

Development of Stab Weapon Exemplars from a Survey of Threats in a Corrections Environment

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Abstract. Current standards to assess the performance of stab resistant body armour have been based on the prevalence of commercial weapons within the civilian population. These weapons typically exhibit well-refined characteristics for optimal performance during puncturing, cutting and penetrating actions under controlled use. In comparison, weapons used in a corrections environment are less refined due to limited access to materials, manufacturing capabilities, and need for concealment. As a result, it has been speculated that a lower level of performance would be exhibited by these improvised weapons placing less demand on body armour. However, characterization of weapons found in correctional institutes has not yet been conducted and until completed, their true performance will not be known. The present study describes the characterization of threats obtained from a large survey of correctional institutions in the United States and their characterization into exemplars for use in performance standards. An Analytic Hierarchy Process (AHP) was applied to the weapon survey data to create a weapon typology for subsequent down selection and detailed performance analysis. Test methodologies for tip sharpness, edge sharpness and weapon system performance were developed for initial characterization of the weapons and for validation of the exemplars. Dynamic tests on commercial armour systems consistent with the NIJ 0115.00 test methodology were conducted to assess the threat exemplar severity and implications on armour design. The study identified bladed and spiked threat classes found in a corrections environment and led to the development of similar exemplar classes. The presence of both threats may require an integrated approach for the development of stab resistant armour. Findings from the study are being considered for revision of the NIJ 0115 standard for assessing the stab resistance of body armour.

1. INTRODUCTION

Injury due to stab or slash attacks is of concern to corrections and law enforcement officers alike. Approximately 13% of law enforcement officers in the United States were assaulted by knives or cutting instruments according to the 2009 Law Enforcement Officers Killed and Assaulted (LEOKA) report. While similar statistics for corrections environment are not collated at present, it is likely that similar concerns exist with spiked, bladed and improvised weapons found in the correctional environment. However, the types of weapons used, mode of use and effectiveness in defeating protective armour is not well documented.

Current standards such as the NIJ 0115.00 *Stab Resistance of Personal Body Armor* [1] have been based on the use of commercial weapons in crimes within the civilian population. These weapons typically exhibit well-refined characteristics for optimal performance during puncturing, cutting and penetrating actions under controlled use. In comparison, weapons used in a corrections environment are less refined due to the limited access to materials, manufacturing capabilities, mode of use and need for concealment. It has been speculated that a lower level of performance would be exhibited by these improvised weapons placing less demand on stab resistant body armour.

The study is motivated by the current efforts of the Special Technical Committee (STC) operating under the NIJ to re-address stab and slash threats in the US and revise the NIJ 0115.00 standard accordingly. The STC operates under two oversight groups appointed by the NIJ: the Advisory Working Group (AWG) and the Standards Steering Committee (SSC). The work is taking place as part of the overall efforts of the STC to address the test methodology, armour certification process and provide guidance to key decision makers and equipment users. Contributions and oversight from the practitioners (law enforcement, corrections, criminal justice subject matter experts and end users) and technical experts (representatives from federal agencies, academia, and private industry including scientists, engineers and laboratory personnel) are intended to ensure that the needs and requirements of practitioners in the field are addressed.

This study aims to answer a knowledge gap identified by the STC in regards to stab weapon performance in the corrections environment. Characterization and assimilation of the weapons was conducted with the objective of producing weapon exemplars representative of correctional threats.

2. WEAPON SURVEY

In 2010, NIJ initiated a research program to identify the threats experienced by law enforcement and corrections officers which operate inside controlled access facilities including jails, detention centres, , prisons or outside the facilities for access control. The threats of concern inside the facility include stab threats, slash threats and blunt impact threats while outside the facility ballistic threats are also prominent. Only stab threats are addressed in the present study and will be the focus of subsequent discussions.

Stab threats made by inmates tend to be improvised from available materials (*e.g.* metal, plastic, wood) and administered to the back of the officer or in close quarters with the officer knocked down and, in the case of stab weapons, the weapon is used in short jabs against the torso. Typical correctional stab type weapons are illustrated in Figure 1 and include blades, spikes, shivs, and stakes. Commercial weapons are rarely found due to the difficulty in importing these into the facility.



Figure 1: Typical improvised weapons found in correctional institutes.

Wayne State University was tasked by the NIJ to provide scientific support for characterizing inmate-manufactured or improvised weapons that a correctional officer faces in the United States. The first step was to procure confiscated improvised weapons from correctional facilities across the US and create a typology where the weapon attributes such as size, shape and sharpness are documented.

A total of 1353 weapons were collected from over 20 facilities representing different prison types and security levels. The weapons were subsequently photographed, measured and entered into a weapons database. The weapons were initially classified into four styles as provided in Table 1 with the distribution of styles presented in Figure 2.

Table 1: Definition of weapon types collected in the survey.

Weapon Style	Description
Blade	Flat blade with rectangular cross section generally having a tip, edge and handle. To be used in a thrust mode and possible drag/slash follow-through.
Ice Pick	A typically round shaft construction having a tip, slender shaft and handle. To be used in a thrust mode.
Stake	Similar to the blade but with an irregular cross section.
Slash	A small flat blade generally without a tip but having a supporting handle. The blade may be oriented perpendicular to the handle for primary use in slashing or sweeping actions.

3. WEAPON TYPOLOGY

Development of a weapon typology must account for the dynamic performance of the weapon and trauma inflicted to the victim. Consideration must be given to the assailant delivering the weapon, the interactions of the weapon with the armour, and the bodily response to the assault. For completeness, the impact of the weapon and potential for injury should also account for the dose-response relationship, exposure assessment and risk characteristics. However, due to the paucity of literature on stab attacks, a more simplistic approach is required to meet the current programs' objective of weapon characterization and exemplar development. Therefore, emphasis was placed on

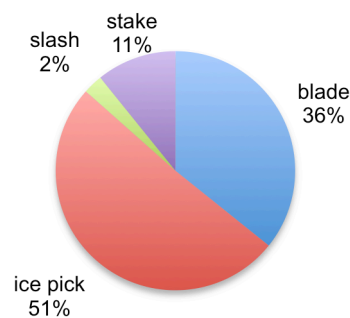


Figure 2: Distribution of weapon type from the survey.

characterizing the physical and geometric attributes of stab weapons found in correctional environments as well as assessing their performance against armour systems.

In regards to stab/slash attacks research studies have discussed the weapon attributes in relation to human injury and armour failure [2, 3, 4, 5, 6, 7, 8]. Terms such as tip sharpness, edge sharpness, body slimness/shape, surface finish and material have been referenced and associated with the weapon's performance. Furthermore, Atkins [2009] study of cutting tools can help understand the mechanisms of weapon performance including piercing, cutting, parting/wedging, and sawing as well as the key physical attributes related to their performance such as the tip and edge approach angle, radius, included cone angle, material strength and others.

Based on the referenced literature, an initial typology was established to document the physical weapon attributes responsible for penetration (tip and edge sharpness, surface finish, slimness, etc.) along with information on the weapons intended method of use. A detailed description of typical parameters was created and later simplified for use in the ranking process as provided in Table 2.

The typology effort and implementation of a weapon database was carried out in a stepwise approach to cope with the large amount of weapons from the survey. Three levels of activity were planned; Level I - was intended to document rudimentary geometric data and qualitative descriptions so that a subset of aggressive weapons could be identified; Level II - was to provide detailed geometric and quasi-static performance measurements for the subset of aggressive weapons, and; Level III - provided performance data and analytical data for exemplar development.

The processes used to accomplish the taxonomy and exemplar development efforts are illustrated in Figure 3 with the first tier encompassing the typology or descriptive information about the weapons. The ranking process in the second tier is intended to assign a weapon performance score based solely on the typology. This information is subsequently used in the third tier to reduce the sample size making more detailed performance assessments manageable within the scope of the program. The performance assessments in the fourth tier are intended to assess tip and edge sharpness with quasi-static tests in lieu of geometric data which was not practical to measure. It is also intended to assess the weapon performance as a system, taking into account armour interactions and weapon configuration and integrity. The fifth tier attempts to consolidate the performance results to help guide the development of exemplar weapons.

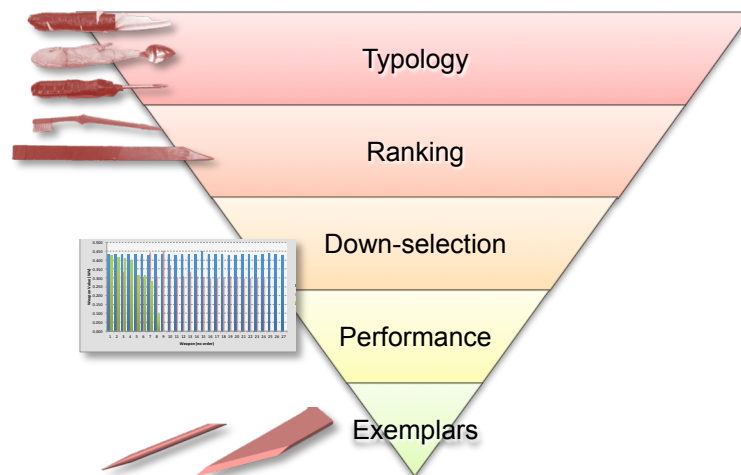


Figure 3: Exemplar weapon development process.

4. WEAPON TAXONOMY AND RANKING

Weapon performance ranking would, ideally, be based on the empirical relationships between weapon typology and performance for all weapons. However, due to the lack of available weapons for empirical investigations and availability of descriptive attributes (*i.e.* geometry, materials, intended mode of use) a weapon performance assessment method is required based solely on the attributes. Further challenges are present with the wide variety of data forms among the attributes including textual, numerical and ordinal types.

To realize a taxonomy scheme, a Multiple Criteria Decision Making (MCDM) process was used to consolidate and rank the weapon information. In principle, a weighted objective function is defined based on fundamental weapon attributes that contribute to its performance. It is of the form:

$$Objective = \sum_{i=1}^n W_i(C_i) \quad (1)$$

where:

C = the objective criterion, W = the weighting factor, n = the number of sub-criteria.

In essence, each sub-criteria, whether it be a descriptor of an attribute or assessment of performance, is prioritized in accordance to their relative contribution to performance. The sum of all the prioritized criteria then reflects the overall performance of the weapon. When completed for each weapon, the values can be ranked and grouped to identify those with the propensity to perform more effectively. It is recognized that this is an approximation of the weapons true performance but until experimentation can be conducted with a small set of down selected weapons, this is considered a viable means to classify the weapons.

Establishing the priorities or weighting factors for the criteria based solely on descriptive information is problematic as qualitative and quantitative information is used. To address this, a subset of the MCDM process called the Analytic Hierarchy Process (AHP) was used [9]. The AHP allows for consistent ranking of seemingly disparate criteria. It involves creating relative linear or non-linear rankings of paired criteria comparisons while providing an assessment of consistency between the rankings. Furthermore, it can be applied to multilevel hierarchic structures where multiple objective functions are used, typically from low level to more global assessments.

Table 2: Weapon system level ranking and contributions.

Description	Function	Attributes	Comments
Attribute Level:			
Tip Feature	Perforation	Tip Material	Materials ranked by compressive modulus.
		Tip Cone	Sharper angles increase penetrability of weapon.
		Tip Width, Dia.	Related to cone angle.
		Tip Length	Related to cone angle and max. penetration possible.
Edge Feature	Cutting	No. Edges	Greater number promotes cutting and penetration.
		Edge Condition	Sharper edges promote cutting or separation.
		Edge Material	See tip material.
Blade Feature	Force delivery	Blade Width	Larger x-section allows greater effort and integrity.
		Spike Dia.	As above.
		Blade Material	Stronger materials more capable of higher loads.
		Weapon Length	Length effects buckling and stability.
		Handle Length	Effects retention of weapon and load transfer.
System Level:			
Tip	Penetrability	Tip Value	AHP method of determination.
Edge		Edge Value	AHP method of determination.
Blade		Blade Value	AHP method of determination.

The structure of the weapon data for the AHP criteria used in the study is presented in Table 2 having similar attributes to those identified in the literature. The attribute level AHP, such as the effectiveness of the tip, is based on the weighted contributions of the tip perforation performance, which in turn is based on the weighted contributions of material, cone angle, diameter/thickness and length. In comparison, the system level AHP criteria take into account the combined weighted contributions from the tip, edge and blade of the weapon.

The hierarchical process is applied to the tip, edge and blade as shown in Figure 4 where the criteria are identified as Tip Value (TV), Blade Value (BV), and Edge Value (EV). The criteria are defined below but are noted to use information directly from the topology database and from computed performance estimates. The weighting factors are denoted by the lower case letters, which are determined for each application level of the AHP.

$$\text{Weapon Value } WV = a(TV) + b(BV) + c(EV) \quad (2)$$

where:

- WV = the system level assessment of the weapon performance,
- TV = Tip Value, performance assessment of the tip,
- BV = Blade Value, performance assessment of the blade,
- EV = Edge Value, performance assessment of the edge, and;
- a, b, c = weighting factors determined from the AHP.

The weighting values are determined through the AHP where expert opinion is provided in terms of relative weightings between matched pairs of criteria. For the Weapon Value, the weightings are provided in Table 3 which indicates that the tip value criteria has the greatest contribution to weapon performance followed by the blade and edge. Total weightings are normalized to a value of one by way of the AHP.

Table 3: Weapon Value weightings.

Criteria	Weightings	
TV - Tip Value	a	0.78
EV - Edge Value	b	0.07
BV - Blade Value	c	0.15
Total		1.00

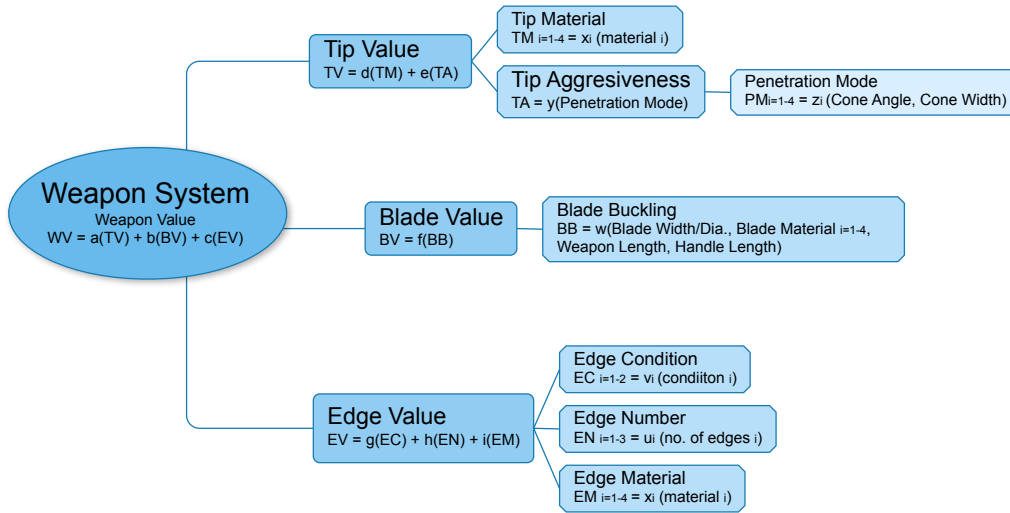


Figure 4: Hierarchical structure of the weighted weapon performance assessment function.

For the Tip Value, there were four calculated modes of penetration depending on the geometry of the weapon and its interaction with stab resistance woven fabrics. For pointed weapons, the mode of penetration was assumed to be one of fibre separation and the cross-sectional area of the weapon presented at maximum allowable penetration depth was used to approximate the resisting forces. For blunt tips, a shear failure mode was assumed and the width or diameter is ranked to approximate the number of fibres involved. In all cases, frictional forces and dynamic effects are ignored due to the lack of data in the initial typology. The Tip Value parameters are provided in Equation (3) and a topographical depiction is presented in Figure 5.

The AHP process was used to develop an overall ranking of the weapons performance as a system including the contributions from the tip, edge and blade. A sample of the Weapon Value for the bladed survey weapons is presented in Figure 6 showing the relative contributions of each attribute. A high Weapon Value predicts an aggressive weapon in terms of its penetrability against woven fabric armour systems. It should be noted that many rankings are based on coarse qualitative descriptions of the weapons and, as a result, the rankings are equally coarse but provide sufficient specificity to identify marginally performing weapons.

$$\text{Tip Value } TV = D*d(TM) + E*e(TA) \quad (3)$$

TV = Tip Value, performance of the tip,
 TM = Tip Material, performance of the tip material,
 TA = Tip Aggressiveness, performance of the tip geometry,
 d, e = weightings for TM (0.04-0.58) and TA (0.06-.53),
 D, E = weightings for TM (0.5) and TA (0.5).

$$\text{Blade Value } BV = F \cdot f(BB)$$

$$\begin{aligned} BV &= \text{Blade Value, performance of the blade,} \\ BB &= \text{Blade Buckling, normalized buckling performance,} \\ F, f &= \text{weighting factors for the BB assessment (0.0-1.0).} \end{aligned} \quad (4)$$

$$\text{Edge Value } EV = G \cdot g(EC) + H \cdot h(EN) + I \cdot i(EM)$$

$$\begin{aligned} EV &= \text{Edge Value, performance of the edge,} \\ EC &= \text{Edge Condition, the qualitative sharpness of the edge,} \\ EN &= \text{Edge Number, the number of cutting edges,} \\ EM &= \text{Edge Material, performance of the edge material,} \\ g, h, i &= \text{weighting factors } g (0.17, 0.83), h (0.16-0.54), i (0.04-0.58) \\ G, H, I &= \text{weighting factors for the relative importance of} \\ &EC (0.26), EN (0.41), EM (0.33). \end{aligned} \quad (5)$$

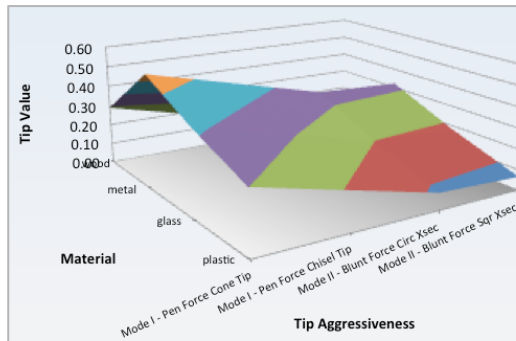


Figure 5: Tip Value topography based on weapon penetrability and material.

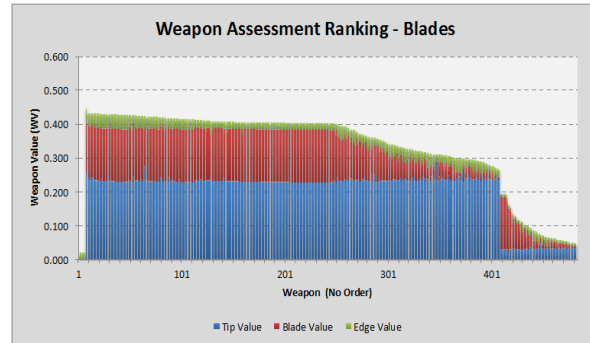


Figure 6: Weapon value rankings for bladed styles.

5. WEAPON DOWN-SELECTION

To reduce the number of weapons from the survey to a manageable amount for performance evaluations, a down-selection process was carried out by selecting the upper quintile of the Weapon Values for each weapon type (*i.e.* blade, spike, stake). In cases where there were insufficient weapons to meet the targeted sample size of 25 weapons, either the upper quartile was selected or lower ranking weapons were selected.

6. WEAPON PERFORMANCE ASSESSMENT

Upon completion of the down selection efforts, a higher degree of detail was required on weapon penetrative performance and geometry for development of the exemplars. Ideally, the geometric details of the weapon can also be used to characterize weapon performance such as the tip radius, tip cone angle, edge radius, edge profile, blade strength, blade stiffness and material strength. However, due to the imprecise manner in which the weapons were fabricated and the difficulty in obtaining extremely precise measures of radii and included angles, an alternate approach was used in which appropriate performance tests of the tip sharpness and edge sharpness were conducted. Additional tests included quasi-static armour push-through performance, blade hardness and flexural stiffness.

6.1 Tip Sharpness

The most current method for tip sharpness evaluation has been proposed in the HOSDB Spike and Knife Resistance standard [10] and adopted by the NIJ 0115.00 stab resistance standard. The methods rank the penetrating force required to indent a controlled material as a means to quantify sharpness and can be used as a relative ranking tool. In the current study, tip sharpness was assessed with a similar setup to NIJ 0115.00 where the indenter of a hardness machine was replaced with the tip of the weapon. The resisting force required to indent a block of pure lead to a depth of 3 mm was measured. This provides constant interaction with the tip and was felt to better represent the interactions with armour systems. Further, the lead indentation block was selected in order to not damage the softer metals used in the improvised weapons.

6.2 Edge Sharpness

The edge sharpness test methodology was based on the principles developed by CATRA and proposed by Watson which measure the force required to press the edge of a weapon into a silicone rubber substrate [7]. For the current study, the force required to press the edge of the blade into a silicone rubber strip of constant width at a given depth was measured. The tip was aligned with the front edge of the silicone rubber and the edge was parallel to the surface. The portion of blade edge interacting with the silicone was controlled by the width of the rubber strip. The rubber strip was wrapped around a rod to provide some surface tension as the edge cuts through the surface, thereby reducing interaction with the sides of the blade and reducing frictional effects, as intended by the CATRA test methods. The selected method provides an approximation of the edge sharpness as there are potentially different edge interactions with various armour materials (*i.e.* fabric, chainmail, metal/ceramic plates).

6.3 Blade Hardness

Knowledge of the weapon's blade material strength can be inferred from its hardness as this relates to the yield strength. A standard Rockwell indenter test method was employed using the Rockwell "B" scale, being more appropriate for soft metals such as mild steel, aluminum and brass. Due to the small size of the indenter used, it provides local hardness measurements and is less susceptible to surface flatness deviations. The hardness test method employs a Rockwell tester to apply a standard preload to a 1.59 mm diameter steel ball indenter followed by a major load (100 kg) after which the depth of indentation is measured and the hardness number determined. For the improvised weapons, accuracy may vary depending on the surface curvature, finish and rigidity of the backing. Very small diameter spikes could not be measured due to the high curvature and small size.

6.4 Push-through Tests

Quasi-static push-through tests were conducted with representative armour, Twaron Microflex® (550 DTEX) Special HS, to provide a rudimentary assessment of weapon system performance. The method involved placing a fabric sample in an Instron machine and clamping the sample around its periphery with slack removed, Figure 7. A NIJ 0115.00 foam backing pack was placed in intimate contact with the underside of the sample to provide some level of support and penetration measurement capability. A weapon was placed in the Instron head and clamped at the handle. The instantaneous force and displacement were measured until a maximum stroke of 25 mm was achieved. Actual penetration derived from the witness paper or backing penetration depth was not possible due to tearing and snap-through effects, respectively.

The number of layers of fabric was chosen to allow the majority of weapons selected to marginally perforate the fabric layers in order to obtain data on the force and work required to achieve perforation. Selection of a more robust armour system preventing perforation would not result in meaningful performance data. A total of 3 layers of Twaron Microflex® was selected for all tests.



Figure 7: Push-through test.

6.5 Results

The force data collected for the weapon subset is presented in Figure 8. The weapons are ranked by peak force measured during the controlled push-through tests. The corresponding forces required to perforate the first and second of the three layers of armour are also presented as Force L1 and Force L2, respectively. The maximum work or energy expended during the 25 mm stroke is also provided for each weapon.

It may be observed that the peak force corresponds well to the perforation forces of individual layers and that the energy also tracks well with the peak force. These trends provide a basis for further creating a weapon subset that eliminate relatively dull and underperforming weapons.

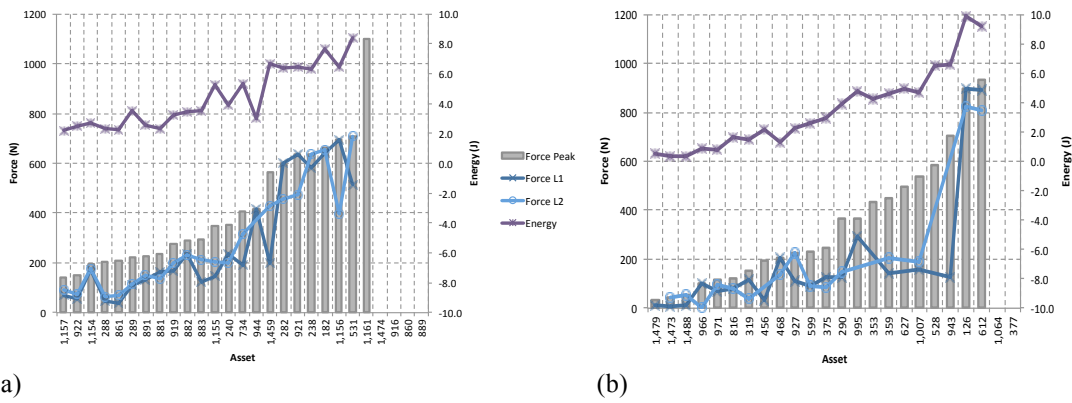


Figure 8: Quasi-static push-through test results; (a) blades; (b) spikes.

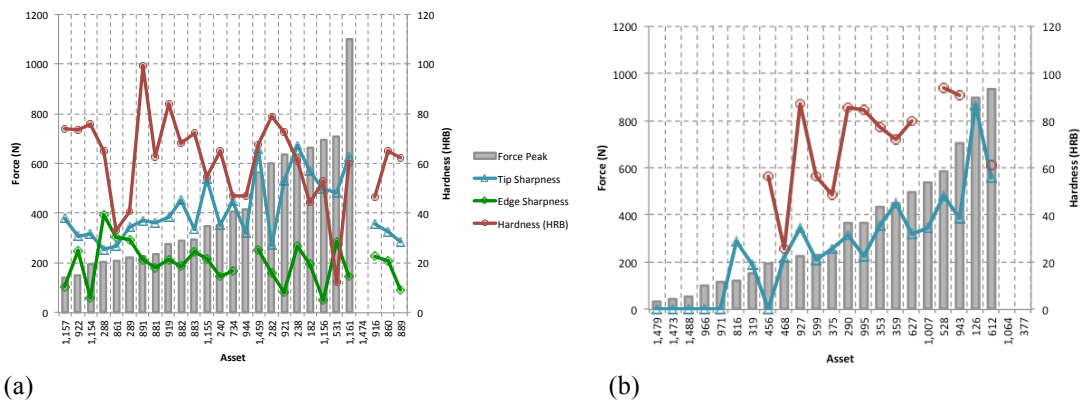


Figure 9: Test results for tip/edge sharpness and push-through; (a) blades; (b) spikes.

The tip and edge sharpness performance results of the weapon subset is presented in Figure 9 and are ordered by push-through force. The sharpness values reference the secondary axis and should be read as Newtons. No spike tip sharpness values were obtained for six weapons due to difficulty in performing the indentation test without significant bending of the weapon body.

The weapons with low peak forces tend to exhibit higher tip sharpness values (lower force) for both the blades and spikes. Edge sharpness for the blades did not correspond to peak force. Material hardness readings for the blades and spikes presented in the figures vary considerably and may be partly due to material composition, weapon geometry or support conditions. The average of three hardness readings was reported to reduce these variations.

7. EXEMPLAR WEAPON DEVELOPMENT

Exemplar development was to be based on the geometric and physical attributes of the weapon subset identified during the quasi-static performance assessments. Upon analysis of the geometric and performance data from the weapon subset, it was decided to create a further subset of 9 bladed and 9 spiked weapons based on the push-through performance. No stakes were chosen due to the small test sample size and overlapping performance with the other weapon types. The selected blades and spikes together represent 1.3% of the weapon survey exhibit higher penetrative performance. An example of the bladed and spiked weapon subset is illustrated in Figure 10.

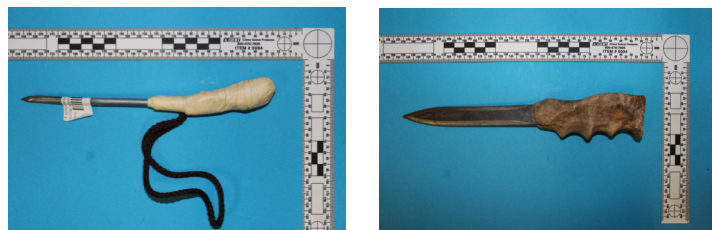


Figure 10: Sample bladed and spiked weapons.

Inspection of the bladed weapons revealed two distinctive blade styles; double-edged symmetrical and single edged with single grind. Similarly, two distinct spike styles were noted; a small diameter short-tapered tip and a larger diameter long tapered tip. From these, four exemplar specifications were created on averaged geometric and physical properties of the weapon subset. The geometry of the exemplars was further influenced by the need to replicate the buckling modes and

lateral flexural stiffness of the weapons in addition to maintaining, to the extent possible, compatibility with the NIJ 0115.00 test equipment and configuration.

The four exemplar types were denoted as: T1 - a blade with single sharp edge, single grind, asymmetrical taper with rectangular cross section; T2 - a blade with double edged, double grind, symmetrical taper with rectangular cross section; T3 - a spike of small diameter, short tapered tip, and; T4 - a spike of medium diameter rod and long tapered tip. These are illustrated in Figure 11. The materials for the exemplars were of mild steel with Rockwell Hardness "B" levels ranging from 55 to 80, *i.e.* much softer than the current NIJ 0115.00 blades. Single hardness levels were selected for each threat style and all subsequent tests.

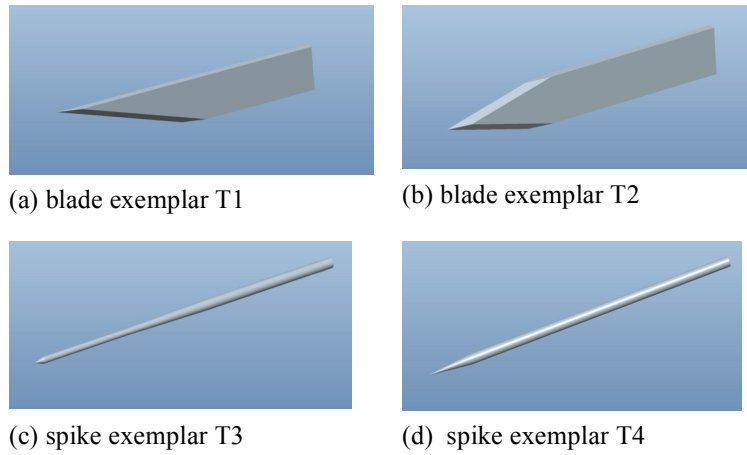


Figure 11: Depiction of the exemplar weapons.

The tip and edge sharpness specifications of the exemplars was based on trials with different sharpness levels achieved by having equal amounts of material ground flat from the tips and edges (approx. 0.005-0.200 inch depth) until a match was found with the averaged push-through performance of each weapon style. Comparison of the exemplar performance from single tests to the averaged survey weapon subset measurements is found in Figure 12. The dashed lines represent the average survey weapon values and the exemplar sharpness levels denoted by the label suffix. For example, the label TIC-1 refers to exemplar T1 (design variant C) with sharpness Level 1 (0.005 inch grind depth). The final exemplars are indicated by the ellipses in the figures.

The bladed exemplars exhibited some push-through performance variability while the peak force increased for spiked exemplars as the tip sharpness decreased. Disparity between the exemplar tip/edge sharpness measurements and the averaged survey weapon data was noted, however, the reasons for this are not fully understood but are thought to be attributed to differences in surface finish, edge geometry, material hardness and test variability.

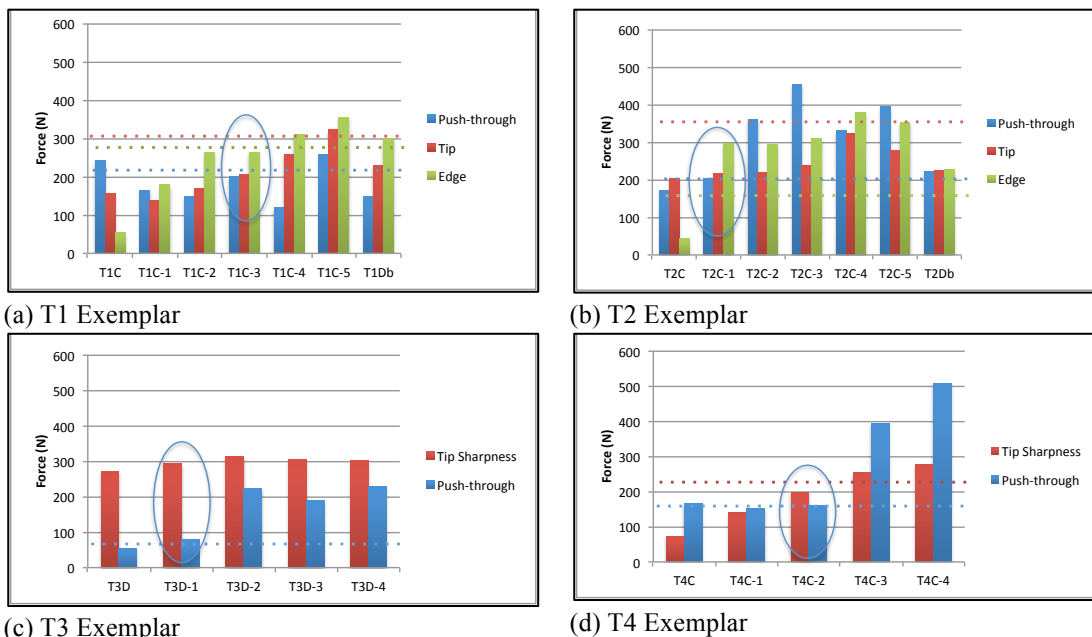


Figure 12: Exemplar quasi-static performance compared to weapon data (dashed lines).

Final performance assessment of the exemplars was carried out with dynamic drop tests with the objective of finding the number of layers required to meet the 7 mm penetration performance limit of

NIJ 0115.00. The test methodology specified in NIJ 0115.00 (Level 3, E1) was used as a basis and augmented with a V_{50} type approach (e.g. MIL-662F, STANAG 2920, NIJ 0101.06), to estimate the number of armour layers required to meet the penetration limit with a 50% risk of failure. This so-called L_{50} level was established for the exemplars best matching the quasi-static performance of the weapon subsets and is presented in Table 4. Armour materials were chosen to best suit the bladed and spike type threats and resulted in less layers to defeat the proposed exemplars compared to published results for the P1/A and S1/G exemplars in NIJ 0115.00.

Table 4: L_{50} assessment results for all exemplars.

Threat	Armour	L50 Mean	Low	High	Std. Dev.
T1C-3	Twaron Aramid SRM 509/930, loose layup	12	10	13	1.3
T2C-1	Twaron Aramid SRM 509/930, loose layup	12	9	14	1.9
T3D-1	Twaron Aramid Fabric - Microflex 60" (550 DTEX) Special HS, loose layup	5	3	6	1.3
T4C-2	Twaron Aramid Fabric - Microflex 60" (550 DTEX) Special HS, loose layup	7	5	8	1.3

8. SUMMARY AND RECOMMENDATIONS

In summary, four exemplar weapons were developed to represent the threats found in correctional facilities and may be considered for future updates of relevant body armour performance standards such as NIJ 0115.00. The following findings and recommendations can be noted:

- a stab weapon typology and taxonomy were successfully developed to identify potentially aggressive threats based on descriptive information,
- quasi-static performance tests were developed to characterize tip, edge and system performance for initial down-selection of stab weapons, additional work is required to establish confidence levels and potential for quality control measures of the exemplars,
- two bladed and two spiked exemplar weapons were developed from the geometric and performance characteristics of a weapons obtained from correctional facilities in the US,
- the proposed exemplars require a lesser number of armour layers to meet the current penetration limits of NIJ 0115.00 in comparison to the P1/A and S1/G exemplars.
- Greater use of the exemplars from the practitioners is required to fully understand their implications on armour design, relevancy and test variability.

Acknowledgements

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