been demonstrated to influence measured V_{50} performance [1].

considered sufficient to mitigate any potential reduction in the measured armour performance for the testing in question.

The knitted silk construction of Tier 1 PP may be towards a worst-case material in terms of highlighting differences in measured V_{50} performance for different backing materials. Both the knit structure and silk yarns allow a large degree of deformation before failure and therefore the backing will play a significant role in how the material is allowed to deform. However, how other material types, constructions, or different threats; in particular handgun or rifle rounds that deform during impact with armour, or projectiles that cause a different failure mode in the armour, influence the effects of backings on the measured V_{50} performance is not known. This paper can be used to highlight the potential effects from different backings that need consideration when defining test standards or requirements, rather than as a method to relate or transfer performance measured on different backings.

Whilst this may appear critical of several backing methods, there is no evidence to say it is negligent to use them (and these backing methods have led to PPE that has saved lives on operations). This paper is aimed to identify areas for improvements and provide evidence. It is recognised that getting the required knowledge to build confidence in suitable backing method(s) will take time.

4. CONCLUSIONS

The backing material or method used during assessment of ballistic material performance (e.g. V_{50} or V_{proof}) can significantly affect the measured performance. Most importantly, the difference in the measured performance may not be consistent in sign or magnitude across different backings and ballistic materials. This effect is dependent on the backing used, as well as the amour (and threat) type.

Differences of -12% to +24% in the measured V_{50} performance were observed (relative to RP1) for what could be considered reasonable and/or common backing methods. This included an increased measured performance on the AEP-2920 frame of 16% for a 20 layer Kevlar® 640G 2.8 kg m^{-2} pack assessed with a 1.1 g FSP and an increase of 24% for the UK Tier 1 PP assessed with a 6 mm glass sphere, compared to the measured performance on Roma Plastilina® no. 1.

The measured V_{50} performance on the metal spaced witness pack showed the same model providing a difference of +4% to -35% to a baseline of RP1 for the materials assessed within this work.

Where possible, backing methods were compared to an 'as worn' performance, estimated by the measured performance on a porcine thigh or thorax. Comparison of the measured V_{50} performance on a porcine thigh and thorax indicated that a single, suitable backing method is likely to be appropriate for assessment of PPE designed to protect the thorax or thigh, at least for lightweight protection systems.

Selection of the backing material or method has the potential to have a much larger effect on the measured V_{50} performance of an armour material or PPE, than other potential sources of error already controlled within various test standards. This should be understood by the testers, users and requirements managers.

It appears challenging to justify the use of the frame as a backing method from an injury modelling perspective: it has potential to provide inaccurate measured performance outcomes, as well as potentially provide unreliable rankings of relative material performance compared to 'as worn' conditions. However, there may be other reasons for its use and there is no evidence to say it is negligent to use the frame providing the limitations and caveats are understood.

Considering the current testing alongside previous research, a different threat (such as 9 mm handgun rounds), a higher AD or stiffer soft armour system may reduce the measured differences in V_{50} performance between different backings.

There is no one backing material/method that should be used in preference to others – it will depend on the requirement and scenario. However, inappropriate choice of the backing method may lead to:

- PPE that does not provide as much protection as it would under 'as worn' conditions, i.e. does not protect against the specified threat.
- Development of PPE with unnecessary burden for the required protection.
- A different ranking performance of PPE/armour materials to their 'as worn' performance rankings.
- Increased resource required to meet specifications.

It is essential to follow good modelling practice (of which the use of a backing material for a ballistic assessment is classed as a model): a fitness for purpose assessment should be conducted each time, before the model is selected or used. The outcomes from this work can be used to support requirements managers or staff setting the requirements with suitable technical advice in order to specify an appropriate backing or test standard for their given scenario and requirements. This will help to prevent PPE with insufficient protection, overburden or wasted resource.

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