

## INVESTIGATION OF THERMO-PHYSIOLOGICAL COMFORT PROPERTIES OF COMPOSITE YARN GLOVES

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**ABSTRACT:** With the increasing awareness of using personal protective products such as cut-resistant gloves to secure hands in accidental injuries, the usage of the products is gaining popularity. For better performance of the user, the comfort properties have become an essential need along with the functional properties. In many occupations, such as in the meat cutting process, metal sheet and glass manufacturing units, during the use of sharp-end tools, workers' hands need protection. In this research, the development and comparison of comfortable & protective cut-resistant gloves were performed by using blends of high-performance fibers, synthetic, and regenerated fibers. Fibers used were para-aramid (Kevlar), high-density polyethylene (HDPE), glass fibers to achieve technical properties, and mod-acrylic, viscose rayon, and polyester were used for thermo-physiological comfort characteristics. Physical properties, cut resistance index, and comfort properties i.e., air permeability, thermal resistance, and relative water vapor permeability %, for all the samples, were investigated. All the results were

analyzed and compared w.r.t comfort characteristics. It was observed that by increasing the percentage (%) of regenerated fiber (mod- acrylic, viscose rayon), the relative water vapor permeability was improved, while by increasing the percentage of synthetic fiber (polyester), the thermal resistance and air permeability were improved. These gloves will fulfill the customers' expected requirements and boost industrial growth.

**KEYWORDS:** *Cut resistance gloves; Comfort properties; Composite yarn; Performance fibers; Core spinning*

## 1.0 INTRODUCTION

Protection of hands while performing occupational tasks in a risky environment is a prerequisite for workers. Protective gloves are used in various circumstances, such as to be safe from burns, chemicals, the weather, and cuts. The gloves that provide cut resistance are widely used in an industrial atmosphere where sharp edges may cause potential accidents. Usually, cut-resistant gloves are used during the meat cutting process, in metal sheet, glass manufacturing units, and while using sharp and edged tools in mechanical workshops [1]. One of the primary aspects of these gloves is the provision of protection while exhibiting cut resistance. In addition to this, comfort for the wearer is equally important for the usage of gloves. Customers are always happy while wearing gloves with comfort, as they are bound to wear them for prolonged periods [2]. Comfortable protective gloves are gaining market share; customers also demand comfort characteristics with their functional needs. Gloves with a knitted structure are common for light assembly activities. These have a better fit on hands, shorter production process, and more possibilities of using a combination of yarns instead of a single yarn [3].

The developed cut-resistant gloves must comply with the international standards regarding their performance. Mollaei et al. studied the comparison of coated (casting polyurethane resin) and pure para-aramid weft knitted fabric and ultra-high molecular weight polyethylene fabric. They concluded that coated para-aramid has better cut resistance than pure material [4]. Beena Zehra et al. studied and analyzed the performance levels of different available safety gloves that were developed by artificial leather (Polyester), PVC, Kevlar, and thermoplastic rubber [5]. Thilagavathi et al. investigated the cut resistance of multilayer fabric by making a three-layer laminate composite of a nylon knitted fabric as the skin layer, knitted Kevlar fabric as the outer fabric, and polyurethane foam in the center [6].

Memon et al. studied the cut-resistant fabric that was made by Kevlar and polyethylene. They concluded that an equal ratio of both yarns in the composite exhibited better cut resistance characteristics [7]. Researchers studied the cut-resistant gloves made by ultra-high molecular weight polyethylene (UHMWPE) as a covering material on the steel core [8]. Composite yarns are developed by combining two or more components. Commonly used blends for composite yarn for gloves are Kevlar®/Dyneema® and steel/glass. Protective gloves made with these yarns have good cut resistance [9]. Using flexible monofilament in the core and covering the core with Kevlar results in the production of flexible and highly cut-resistant yarn [10, 11]. DREF-spun compound yarn was made by using Kevlar® 29 fibers at the core with wool fibers by another researcher [12]. The use of glass fiber in gloves led to problems of broken ends, primarily due to the brittleness of fibers. In order to negate the issue, Yongqi Wang et al applied curing over glass-based composites in polyurethane acrylate resin. The treatment helped significantly in the improvement of cut resistance, tensile, wearing, and washing properties of gloves [13]. The major challenge for cut-resistant gloves is to attain optimization in comfort and extensibility. In conventional textiles, yarn made of stretchable material is used for extensibility. In cut-resistant gloves, this doesn't work the same way. Normally, cut-resistant and other protective textiles are designed with materials that are stiff in nature, but the major issue with usage is discomfort during wearing. From the literature, it can be observed that intensive research in protective clothing, especially protective gloves, has been done. Most of the research is intended to improve the performance of protective gloves, and little attention is paid to improving the comfort properties. Knitted fabrics offer good comfort properties due to inherent flexibility in the structure [14]. Thermal and comfort performance is engineered by combining para-aramid with polyester-cotton blends and using channelled polyester as the plating yarn. It was observed that channelled polyester yarn samples showed better comfort characteristics [15]. Some other researchers studied different parameters of gloves to improve their comfort properties [16-18]. The main purpose of the present investigation is the development of composite yarns by changing fiber material in the sheath with core spinning technology to improve the comfort properties without compromising cut performance.

## **2.0 EXPERIMENTAL PROCEDURE**

Core yarns were made on the DREF 2000 friction spinning machine (Qingdao Leaf's Machinery Co. Ltd, China). Glass fiber is used in the core, and a blend of poly-p-phenylenediamine-terephthalamide fibres (PA), Kevlar®/ High density polyethylene (HDPE), Polyester (PET), Viscose rayon (V) / Mod acrylic (MA) in the sheath. A core sheath yarn of 36.91/2 Tex yarn was developed in which glass fiber is in the core for all samples, and for the sheath, different blended materials were used. As the core is expected to bear the load, a stronger material is used for it. A total of 4 hybrid yarns were developed, in which the sheath of sample 1 has a blend of (50/50) Kevlar and Polyester fibers, for sample 2, Kevlar and Modacrylic fibers were blended (50/50), for sample 3, Kevlar and Viscose rayon (50/50), and in sample 4, HDPE and Viscose rayon were blended.

Four seamless glove samples were developed as shown in Table 1 on the Shima Seiki SFG-I, Gauge E 13, no. of needles 156, feeder 3 machine at the same settings. The sample coding and sample IDs are mentioned in Table 1. The stitch length was kept constant for all samples i.e., 7 mm.

For all gloves, the influence of core and sheath components on the different properties is characterized. The physical properties, such as Courses/cm, Wales/cm, thickness, and GSM, according to the developed method, ASTM D 1777 and ASTM 3776, respectively. For performance properties, the samples were tested for cut level/performance level as per standards EN-388 -2016 on the Coup Cut Resistance Tester (Sodemat Coup Test XP, CT3-051, France). In this test, a 500g fixed-load circular blade is used to determine the cut resistance. Thermo-physiological comfort characteristics i.e, air permeability, thermal resistance, and relative water vapor permeability (RWVP%) were tested. The air permeability was evaluated on tester M021A; SDL, Atlas UK, the thermal resistance and RWVP were tested on Permeatest M290 Sensora Instrument, Czech Republic, as per standards ISO 9237 and ISO11092, respectively. Mean and S.D. were taken for all results.

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Physical Properties:

As a structural baseline for later comparisons, the physical construction of each fabric's areal density, thickness, and loop counts (courses and wales) was quantified. Table 1 summarizes these characteristics, which describe fabric compactness and porosity and underpin the interpretation of comfort-relevant behavior and finish add-on in the subsequent analysis.

Table 1: Physical Properties.

Sample code	Sample description	Areal density (g/m <sup>2</sup> )	Thickness (mm)	Course (cm)	Wales (cm)
S1	KGP	285	1.15	7	5
S2	KGM	386.4	1.32	7	7
S3	KGV	327.1	1.24	6	6
S4	UGV	404.2	1.39	9	7

From the physical testing, S4 is the heaviest and thickest fabric (404.2 g m<sup>-2</sup>; 1.39 mm), exceeding S1 by 41.8% in areal density and 20.9% in thickness, with smaller gains over S2 (4.6% and 5.3%) and S3 (23.6% and 12.1%). This aligns with a denser construction (higher course count) and/or shorter loop length, as reflected by the compactness metric areal-density-to-thickness, where S2 and S4 ( $\approx 292.7$  and  $290.8$  g m<sup>-2</sup> mm<sup>-1</sup>) exceed S1 and S3 ( $\approx 247.8$  and  $263.8$  g m<sup>-2</sup> mm<sup>-1</sup>). If S4 employs HDPE filaments, the polymer's lower specific gravity and higher specific volume could further promote thickness at a given mass, consistent with prior observations [11]. Overall, the elevated areal density in S4 likely reflects the combined effects of yarn linear density, loop geometry, and stitch parameters rather than material density alone.

#### 3.2 Cut Resistance

Cut resistance is an essential property for protective gloves, and it is the capability of a material to resist damage when exposed to a sharp-edged object [16]. The performance level of all glove samples was also investigated. All the samples have a performance level 5, as all samples have glass filament in the core. As glass fibers have smoothness and gloss, they will be helpful with sliding during the application of force [19].

### 3.3 Air Permeability

In the thermo-physiological comfort properties, the air permeability of the sample is the measurement of air passing through it and is often used to evaluate the breathability characteristics [9]. Keeping the cut index level 5 for all samples, the breathability of all samples was investigated. If gloves are not breathable, they make hands hot and sticky, which leads the wearer to take them off, and the challenge of cut protection vs comfort begins.

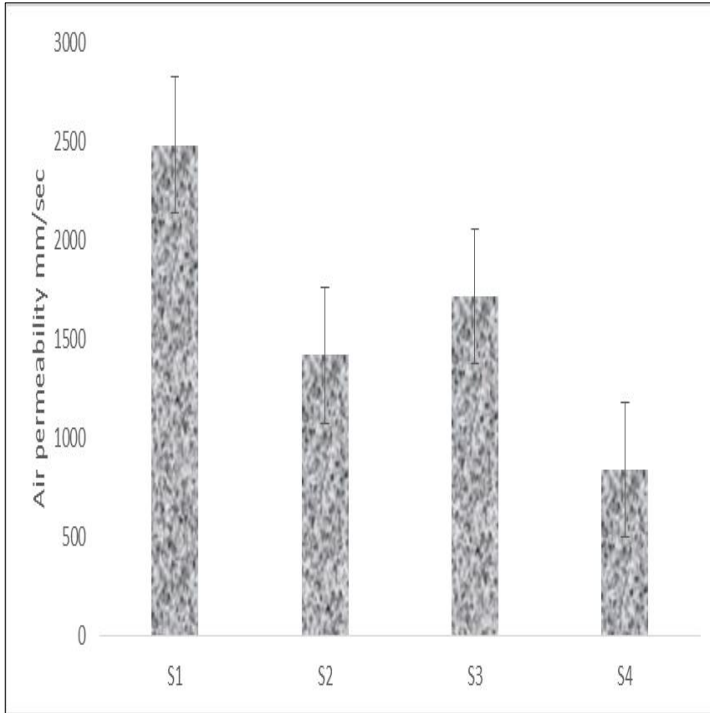


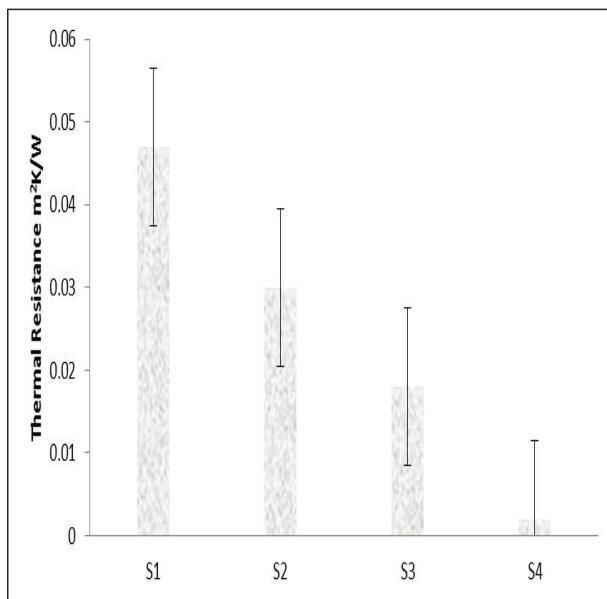
Figure 1 : Air permeability of knitted glove fabrics (mm/ s), (n=3).

It was observed from Figure 1 that the air permeability of the sample S1 is better than S2, S3, and S4 due to its fiber composition ratios, lower areal density, and thickness, which are the main factors of air permeability [20]. S4 has minimum air permeability, due to lower fiber density and high specific volume [11]. S1, which is composed of Kevlar & Polyester fibers blended in a sheath, exhibited the highest value of air permeability. There are several factors that are involved, such as the fact that this sample has a minimum thickness value. This can be attributed to the smaller diameter and smooth surface of polyester fiber, which results in better packing of fibers in the sheath. This higher

packing results in formation of thinner fabric. This uniform structure also helps in lower areal density. These all factors contribute to better porosity and the highest air permeability of the fabric [21].

### 3.4 Thermal Resistance

Thermal resistance is the total heat resistance per unit area through the fabric under standard conditions. The fabric material type and thickness are factors that greatly influence the thermal resistance properties [12, 14]. From Figure 2, it can be seen that the S4 sample has the lowest thermal resistance. This is, primarily, due to fiber conductivity. HDPE fibers stay cool against the skin. This is because of the greater thermal conductivity of HDPE fibers, which results in a reduction in the ability to insulate or trap heat.



HPPE is the polymeric fiber that has a high degree of orientation in its  
Figure 2: Thermal resistance (m<sup>2</sup> K/W).

polymeric structure, which results in inherently greater thermal conductivity [22, 23]. Similarly, viscose rayon is also a good conductor of heat. S4, comprising HDPE and viscose rayon fibers, has minimum thermal resistance. S1 has the highest thermal resistance due to its

conductivity values, with a higher percentage of polyester fiber in the blend being the dominant factor; it is considered that polyester fibers keep more air in their structure, which makes it more thermally resistant [24].

### **3.4 Relative Water Vapor Permeability**

Water vapor permeability is the ability to transmit vapor from the body, and it is an important ability of clothing to transport water vapor for improving breathability. If clothing is unable to evaporate sweat into the surrounding atmosphere, it will increase the humidity on the surface of the skin, which can increase a damp and clammy perception for the wearer. Liquid transfer through a porous structure involves two processes, i.e., wetting and wicking. Wetting is the initial process, as the liquid wets the fibers, and then, through wicking, the liquid reaches the spaces between fibers and produces a capillary pressure [25, 26]. When comparing fabrics of the same yarn, the water vapor transmission properties depend mainly on fabric physical properties, but when comparing different materials, the type of raw materials i.e. fiber wetting and wicking properties [25].

In the results of Relative Water vapor permeability % in Figure 3, it is evident that the glove sample composed of Kevlar and viscose rayon fibers in a sheath has the maximum value. The moisture transport or wicking properties are very much dependent on the raw material, like fiber [27]. The higher moisture transportation in S.4 is due to the presence of viscose fibers, which have better moisture management properties [28]. Moreover, the moisture transportation is done through capillary action, and the more finely tuned polymeric structure of HDPE also facilitates capillary transport of moisture. By using a blend of hygroscopic and hydrophobic fibers, improvement in the moisture transfer rate can be achieved [29]. HDPE also does not absorb water, which means it will wick moisture and sweat away from your skin, while viscose rayon absorbs water, so the highest RWVP% % is of S4, followed by S3, S2, and S1, as Kevlar also tends to absorb moisture, which can be visible in Figure 3.

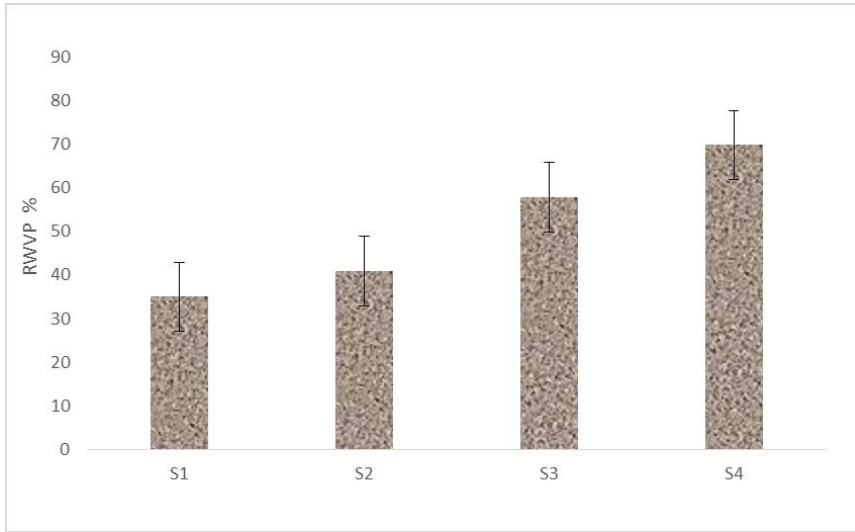


Figure 3: Relative water vapour permeability (RWVP, %)

#### 4.0 CONCLUSION

In this study, seamless gloves were knitted from core-spun yarns comprising a glass-filament core and sheaths of Kevlar, polyester, viscose rayon, modacrylic, and HDPE. All samples were evaluated for cut resistance, air permeability, thermal resistance, and RWVP, and all achieved Level-5 cut performance. Results indicate that thermophysiological behaviour is strongly governed by fiber properties and blend composition: thermal resistance was maximized in the para-aramid/polyester blend (S1), making it more suitable for cooler conditions, whereas moisture management was highest in the viscose/HDPE blend (S4), which is preferable for hot/humid environments. HDPE remains cool against the skin and, being hydrophobic, does not absorb water but aids wicking and sweat transport, while viscose contributes hygroscopic uptake. Overall, the findings show that comfort can be engineered without compromising cut protection, providing design guidance for climate-specific glove selection and offering practical benefits for worker safety and the protective-clothing sector.

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## **AUTHOR CONTRIBUTIONS**

J. Hafsa: Conceptualization, Methodology, Software, Writing- Original Draft Preparation; A. R. Waqar: Data Curation, Validation, Supervision; N. Muhammad, K. A. Ahmed, M. Sanam, and S. H. Nasir: Validation, Writing-Reviewing and Editing.

## **CONFLICTS OF INTEREST**

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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