The riot-control para-military forces use impact and stab-resistant body protectors (Figure 1), however the uniform (or undergarments) worn underneath body protectors are not cut or slash resistant which may lead to damage of important body organs especially the groin and below naval area while controlling mob or aggressive individuals. Also, the body protectors are designed to be worn on top of the uniform and are rigid in nature which makes side edges under arm and neck area vulnerable to the potential attacker which could attach away from the body protector (1).

In such cases, a cut-resistant uniform can be used to provide protection against sharp edged weapons (knife, screw drivers, blades, pointed stones, broken glass, sheet metals, injection moulded plastics, etc). These uniforms can be worn throughout the shift and can be designed for both male and female para-military forces. Further, the cut-resistant uniforms can also be recommended for jail/traffic controllers, private security forces or bodyguards dealing with violent/aggressive prisoners, protecting properties, events or people. This innovative cut-resistant
uniform can also be useful for bikers/two-wheeler riders for protection against road crashes.

In this part of the paper, we have discussed development of cut-resistant uniform made-up of HPT Flex? yarn based knitted fabric, further work is being done on using woven structures which will be introduced in our next paper. This newly designed cut resistant fabric is lighter and comfortable in comparison with currently used uniforms.

Materials & Methods Materials: The currently designed fabric is
manufactured using HPT Flex® yarn which is composed of Ultra high molecular weight polyethylene filaments (UHMWPE/HPPE), also called as high performance polyethylene fibres (HPPE), or sometimes extended chain polyethylene fibres (e.g. Spectra® by Honeywell, Dyneema® by DSM) blended with polyester and multifilament core component to produce high strength cut-resistant composite structure. The properties of HPPE/UHMWPE filaments are shown below (Table 1).

![Table 1: Properties of HPPE/UHMWPE filaments](image)

Testing of cut performance: The BS EN 388:2016 standard was used to study the abrasion resistance, blade cut resistance, tear resistance of newly developed cut-resistant uniform. The cut-performance was conducted as per ISO 13997. Table 2 shows comparison of various cut-performance standards which are used globally (2,3) and Table 3 demonstrates comparison between different test standard methods and their similarity/connection with each other. Currently three standards are used for measuring cut resistance; these standards are ASTM F1790-04, ISO 13997 and CEN 388. In ASTM F1790-04, ISO 13997 standard, the cut resistance is identified as the cutting force to be applied to a straight blade that slides to cut through the sample in a 20 mm blade stroke.
Results & discussions The cut-resistant uniform discussed in this paper is a lightweight and comfortable fabric, which provides protection underarm area, legs, spine, ribs and all major arteries and key vulnerable areas from slash/cut hazards. The body protector used on top of these uniforms to provide protection against stab injuries is discussed in previous part of the paper (1). The newly-developed uniform can be worn throughout the shift and is washable at room temperature providing durability of over three years (2,3). Table 4 shows the abrasion, cut, tear results of this uniform as per EN 388 standard. The puncture and impact test were not applicable for this uniform.
It is worthwhile to mention that the strength, hardness, slipperiness of yarns contribute to the overall cut-resistance of textiles. Our HPT Flex? yarns are manufactured using high strength Ultra high molecular weight polyethylene (UHMWPE/HPPE) reinforced with multifilament core component e-glass which is hard and brittle in nature (5,6). The natural lubricity of HPPE filaments help blades and other shard edges slide pass through the textiles (7). During cut-testing, the sharpness of the blade degrades even after single use, so blade should be changed for each new sample for testing (9). Also, it’s well established fact that the cut resistance level should be determined using range of loads, not just using only one load (5,9). The yarns can be reinforced with stainless steel or tungsten wire to achieve higher cut performance as compared to e-glass reinforced yarns used in the current study (8, 10, 12).

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>EN 388 Parameters</th>
<th>Performance Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Abrasion</td>
<td>Level 4</td>
</tr>
<tr>
<td>2</td>
<td>Cut-Resistance (Coupe Test)</td>
<td>NA</td>
</tr>
<tr>
<td>3</td>
<td>Tear Resistance</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Puncture</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>Cut-Resistance (TDM)</td>
<td>Level C</td>
</tr>
<tr>
<td>6</td>
<td>Impact Resistance</td>
<td>NA</td>
</tr>
</tbody>
</table>

Although glass, basalt, steel wire/tungsten are used to reinforce HPPE yarns to achieve higher cut-performance, none of the above mentioned products can be used alone to manufacture effective cut-resistant gloves, i.e. steel wire alone would break and glass would fracture while knitting (2,3,6). For this reason, it’s important to use steel wire or glass in core and HPPE on sheath to produce a composite yarn which is more cut-resistant than it’s components.

A new technology is developed where glass is introduced in the core of a
HPPE based ring spun yarn technology (11,12). This will also enable to have HPPE inside core and cotton/nylon/polyester fibres on sheath which can be easily dyed in any colour as HPPE can’t be dyed due to its inertness towards chemicals (Figure 3). Furthermore, the innovative HPT Flex? yarn can also be designed to manufacture new generation of uniforms which can provide both slash/cut alongwith stab protection to the end-users (13,14). Aramid fibres can be used in place of HPPE fibres if there is requirement of protection against thermal hazards such as conductive heat, molten metals, etc (4,6,9,10).

![Figure 3. HPPE in core with Hi-vis nylon orange and green on sheath](image)

**Conclusions** The newly-developed cut-resistant uniforms can be used by para-military forces or two-wheeler bikers for protection against sharp weapons or objects. The uniforms can be designed for both male and female end-users in different colours. Owing to its knitted structure, they are comfortable to the end users and allow better air circulation alongwith higher level of abrasion and cut/slash resistance. These uniforms are anti-bacterial and anti-fungal in nature due to presence of HPPE/UHMWPE which is hydrophobic in nature. Further, research is being done on recycling of these composite yarns so that the uniforms can be recycled once discarded after multiple use. It would be worthwhile to develop light weight stab-resistant panels which can be incorporated with cut-resistant uniforms to replace the currently used body protectors.

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