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Development of an advanced personal protective equipment garment for protection against slashes and pathogenic bacteria. Part 1: Development and evaluation of slash resistant garments.

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Development of an AdvaSnced Personal Protective Equipment Garment for Protection against Slashes and Pathogenic Bacteria
Part 1: Development and Evaluation of Slash Resistant Garments

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ABSTRACT: Knife is the most commonly used single weapon in the UK, being 32% of the weapons employed in violent incidents. Studies reveal that the majority (63.3%) of the knife inflicted wounds were slash type and could be disfiguring or life threatening if the blood vessels are ruptured. The stab resistant armours currently available do not protect the arms, neck and face as they are very rigid to be worn comfortably and are expensive and heavy for everyday use by the civilian population. The main objectives of this research programme are; a) to develop and characterise a novel cut resistant and slash proof material that is lightweight, comfortable and efficient; and b) to integrate barrier properties in such garments which would incorporate suitable antimicrobial and other suitable chemicals to provide protection against a range of micro organisms.

During this research programme, various composite yarns were thoroughly investigated, at different proportions, to determine the most appropriate yarn for the slash proof material. The slash proof fabric structures were developed by using knitting technology as it offers significant advantages in terms of cost, design flexibility and versatility. The fabrics were characterised by using the most stringent test method stipulated for a slash proof application, namely, Home Office Scientific Development Branch (HOSDB) Slash Resistance Standard for UK Police (2006), Publication No. 48/05.

The paper discusses the results obtained during the development of the novel slash proof material for the police, armed forces, children and the public, that is lightweight, comfortable and efficient, and can be utilised for long periods.

KEYWORDS: Slash, Stab, Personal Protective Equipment, PPE, Garments, Test Methods, Standards.

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INTRODUCTION

Knives are being used more commonly now-a-days in street fights and muggings. Therefore the law enforcement and medical personnel require high-level of protection when dealing with physical threats. The general public also requires a high-level protection from crimes which have doubled in the UK in the past 2 years, from 25,500 in 2005 to 64,000 in 2007[1]. The demand for protective garments are ever increasing and is more focused on ballistic protection and anti-stab protection. Ballistic protection provides protection against projectile penetration including the new kind of bullets and anti-stab offers protection from sharp pointed objects with or without sharp cutting edges such as knives and needles.

This paper presents a comprehensive review of the need for protection against slash and stab; the requirements for such a protection; and the test standards currently used to characterise these products. The paper also fully describes the design, development and characterisation of novel slash proof materials for the police, armed forces, children and the public, which are lightweight, comfortable and efficient, and can be utilised for long periods.

NEED FOR PERSONAL PROTECTIVE GARMENTS

Resistance against Knife

In England, where criminal use of hand guns is not prevalent, it is the police officer who also faces assaults from individuals wielding knives, ice picks, and the like[2]. The British Crime Surveys (BCS) 2001/02 and 2002/03 revealed that 12.6%, of the people engaged in protective service occupations have been the victims of assault followed by 3.3% of health and social welfare professionals and 1.95% of transport and mobile machine drivers and operatives.

The perception of risk of violent assault at work is also the highest for the protective service occupations at 54% and 28% for the health and social welfare professionals. According to BCS 1994, 1996 and 1998, there have been 3225 assaults per 10,000 workers per year in the security and protective services.
The British Crime Survey (1994/96/98) lists “Security and Protective Services” as the occupation with the highest risk of violence while at work at 11.4%, whereas the average risk of violence while at work is only 1.2%. The police are at most risk followed by social workers, probation officers, publicans, bar staff and security guards[3]. 15.3% of security and protective services are the victims of violence at work, 11.4% of it being assault. Among the 11.4% of assault, 25% of the victims are police officers followed by security guards at 3.1%.

Knife, at 7%, is the most commonly used weapon in a violent incident[4], and it has been found that 28% of children in school and 57% of excluded children have carried knife in the previous year. This poses a threat to the officers working in the community, especially the youth and community workers and officers in the protective service occupations. Available evidence indicates that significant minority of school children and young people carry knives and this problem may be growing. Official statistics suggests that the use of knives in the commission of violent crimes and homicide has remained steady[2]. In London alone, there have been 25 fatal knife attacks on young people in the first six months of 2008[5].

Slash Resistance

A review of the real life wounding patterns[6] that investigated 500 patients attending an Accident and Emergency unit in Glasgow, revealed that the majority (63.3%) of the wounds caused by knives were slash type and the attacks of such type could be disfiguring and could also be life threatening if it involves the blood vessels.

Less than a quarter of fatal wounds caused by stabs are inflicted in the chest region and the distribution of the wounds suggests that, in real life attacks, most of the knife assaults are slash attacks at the arms, neck, shoulder and thigh regions.

Even though stab resistant armour defeats slash attempts, it is impractical to provide stab protection to the arms, neck, shoulder and thigh regions due to the thickness and stiffness required for the armour materials to withstand the force of a stab attack. Slash resistant armours, in contrast, need not be bulky or stiff[7]. They can be more flexible and lighter as the maximum load exerted by a slash is approximately 25% of the loads measured in stab attacks[6]. Studies show that the maximum energy produced could reach up to 115J for an over-arm stabbing action and 64J for an underarm stabbing action[8,9].

The areas in which custodial and corrections officers perform their duties differ greatly from their street counterparts. Cells and hallways are sometimes small or narrow and the ability to move or fight off an attacker is very important. The major threat in these areas is from edged and hand-made weapons. The use of metal or plastic plates in stab resistant vests are not required in this situation and it can restrict an officer's ability to defend himself or herself, bend quickly or get up from the floor if knocked down. This inability to defend one-self can cause more injury than the initial attack[10].

AIMS OF THIS INVESTIGATION

The major objectives of this research programme are:

- To design, develop and characterise novel cut resistant, slash and stab proof material for the police and armed forces.
- To engineer, test and analyse lightweight, comfortable and efficient system which can be utilsed for long periods.
- To test these novel materials by using standard test methods and techniques.
- To incorporate suitable antimicrobial and other chemicals in these novel materials to provide protection against a range of viruses known as prokaryotes.

- To fully characterise the barrier properties of these chemicals / finishes etc.
- To formulate theoretical relationships between fabric elements and properties in order to predict the performance standards of novel materials.

The ultimate objective of this research programme is to design novel cut resistant and slash proof materials for the police, armed forces, children and the public that would be lightweight, comfortable and efficient, and can be utilised for long periods of time.

TEST METHODS TO CHARACTERISE SLASH RESISTANCE

There are two European standards that specify a method of testing cut resistance of a fabric against sharp objects. These are BS EN 388:2003 and BS EN ISO 13997:1997.

BS EN 388:2003 was developed specifically for gloves and it details the test methods for measuring abrasion resistance, blade cut resistance, tear resistance and puncture resistance. BS EN ISO 13997:1997 was developed for any protective clothing and specifies the test method for determination of resistance of a fabric to cutting by sharp objects. The European standard stipulated for measurement of cuts and stabs is the BS EN 1082-3:2000. The 3rd part of this standard specifies the impact cut test for fabrics, leather and other materials. It was developed for testing of gloves and arm guards for cut resistance[11,12]. All the afore mentioned standards do not replicate a slash mechanism.

Measurement of Slash Resistance

The Home Office Scientific Development Branch (HOSDB) released a standard, HOSDB slash resistant standard for the UK Police (2006) that describes a test method for measuring slash resistance. It is the first standard in the UK that provides information on the test methodology and protection levels required for slash resistant protection[13].

Test Equipment:
The test equipment consists of a guided drop assembly, a force table and a slash missile(see Figure 1). The slash missile has a mass of 2.0 kg ± 0.1 kg and houses the test blade. The missile is guided by the guide rails to drop under the influence of gravity. The blade contacts the force table at 2 ° from vertical. The guided drop assembly prevents the slash missile from rotating about its vertical axis during its descent.

The blade is a standard Stanley® knife blade model 1992 that is held at an angle of 30° ± 1° from the horizontal by the supporting arm, (see Figure 1) which is free to move around the pivot point. An electrical connection exists between the force table and the supporting arm to form a contact circuit.

The force table consists of two load cells, preloaded to a force of 30% of their rated value. The force table is mounted at an angle in such a way that the blade tip force reaches the minimum force required to cut through the specimen within a distance of 200mm from the point of contact.

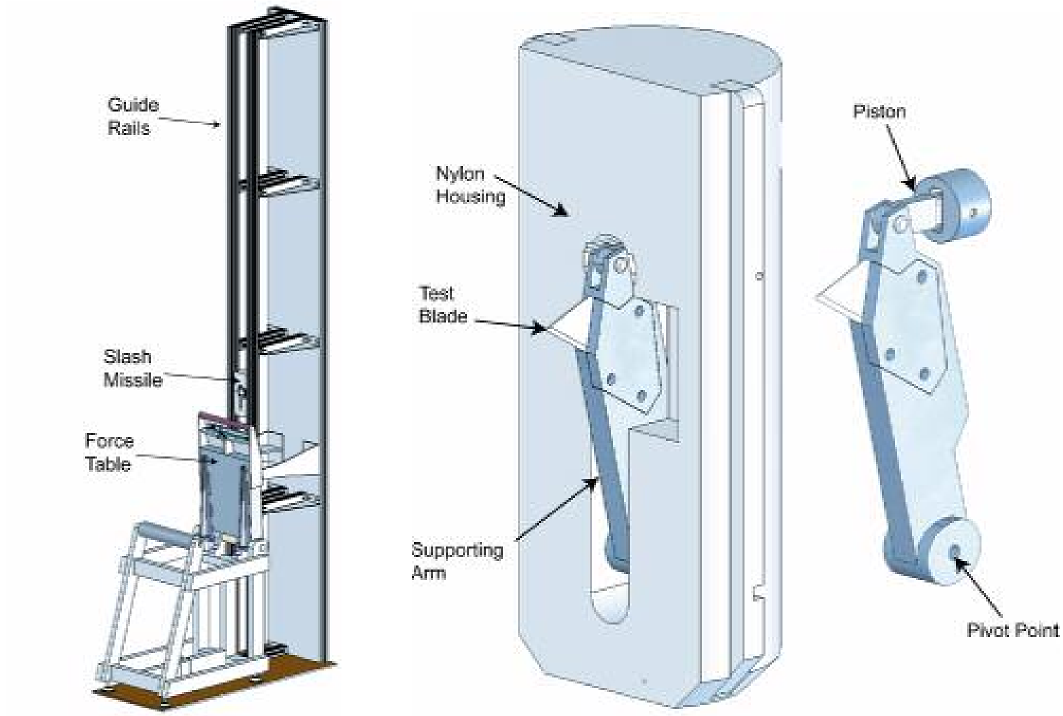

Figure 1: Slash Resistance Test Assembly, Slash Missile and the Supporting Arm.

Test Specimen:

Three test packs are required for a single slash compliance test. Each pack must contain a specimen of 500mm length and 300mm width. The construction of the specimen must conform precisely to the description specified in the declaration. If the slash resistant pack is manufactured from more than one layer, all layers of the test specimen should be stitched together along each edge in addition to any stitching pattern which is inherent to the protection provided by the panel. If the design or pattern of the materials used in the slash resistant panel is not homogeneous, one panel must be supplied to the size required with the design or pattern rotated through 90°. The design or pattern directions should be clearly marked by the manufacturer or supplier for compliance testing.

Test Procedure:

The test requires three test packs with 3 specimens in each pack. During the test the vertical edges of the specimen are aligned parallel to the force plate in the first set, perpendicular in the second and at an angle of 30^o to the long axis of the force table in the third set. In each set, the slashes are made at 50 ± 5mm from the right edge, 50 ± 5mm from the left edge and then one in the centre of the specimen.

Pass Criteria:

To pass the specification, the test specimen that is placed on the force table should have no penetration at an average of 80N force and a minimum of 60N force in the following three directions,

- Walewise direction (0 ^{o})
- Coursewise direction (90 ^{o}) and
- 30 ^{o} diagonal to the walewise direction.

MATERIALS USED FOR SLASH RESISTANCE

The fibres that are used extensively for the armour products are aramids, Ultra High Molecular Weight Polyethylene (UHMWPE) and Polybenzoxazole (PBO). The properties of the main fibre types used in personal protective equipment garments are summarised in Table 1.

Table 1: Comparison of Fibre Properties[14, 15].

	Tenacity		Modulus		Breaking Extension	Density	Moisture Regain	LOI	Heat Resistance
	cN/dtex	GPa	cN/dtex	GPa	%	g/cm^3	%		^{o}C
PBO (Zylon®)	37	5.8	1150	180	3.5	1.54	2.0	68	650
UHMWPE (Spectra® / Dyneema®)	35	3.5	1300	110	3.5	0.97	0	16.5	150
Aramid (Kevlar®)	19	2.8	850	109	2.4	1.44	4.5	29	550

During this research, several yarns were tested to choose the appropriate yarn for slash resistant garments. PBO yarn was not used as the fibre degrades by hydrolysis in warm and moist conditions which makes the fibre unsuitable for applications that expose the material to warm and moist environment[16].

Yarns Used for Stab/Slash Resistance

Various composite yarns consisting of: a) blends of Spectra® (Ultra High Molecular Weight Polyethylene), glass and polyamide; b) Stainless steel core with wraps of Dyneema® (Ultra High Molecular Weight Polyethylene) and polyester; and c) Kevlar®, in different compositions, were thoroughly investigated to determine the most appropriate yarn for the slash proof material. The results of the various tests carried out on the yarns are summarised in Table 2 and are discussed below:

Table 2: Yarn Test Results

Name of the Yarn	Linear Density (Tex)	Coefficient of Friction (µ)	Tenacity (cN/Tex)	Breaking Extension (%)	Initial Modulus (cN/Tex)	Breaking Time (at 300 mm/min)	Force (cN)
Spectra WF 408	268.77	0.24 - 0.25	56.48	3.98	1058.2	3.99	15182.59
Spectra WF 271	95.16	0.32 - 0.34	79.3	4.19	870.25	4.2	7549.3
Spectra WF 528	57.16	0.36 - 0.37	98.49	3.02	995.86	3.02	5633.77
Wykes E669	201	0.29 - 0.30	25.83	15.25	475.91	15.27	5191.39
Kevlar TW (1 Ply)	61	0.27 - 0.31	76.4	4.68	486.93	4.68	4660.63
Kevlar TW (2 Ply)	2/122	--	71.39	4.51	444.45	4.51	8709.94

The highest tenacity amongst the five yarns was achieved by Spectra WF 528, itself being the yarn with the lowest linear density. The breaking extension of the Spectra WF 528 is also the lowest amongst the five with a value of 3.02%. It also showed the second highest initial modulus. The maximum force required to break the yarn was only 5633 cN. The yarn that required the highest force was Spectra WF 408 at 15182.59 cN, but it also had the highest linear density (268.77 Tex) which reduced its tenacity to 56.48 cN/Tex.

The Wykes E669 Yarn had the least tenacity with 25.83 cN/Tex. It also displayed the highest breaking extension of 15.25% for which it took 15 seconds. One thing to be noted here is that the yarn had an intermittent breakage. The breaking force of 5191 cN was recorded within the first 4 seconds, but due to its intermittent breakage, it took longer time to complete the test, see Figure 2.

The Kevlar yarns were tested with single yarn and as a 2 ply with '0' Twist. The yarns were tested with 2 ply as the fabrics that were knitted used a 2 ply yarn. The results were fairly similar and the stress/strain curve was almost exactly the same. The Kevlar yarn did not provide the highest strength. It can be seen from the stress/strain curves in Figure 2 that Spectra WF 528 had the highest tenacity and second highest specific modulus.

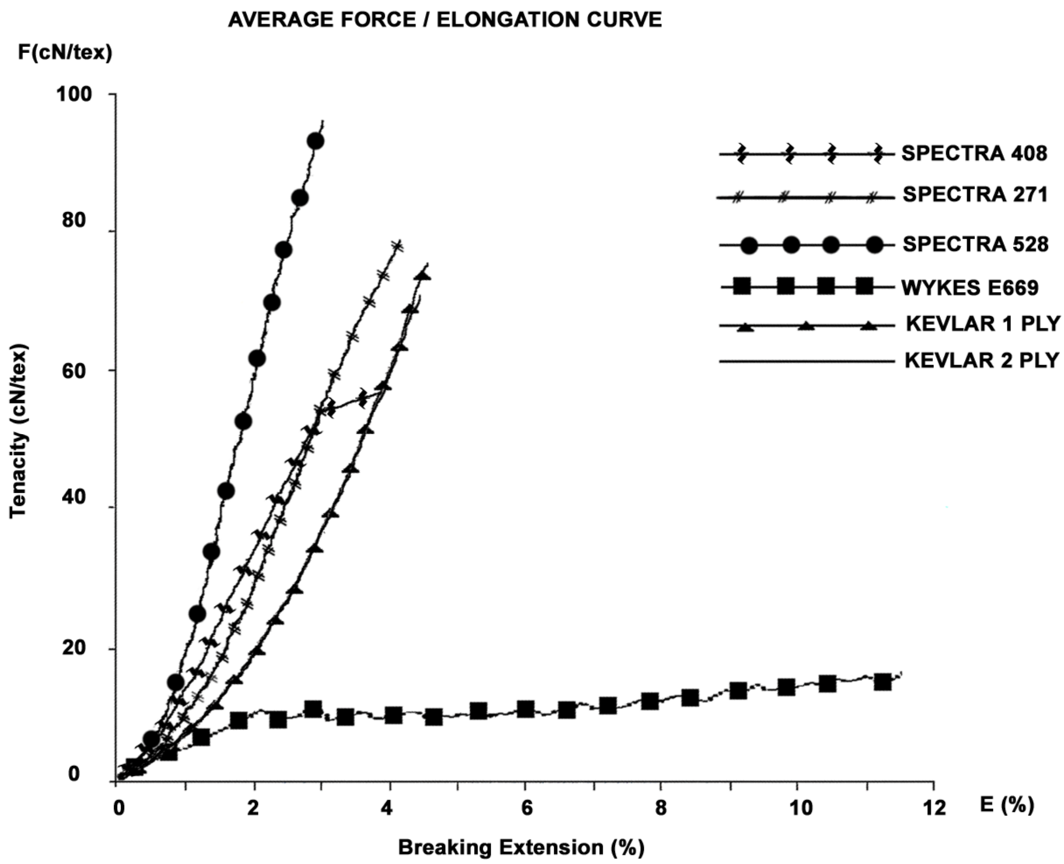

Figure 2: Stress/Strain Curve of the Yarns

Development of Knitted Structures

Knitting technology offers considerable advantages in terms of cost, flexibility and versatility in the production of suitable structures for a contoured armour, but it has not proved successful, probably because of the high degree of interlocking of the yarns that occurs in the knitting process which results in a fabric with too low an initial modulus. For slash resistance, it is the low initial modulus which aids in the relative slippage of the yarns which assists in distributing the stresses over a larger area and hence prevents the blade from striking through the fabric, therefore, weft knitting technique was utilised to design the slash resistant fabric. Weft knitting process is also attractive when factors such as cost, design potential and versatility are considered[17].

A series of fabric samples were knitted by using different combinations of various yarns and innovative two-layer weft knitted structures. The following yarns were used:

- Spectra WF 408,
- Spectra WF 528,
- Wykes E669,
- Tilsa, and
- Kevlar.

The above yarns were used in combination with Kevlar and the fabrics were knitted with Kevlar on one face and one of the other yarns in the other face and vice versa. The knitting machine used to produce the fabrics was an E10 gauge electronic flat knitting machine.

The grey or unfinished fabrics were tested against the HOSDB slash resistant standard for the UK police. Table 3 shows the results from the initial set of tests that were carried out to compare various two layer weft knitted structures and are discussed in the subsequent sections.

Table 3: Slash Test Results (Initial Tests)

Test Face-1	Face Yarn	Test Direction	Force (N)		Test Face-2	Face Yarn	Test Direction	Force (N)
Fabric 1: KEVLAR / WF 408 (GSM 1292.4)								
Racked	Kevlar	Walewise	45.37		Jersey	WF408	Walewise	22.68
Racked	Kevlar	Coursewise	88.7		Jersey	WF408	Coursewise	86.57
Fabric 2: WF 408 / KEVLAR (GSM1248.1)								
Jersey	Kevlar	Walewise	84.49		Racked	WF408	Walewise	24.25
Jersey	Kevlar	Coursewise	61.24		Racked	WF408	Coursewise	91.18
Jersey	Kevlar	Diagonal	59.08		Racked	WF408	Diagonal	112.71
Fabric 3: KEVLAR / WF 528 (GSM 879.5)								
Racked	Kevlar	Walewise	23.99		Jersey	WF528	Walewise	27.49
Racked	Kevlar	Coursewise	86.52		Jersey	WF528	Coursewise	319.25
Fabric 4: WF 528 / KEVLAR (GSM 759.5)								
Jersey	Kevlar	Walewise	21.52		Racked	WF528	Walewise	29.18
Jersey	Kevlar	Coursewise	28.3		Racked	WF528	Coursewise	16.95
Jersey	Kevlar	Diagonal	19		Racked	WF528	Diagonal	30.54
Fabric 5: KEVLAR / TILSA (GSM 838.8)								
Racked	Kevlar	Walewise	16.47		Jersey	Tilsa	Walewise	73.43
Racked	Kevlar	Coursewise	43.22		Jersey	Tilsa	Coursewise	30.22
Fabric 6: WF 528 / TILSA (GSM 881.6)								
Racked	WF528	Walewise	18.24		Jersey	Tilsa	Walewise	26.28
Racked	WF528	Coursewise	64.16		Jersey	Tilsa	Coursewise	19.97
Racked	WF528	Diagonal	29.58		Jersey	Tilsa	Diagonal	19.8
Fabric 7: KEVLAR / E669 (1089.1)								
Racked	Kevlar	Walewise	47.66		Jersey	E669	Walewise	17.23
Racked	Kevlar	Coursewise	84.77		Jersey	E669	Coursewise	65.97
Racked	Kevlar	Diagonal	91.84		Jersey	E669	Diagonal	67.81
Fabric 8: E669 / KEVLAR (GSM 997.5)								
Jersey	Kevlar	Walewise	15.03		Racked	E669	Walewise	52.51
Jersey	Kevlar	Coursewise	234.4		Racked	E669	Coursewise	22.28
Jersey	Kevlar	Diagonal	56.8		Racked	E669	Diagonal	32.43
Fabric 9: KEVLAR / E669 (First Set) (GSM 837.8)								
Racked	Kevlar	Walewise	48.69		Jersey	E669	Walewise	13.71
Racked	Kevlar	Coursewise	84.77		Jersey	E669	Coursewise	24.53
Racked	Kevlar	Diagonal	101.73					

Note: Jersey: Straight wales; Racked: Zig-zag wales; and Test face: Fabric face under test.

DISCUSSION OF RESULTS

The innovative fabrics designed and knitted to test and evaluate their slash resistance have a novel two layer structure. One of their faces can have the appearance of a single jersey weft knitted structure and the other face can have the racked structure. The fabrics were tested on both sides and the side which comes in contact with the blade, during the test, is referred to in the column titled 'Test Face -1 or -2' and the yarn used in the test face is stated under the column title 'Face Yarn', in Table 3. The column titled 'Test Direction' states one of the three directions in which the test was carried out, namely, i) Walewise (lengthwise); ii) Coursewise (widthwise); and, iii) Diagonal (30^o to walewise). The force at which the blade strikes through the fabric is given in Newton (N). The highlighted values in Table 3 indicate that the fabric has passed the slash test in that particular direction.

During the analysis of the results shown in Table 3, comparisons were made between different yarns and structures to optimise the best combination for a lightweight slash resistant personal protective equipment garment.

The knitted structures developed and used during this work have not been discussed in this paper intentionally, because they are a vital part of the patent applications pending to protect the Intellectual Property Rights (IPR) of this invention.

Comparison of Different Yarns

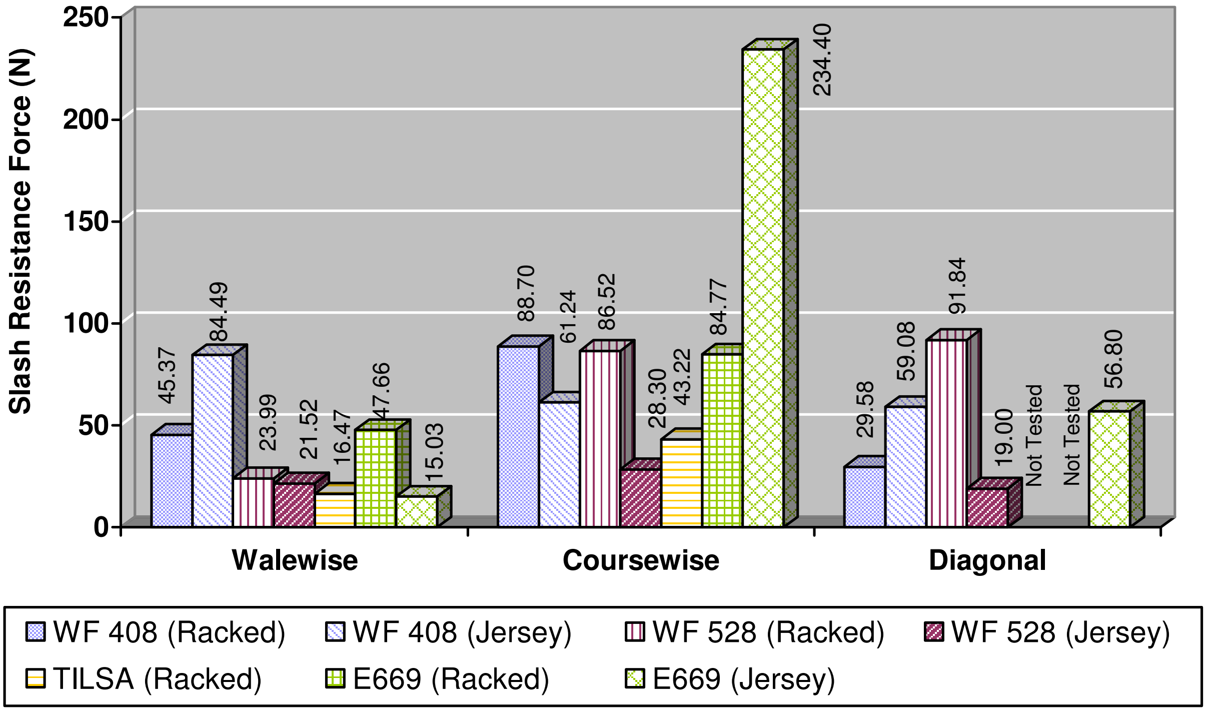

Figure 3: Slash Resistance Force for Different Yarns in all Three Directions

The resistance to slash for different yarns knitted in different structures are shown graphically in Figure 3. WF 408 yarn is the closest to passing the test with just 1N short in the diagonal direction for the jersey structure tested with Kevlar as test face. It passed with a value of 84.49 N in walewise direction, 61.24 N in coursewise direction and with 59.08 N in diagonal direction.

The fabrics knitted with WF 528 on the racked test face passed in both coursewise and diagonal direction with values of 86.52 N and 91.84 N respectively, but failed badly in walewise direction with a value of 23.99 N.

Comparison of Different Structures

Figure 4 shows the slash resistance force of different structures tested with Kevlar used as the test face. This comparison shows that, even though the jersey structure exhibited the highest resistant of 234.4 N to the slash in the coursewise direction, it failed badly in the walewise direction with a value of 15.4 N and failed marginally in the diagonal direction at 56.8 N. Racked structures showed consistency of results in all three directions, with 'Racked 2' structure performing well in comparison to the other two racked structures. Racked 1, 2 and 3 in Figure 4 denote the different racking sequences that were used to compare the effect of different racking patterns on slash resistance. The 'Racked 2' structure withstood the slash resistance force of 84.77 N in coursewise direction, 101.73 in diagonal direction and failed at 48.69 in walewise direction.

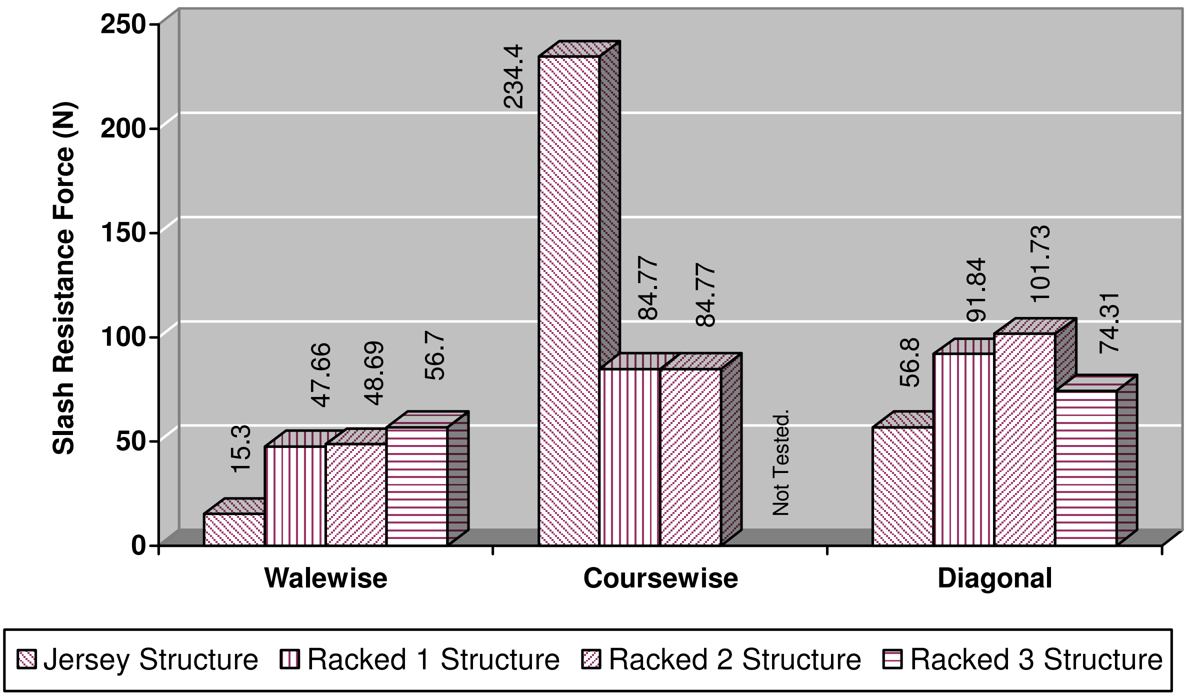

Figure 4: Slash Resistance Force for Different Structures with Kevlar as the Face

The high value of 234.4 N in the coursewise direction achieved with jersey structure used as the test face has been confirmed by retesting the fabric.

SLASH RESISTANT PERSONAL PROTECTIVE EQUIPMENT GARMENT

Apart from Kevlar, the best resistance to slash was recorded by using Spectra WF408 yarn (see Figure 3), but this was replaced by 3 ends of WF 528 which reduced the linear density by 30% but maintaining the same breaking force (see Table 2).This in turn reduced the area density of the knitted fabric by 250 g m^{-2} thus making it lighter and more comfortable to wear.

The novel two layer structure, named SARK-1, which passed the HOSDB slash resistant standard for the UK police on both the faces, was knitted with 2 ends of Kevlar as the racked face and 3 ends of WF 528 as the other face. The results of this fabric are shown in Tables 4 and 5.
It has already been stated earlier that the various fabric structures designed, developed and fully characterised have not been revealed in this paper intentionally, because various patents are in the process of being applied for.

Table 4: HOSDB Slash Resistant Test Results for SARK-1 with Kevlar as Face

Test Direction	Failure Force (N)	
	Test 1	Test 2
Walewise	71.64	62.44
Coursewise	293.77	389.41
30^o to walewise	109.74	-
Average :	**158.38**	**-**

The results of the slash tests shown in Table 4 reveal that a minimum failure force of 71.64 N and average failure force of 158.38 N were achieved. The average force of 158.38 N was almost twice the minimum average required to pass the test. A second set of walewise and coursewise slash tests were performed in order to substantiate the results obtained. The same was not done with Spectra WF528 used as the test face as there was not enough sample left to conduct the slash test.

Table 5: HOSDB Slash Resistant Test Results for SARK-1 with WF 528 as Face

Slash Direction	Force (N)
Walewise	65.81
Coursewise	122.17
30o to Walewise	61.61
Average Force:	**83.20**

The above fabric also passed the slash resistance standard with the WF 528 as the test face. It passed with a force of 65.81 N in walewise direction, 122.17 N in coursewise direction and 61.61 N in diagonal direction. The high resistance of 122.17 N to slash in the coursewise direction enabled the fabric to obtain the required average of 80 N.

The results in table 4 and table 5 are those obtained for a straight jersey structure. Modifications were made to the above structure to achieve a special racked structure in one of the faces, results of which are shown in table 6 and table 7.

Table 6: HOSDB Slash Resistant Test Results for SARK-2 with Kevlar Face

Slash Direction	Force (N)
Walewise	92.49
Coursewise	84.25
30^{o} to Walewise	97.68
Average :	**91.47**

Table 7: HOSDB Slash Resistant Test Results for SARK-2 with WF528 Face

Slash Direction	Force (N)
Walewise	115.78
Coursewise	144.41
30^{o} to Walewise	64.89
Average :	**108.36**

The novel two layer racked structure, named SARK-2, passed the standard on both faces of the fabric with an average value of 91.47N on the Kevlar face and 108.36N on the WF528 face. SARK-2 achieved similar slash performance in all three directions, as shown in Table 6. This indicates that the structure is more or less isotropic with regard to this property.

UNIQUENESS OF THIS INVENTION

The unique features of this invention are:

1. Special yarns have been developed and utilised in this innovative material.
2. Standard electronic flat weft knitting equipment has been utilised to produce the novel two layer structures.
3. Although different yarn types were used on the two faces of the two layer structure, both materials exhibited similar performance.
4. The material has successfully passed the most stringent test method stipulated for such products and applications
5. This unique material is relatively light, soft, elastic and above all comfortable to the wearer for long periods of continuous use.

The two novel fabric structures are two-layer materials which would be comfortable to the user and show similar slash or cut resistance performance when tested on both faces in spite of the fact that two completely different yarn types were used on the two faces.

CONCLUSIONS

The demand for protective garments is ever increasing among the law enforcement officers and medical personnel. With knives being used more commonly now-a-days in street fights and muggings, the demand for a personal protective garment against knives is escalating among the general public. This paper has reviewed the need for a slash resistant personal protective equipment garment and has described the design, development and characterisation of a novel slash proof material for the police, armed forces, children and the public that provides the following benefits:

- The material can be used as a complete garment such as balaclava, jumper, track suit, etc.
- It can be produced on standard weft knitting equipment.
- It is soft and elastic with good drapability.
- The fabric is a two-layer structure, which can incorporate various antibacterial or antimicrobial barrier properties if required.
- The material is breathable and comfortable to the wearer and can be used for long periods at a time.

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REFERENCES

1. Wooding, D. (2007). Anarchy in UK: Have the Yobs Taken Over?, *The Sun*, 20 August: 4.

2. Anon. (2006). 'Knife Crime': In-effective Reactions to a Distracting Problem, *The Centre for Crime and Justice Studies*, August: 20.

3. Budd, T. (1999). Violence at Work: Findings from the British Crime Survey, Home Office, London.

4. Youth Justice Board for England and Wales. (2005). *MORI Youth Survey 2004*, 32.

5. Anon. (2008, August 31). *B.B.C Radio 4 News* [Radio broadcast]. London: BBC.

6. Bleetman, A., Watson, C.H., 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** (4): 243-248.

7. Buster, C. (2007). Body Armor Update, *Law & Order*, **55** (1): 50-62.

8. Horsfall, I., Prosser, P.D., Watson C.H. and Champion, S.M. (1999). An Assessment of Human Performance in Stabbing, *Forensic Science International*, **102** (2-3): 79-89.

9. Chadwick, E.K.J., Nicol, A.C., Lane J.V. and Gray T.G.F. (1999). Biomechanics of Knife Stab Attacks, *Forensic Science International*, **105**: 35–44.

10. Fenne, P. (2005). Protection Against Knives and Other Weapons, In Scott, R.A. ed. *Textiles for Protection*, 652-662, Woodhead Publishing, Cambridge.

11. British Standards Institution. (2003). BS EN 388:2003 *Protective Gloves Against Mechanical Risk,* BSI, London.

12. British Standards Institution. (1999). BS EN ISO 13997:1999 *Protective Clothing -Mechanical Properties - Determination of Resistance to Cutting by Sharp Objects,* BSI, London.

13. Malbon, C. and Croft. J. (2006). *Home Office Scientific Development Branch Slash Resistance Standard for UK Police*, Home Office Scientific Development Branch, London.

14. Yang, H.H. (1993). *Kevlar Aramid Fibre*, Wiley & Sons, New York.

15. Miraftab, M. (2000). Technical Fibres, In Horrocks, A.R. and Anand, S.C. ed. *Handbook of Technical Textiles*, 29-30, Woodhead Publishing, Cambridge.

16. Young, R.J. and So, C.L. (2001). PBO and Related Polymers, In Hearle, J.W.S. ed. *High-* P*erformance Fibres*, 101-103, Woodhead Publishing, Cambridge.

17. Spencer, D.J. (2001). *Knitting Technology: A Comprehensive Handbook and Practical Guide,* **3rd Edition**, Woodhead Publishing, Cambridge.

[1] Wooding, D. (2007). Anarchy in UK: Have the Yobs Taken Over?, *The Sun*, 20 August: 4.

[2] Anon. (2006). 'Knife Crime': In-effective Reactions to a Distracting Problem, *The Centre for Crime and Justice Studies*, August: 20.

[3] Budd, T. (1999). Violence at Work: Findings from the British Crime Survey, Home Office, London.

[4] Youth Justice Board for England and Wales. (2005). *MORI Youth Survey 2004*, 32.

[5] Anon. (2008, August 31). *B.B.C Radio 4 News* [Radio broadcast]. London: BBC.

[6] Bleetman, A., Watson, C.H., 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** (4): 243-248.

[7] Buster, C. (2007). Body Armor Update, *Law & Order*, **55** (1): 50-62.

[8] Horsfall, I., Prosser, P.D., Watson C.H. and Champion, S.M. (1999). An Assessment of Human Performance in Stabbing, *Forensic Science International*, **102** (2-3): 79-89.

[9] Chadwick, E.K.J., Nicol, A.C., Lane J.V. and Gray T.G.F. (1999). Biomechanics of Knife Stab Attacks, *Forensic Science International*, **105**: 35–44.

[10] Fenne, P. (2005). Protection Against Knives and Other Weapons, In Scott, R.A. ed. *Textiles for Protection*, 652-662, Woodhead Publishing, Cambridge.

[11] British Standards Institution. (2003). BS EN 388:2003 *Protective Gloves Against Mechanical Risk,* BSI, London.

[12] British Standards Institution. (1999). BS EN ISO 13997:1999 *Protective Clothing - Mechanical Properties - Determination of Resistance to Cutting by Sharp Objects,* BSI, London.

[13] Malbon, C. and Croft. J. (2006). *Home Office Scientific Development Branch Slash Resistance Standard for UK Police*, Home Office Scientific Development Branch, London.

[14] Yang, H.H. (1993). *Kevlar Aramid Fibre*, Wiley & Sons, New York.

[15] Miraftab, M. (2000). Technical Fibres, In Horrocks, A.R. and Anand, S.C. ed. *Handbook of Technical Textiles*, 29-30, Woodhead Publishing, Cambridge.

[16] Young, R.J. and So, C.L. (2001). PBO and Related Polymers, In Hearle, J.W.S. ed. *High- Performance Fibres*, 101-103, Woodhead Publishing, Cambridge.

[17] Spencer, D.J. (2001). *Knitting Technology: A Comprehensive Handbook and Practical Guide,* **3rd Edition**, Woodhead Publishing, Cambridge.