Protecting from slash knife attacks

Ian Horsfall*, and Mathew Arnold.

Impact and Armour Group
Department of Engineering and Applied Science
Cranfield University
Defence Academy of the United Kingdom
Shrivenham
Wiltshire
SN6 8LA
UK

i.horsfall@cranfield.ac.uk

Abstract

The provision of stab- and bullet-resistant body armour to UK police officers is now commonplace. These garments comprise of a multi-layer pack which contributes to thermo-physiological loading and reduction in mobility. Recently interest has turned towards slash protection, culminating in the publication of a standard method for testing slash resistance (Malbon and Croft, 2006). A retrospective survey of hospital admissions data that contributed to the development of the standard suggested that 63 % of wounds attributable to sharp edged weapons were slash events. The most vulnerable areas were the head, arms, thighs and neck (Bleetman, Watson, Horsfall and Champion, 2003). The incorporation of successful slash protection into garments should not affect mobility, and is required to be covert. In the current research the effectiveness of a quilting pattern applied to a 100 % cotton plain woven fabric (nominally mass per unit area 360 g/m^2, thickness 0.62 mm, sett 14 x 14 yarns / 10 mm) on resisting slash attacks was investigated. In this preliminary study, quilting was applied to a single layer of fabric by hand (stitch type ISO 209, stitch length ~ 3 mm) using titanium wire, braided Dyneema, braided Kevlar and plaited Kevlar in 5 x 5 mm and 10 x 10 mm patterns orientated on-grain and in the bias directions. All slash events were conducted in the weft direction of the fabric. Number of slashes to penetrate, the effect of dry and wet conditions, the effect of backing materials and failure mechanisms were determined.

Keywords: Slash resistant, body armour, cut resistance, quilting, aramid.

1 Introduction

Knife wounds can be subdivided into two broad categories; deeply penetrating stab wounds and long slashing wounds of limited penetration. The former have a high probability of causing death or serious injury when they occur on the thorax as they have the depth of penetration necessary to cause injury to major organs. Stab attack typically consists of an impact with energy of 10-50 J concentrated on a very small area (Horsfall, Prosser, Watson and Champion 2009). This leads to a requirement for highly penetration resistant armour system typically consisting of 10 or more layers of specialised fabric. These solutions are bearable on the thorax and to some extent the abdomen where only limited flexibility is required. Test standards for stab resistant garment are commonplace and in the UK the Home Office Scientific Development Branch is now on its third generation of such standards (Croft and Longhurst 2007).

Although stabbing injuries are probably the most likely to cause death or serious injury they are not the most common type of wounds from edged weapons. The most prevalent wound is a slashing wound which results from attack with a short bladed weapon or is a result of defensive action of the victim. These defensive wounds typically occur on the extremities and although not usually fatal they can result in serious blood loss (Bleetman, Watson, Horsfall and Champion, 2003). Slashing wounds to some areas of the body such as the upper thigh or neck can cause catastrophic blood loss with a consequently high chance of fatality. The location of both these serious slash injuries and typical defensive wounds is not conducive the use of the heavy stab resistant systems developed for thorax protection. This is balanced by the observation that a slashing action spreads the contact load over the length of the blade and so is relatively easy to defeat and probably requires a much lighter solution than stab protection.

In the present work an initial study is made of fabric based solutions which might provide protection from slashing attack. They are typified by being lightweight and flexible so that they are suited to use on the more articulated areas of the body such as arms legs and neck. This work formed part of the studies leading up to the publication of the 2006 HOSDB standard (Malbon and Croft 2006).

2 Equipment

The fabrics were tested using a purpose designed slash test rig which is illustrated in figure 1. This consisted of a 300mm straight edged blade which was held stationary whilst the sample was drawn along under it by a pneumatically operated table. The sample was clamped over a 100mm diameter cylinder which was either a rigid PVC rod or a soft polyethylene foam. The table moved at $1ms^{-1}$ and the blade was lifted at the end of each stroke as the sample was returned to the staring position. The contact load due to the weight of the blade was 18N at the centre position but varied with position. Tests were conducted in either a static mode, in which the blade was positioned gently on the sample prior to the table moving, or an impact mode in which the blade was dropped 100mm at the start of the stroke. Care was taken that successive strokes were applied to the same location on the sample. Sample failure was determined by electrical contact between the blade and an aluminium foil contact positioned under or within layers of the sample. The effectiveness of any protective layer was assessed by the number of passes required to cause blade contact through the sample.

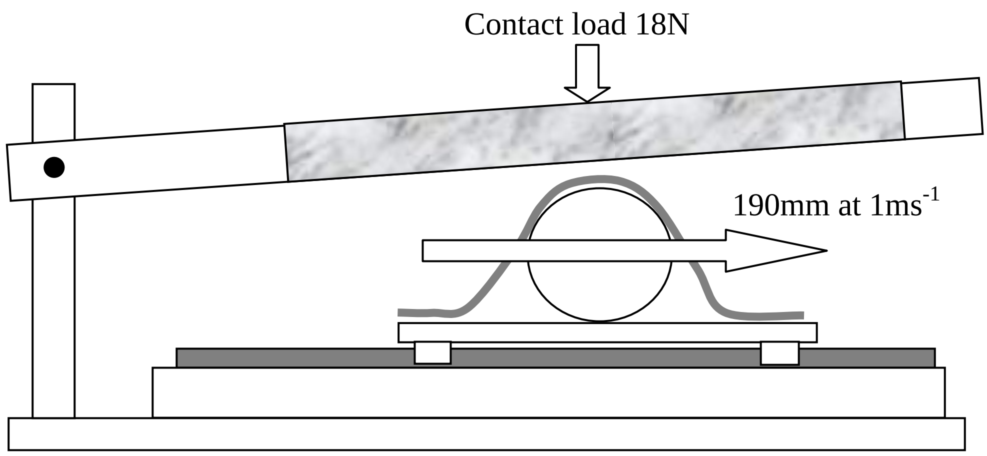

Figure 1 A diagrammatic representation of the slash test equipment.

3 Materials

Initially a set of tests were performed on a range of woven fabrics and waddings. This was followed by a series of tests on specially made reinforced fabrics in which a woven fabric base layer was quilted with high strength yarns. Details of the fabrics are given in table 1.

Table 1 Fabric characteristics

Description	**Compressed thickness (mm)**	**Mass per unit area (gm^{-2})**	**Structure (Sett yarns per 10mm)**
Aramid (Kevlar 49)		220	Plain weave 8x8
Light cotton	0.20	113	Plain weave 25x25
Medium Cotton	0.28	173	Plain weave 33x33
Batting	0.65	376	Non-woven
Coarse Batting	1.6	376	Non-woven
Quilted wadding	2.0	577	Non-woven

In a further series of tests an attempt was made to produce purpose-designed slash resistant fabrics by quilting with cut resistant yarns. A quilting pattern was applied to a 100 % cotton plain woven fabric (nominally mass per unit area 360 g/m^2, thickness 0.62 mm, sett 14 x 14 yarns / 10 mm). Quilting was applied to a single layer of fabric by hand (stitch type ISO 209, stitch length ~ 3 mm) with a variety of high tenacity yarns. The quilt pattern was on 5mm or 10mm pitch in diamond and square pattern. Details of the quilting yarns are given in table 2.

Table 2 Quilting yarns details

	Diameter (μm)	**linear density (tex)**	**Yarn structure**
Titanium niobium wire	50	1150	100 filaments no twist
Aramid tow	10	163	1000 filaments no twist
Aramid braid	10	920	4x1000 filaments twisted and braided

4 Results

In the first series of tests a plain woven aramid fabric was used as a standard then a variety of fabric solutions was placed between this layer and the sample support in order to determine the protective effect. The results of these tests are given in table 3. Tests were repeated three times and the number of passes to fully penetrate the sample was measured in each case then averaged.

Table 3 Results of slash test on fabric samples

Sample and support type	**Number of passes to failure**			
	Test 1	Test 2	Test 3	Mean
Rigid cylinder support aramid fabric	0.5	2	1	1.2

Rigid support aramid fabric backed with light cotton	1	2	1	1.3
Rigid support aramid fabric backed with medium cotton	2	2	1	1.7
Rigid support aramid fabric backed with wadding	2	2	2	2
Rigid support aramid fabric backed with coarse wadding	2	3	3	2.7
Rigid support aramid fabric backed with polyester quilted wadding	3	5	2	3.3
Soft cylinder support aramid fabric	4	3	5	4
Rigid support aramid fabric backed with 2 layers polyester wadding	5	5	8	6

It is apparent from these results that the thickness of the sample has a very significant effect on its ability to resist cutting. As the thickness is increased then the contact length of the blade is also increased with a consequent decrease in the contact stress. Using a soft support has a similar effect in spreading the contact load and increasing the number of passes required to breach the sample.

A similar set of test was then performed using quilted cotton fabric, again placed under the aramid fabric. The results of these tests are given in table 4 and the samples are shown in figures 2-5

Table 4 Results of test on quilted fabrics

Reinforcement	Number of passes		
	Quilt pattern	Rigid cylinder	Soft cylinder
Titanium wire	Square 5mm	2	17
	Square 10mm	1	8
	Diagonal 10mm	2	17
Aramid braid	Square 5mm	7	67
	Square 10mm	12	53
	Diagonal 5mm	8	74
	Diagonal 10mm	16	61
Aramid tow	Square 5mm	2	9

Figure 2 Titanium wire 5mm untested

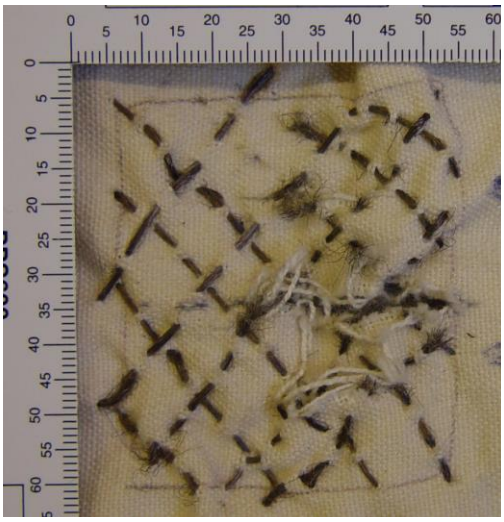

Figure 3 Titanium wire 10mm diamond

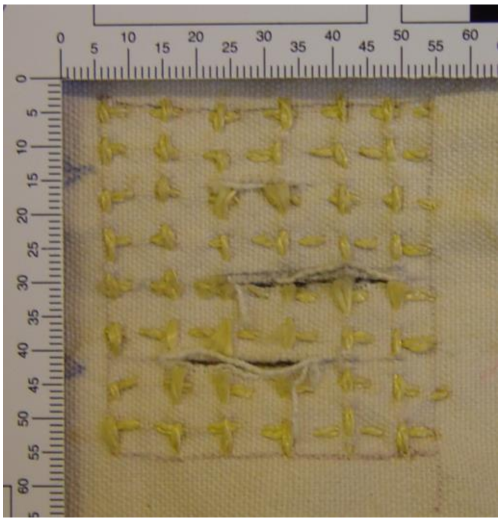

Figure 4 Kevlar tow 5mm

Figure 5 Kevlar braid 5mm

In figures 3-5 at least three cutting test have been performed on each sample, the hard backed test is between two and three quilt rows from the top and produces a cut of typically 10-20mm length. The soft backed test is between two and three quilt rows from the bottom of each sample and the cut lengths are much greater, typically 20-40mm in length. The cuts in the centre of the samples are additional soft backed or impact tests.

Table 5 shows a comparison of static and impact test data for a further sample type. This used a commercially available ultra high molecular weight polyethylene (Dyneema®) fishing line as the quilting yarn. The quilting was on a 5mm square pattern on a medium weight cotton fabric.

Table 5 A comparison of static and impact test using a UHMWPE quilted sample

	Number of passes	
	Rigid cylinder	Soft cylinder
Sliding test	7	11

Impact test	3	31

It can be seen that against the hard cylinder the impact test causes breach of the systems in only half the number of passes, whilst for the soft backed test this is reversed. But the soft backed test results are misleading as the blade tended bounce so that contact was not maintained during the pass and additionally the blade would not necessarily land in the same location on each impact.

5 Discussion

The test method was chosen as it allowed a relatively small sample of material to be tested and the test geometry matched that of a protection system applied to the arm of a garment. This method should be compared to the test standard for industrial gloves BS EN ISO 13397 which uses a similar geometry or the UK Home office slash standard (Malbon and Croft, 2006) which uses a Stanley blade propelled across a large inclined sample.

In the present work the results were shown to be repeatable but this used a single blade which was not significantly blunted (or re sharpened) during the period of testing. Methods to calibrate the sharpness of blades are not highly developed, particularly for blades used in a slicing or sawing motion such as this. Consequently BS EN ISO 13397 relies on a calibration test against a known sample. An alternative approach used in the HOSDB relies on the use of mass produced blades of fixed construction which are calibrated by a destructive test on blades from the same batch (BS EN ISO 8442-5). However the destructive test still relies upon the use of a known calibration sample and is also somewhat complex.

An impact test was tried and showed some promise when using a rigid backed sample but the difficulty of accurately striking the same impact location caused significant difficulties.

For a sliding contact with a straight edge blade as carried out in the present work, the severity of the test is directly related to the contact length and hence contact stress on the layer being cut. Using a soft support cylinder increases the number of passes to failure by a factor of approximately eight. Therefore any system which increases thickness or pads the contact will have a beneficial effect. This may explain why increasing the quilt spacing of the aramid braid led to an increase in protection for some tests as it may be the padding action of the quilting as well as the number of quilts which determines cut resistance.

The aramid braid showed the best performance of all the quilting materials being approximately four times more effective than the titanium wire and similarly better than the aramid tow. However as the aramid tow was of only one quarter the filament count the weight for weight performance of the two aramid systems was similar. The titanium wire was of a relatively poor mechanical strength as the titanium niobium alloy is primarily produced for its electrical properties. This alloy was used because it was available as a multi filament wire of the correct weight and flexibility to be easily used in quilting. The titanium wire was markedly more difficult to work with as it was not easy to handle.

The tests carried out in the present work indicate that cut slash resistance can be enhanced by the use of high tenacity yarns and by the use of padding or wadding systems. Both these approaches offer potential for the development of slash resistant clothing for the protection of police officers.

6 References

Bleetman, A., Watson, C.A., Horsfall, I. and Champion, S.M. 2003. Wounding patterns and human performance in knife attacks: optimising the protection provided by knife-resistant body armour. Journal of Clinical Forensic Medicine 10: 243-248.

British Standards Institution (2004) BS EN ISO 8442-5:2004 Materials and articles in contact with foodstuffs. Cutlery and holloware. Specification for sharpness and edge retention test of cutlery, British Standards Institution, London

British Standards Institution (1999) BS EN ISO 13997:1999 Protective clothing - Mechanical properties - Determination of resistance to cutting by sharp objects. British Standards Standards Institution, London

Croft, J. and Longhurst, D. 2007, HOSDB Body Armour Standards for UK Police (2007) Part 3: Knife and Spike Resistance, Publication No. 39/07/C, St Albans, UK; Home Office Scientific Development Branch.

Horsfall, I. Prosser, P.D. Watson C.H. and Champion S.M. An assessment of Human Performance in Stabbing, Forensics Science International, 102, 79-89, (1999).

Malbon, C. and Croft, J. 2006. HOSDB slash resistance standard for UK police. Publication no. 48/05. St Albans, UK; Home Office Scientific Development Branch.