

Study on the cut-resistant properties of UHMWPE knitted gloves coated with water-based polyurethane

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The article presents a comparative study of water-based polyurethane (PU)-coated ultra-high-molecular weight polyethylene (UHMWPE) gloves knitted at various gauges on a seamless glove knitting machine in terms of their cut-resistance and thermal comfort properties. The gloves used in this study are made of composite yarns that consist of UHMWPE multifilament in the sheath and E-glass multifilament/stainless-steel wire in the core. The results indicate that 13-gauge UHMWPE gloves offer the best balance of dexterity and physical handling properties compared to 60-micron steel wire-reinforced UHMWPE (10 gauge) gloves and 40-micron steel wire reinforced-UHMWPE (15-gauge) gloves. Additionally, to achieve higher cut-performance Levels, composite UHMWPE yarns are developed using 30, 50 and 70-micron wires and 100 and 200 denier glass filaments in the core. These final composite yarns are knitted on a 13-gauge glove knitting machine. It is observed that the 13-gauge-70-micron stainless-steel wire HPT-13W-70 UHMWPE gloves provide the highest level of mechanical protection, making them ideal for industrial use.

Keywords: Cut-resistance, Dexterity, Safety gloves, UHMWPE gloves, Water-based PU coating, Tomodynamometer

1 Introduction

Inadequate workplace protection can occasionally result in workplace mishaps that result in worker injuries. Hands and fingers are the body parts most often affected in such accidents¹. Hand activities are mostly involved in sectors like manufacturing, construction, and food preparation, which carry a higher risk of hand injuries in specific jobs². Workers' exposed hands are vulnerable to mishaps that result in scorching, cutting, and rubbing. Consequently, wearing protective gloves can prevent such injuries. Protective gloves are elements of personal protective equipment that shield hands from workplace accidents. These gloves should provide good grip and dexterity, along with tear strength and abrasion resistance³. Cut-resistant gloves are widely used in industries, including automobile, construction, machine and compartment assembly, recycling, glass handling, electrical installation, and food and meat packing. They protect hands, fingers, arms, and wrists from injuries caused by contact with sharp objects or equipment such as sharp metal, blades, and broken glasses⁴. The cut-resistant gloves' performance can be

assessed based on cut performance, tear strength, abrasion resistance, and puncture resistance. High-performance fibres such as para-aramid, ultra-high molecular weight polyethylene (UHMWPE) or Dyneema, Spectra are commonly used to make industrial cut-resistant gloves⁵.

UHMWPE-based protective gloves are mostly used in various industries because of their durability and good performance against mechanical risks, attributed to their high crystallinity and orientation compared to other high-performance fibres. This material is extremely strong and has the highest impact strength of any thermoplastic⁶. Although UHMWPE fibre has a high strength, reinforcing it with composite materials such as E-glass and stainless-steel wire improves its cut-protection properties against mechanical hazards. These gloves are coated with water-based polyurethane (PU) coating for chemical and water repellence. The water-based PU coating offers an advantage over standard solvent-based PU coating, which is made from water-borne polyurethane resin that replaces organic solvents (e.g., DMF, acetone) with water. The manufacturing process is pollution-free, non-toxic, free of dangerous compounds such as DMF, and has no VOC emissions, which makes it ecologically friendly⁷.

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Various studies on cut-resistant protective gloves have primarily focused on solvent-based PU/latex/nitrile coated protective gloves made from fibres like m-aramid, p-aramid, p-aramid-glass reinforced, and UHMWPE. However, no comparative study is available on water-based PU-coated 100% UHMWPE and UHMWPE reinforced with stainless steel wire and glass-reinforced cut-resistant protective gloves knitted on 10, 13 and 15-gauge machines. This study compares 10, 13 and 15-gauge seamless knitted gloves manufactured using UHMWPE reinforced with stainless steel wire (40-70 microns) and glass (100, 200 denier) to achieve higher cut performance. Further, a comparative study is conducted after coating the palms of these gloves with water-based PU.

2 Materials and Methods

2.1 Yarn Production

Eight types of yarns were manufactured using polyester and UHMWPE filaments (Table 1). In the study's first phase, three yarn types were developed for knitting 10-gauge, 13-gauge and 15-gauge gloves. The 10-gauge glove used a yarn composition of 400 denier UHMWPE fibre reinforced with a 60-micron stainless-steel wire and polyester in the core (HPT-10W-60), making it highly cut-resistant. Similarly, for the 13-gauge glove, the yarn comprised 400 denier UHMWPE with polyester in the core (HPT-13). For the 15-gauge glove, the yarn contained 400 denier UHMWPE reinforced with a 40-micron stainless steel wire and polyester in the core (HPT-15W-40), making it highly cut-resistant.

In the second part, five additional yarn types were developed for 13-gauge knitted gloves. The composition for the 13-gauge HPT-13 glove yarn (400 denier UHMWPE with polyester in core) was reinforced with 30-micron, 50-micron and 70-micron stainless-steel wires in the core as well as with 100

denier and 200 denier glass fibre in the core. The resulting yarn were codes as follows: HPT-13W-30-Steel wire reinforced UHMWPE yarn, HPT-13W-50-Steel wire reinforced UHMWPE yarn, HPT-13W-70-steel wire reinforced UHMWPE yarn, HPT-13E-92-100D glass fibre reinforced UHMWPE yarn and HPT-13E-92-200D glass fibre reinforced UHMWPE yarn.

2.2 Production of Cut-Resistant Gloves

Gloves were knitted on fully automatic V-flatbed seamless gloves knitting machines set to 10-gauge, 13-gauge and 15-gauge, using UHMWPE yarns and stainless-steel reinforced and E-glass reinforced UHMWPE yarns (Fig. 1).

Following knitting, the glove samples were coated with a water-based PU and then dried in a drying unit for 2 h at 85°C. The specifications of the coated gloves, including structure, coating thickness, and weight, were detailed in Table 2.

2.3 Testing of Cut Resistant Gloves against Mechanical Risks

The cut-resistant glove samples were tested against mechanical risks in accordance with EN 388:2016 and



Fig. 1 — Developed glove samples on 10, 13, and 15-gauge glove knitting machine

Table 1 — Specifications of yarns

Yarn	Core-steel wire thickness micron	Core-glass fibre fineness denier	UHMWPE yarn fineness denier	% UHMWPE in yarn composition
HPT-10W-60	60	---	400	53.0
HPT-13	---	---	400	88.8
HPT-15W-40	40	---	200	45.4
HPT-13W-30	30	---	400	44.0
HPT-13W-50	50	---	400	47.8
HPT-13W-70	70	---	400	48.3
HPT-13E-92-100D	---	100	400	53.3
HPT-13E-92-200D	---	200	400	61.5

ISO 13997 standards. Abrasion resistance, tearing resistance, and puncture resistance tests were conducted following standard EN 388:2016, while cut resistance tests were measured according to ISO 13997, with level of performance shown in Tables 3a and b.

In the TDM cut resistance tester, vertical pressure is applied to the blade, which moves horizontally at a constant speed of 2.5 mm/s to cut the specimen. Cut-through is detected when the blade makes contact with the copper conducting strip beneath the sample. By applying different normal loads, varied cut distances are achieved. For each sample, 15 pairs of load-distance data are collected, with five pairs corresponding to cut distances of 5–15 mm, five pairs between 15–30 mm, and five pairs within 30–50 mm⁸.

2.4 Thermal Conductivity Test

Thermal conductivity, denoted as λ and unit is $\text{W m}^{-1}\text{K}^{-1}$, and calculated using the following equation:

$$\lambda = \frac{Q}{t} \times \frac{h}{A \times \Delta T} \quad \dots(1)$$

where A is the fabric test area; Q, quantity of heat applied; t, passing time; h, thickness of fabric sample; and ΔT , temperature difference.

The Alambeta thermal tester was used to evaluate thermal conductivity⁵. All tests were conducted at room temperature (25°C - 30°C) and 65% relative humidity. For each test, four samples were tested from two pairs of gloves within the same series, and results were determined by averaging the four readings.

2.5 Surface Analysis

Surface analysis of water-based PU coated UHMWPE knitted gloves was conducted using a Leica microscope to analyse effect of abrasion on coating uniformity, texture, and defects on glove surface at magnification of 10x.

3 Results and Discussion

3.1 Mechanical Testing of Water-Based PU-Coated Knitted Gloves

In the first phase, the properties of three glove samples, HPT-10W-60, HPT-13 and HPT-15W-40, in terms of abrasion resistance, blade cut-resistance, tear resistance and puncture resistance are compared (Table 4).

Table 4 shows that the abrasion resistance of HPT-15-W-40 (Level 1) is insufficient for applications requiring high abrasion resistance, while HPT-13

Table 2 — Specifications of water-based PU-coated knitted gloves

Yarn	Structure	Coating thickness, mm	Weight of single glove, g	CPI/WPI	GSM
HPT-10W-60	Single Jersey	0.22	48.0	10/18	822.8
HPT-13	Single Jersey	0.23	48.0	19/25	720.2
HPT-15W-40	Single Jersey	0.20	46.0	21/23	835.4
HPT-13W-30	Single Jersey	0.20	50.0	18/26	701.8
HPT-13W-50	Single Jersey	0.35	53.0	15/22	825.6
HPT-13W-70	Single Jersey	0.85	58.0	15/22	836.1
HPT-13E-92-100D	Single Jersey	0.30	52.5	19/22	807.5
HPT-13E-92-200D	Single Jersey	0.24	51.8	16/24	734.6

Table 3 (a) — Performance levels of tested materials

Test	Level-1	Level-2	Level-3	Level-4	Level-5
Abrasion resistance (no. of rubs)	0-100	101-500	501-2000	2001-8000	>8000
Tear resistance, N	0-10	11-25	26-50	51-75	>75
Puncture resistance, N	0-20	21-60	61-100	101-150	>150

Table 3 (b) — Performance Levels for materials tested with standard ISO 13997

Test	Level-A	Level-B	Level-C	Level-D	Level-E	Level-F
Cut resistance, N	0-2	3-5	6-10	11-15	16-22	>22

Table 4 — Mechanical properties of glove samples

Parameter	HPT-10W-60	HPT-13	HPT-15W-40
Abrasion resistance	200 (Level -2)	1500 (Level -3)	100 (Level -1)
Tear resistance	348.13 (Level -5)	369.71 (Level -5)	176.52 (Level -5)
Puncture resistance	102.94 (Level -4)	152.57 (Level-5)	150.94 (Level -4)
Cut resistance	21 (Level E)	15 (Level -D)	17 (Level -D)

gloves achieve Level 3, and HPT-10W-60 gloves reach Level 2. The HPT-13 gloves provide better abrasion resistance, likely due to a higher percentage of UHMWPE lacking steel wire or glass in the core (Fig. 2).

In terms of tear resistance, all three gloves attain Level 5 performance. Notably, HPT-13 shows a higher tear resistance at 369.71 N in comparison to HPT-10W-60 (348.13 N) and HPT-15W-40 (176.52), which can be attributed to its higher percentage of UHMWPE (88%) and optimal GSM. Tear strength is influenced by GSM, fibre composition in core/sheath of yarn cross-section and type of coating on the glove surfaces, with higher GSM gloves exhibiting greater tear resistance due to increased durability and tensile strength of UHMWPE fibres⁹.

The puncture resistance test results indicate that HPT-13 and HPT-15W-40 gloves achieve Level 5 performance, while HPT-10W-60 reaches Level 4. HPT-13's superior puncture resistance is attributed to its higher percentage of UHMWPE. The puncture resistance of textile materials is influenced by the thickness and structure of the fabric. In general, multilayer fabrics offer better puncture resistance than single-layer fabrics. For knitted glove samples, puncture resistance depends on the open and closed structure of the knitted fabric. A 10-gauge knitted glove is more open than 13- and 15-gauge gloves because it uses 10 needles per inch (forming 10 loops per inch), while 13- and 15-gauge gloves have 13 and 15 loops per inch, respectively. Open-knit structures tend to have lower puncture resistance than close-knit structures, which explains why the HPT-10W-60 glove shows the lowest puncture resistance due to its open structure. While HPT-13 and HPT-15W-40 gloves reach Level 5 in puncture resistance, HPT-13 performs slightly better due to its higher percentage of UHMWPE.

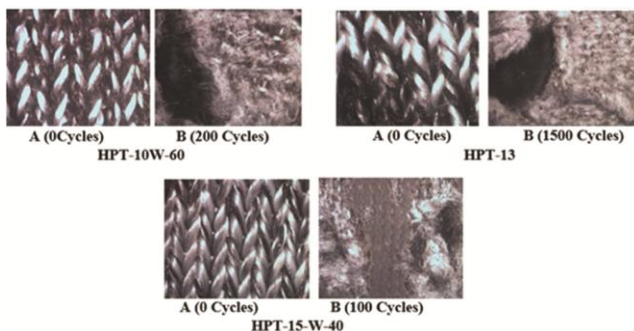


Fig. 2 — Surface image analysis of glove samples (A) before abrasion and (B) after abrasion

For cut resistance, a correlation graph (Fig. 3) was plotted between the cutting distance and values of load applied on the blade. It is observed that HPT-10W-60 demonstrates slightly better cut performance (Level E) compared to HPT-13 (Level D). It is mainly due to the heavier weight and higher GSM of HPT-10W-60 gloves and reinforcement provided by stainless-steel wire, which enhances cut resistance by increasing the blade penetration threshold⁹. Cut performance also increases with increasing the thickness of stainless-steel wire.

Overall, HPT-13 gloves provide high abrasion, tear and puncture resistance, making them suitable for rough applications where dexterity and handling are crucial. Although HPT-10W-60 offers better cut resistance, market surveys suggest that 13-gauge gloves are preferred due to their versatility and physical handling properties. For further research, HPT-13 gloves are reinforced with varying thicknesses of stainless-steel wire (30, 50 and 70 microns) and different deniers of glass fibre (100 and 200 denier) to enhance cut resistance while maintaining the same yarn composition.

In the second phase, the performance of the modified gloves — HPT-13W-30, HPT-13W-50, HPT-13W-70, HPT-13E-92-100D and HPT-13E-92-200D — are tested for abrasion resistance, cut-protection, puncture resistance and tear resistance (Table 5).

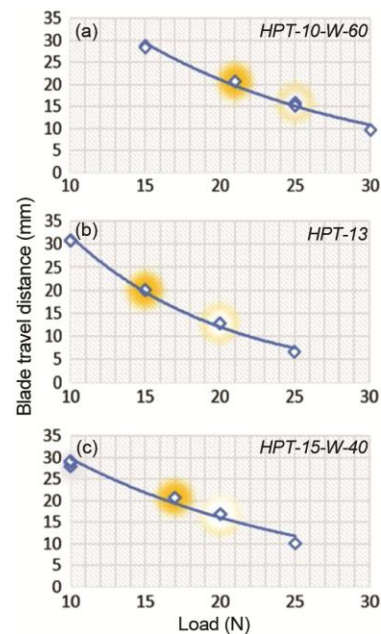


Fig. 3 — Blade travel distance (mm) - load data and regression line obtained by cut testing of glove samples for (a) HPT-10W-60 (b) HPT-13 (c) HPT-15W-60

Table 5 — Level of performance achieved by glove samples

Yarn	Abrasion resistance no. of rub	Tear resistance, N	Puncture resistance, N	Cut resistance, N
HPT-13-W-50	500 (Level-2)	434.9 (Level-5)	174.7 (Level-5)	40 (Level-F)
HPT-13-W-70	1250 (Level-3)	453.0 (Level-5)	178.9 (Level-5)	45 (Level-F)
HPT-13-E-92-100D	300 (Level-2)	306.2 (Level-5)	214.3 (Level-5)	15 (Level-D)
HPT-13-E-92-200D	400 (Level-2)	298.0 (Level-5)	238.0 (Level-5)	18 (Level-E)

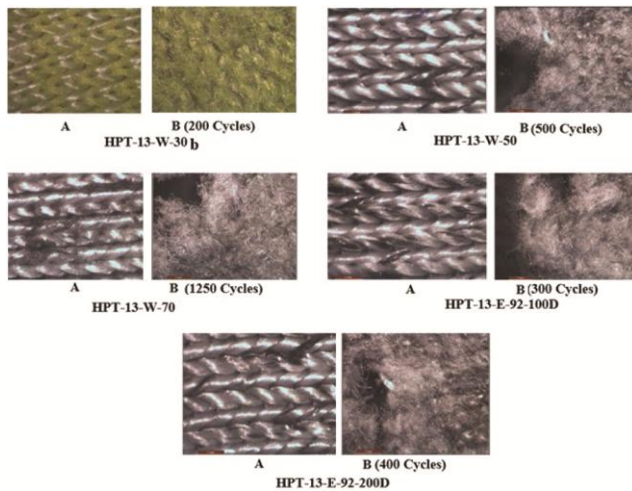


Fig. 4 — Optical images of different glove samples (a) before abrasion and (b) after abrasion

HPT-13W-70 achieves Level 3 abrasion resistance with a performance value of 1250 cycles, outperforming other samples (Fig. 4). The results indicate that abrasion resistance improves with increased thickness of steel wire or higher glass fibre count in the core of a 13-gauge glove liner while keeping the yarn composition constant. This improvement is due to the fact that as the thickness of stainless-steel wire or count of glass fibre increases, the thickness of single dipping water-based PU coating on the gloves also increases. This thicker coating enhances the glove's resistance to abrasion. Therefore, the present study demonstrates that the HPT-13W-70 glove offers better durability against abrasion than other samples, making it ideal for applications requiring high abrasion resistance.

All glove samples achieve Level 5 tear resistance, with HPT-13W-70 exhibiting the highest level at 453.6 N. In comparison, HPT-13W-30, HPT-13W-50, HPT-13E-92-100, and HPT-13E-92-200 gloves tear at 291.2 N, 434.9 N, 306.2 N and 298.0 N, respectively, making the HPT-13W-70 the top performer among these samples. This superior tear strength in the HPT-13W-70 glove is attributed to its higher GSM and greater percentage of UHMWPE fibre. As mentioned previously, the tear strength is influenced by GSM,

the percentage of high-performance fibre in the core or sheath of the yarn and type of coating on the glove surfaces, with higher GSM gloves exhibiting greater tear resistance. Additionally, the yarn's higher UHMWPE fibre content contributes to higher tensile strength and durability. The coating thickness also affects the tear strength of gloves, providing an extra layer of durability.

The puncture resistance test confirms that all glove samples withstand puncturing, achieving Level 5 performance. However, a comparative analysis shows that HPT-13E-92-100D and HPT-13E-92-200D, reinforced with glass fibre, exhibit superior puncture resistance compared to those reinforced with stainless-steel wire. This advantage may be attributed to the formation of a highly compact and close structure, filling the interstices with fractured glass and creating a closer structure. Consequently, glass-reinforced gloves require more force to puncture than steel-reinforced samples.

Table 5 reveals that the HPT-13W-70 glove requires 45 N (Level F protection) of force to cut through the glove sample with a 20 mm blade displacement, marking it as the best-performing glove. Although HPT-13W-50 also achieves Level F protection with 40 N force, the HPT-13W-70's higher cut-through force (45 N) signifies better performance. Both are suitable for industrial applications requiring efficient cuts and sharp edge protection. Conversely, HPT-13W-30 and HPT-13E-92-100D only provide Level C and D cut protection, respectively, and are less suitable for industrial purposes requiring high cut resistance.

The present investigation clarifies that the cut performance properties of the fabric are mostly determined by the materials used in the core of the yarn. Yarn reinforced with stainless-steel wire and glass fibre significantly improves its cut resistance. The cut performance improves with increases in both the diameter and linear density of the stainless-steel wire and E-glass used in the core⁹. A comparative study of glove samples shows that the HPT-13W-70 glove offers the highest cut protection attributed to its

Table 6 — Thermal conductivity results of glove samples

Yarn	Thermal conductivity, λ (mW m ⁻¹ K ⁻¹)
HPT-13W-30	74.78
HPT-13W-50	84.20
HPT-13W-70	86.50
HPT-13E-92-100D	83.32
HPT-13E-92-200D	80.38

thicker stainless-steel wire in the core (70 micron). Similarly, in E-glass reinforced gloves, cut resistance increases with increasing the count of glass fibre; thus, the HPT-13E-92-200D (Level E) outperforms HPT-13E-92-100D (Level D). But, glass-reinforced gloves demonstrate lower cut performance than steel core gloves (50 and 70 micron) due to thinner coating. The type and thickness of the coating on the glove surface also affect cut resistance. When comparing water-based PU-coated gloves to those with other coatings (latex, nitrile), it is observed that water-based PU-coated gloves provide better cut performance.

3.2 Thermal Comfort Properties

The thermal conductivity of glove samples is measured using the Alambeta thermal testing instrument (Table 6).

It is observed that the HPT-13W-70 glove, which contains the thickest stainless-steel wire in its yarn core, exhibits the highest thermal conductivity among the samples. This is because thermal conductivity, or the ability of a material to conduct heat, is influenced by the type of fibres or material used in the core/sheath of the yarn structure. The higher GSM and weight of the HPT-13W-70 glove also contribute to its superior thermal conductivity, while the light-weight HPT-13W-30 glove, with a lower GSM, demonstrates the lowest thermal conductivity.

The thickness of the coating applied to the palm of the gloves also impacts thermal conductivity. Increasing the coating thickness can increase the glove's weight and GSM, potentially enhancing thermal conductivity. This aspect of coating thickness is a possible area for further research, as it could enable regulation of not only thermal comfort but also puncture resistance, tear strength, and cut-resistance properties.

4 Conclusion

The cut resistance property of knitted gloves is investigated using ultra-high molecular weight polyethylene (UHMWPE) fibre. The gloves are coated with environment-friendly water-based PU using the dipping technique. The study shows that the water-based PU coating provides better cut resistance and thermal comfort properties, allowing for prolonged wear with improved dexterity compared to traditional gloves coated with latex, nitrile, or solvent-based PU. This makes these gloves suitable for rough and tough applications. The results show that the HPT-13W-70 glove offers superior cut protection and is highly effective for use in various industries. Additionally, the durability and thermal comfort properties of the 70-micron stainless-steel wire-reinforced, water-based PU-coated HPT-13W-70 UHMWPE gloves are better than those of the E-glass-reinforced (100 and 200 denier) and stainless-steel wire-reinforced (30 and 50 micron wire thickness) UHMWPE gloves. It is concluded that being cost-effective, the water-based PU-coated HPT-13-W-70 gloves offer excellent thermal comfort and durability against mechanical risks, making them highly suitable for various industries.

References

- 1 Khan M M A, Halim Z I & Iqbal M, *Int J Occup Saf Ergon*, 12 (2006) 327.
- 2 Sorock G S, Lombardi D A, Courtney T K, Cotnam J P & Mittleman M A, *Saf Sci*, 38 (2001) 241.
- 3 Malik M H, Akhtar N, Bakkar A & Fraz A, *IOP Conf Ser: Mater Sci Eng*, 507 (2019) 012001.
- 4 Vu-Thi B N, Vu-Khanh T & Lara J, *J Thermoplast Compos Mater*, 18 (2005) 23.
- 5 Ertekin M, Ertekin G & Marmarali A, *J Text Inst*, 109 (8) (2018) 1091.
- 6 Prevorek D C & Brody E H, New York: Longman publishing group, (1994) 263.
- 7 Daniel Li, *Book-Cut protective textiles*, Woodhead publishing publications-The textile institute book series, (2020).
- 8 Dhyani H, Sinha S K & Kumar N, *J Text Cloth Sci*, 3 (2020) 15.
- 9 Bhardwaj A, Kaushik J, Jajpura L & Kumar N, *Manmade Text India*, 46 (2018) 303.
- 10 Cook L, Advantages of waterborne polyurethane coated gloves & antistatic coated gloves, website link-<https://www.ppein.com/advantages-of-waterborne-polyurethane-coated-gloves-antistatic-coated-gloves/> (2020).
- 11 Katyal A & Kumar N, *Asian Text J*, (2006) 61.
- 12 Hu H & Zhu M, *AUTEX Res J*, 5 (3) (2005) 142.