Rajesh and Shyam were working on assembly line of a leading automotive company in India. Although, they were wearing cotton gloves, Rajesh got a minor cut on his left hand during handling of spare parts as cotton gloves are easier to cut through. Rajesh showed to Shyam and they decided to get their hands washed and to visit the nearest departmental first-aid store. After 15 minutes, they reached the store as they had to wash hands as well.

This paper presents various types of cut-resistant knitted textiles with protection against mechanical hazards.

The lady at the store was very efficient and managed to get Rajesh first-aid and asked him to be very careful and not to hurt his hands again. On way back, Shyam asked Rajesh if he would like to have a cup of tea as Rajesh was stressed after seeing blood in his hands. Both of them went for a quick tea and came back to their work station after 75 minutes.

This case study demonstrates that even for a minor slash/cut during working hours cost a company almost over 4 times the cost of a standard cut-resistant gloves (average cost of cut-resistant gloves available in India @ INR 110-150 per pair), however due to lack of knowledge, training programs, strict regulations, majority of our workers are still using cotton/polyester/nylon gloves having no cut-resistant properties. Owing to use of cut-resistant gloves and sleeves, various injuries due to mechanical hazards (cut, slash, lacerations) can be reduced or minimized to a greater extent. In addition to gloves and sleeves, same concept can be used to manufacture cut-resistant knitted and woven fabrics for manufacturing of cut & stitched garments for sports or protective garments (such as body protectors, aprons, socks, undergarments etc). These garments are used by Para-military forces during riot control and jail security forces that face a common threat of getting attacked by knife or other sharp edged weapons.

Most industrialized nations have performance and safety standards for the most common groups of protective gloves. The European Union has the most comprehensive legislation in the form of Directive 89/686/EEC for Personal Protective Equipment (PPE), which includes requirements to check for restricted or banned substances used during manufacturing of gloves. These standards have been developed by European, national and international...
standards bodies such as CEN (European standards), ISO (International standards) and ASTM (American standards) to provide test methods and performance criteria for the assessment of key protective features. The European requirements EN 420 and EN 388 cover the mechanical risks (e.g. abrasion, cut, tear, puncture and impact) and material characteristics whereas EN 407 relates to the thermal hazards (e.g. vertical flammability, contact heat, radiant and conductive heat, protection against small and large molten metal splashes). The ISO 13997 standard deals with cut resistance of e-glass and metal reinforced gloves/sleeves which can’t be tested as per EN 388 due to dulling of blades. The following factors may influence the selection of protective gloves for a workplace:

- Thermal protection (Contact, convective or Radiant Heat)
- Mechanical Protection (Abrasion/ cut resistance requirements)
- Duration of contact
- Area requiring protection (hand only, forearm, arm)

- Grip requirements (dry, wet, oily) and general dexterity
- Size and comfort.

In this paper we have tested multiple variants of HPT Flex® gloves and studied a comparative analysis on mechanical risks such as abrasion, cut resistance, tear resistance and puncture resistance of the gloves. High Performance Textiles Pvt Ltd has recently introduced multiple variants of high performance yarns called HPT Flex® which is manufactured by reinforcing Ultra high molecular weight polyethylene (e.g. Dynema®, Spectra®, Forpe®) along with e-glass (e.g. 100 denier, 200 denier and 300 denier) and stainless steel wires (e.g. 30-70 microns) to achieve highest level of cut protection (level 4 and 5 as per EN 388 and A4 and above as per ISO 13997). UHMWPE (also known as HPPE) is produced by gel spinning technique with extremely long chains of polyethylene (with 'n' over 100,000, Figs. 1 & 2) in parallel orientation of greater than 85%, hence providing high strength of 28-37 g/denier. Owing to the presence of weak Van der Waals bonds between the molecules in UHMWPE/HPPE, the heat resistance is very poor and fibres melt at 150°C and properties degrade with the increase in room temperature. Due to its hydrophobic nature, these fibres are extremely resistant to chemical and biological attack and have better abrasion and fatigue resistance than aramid fibres.

**Materials and methods**

**Materials**

**Knitted seamless gloves using HPT Flex® Yarns**

HPT Flex® yarns are knitted into seamless gloves using Gauge 7, 10, 13 and 15 knitting machines (Fig. 3). The knit sequence of seamless gloves knitting is as below:

- Tip of little finger → ring finger → four fingers completed → palm (width equal to four fingers) → thumb knitting from tip → palm with five fingers width → rib knitting width equal to 5 fingers

These gloves further dipped with polyurethane (PU), neoprene...
ene, latex, nitrile to provide chemical and water repellency. Table 1 shows specifications of seamless gloves/sleeves used for this study and pictures of these gloves are shown in Fig 4.

**HPT Flex knitted fabrics**

Multiple knitted fabrics in different GSM were also developed using HPT Flex yarns (Table 2 & Fig 5). These fabrics are used for manufacturing of cut & sewn protective clothing for protection against stabs/Slash/lacerations.

**HPT Flex woven fabrics**

HPPE based woven fabric (590 GSM) was also developed using HPT Flex yarn to manufacture cut & stitched protective clothing e.g. cut-resistant jackets, trousers, body armor, antivandal curtains (Fig 6).

**Performance standards**

**EN 420**

The seamless gloves (Gauge 7, 10 and 13 gloves as per Fig 4) are manufactured as per EN 420. This standard defines the general requirements valid for all protective gloves/sleeves:

- The gloves/sleeves shall not be a risk to wear or cause injuries to the user.
- The glove material shall have a pH value between 3.5 - 9.5
- The Chrome VI level in the glove leather must stay at 2.9 mg/kg or lower.
- If the glove contains any substances known to cause allergic reactions, it shall be stated in the product information.
- The glove sizes are standardized according to minimum length specified as per the Table 3. This Glove size chart should be followed for hand and fingers dimensions.

**EN 388:2016**

This standard specifies that the gloves are intended to give protection against mechanical hazards. This standard involves testing of resistance to abrasion, blade cutting, tear and puncture resistance as follows. Tables 4 & 5 and Fig 7 depicts EN 388-2016 for better understanding.

**Abrasion resistance**

The material of the glove is abraded with sand paper under pressure and the number of cycles required to wear a hole in the material is measured. The highest performance level is 4, which corresponds to 8,000 cycles.

**Cut resistance (Coupe tester and ISO 13997 using TDM and CPP testers)**

This can be tested using coupe tester which consists of a circular blade that moves back and forth under 5N contact force until it cuts through the material. The blade cut resistance is stated on a 0-5 scale based on the number of rotations it takes to cut through the sample, using a standard canvas control material before and after to take the sharpness of the blade into consideration. Owing to its lower constant load of 5 N and much higher blade speed of 110 mm/sec, coupe tester is not applicable for highly cut-resistant materials containing glass since the blade will dull during testing at higher speed. For this reason, EN388 added a second test required for high cut-resistant materials: the ISO 13997 TDM test (Table 5). The ISO method Tomodynamometer-100 (TDM) is capable of loads up to 100 N but operates at a much lower blade speed of 2.5 mm/sec. This cut test determines the resistance of a safety glove by applying the sample fabric from the palm with great force in a single movement. To this end, a sharp-
edged blade is dragged over the sample fabric once. This allows the accurate calculation of the minimum force required to cut the sample material at a thickness of 20mm. This test is most widely used to determine the cut resistance of safety gloves reinforced with glass and steel wire which gives a precise result in every test.

Further, cut testing can also be done as per ASTM F 1790 Cut Protection Performance Tester (CPPT) which operates at a sinusoidal blade speed ranging from 0-14 mm/sec with a maximum load of 40 N. CPP testing instrument is designed to assess the cut resistance of a material when exposed to cutting edge under specified loads. Some of the limitations of this cut tester that it is not valid for high porosity materials that allow cutting edge contact with the mounting surface prior to cutting or for materials greater than 3 mm in thickness. Also, materials having a high coefficient of friction such as elastomers can bias the result obtained using the CPP tester.

**Tear resistance**

An incision is made in the test specimen. The amount of force required to tear the material apart is then measured. The highest performance level is 4, which corresponds to a force of 75 N.

**Puncture resistance**

The test involves measuring the amount of force required to pierce the test specimen with a standard sized point and at a given speed (10 cm/min). The highest performance level is 4, which corresponds to a force of 150N.

**Impact resistance**

It is the transmitted force of a pre-defined weight of 2.5 kg with impact energy of 5 Joules onto the glove. In addition, material may not crack. It depicts a 'Pass' or 'Fail' test for areas requiring impact protection as mentioned in Table 5.

**Results and discussion**

The mechanical hazards as per EN 388-2016 was tested in terms of abrasion resistance, cut resistance, tear strength, puncture and impact resistance. As discussed, ISO 13997 TDM test recommended for high cut resistant materials where e-glass, basalt or stainless steel is used as reinforcement. It was

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**Table 4: EN 388 Performance levels**

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<th>Performance Levels</th>
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<tr>
<td>Abrasion Resistance-cycles</td>
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<tr>
<td>Blade Cut Resistance-cut index</td>
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<tr>
<td>Tear Resistance-Newton</td>
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<tr>
<td>Puncture Resistance-Newton</td>
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</table>

**Table 5: ISO 13997 and Impact levels as per EN 388-2016**

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<th>Performance Levels</th>
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</tr>
<tr>
<td>Cut Resistance ISO 13997(N)</td>
<td>NA</td>
</tr>
<tr>
<td>Impact Resistance(KN)</td>
<td>4</td>
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</table>

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*Fig 7: TDM & CPP cut tester*

*Fig 8: Pictogram shows the rating and symbol used in gloves to depict the EN 388-2016 levels*
reinforced gloves outperformed as compared to steel wire reinforced options. However, there are chances of e-glass getting fractured during multiple washing; hence reinforcement with stainless steel (SS) wire is preferred to achieve consistent cut-performance after multiple washing.

Further, it's important to point that the composite yarns designed for cut-slash protection must have high tenacity of over 10 g/denier and modulus over 150 g/dtex as lower strength yarn doesn't exhibit adequate strength for the required protection and lower modulus yarns will result in fibre stretching and ineffective restriction of the cutting knife/ blades. Table 6 shows that gauge 7 gloves are higher cut-resistant than that of gauge 10 gloves due to higher areal density; hence more force required to cut through gauge 7 gloves. However, gauge 7 gloves (70 g/pair) are heavier than gauge 10 gloves (55 g/pair). It is also observed that stainless steel reinforced yarns are more cut-resistant than that of glass reinforced yarns on same weight to weight basis. Further, it's important to mention that stainless steel reinforced yarns are more durable during multiple washing as compared to glass reinforced yarns as glass may get fractured during multiple washing of gloves. For electrical applications, SS wire reinforced yarns are not recommended due to its conductive nature, hence, glass reinforced yarns are used for electrical and electrical arc flash fire hazards.

Table 7 shows result for gauge 13 and 15 gloves which are lighter and more dexterous than that of gauge 7 and 10 gloves. The 15 gauge knitted gloves are recently launched in the Indian market and mostly polyester/nylon liners are used with polyurethane or nitrile coating on the palm area. The recently developed HPT Flex® yarns for 15 gauge gloves are manufactured using 200 denier HPPE along with 30 micron stainless steel wire and polyester. It is evident from Table 7 that the yarn reinforced with stainless steel wire is more cut-resistant than that of glass reinforced yarns. Both SS wire and e-glass reinforced yarns blunt and deform the blades during testing, so new blades should be used for each cut testing. Gloves will exhibit higher cut resistance when tested with a blunter blade. Due to lower density of glass fibres (2.58 g/cc) as compared to stainless steel (8.00 g/cc), gloves reinforced with glass are lighter as compared to that of SS wire reinforced yarns with same liner density. However, poor covering of glass fibres may cause irritation to the end users. For this reason, HPT Flex® yarns are doubly covered both in case of SS wire or glass fibres.

The same HPT Flex® yarn is also used to knit seamless sleeves (16 inches) using gloves knitting machine. Table 8 shows that both SS wire and glass reinforced yarns based sleeves achieve
Level D for cut performance which is above 15 Newton as per TDM tester (ISO 13997) and same abrasion Level 2 for both types of sleeves.

With a view to develop protective garments (body protectors, cut resistant work wear, balaclava, undershirts) HPT Flex yarns are used to study the cut-resistant properties of woven and knitted structures. Both knitted and woven HPT Flex fabrics can be used to develop cut, stab-resistant body armours which could be suitable for riot and jail security forces that face a common threat of getting attacked by knife or other sharp edged weapons. Stab threats can be classified into two categories: puncture and cut. Puncture refers to penetration by instruments with sharp tips but no cutting edge, such as a spike. Cut refers to contact with knives with continuous cutting edge. Knife threats are generally more difficult to stop than puncture, since the long cutting edge presents a continuous source of damage initiation during the stab event. A stab-resistant body armour system should afford protection against injury from penetration by knives, edged weapons, and sharp-pointed weapons while ensuring that the movement of the wearer is not unduly restricted. The protected area ensures coverage of the vital organs, in particular, the heart, liver, spine, kidneys and spleen. Tables 9 and 10 show that both knitted and woven HPT Flex fabrics can provide protection against cut, slash, lacerations in pursuit to protective textiles.

### Conclusion

This has been observed that there is an increase in cut performance of gloves when specialized reinforced HPT Flex® yarns are used as compared to 100% HPPE yarns. The former is widely used in the seamless safety gloves to provide protection against mechanical hazards. The composite yarns designed for cut-slash protection must have high tenacity of at least 10 g/denier and modulus of 150 g/dtex. Also, it is evident that the cut resistance can be significantly upgraded if HPPE yarns are reinforced with e-glass and steel wire. Based on the end-users requirements, e-glass can be selected from 100 to 300 denier range and stainless steel from 30-80 microns. The core components can be selected as per risks involved e.g. for applications where serrated edges are being handled such as in glass or metal industry, steel wire reinforced gloves perform better as compared to e-glass. Further, gloves are stitched with leather on palm for improvements in abrasion, tear and impact resistance. It also makes glove chemical resistant due to non porous nature of leather. Also we have seen better precision in the results of CPPT and TDM testers as compared to coupler tester due to lower constant load of 5 N and much higher blade speed of 110 mm/sec, the latter is not applicable for highly cut-resistant materials containing glass since the blade will dull during testing at higher speed.

As India is a developing nation, the cost of cut-resistant gloves may initially look higher to small & medium sized enterprises. However, due to higher durability (up to 30-45 days after washing), these gloves can be recommended in any manufacturing set-up. More studies required to understand risks involved in a manufacturing company and gloves should be selected based on end-users requirements. Further study needs to be done in the development of dipped gloves (e.g. with nitrile, latex, PU) for protection against chemicals and hazardous liquids. More awareness is required amongst the industry to implement the strict safety regulations for personal protective equipments (PPE) in India.

### References