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Comparing the penetrative stab performance of the UK HOSDB P1/B and Stanley Tools 1992 trimming blades on certified body armour specimens

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Abstract

This body of research assessed the penetrative stab performance of the United Kingdom Home Office Scientific Development Branch's (HOSDB) P1/B certified blades against the readily accessible Stanley Tools 1992 trimming blade. All tests were performed against the HOSDB KR1-E1 impact energy of 24 Joules on HOSDB KR1 certified body armour specimens. Results demonstrated that the Stanley 1992 trimming blade posed a 30% greater stab threat in comparison to the HOSDB P1/B blade.

This paper demonstrates the threat imposed by readily available utility blades and a requirement to enhance existing body stab resistant body armour test procedures testing procedures.

KEYWORDS: Body Armour, HOSDB, Stab Resistance, Stanley Blade, Protective Clothing,

1. Introduction

Within the United Kingdom (UK) the Home Office Scientific Development Branch (HOSDB) is tasked with establishing and enforcing standards for the design and certification of body armour for use by Police officers (Croft and Longhurst, 2007a; Johnson, 2014). Body armour used by these professionals is typically required to provide protection against an array of blunt force, stab, and/or ballistic threats (Croft and Longhurst, 2007b, 2007c).

In 2007 the UK HOSDB published comprehensive documentation outlining the *"...test requirements and methods for manufacturers of body armour to achieve successful compliance..."* when developing stab resistant body armour - entitled HOSDB Body Armour Standards for UK Police, Part 3: Knife and Spike Resistance (Croft and Longhurst, 2007c).

Three levels of stab resistant protection were outlined within the UK HOSDB knife resistant (KR) body armour standard; KR1 at 24 joules (J) of stab energy, KR2 at 33 J, and KR3 at 43 J. The standard also outlined use of instrumented drop-test apparatus, appropriately conditioned backing material, and HOSDB P1/B engineered test blades should be used for test certification (Croft and Longhurst, 2007c).

At each of the stab energy levels previously documented, the maximum acceptable level of blade penetration through the underside of any test specimens is set at 7.00 mm. Blade penetration greater than this depth would result in an unacceptable level of protection, and could potentially lead to significant injuries being sustained by the wearer of such armour (Croft and Longhurst, 2007c; Johnson et al., 2013).

Police officers face an array of bladed threat during operation, including but not exclusive to: (Scott, 2005)

- Domestic knives – Primarily a stainless steel construction and very sharp when new, however become blunt relatively quickly.
- Lock knives – Lock in an extended position to prevent closure.
- Sheath knives – Typically used in outdoor activities and possess strong blades.
- Combat knives – Such knives include flick-knives and butterfly knives.
- Utility knives – Typically disposable blades which are often used in DIY applications

Research has documented that short, stiff, thin blades such as those found within lock, sheath and utility knives can penetrate the skin using a level of force which *"...can be applied with a finger and thumb"* (Green, 1978). To put this into context, such blades have been shown to penetrate skin with a mass of less than 1 kg, whilst kitchen knives required a mass of 4 kg to penetrate (Green, 1978)**.**

It could therefore be suggested that body armour designed to provide protection against the HOSDB P1/B blade may not be suitable at providing the same level of stab protection when tested using a comparably thinner and arguably more readily available threat. The primary objective of this experiment was therefore to assess the stab performance of HOSDB P1/B blades specified within the UK HOSDB Body Armour standard, against more readily available Stanley 1992 utility trimming blades, via the stab testing of HOSDB KR1 certified body armour specimens (Johnson, 2014).

2. Experimental Methodology

To assess blade penetrative performance, there was a requirement to establish a stab test methodology in which the chosen blades were dropped in a controlled experimental environment. The following sections therefore detail the methodology used within this experiment.

2.1 Stab Test Procedure

2.1.1 Drop Tower

All stab tests were performed using an 'Instron 9250HV' instrumented impact tower, as shown within Figure 1.

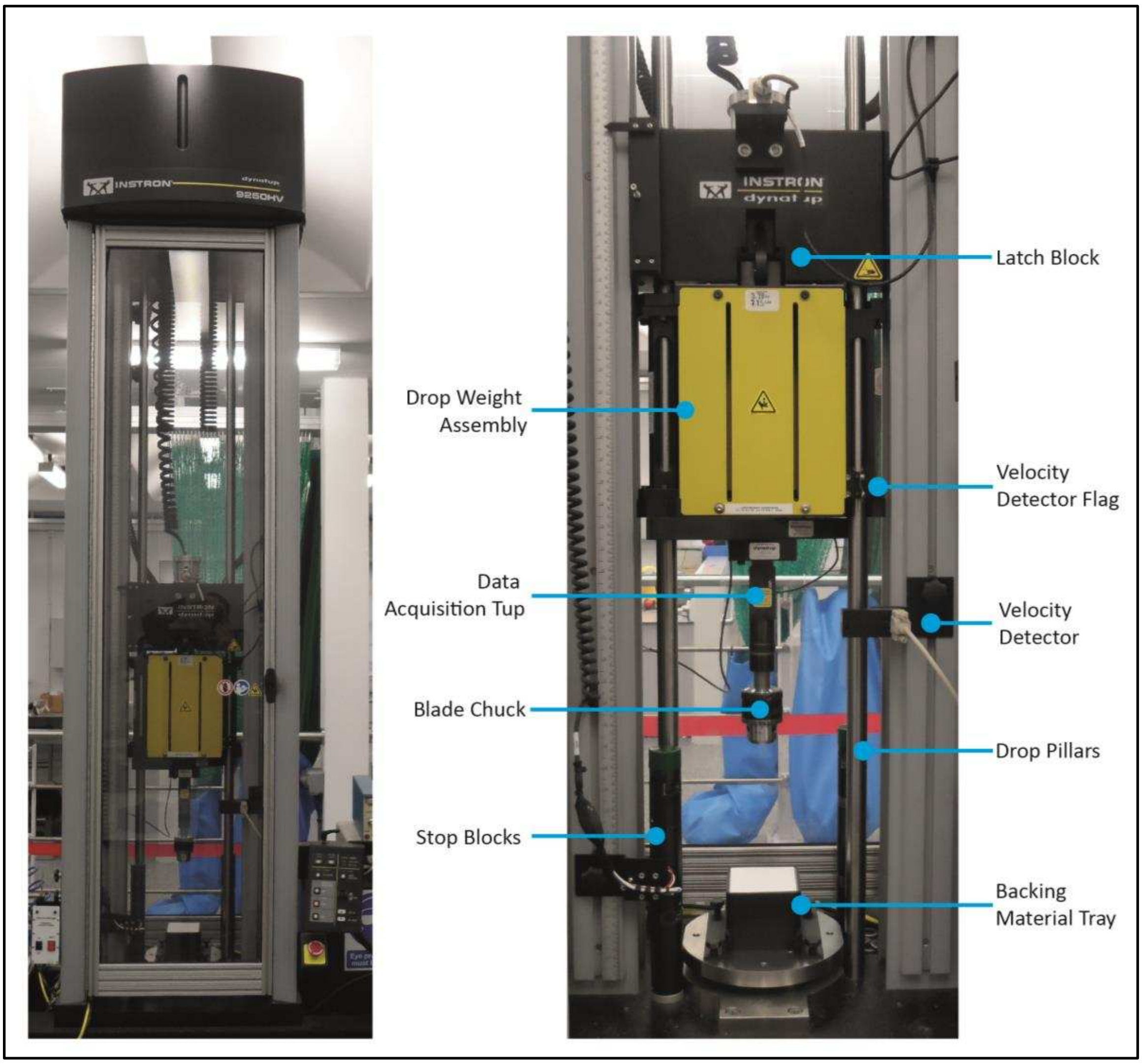

Figure 1: Instron 9250HV Drop Tower (left) & schematic (right)

The latch block shown in Figure 1 was used to hoist the drop weight assembly and attached blade to the required drop height. The drop weight assembly was then released using the drop pillars as guides [1]. Prior to installation of the test blades, the total mass of the drop weight assembly, including the data acquisition tup and blade chuck was calibrated at 6.50 kg.

Velocity detecting apparatus was used to validate the performance of each impact test. A velocity detector was mounted within the drop tower enclosure, while a velocity detector flag located on the drop vehicle assembly was used to activate the detector [1]. Two stop blocks were also installed to prevent damage to the drop vehicle and to control the maximum distance the blade was able to travel.

Operation of the drop tower was controlled via the Instron Dynatup Impulse data acquisition software system which accurately controls machine parameters and records the data gathered from testing (Instron Corporation, 2003).

2.1.2 Level of Impact Energy

Testing was performed to the first level of stab impact energy as defined by the UK HOSDB KR1-E1 (Croft and Longhurst, 2007c). These requirements are documented within Table 1.

Table 1: UK HOSDB Knife Resistant Level One Protection Requirements

Energy Level	Stab Energy (Joule)	Maximum Blade Penetration (mm)
KR1-E1	24 +/- 0.5	7.00

By using the requirements outlined within Table 1, and the settings documented within section **Error! Reference source not found.**, the estimated height and velocity of the drop vehicle was calculated assuming the following conditions:

- Drop vehicle mass - 6.5 kg
- Stab impact energy - 24 J
- Acceleration due to gravity - 9.81 m/s (assuming no friction/air resistance)

To establish the drop height required to generate stab impact energy of 24 J, the formula outlined within Equation 1 was rearranged.

Equation 1: Calculating drop height (Georgia State University - Department of Physics & Astronomy, 2013)

$$Energy\ (PE) = Mass\ (m) x\ Gravity\ (g) x\ Height\ (h) \quad (2a)$$

$$\frac{PE}{m\ x\ g} = h \quad (2b)$$

$$\frac{24}{6.50\ x\ 9.81} = \mathbf{0.376\ m} \quad (2c)$$

The velocity of the drop vehicle was also calculated using Equation 2.

Equation 2: Calculating drop vehicle velocity (Trimm, 2005)

$$Potential\ Energy\ (PE) = Kinetic\ Energy\ (KE) \quad (3a)$$

$$mgh = \frac{1}{2}mv^2 \quad (3b)$$

$$gh = \frac{1}{2}v^2 \quad (3c)$$

$$\sqrt{2gh} \quad (3d)$$

$$\sqrt{2\ x\ (9.81\ x\ 0.376)} \quad (3e)$$

$$\sqrt{7}.377 \quad (3f)$$

$$= \mathbf{2.716\ m/s} \quad (3g)$$

The test requirements previously outlined within Table 1 were therefore enhanced with the inclusion of the calculated drop mass, height and velocity settings – as documented within Table 2.

Table 2: Stab test experimental requirements

Energy Level	Stab Energy (Joule)	Drop Mass (kg)	Drop Height (m)	Drop Velocity (m/s)	**Maximum Blade Penetration (mm)**
KR1-E1	24 +/- 0.5	6.50	0.376	2.716	7.00

At the KR1-E1 impact energy of 24 J (+/- 0.5 J) and featuring a vehicle drop mass of 6.50 kg, a drop height of 0.376 m and velocity of 2.716 m/s was calculated. These figures were in-line with those automatically generated as part of the Instron Impulse control system.

All experimental tests were performed in an ambient environment within a temperature range of 21°C +/-6, and a relative humidity range of 30-70% as defined by the HOSDB (Croft and Longhurst, 2007c).

2.1.3 Backing Material

Roma Plastilina® No. 1 clay was used as the backing material for all tests – as defined by HOSDB body armour standards (Croft and Longhurst, 2007b; Croft, 2003). The backing material was housed within a series of three steel fabricated trays filling a volume measuring 84 x 84 x 70 mm, as shown in Figure 2.

Figure 2: Roma Plastilina® No.1 clay and backing tray

During testing, each clay housing tray was temporarily secured to the bed of the drop tower via the attached angle iron bars, as previously shown in Figure 1. Each tray was thermally conditioned at a temperature of 30°C for three hours using an Alpha 190H temperature chamber manufactured by Design Environmental Ltd. When conditioned to this temperature, the Roma Plastilina® clay is regarded as a flesh simulant, and therefore provides appropriate mechanical support and a means to measure armour deflection and penetration (Horsfall, 2000).

2.2 Blade Selection

The penetrative performances of two blade types were compared within this experiment:

1. HOSDB P1/B OEM engineered blade - long and thick.
2. Stanley Tools 1992 Trimming blade - short and slender.

HOSDB stab resistant body armour standard calls for the use of the standardised HOSDB P1/B blades which were manufactured and supplied by 'High Speed and Carbide Ltd.' – an approved HOSDB blade supplier (Croft and Longhurst, 2007c). An example of the P1/B blade is shown within Figure 3.

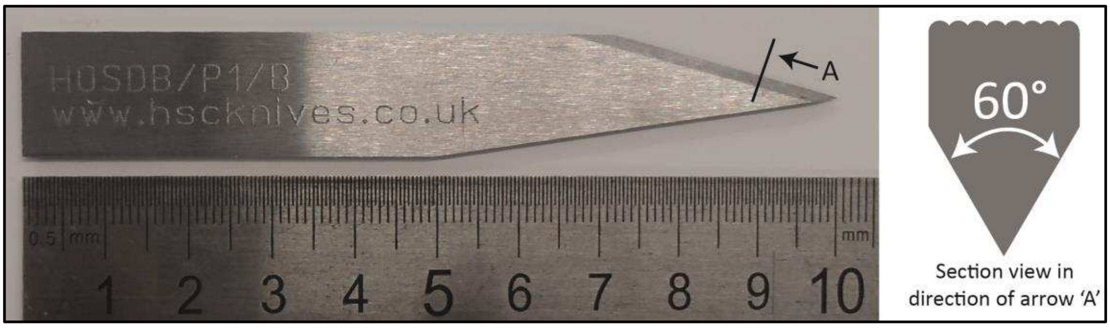

Figure 3: HOSDB P1/B Blade

Supplied by 'High Speed and Carbide Ltd', the P1/B blades measured 2.00 mm (+/- 0.05 mm) thick, and featured a double sided cutting edge with an angle to each other of 60° (Croft and Longhurst, 2007c). Each blade had a measured mass of 18.15 grams, and was manufactured from BO1 grade ground flat stock BS4659 steel – a non-shrinking, oil hardened tool steel, and were hardened and tempered to 52-55 Rockwell C (Croft and Longhurst, 2007c).

As previously noted, documented literature has suggested that short, thin blades could potentially be more potent in their stab performance. Therefore it was determined that the second blade used within this experiment would be one of the most common utility blades currently available – the Stanley Tools 1992 Trimming blade. This blade is shown within Figure 4.

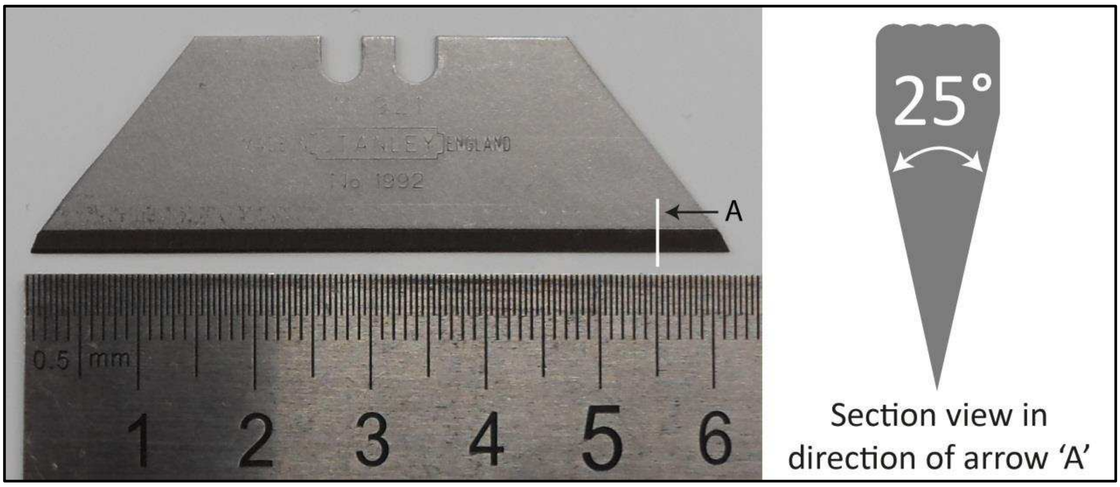

Figure 4: Stanley Tools 1992 Trimming Blade

Each Stanley blade had a mass of 3.80 grams, measured 62.00 mm in length, 19.00 mm high, was 0.65 mm thick, and also featured a double sided cutting edge with an angle to each other of approximately 25° (Stanley Black & Decker UK Ltd, 2013).

A summary of both the HOSDB P1/B and Stanley 1992 trimming blades is outlined within Table 3.

Table 3: HOSDB P1/B and Stanley 1992 Trimming Blade Summary

	HOSDB P1/B	1992 Trimming Blade
Length (mm)	100.00	62.00
Height (mm)	15.00	19.00
Thickness (mm)	2.00	0.65
Mass (g)	18.15	3.80
Angle between cutting edges (°)	60	25
Material	BO1 grade ground flat stock BS4659	Polished steel (grade unknown)
Manufacturer	High Speed and Carbide Ltd	Stanley Black & Decker UK Ltd

2.3 Body Armour Test Specimens

Test specimens were taken from a rigid PC stab resistant breastplate certified to provide protection to the UK HOSDB KR1 standard. The PC breastplate is shown within Figure 5.

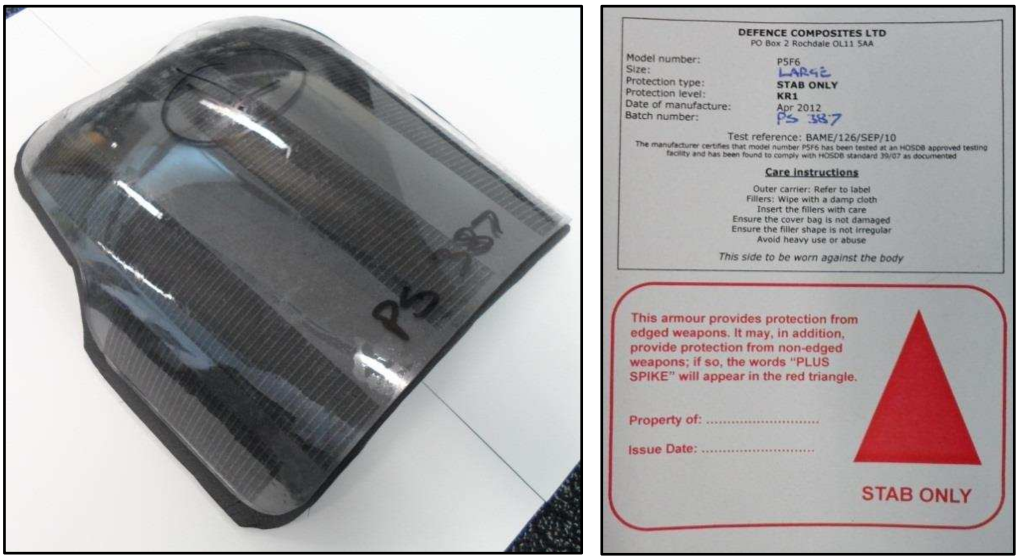

Figure 5: KR1 Polycarbonate Body Armour Breastplate (courtesy of PPSS Group)

The armour was manufactured by Defence Composites Ltd., and was kindly supplied by Robert Kaiser of the PPSS Group – specialists in high performance body armour and PPE (PPSS Group, 2012).

A series of 12 specimens were extracted from the armoured breast plate, each measuring 60 x 60 mm in length and width. The locations in which the test specimens were extracted from the armoured breastplate are identified within Figure 6.

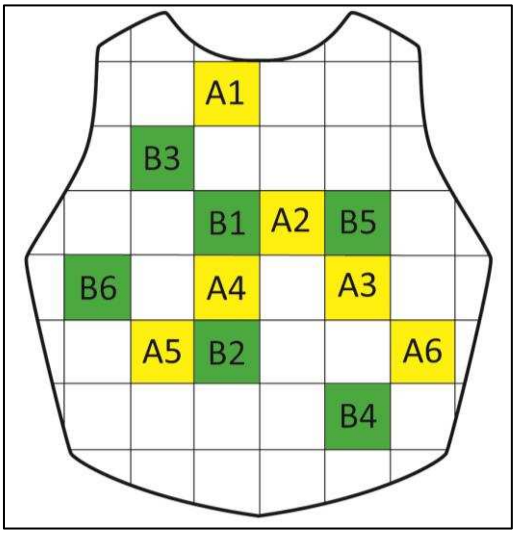

Figure 6: Experiment One body armour test specimen locations

Specimens were randomly selected to minimise any stab performance effects as a result of their location within the body armour breastplate. Test specimens designated 'A' were used when testing the Stanley blades; while 'B' designated specimens were used during testing of the HOSDB P1/B blades. An example of the body armour test specimens is shown within Figure 7.

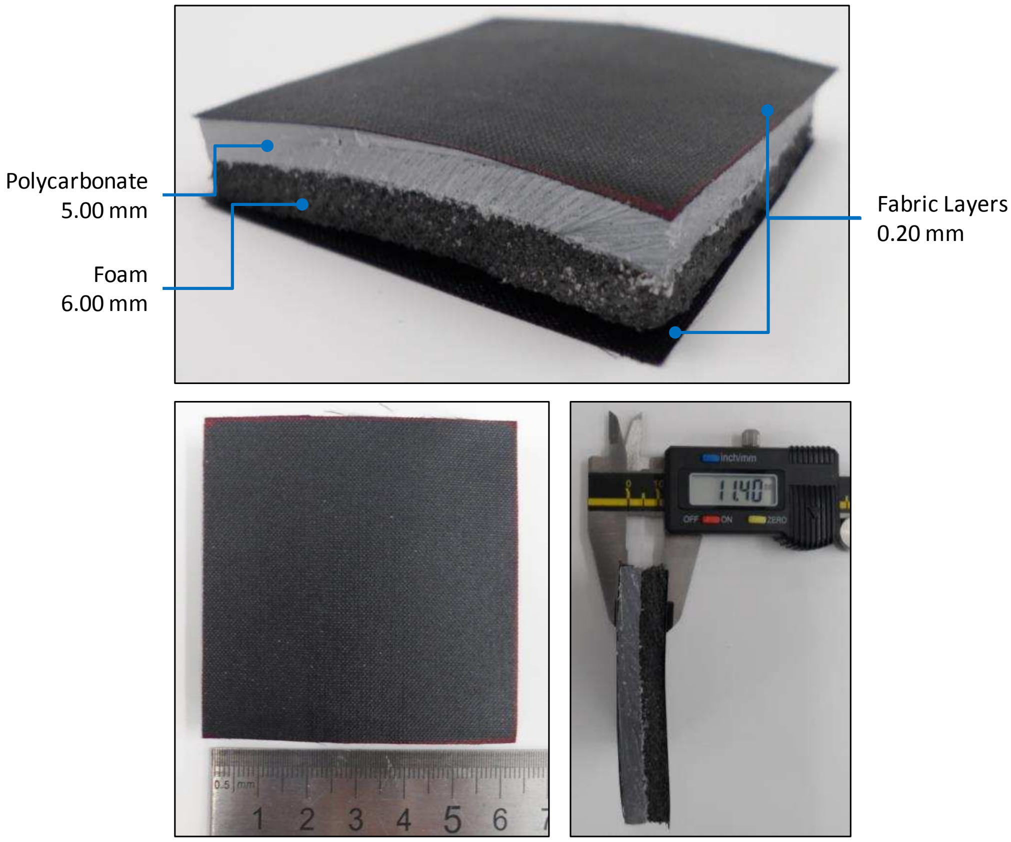

Figure 7: KR1 body armour test specimens

Each test specimen measured 11.40 mm thick, and comprised of a 5.00 mm thick layer of moulded polycarbonate and a 6.00 mm thick foam backing layer, sandwiched between two 0.20 mm thick layers of fabric (PPSS Group, 2012).

2.4 Experimental Design

The stab test methodology and operational procedure previously defined within section 2.6 was used within this experiment.

In total 12 tests were performed, with six tests each using both Stanley and HOSDB P1/B blades. The order of testing is outlined within Table 4.

Table 4: Experimental Order of Testing

Test Number	Blade Type	Sample Identifier	Backing Tray
1	Stanley 1992	A1	1
2	Stanley 1992	A2	2
3	HOSDB P1/B	B1	3
4	HOSDB P1/B	B2	1
5	Stanley 1992	A3	2
6	HOSDB P1/B	B3	3
7	Stanley 1992	A4	1
8	Stanley 1992	A5	2
9	HOSDB P1/B	B4	3
10	HOSDB P1/B	B5	1
11	Stanley 1992	A6	2
12	HOSDB P1/B	B6	3

To reduce the likelihood of variance within the stab penetration results obtained, the order in which the tests were performed was randomised. Additionally, a virgin blade was used for each test, and the backing trays were replaced between each experiment to maintain the thermal conditioning of the backing material.

2.5 Recording Blade Penetration

Two methods of recording knife penetration were identified. The first method of which is described within the HOSDB body armour standard for knife and spike resistance (Croft and Longhurst, 2007c).

- Method one: Measuring cut lengths in Polyart® witness paper placed between the test sample and backing material (Croft and Longhurst, 2007c) - as shown within Figure 8.
- Method two: Directly measuring blade penetration through the underside of each test sample using digital callipers - also shown within Figure 8.

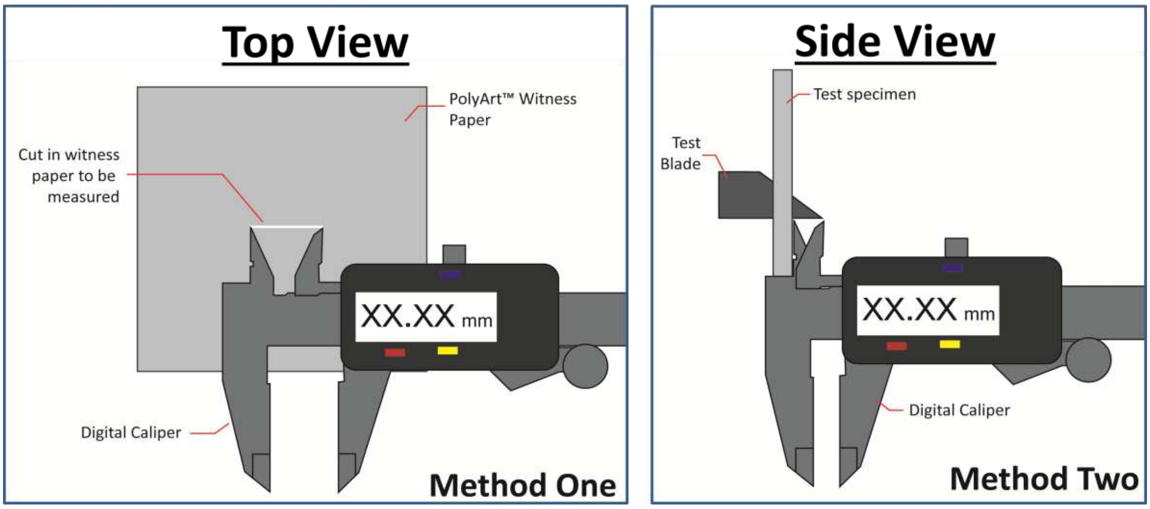

Figure 8: Illustrated examples of the two methods used to measure blade penetration

The witness paper used within the first method was 140 g/m² Polyart® paper (Arjobex Ltd, 2014; Croft and Longhurst, 2007c). Each piece of witness paper measured 80 x 80 mm and was placed between the top surface of the clay backing material, and the underside of each test specimen. The paper was used to measure the level of blade penetration through the underside of the test sample, where the length of cut in the paper related to the geometry of chosen test blades (Croft and Longhurst, 2007c). A chart for converting the cut length in the witness paper to the level of blade penetration has previously been established by the HOSDB (Croft and Longhurst, 2007c). A virgin piece of Polyart® paper was used for each stab test, with used witness paper labelled and archived accordingly (Croft and Longhurst, 2007c).

The second method of measuring blade penetration was directly measuring blade penetration via the use of digital callipers, as previously illustrated within Figure 8. This method was also chosen to assess the validity of the results gathered via use of the witness paper.

2.6 Stab Test Operational Procedure

A detailed stab test operational procedure was established (Johnson, 2014). Prior to testing all test samples were securely left in the experimental environment for a period of 24 hours. In addition, clay backing trays were conditioned for 3 hours at 30°C using an Alpha 190H temperature chamber.

A new test 'Method' was established within the Instron Dynatup software system was set up to ensure the primary test requirement of 24 Joules of impact energy was met. Appropriate visual safety checks and calibration exercises were performed to ensure the test apparatus was fit for purpose. One such calibration exercise included ensuring the velocity detector was aligned with the lower surface of the velocity flag - as shown in Figure 9.

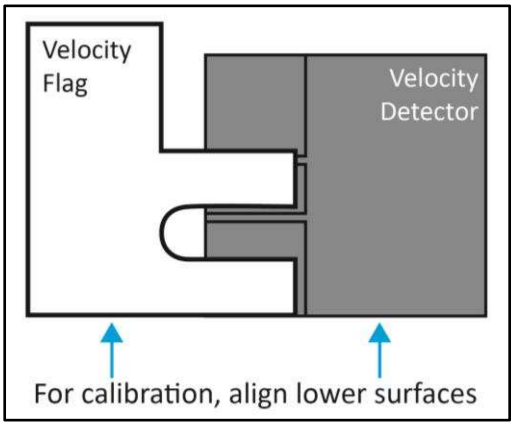

Figure 9: Calibrating the Instron 9250HV Velocity Detector [8], [9]

Once appropriate aligned, the impulse data acquisition system was able to accurately establish the required height of the drop vehicle.

To facilitate testing, a conditioned backing material tray was affixed to the bed of the drop test apparatus, with witness paper placed on the top of the clay when testing HOSDB P1/B specification blades. The designated sample was then placed on top of the witness paper and backing material tray in preparation for the commencement of testing.

The methods used to securely attach the P1/B and Stanley 1992 trimming blades to the drop tower chuck are shown within Figure 10 and Figure 11 respectively.

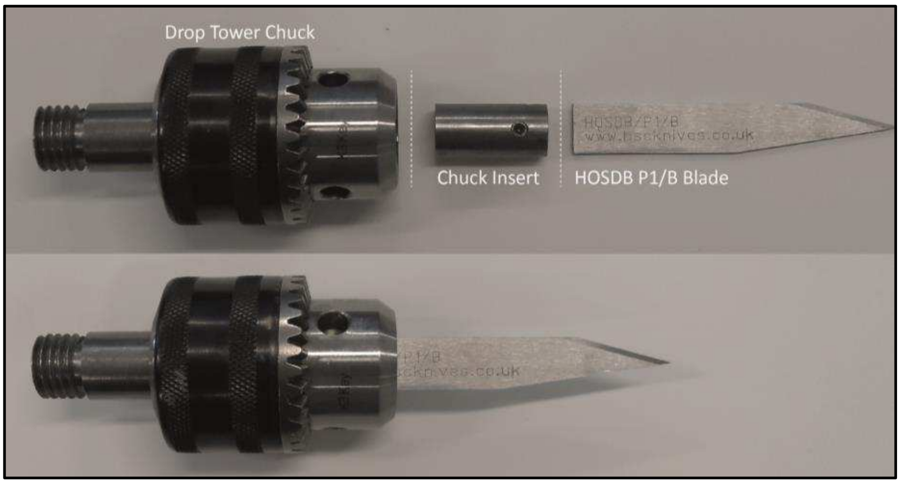

Figure 10: HOSDB P1/B Blade Assembly

P1/B blades were fastened within the chuck insert via grub screw, thus allowing both the blade and insert to be securely held within the drop tower chuck.

An assembly of the drop tower chuck featuring the Stanley 1992 trimming blade is shown within Figure 11.

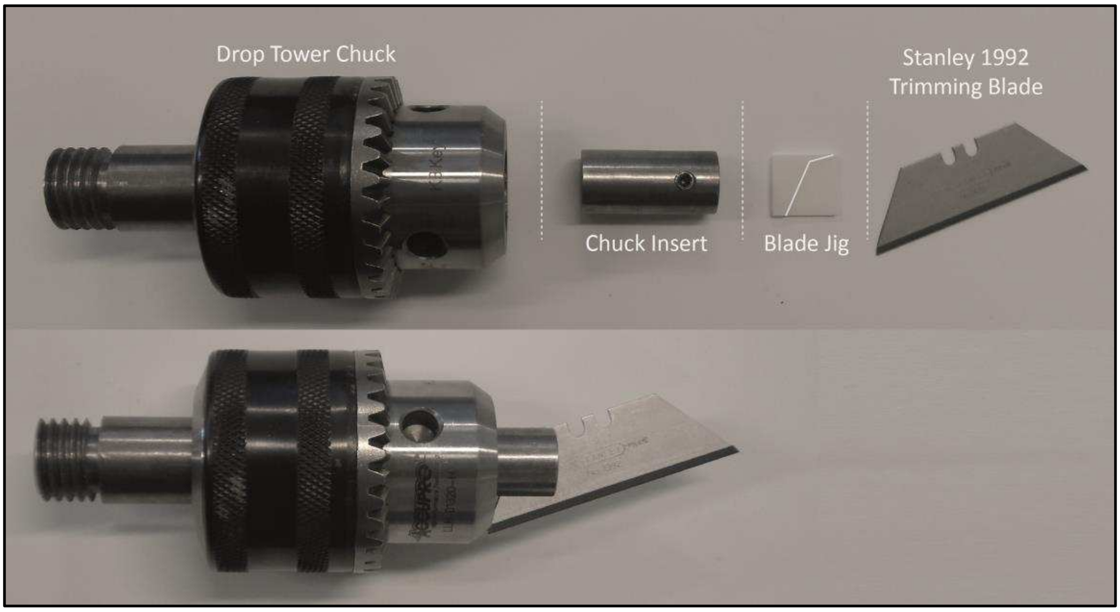

Figure 11: Stanley 1992 Trimming Blade Assembly

The Stanley trimming blade was positioned using a jig and secured within the chuck insert – allowing both P1/B and Stanley blades to feature a 15° angle between the cutting edge and central axis. The orientation of both blades is shown within Figure 12.

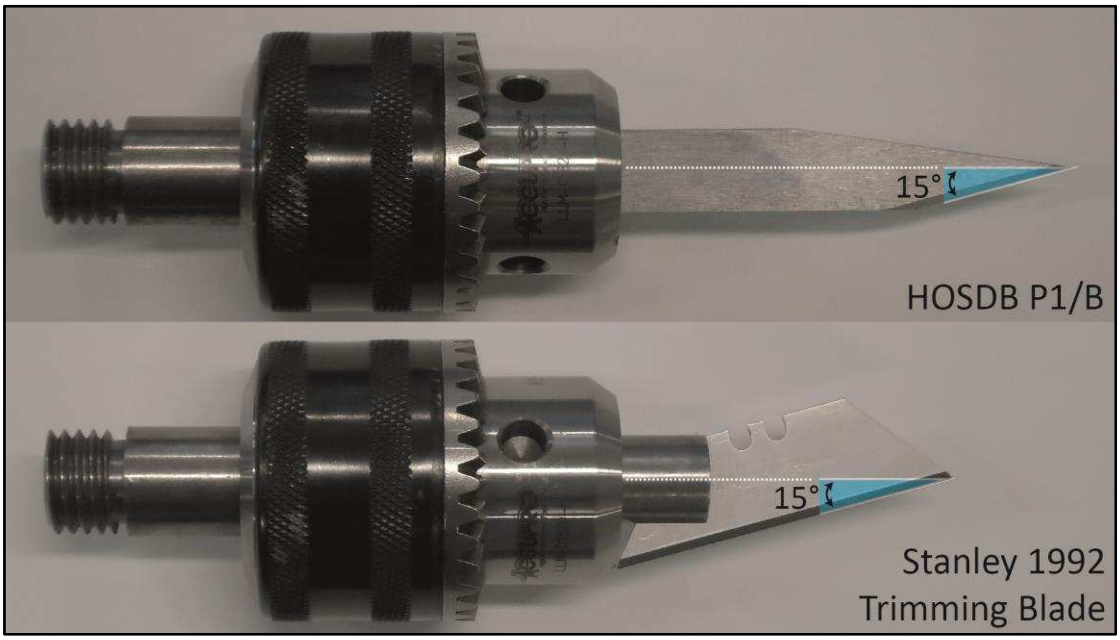

Figure 12: HOSDB P1/B and Stanley 1992 Trimming Blade cutting edge angle comparison

This process was performed to ensure that the double sided cutting edges of both blades contacted the strike surface of the test specimens at the same angle to provide a more direct comparison between blade types.

Following installation of the selected test blade and drop chuck, there was a need to zero the height of the Instron 9250HV test apparatus to allow real velocity and impact energy values to be established. The pre-established test 'method' was then run to safely raise and release the drop weight assembly to the desired impact test requirement. Following impact any blade penetration was appropriately recorded and the experimental apparatus was refreshed for further experimentation.

3. Experimental Results and Discussion

P1/B blade penetration depths were established by comparing the length of cut in the Polyart® witness paper to their respective figure - as previously documented within section 2.5. The *'Conversion Chart for P1/B Knife Penetration Depths from Witness Paper Cut Length'* documented within the HOSDB Knife and Spike Resistance Standard and Conversion Chart for P1/B Knife Penetration Depths were used (Croft and Longhurst, 2007c). Direct calliper measurements of blade penetration through the underside of all six body armour test specimens were also recorded. The highest calliper recorded blade penetration depth was 11.50 mm. In addition, blade penetration using the HOSDB P1/B blades failed to provide stab resistance below the 7.00 mm permissible HOSDB limit, as documented within Table 5.

Table 5: HOSDB P1/B Results

Sample	Mass (g)	Impact Velocity (m/s)	Impact Energy (J)	Penetration: Witness Paper (mm)	Penetration: Calliper (mm)	Difference between measurement methods (%)
1	22.74	2.71	23.75	9.04	8.99	0.55
2	21.89	2.71	23.76	8.00	8.01	0.12
3	21.58	2.70	23.67	9.13	8.92	2.32
4	21.86	2.70	23.69	9.54	9.19	3.73
5	22.46	2.71	23.72	8.89	8.75	1.58
6	22.33	2.71	23.75	11.31	11.50	1.66
Std. Deviation		0.00516	0.036697	1.100026	1.18549	-
Mean		*2.71*	*23.72*	*9.32*	*9.23*	*1.66*

An example of blade penetration using the P1/B blade is shown within Figure 13.

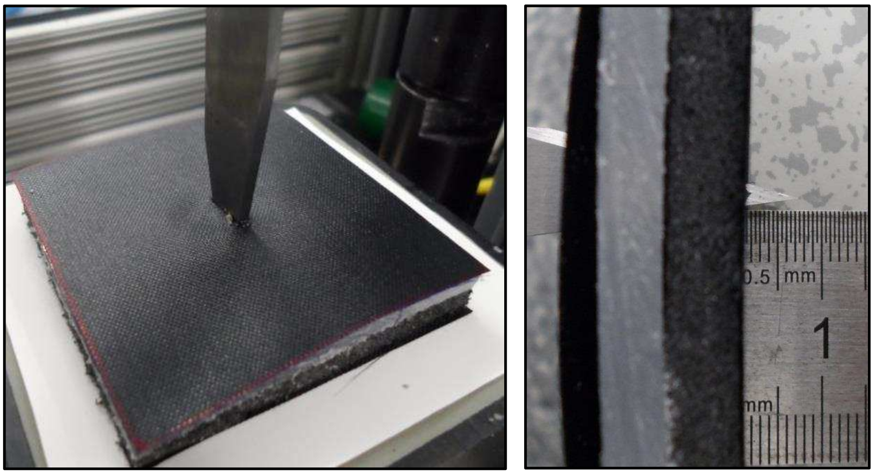

Figure 13: Test specimen two using the HOSDB P1/B blade

In contrast, the results from stab testing the KR1 certified body armour test samples using the Stanley 1992 trimming blade are shown in Table 6.

A maximum 30.00 mm blade penetration was assigned to each Stanley blade test as the maximum distance of travel for the drop vehicle within the tower apparatus was experienced. In addition, measurements of the witness paper were unable to be gathered due to the blade creating a cut greater than the length of the blade.

Table 6: Stanley 1992 Trimming Blade Test Results

Sample	Mass (g)	Impact Velocity (m/s)	Impact Energy (J)	Penetration – Witness Paper (mm)	Penetration - Calliper (mm)
1	22.11	2.71	23.71	N/A	30.00
2	21.67	2.71	23.70	N/A	30.00
3	22.90	2.71	23.72	N/A	30.00
4	21.82	2.70	23.59	N/A	30.00
5	22.10	2.71	23.72	N/A	30.00
6	22.03	2.71	23.73	N/A	30.00
Std. Deviation		0.004082	0.05244	N/A	0.00
Mean		*2.71*	*23.70*	N/A	*30.00*

In all six tests using the Stanley blade, a maximum blade penetration of 30.00 mm was recorded. The level of blade penetration using the Stanley 1992 trimming blade is shown within Figure 14.

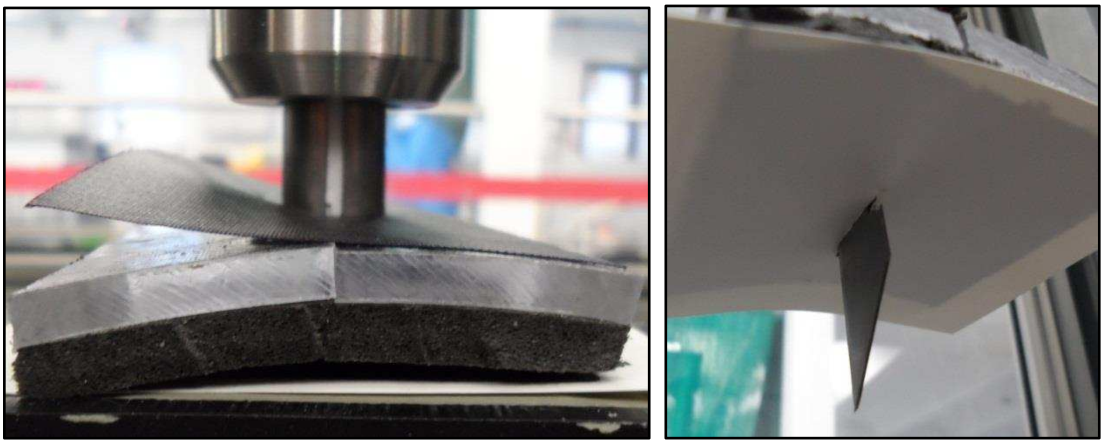

Figure 14: Test specimen one using the Stanley 1992 trimming blade

Impact velocity and stab energy data was automatically gathered by the Instron drop tower data acquisition system – with results previously documented within Table 4 and 5. Upon review of the data, a mean velocity of 2.71 m/s and stab impact energy ranging between 23.59 – 23.76 J were recorded with a low standard deviation. These figures were within the HOSDB acceptable limits.

4. Discussion and Conclusions

Results from this experiment clearly demonstrated that the Stanley Tools 1992 trimming blades were at least three times more potent in their stab penetration than that of the HOSDB P1/B blades when tested against certified KR1 body armour specimens. There is therefore a significantly greater threat imposed by the more readily available and accessible utility blade.

It should however be noted that upon visual inspection of the HOSDB P1/B test samples, the foam underlay of each specimen compressed before the HOSDB P1/B blades punctured the polycarbonate layer - potentially causing the blade to be trapped and unable to penetrate further. Although the measured penetration depths of these test samples using the HOSDB P1/B were greater than 7.00 mm maximum limit, it should be noted that testing was performed on only the protective insert in order. Therefore further protection to within certified levels may have reached if testing incorporated the external fabric carrier.

From the results attained within this experiment, difference between the methods used to measure blade penetration when testing the HOSDB P1/B blades was assessed – with a mean difference between the measurement techniques established at 1.66%.

It was noted within the results attained from testing the Stanley 1992 trimming blades that the PC layer within some of the certified body armour specimens fractured – therefore potentially enabling the test blade to further penetrate the through the test specimen. Previously published research suggested that short, slender blades were more potent in their stab performance in comparison to longer, thicker blades (Green, 1978; Research meeting with Roger Hamby of the Cutlery & Allied Trades Research Association (CATRA) - 5th December 2012, 2012). This was supported by the results gathered from this experiment when comparing the stab performance of Stanley 1992 trimming blades and HOSDB P1/B engineered blades tested using current HOSDB KR1 approved body armour. Selection of the Stanley 1992 trimming blades for future stab testing represents a more likely real-world threat in comparison to the standardised and engineered HOSDB approved blade. Such blades are also more easily accessible to purchase from various home improvement and supermarket stores on the UK high street, and therefore may pose a greater real-world threat.

5. Further Work

Further work is required to investigate methods to enhance the stab protective characteristics of body armour in order to withstand the greater penetrative threat demonstrated by the Stanley 1992 trimming blade.

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