TECHNICAL ARTICLE

Performance study of E-glass reinforced HPPE and cotton cut resistant gloves with repeated laundering and industrial use

Anju Bhardwaj, Jyoti Kaushik, Lalit Jajpura

Bhagat Phool Singh Mahila Vishwavidyalaya, Department of Fashion Technology, Sonepat

and

Nandan Kumar

High Performance Textiles Pvt. Ltd, Sonepat

The present study emphasizes on the comparison of E-glass reinforced High performance polyethylene (HPPE) and cotton based protective gloves (7 and 10 gauge). Cut resistant properties of these gloves were analysed as per test standard EN 388:2003. Further, the effect of repeated laundering and industrial use on performance of cut resistant properties of gloves was analysed. The result of the study showed that both types of gloves i.e. E-glass reinforced HPPE (7 and 10 gauge) as well as cotton provide excellent level of cut protection which is durable even up to 20 laundering cycles and applications in various industries. Although, E-glass reinforced HPPE have high level of abrasion resistance than E-glass reinforced Cotton. The comparative study shows that the cut resistance performance and durability of E-glass reinforced HPPE (7 gauge) gloves was found best in comparison to E-glass reinforced HPPE (10 gauge) gloves and least was shown by E-glass reinforced cotton gloves.

Key Words: Protective clothing, Cut resistance gloves, reinforced, HPPE, Cotton, E-glass, Laundering

Introduction

Human body is very sensitive against harsh climatic and working conditions which are not easily tackled without protection. Protection of human body during daily activities and in work conditions is one of the important concerns for humans. Though, there are so many type of protection available to protect human body but protection by clothing is one of the most effective ways to protect the human body against harsh climatic conditions and other associated risks like mechanical, chemical, bio-logical and radiation hazards. Cut-resistant clothes are available in the form of gloves, caps, sleeves, body armour, etc. Gloves and forearms are used to protect human hands against mechanical and thermal risks such as broken glasses, metal shards, razor sharp machinery, molten metal splashes, etc involved during performing task at workplace.

Cut protective clothing is manufactured using high performance fibres (e.g. aramids, high performance polyethylene, polyamides) and their blends with reinforcement of multifilament materials such as e-glass, basalt, stainless steel to name a few.

Protective clothing is the special clothing which protects human body from harsh climatic conditions or from various work hazards existing at work place. No one can ignore or eliminate the risk available at work place but reduction of body injury is possible by using appropriate personal protective equipment. Personal protective equipment can be used according to the level of danger and type of risk available at work place. Level of protection provided by the protective equipment is depends upon the design, structure and construction of personal protective clothing. Injuries to hands constitute a considerable share of the total number of accidents. These injuries can be eliminated or reduced by use of protective gloves [1].

In concern to repeated laundering, gloves were laundered for 10 and 20 times in IFB fully automatic washing machine. Whereas gloves have been used in various industries viz., carpentering workshop, floor construction, tin and general handling workshops to assess the durability of Cut resistant performance of gloves. In experimental procedure the durability of cut resistant gloves was analysed via visual appearance and change in colour, weight loss and EN 388:2003 standard.

Out of all categories of protective gloves, demand for cut resistant gloves is mushrooming day by day as approximately, 80 % of all hand injuries occurred due to cuts with sharp protruding or moving objects. Therefore there is a massive requirement of protective gloves which not only resist cuts but also comfortable to wear and according to trend [2]. Basic properties required in cut resistant materials are cut resistance, tear strength and abrasion resistance as well as grip ability and dexterity to wearer [3, 4].

Hand protection varies from industry to industry and they come in various products like gloves, arms and forearms, protective sleeves, etc. made from separate materials designed to confirm the best protection against the specific hazards [5]. Cut resistant gloves are very much suitable for glass, construction, meat cutting industries, etc. [6].

The cut resistant gloves can be manufactured from high performance fibre alone or in association with traditional fibres. In present investigation performance study with repeated laundering and industrial use of two types of gloves were analysed, one which was manufactured from HPPE fibre with e glass reinforcement and other from traditional cotton fibre with e glass reinforcement. High Performance Poly Ethylene (HPPE) is a very tough material, with the highest impact strength of any thermoplastic due to high crystallinity and orientation [7]. Though HPPE fibre itself have very high strength but reinforcement of composite material like E-glass and other high performance fibre improves their protection properties further against mechanical hazards [8].Whereas, cotton is known for its comfort properties but due to low strength it can't be used alone in protective gloves. The needed strength in protective gloves of cotton can be achieved by reinforcement with high performance fibres such as E-glass, steel wire, etc [9, 10]. The E-glass fibres were chosen for reinforcement as they are extremely fine, light weight, extremely strong, electrically insulator and robust. E-glass fibre is also being used in thermal insulation, electrical insulation, sound insulation, high-strength fabrics or heat and corrosion-resistant fabrics [9]. Commercially, E-glass is a cost effective solution in comparison with reinforcement with stainless steel wire.

The repeated laundering and continual use of protective clothing in work place affects its durability [11 – 13]. Therefore, the first part of study involves checking the durability of gloves after repeated laundering for 10 and 20 times and second part of study involve evaluating durability after regular wear in industries for 10 days. In first study, fully automatic IFB machine was used to wash the samples to solve the purpose of home laundering. In concerned to second part of study, samples were supplied to the local industries like welder, floor maker, carpenter, etc. for industrial use. Further durability of gloves was examined by visual appearance and change in colour, weight loss and EN 388 testing standards. The current finding is restricted to the liners only, further research is being carried out to develop palm coating /dipping of these liners with latex and nitrile rubber compounds.

Materials and Methods

Materials

High performance knitted E-glass reinforced HPPE and Cotton gloves (Figure 1), complementarily given by High Performance Textile Pvt. Ltd, Panipat, Haryana, India were used for the study with following specifications:

1. **(a) E-glass reinforced HPPE (7 Gauge) Gloves:**

   Composition: HPPE (400 denier) with E-glass (200 denier) in core; Gauge: 7G; Sizes: 10''

   (b) E-glass reinforced HPPE (10 gauge) Gloves:

   Composition: HPPE (400 denier) with E-glass (200 denier) in core; Gauge: 10G; Sizes: 10''

2. **E-glass reinforced Cotton (7 gauge) Gloves:**

   Composition: Cotton reinforced with E-glass (200 denier) in core; Gauge: 7G; Sizes: 10''

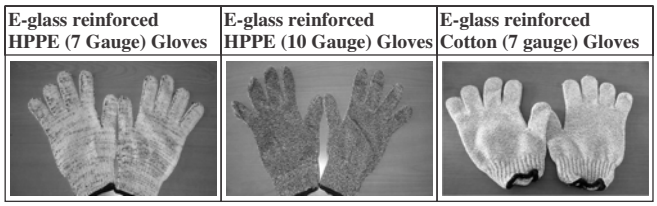


Figure 1 : Photographs of High performance knitted E-glass reinforced HPPE and Cotton gloves

Detergent used

Commercially available washing detergent i.e. Tide® was used for washing.

Machines used

IFB 7 Kg Elite Aqua VX 1000 RPM fully automatic front load washing machine. Laundering was done on IFB fully automatic machine according to standard EN : 61456 / ICE:60456. Gloves samples were laundered for 1 hour 6 minutes and allowed to dry at 40 °C. In the same way laundering process was repeated for 10 and 20 washes.

Procedure to check durability of sample gloves

The change in appearance and durability of gloves after repeated laundering and regular use in industry was determined in following ways:

1. A visual comparison was carried out between the washed-unwashed and used-unused gloves samples [12,13].
2. Change in colour of gloves before and after wash by using CCM was analysed.
3. Weight of gloves before and after wash was analysed.
4. Testing of gloves samples was carried out according to EN 308:2003 standard : (for Cut resistant gloves).

Testing standard for cut resistant gloves: EN 388:2003

This standard specifies that the gloves are intended to give protection against mechanical hazards. This standard involves testing of resistance to abrasion, blade cutting, tearing and puncture resistance as follows [11]

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 5, which corresponds to 8,000 cycles.

Resistance to cutting

The test involves measuring the number of cycles required for a circular knife rotating at constant speed to cut through the test specimen. The highest performance level is 5, which corresponds to an index of 20.

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 (10cm/min). The highest performance level is 4, which corresponds to a force of 150 N [11].

Results and Discussions

E-glass reinforced HPPE (7 Gauge) gloves

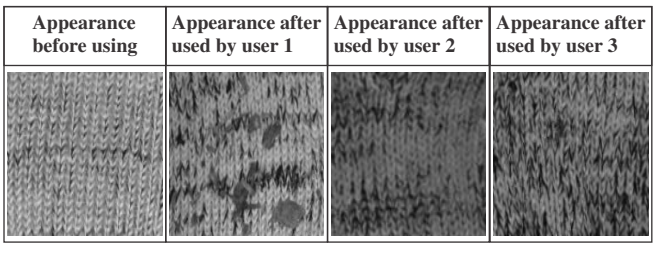
Visual appearance and change in colour

Visual comparison between washed and unwashed samples as well as used and unused samples was carried out. It was observed that the gloves have compact knitting structure before washing. Although with repeated washes negligible fuzzy appearance noticed on gloves surface as loose fibres protrude and entangled with each other during laundering operation. The colour values of laundered and unlaundered E-glass reinforced HPPE (7 gauge) gloves was determined and colour difference values are indicated in Table 1. It can be observed from the Table that there was no significant change in colour of gloves being negligible Δa, Δb values even after repeated washing but slight fading was there in gloves as seen from Δl values.

Table 1 : Color difference values

Colour difference	Δl	Δa	Δb
After 10 washes	+ 5.55	- 0.58	- 0.72
After 20 washes	+ 5.06	+ 0.003	+ 0.27

The appearance of gloves after use in various industries is shown in Figure 2. It can be observed from the photographs that wooden particles entangled with protruding fibres on surface of gloves during use of gloves take place in carpenter industry. Similarly dirt and dust is adhered on gloves surface during use of gloves in floor construction industry. The gloves were also soiled with foreign metal particles and rust during their use in Tin industry. Overall after continual use, gloves become soiled with various foreign particles associated in industry and its environment.



User 1- Carpenter workshop; User 2-Floor construction; User 3-Tin industry; User 4- General handling

Figure 2 : Photographs of E-glass reinforced HPPE (7 gauge) gloves sample before and after industrial use

Weight measurement

The weight of laundered gloves was determined and shown in Table 2. It can be observed from the Table 2 that there is slightly reduction in weight of gloves after 10 and 20 washes of glove samples. The negligible decrease in weight indicates that structure of gloves is stable.

Table 2 : Weight of E-glass reinforced HPPE (7 gauge) gloves before and after wash

Weight of gloves before wash	Weight of gloves after 10 washes	Weight of gloves after 20 washes
116.45 g	115.82 g	115.70 g

Experimental testing according to EN and 308:2003 standard

The cut resistance properties in terms of abrasion resistance, blade cut resistance and tear resistance of E-glass reinforced HPPE (7 gauge) gloves were determined after repeated laundering and use in various industries as shown in Table 3.

Table 3 : Performance level achieved by the E-glass reinforced HPPE (7 gauge) glove before and after washing as well as before and after industrial use.

Sr. No.	Test Parameter	Unit	Test results before wash and use		Test results after 10 washes	Test results after 20 washes	Test results after user 1	Test results after user 2	Test results after user 3	Test results after user 4
			Test results	Level achieved	Level achieved	Level achieved	Level achieved	Level achieved	Level achieved	Level achieved
1.	Abrasion resistance:	No. of cycles	Breakdown observed up to 8000 rubs	4	4	4	4	4	4	4
2.	Blade cut resistance	Index	64.07	5	5	5	5	5	5	5
3.	Tear resistance across length		>75	4	4	4	4	4	4	4
	Tear resistance across width		>75	4	4	4	4	4	4	4

User 1 - Carpenter workshop; User 2 - Floor construction; User 3 - Tin industry; User 4 - General handling

It can be observed from above Table 3 that E-glass reinforced HPPE (7 gauge) have excellent cut protection properties being high level of abrasion, blade cut resistance and tear resistance value of 4, 5 and 4 respectively. The E-glass reinforced HPPE (7 gauge) gloves also shows excellent durability in cut protection properties even after repeated 10 and 20 washes and after industrial use being no change in level of abrasion, blade cut resistance and tear resistance value. This is mainly due to high strength, abrasion resistant high performance polythene filaments (400 denier) which are hydrophobic in nature.

E-glass reinforced HPPE (10 Gauge) gloves

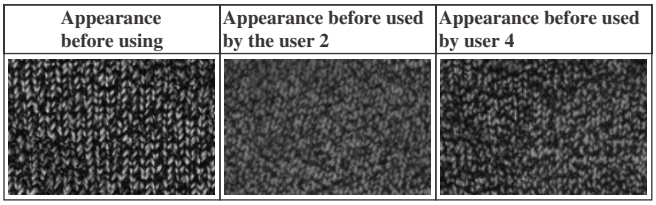
Visual appearance and change in colour

Visual comparison between washed and unwashed as well as used and unused HPPE gloves (10 gauge) was carried out. Similar to HPPE gloves (7 gauge), negligible fuzzy appearance was also noticed on 10 gauge gloves surface as loose fibres protrude and entangled with each other during laundering operation. This is mainly due to change in design of yarn where black polyester filaments are twisted on HPPE to reduce the slippery nature of HPPE and to provide additional grip on the 10 Gauge gloves to the end user. The colour values of laundered and unlaundered HPPE reinforced with E-glass (10 gauge) gloves was also determined and colour difference values are indicated in Table 4. It can be observed from Table that there was significant change in colour of repeated laundered gloves being high Δb negative values This is mainly due to removal of black polyester filaments present on the surface of 10 gauge HPPE gloves, although the composition is same as that of 7 gauge HPPE gloves.

Table 4 : Colour difference values of repeated laundered E-glass reinforced HPPE (10 gauge) gloves before and after washing by using CCM

Colour difference	Δl	Δa	Δb
After 10 washes	+4.61	+0.27	-10.16
After 20 washes	+0.89	-0.19	-12.79

The appearance of gloves HPPE (10 gauge) after use or application in various industries is shown in Figure 3. It can be observed from the photographs that entanglement of protruding fibres on surface of gloves during use of gloves takes place in floor construction industry. There is adherence of dirt and dust particles noticed on gloves surface during use of gloves in floor construction industry. Overall gloves used become soiled with various foreign particles associated in industry and environment of application



User 1 - Carpenter workshop; User 2 - Floor construction; User 3 - Tin industry; User 4 - General handling

Figure 3 : Photographs of E-glass reinforced HPPE (10 gauge) gloves sample before and after industrial use

Weight measurement

The weight of laundered HPPE (10 gauge) gloves was determined and shown in Table 5. It can be observed from the Table 5 that similar to 7 gauge there is slightly reduction in weight of HPPE (10 gauge) gloves after 10 and 20 washes. The negligible decrease in weight indicates that structure of HPPE (10 gauge) is also stable.

Table 5 : Weight of E-glass reinforced HPPE (10 gauge) gloves before and after wash

Weight of gloves before wash	Weight of gloves after 10 washes	Weight of gloves after 20 washes
64.89 g	64.32 g	64.28 g

Experimental testing according to EN and 308:2003 standard

The cut resistance properties in terms of abrasion resistance, blade cut resistance and tear resistance of E-glass reinforced HPPE (10 gauge) gloves were determined after repeated laundering and use in various industries as shown in Table 6.

Table 6 : Performance level achieved by the E-glass reinforced HPPE (10 gauge) gloves before and after washing as well as before and after industrial use

Sr. No.	Test Parameter	Unit	Test results before wash and use		Test results after 10 washes	Test results after 20 washes	Test results after user 1	Test results after user 2	Test results after user 3	Test results after user 4
			Test results	Level achieved	Level achieved	Level achieved	Level achieved	Level achieved	Level achieved	Level achieved
1.	Abrasion resistance:	No. of cycles	Breakdown observed upto 1500 rubs	2	2	2	-	1	-	2
2.	Blade cut resistance	Index	137.99	5	5	5	-	3	-	4
3.	Tear resistance across length	newton	>75	4	4	4	-	3	-	4
	Tear resistance across width		>75	4	4	4	-	3	-	4

User 1 - Carpenter workshop; User 2 - Floor construction; User 3 - Tin industry; User 4 - General handling

It can be observed from above Table 6 that there is no significant change in quality of gloves after 10 and 20 washes and after industrial use. Although gloves quality reduced from level 2 to level 1, level 5 to level 3, level 4 to level 3, in abrasion resistance, blade cut resistance, tear resistance (across length as well as width), respectively after use in floor construction industry (user 2). This may be due to fracture of E-glass during end user application. In general handling (user 4) HPPE (10 gauge) gloves shows good protection as there was no change in abrasion and tear strength protection level after use. Although, blade cut resistance were reduced slightly from level 5 to level 4 after use of gloves in general handling, again this may be due to fracture of E-glass present in the core during end user trial.

E-glass reinforced cotton gloves

Visual appearance and change in colour

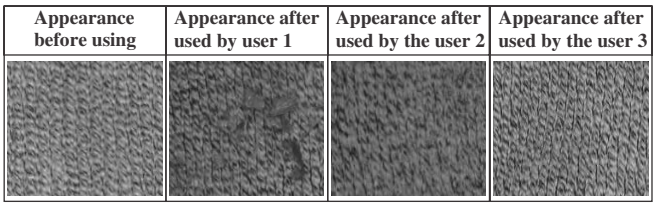
Visual comparison between washed and unwashed samples as well as used and unused samples of E-glass reinforced with cotton gloves was carried out. It was observed that slightly fuzzy appearance occurred in E-glass reinforced cotton gloves after repeated laundering as similar to results of HPPE knitted gloves

Table 7: Colour difference values of repeated laundered E-glass reinforced cotton gloves before and after washing

Colour difference	Δl	Δa	Δb
After 10 washes	+ 6.405	+1.38	- 0.59
After 20 washes	+ 3.96	+ 1.35	+ 0.97

It can be observed from Table 7 that there was no significant change in colour of gloves being low Δa and Δb values but slight fading is there due to repeated washing.

The appearance of E-glass reinforced cotton gloves after use in various industries is shown in Fig 4. It can be observed from the photographs that wooden particles entangled with protruding fibres on surface of gloves during use of gloves in carpenter industry. Similarly dirt and dust is adhered on gloves surface during use of gloves in floor construction industry. The gloves were also soiled with foreign metal particles and rust during their use in Tin industry. Overall after use in different industries the E- glass reinforced gloves became soiled with various foreign particles associated in industries and environment of application.



User 1 - Carpenter workshop; User 2 - Floor construction; User 3 - Tin industry; User 4 - General handling

Figure 4 : Photographs of E-glass reinforced cotton gloves before and after industrial use

Weight measurement

The weight of laundered E-glass reinforced cotton gloves was determined and shown in Table 8.

Table 8 : Weight of E-glass reinforced with cotton gloves before and after wash

Weight of gloves before wash	Weight of gloves after 10 washes	Weight of gloves after 20 washes
111.13 g	108.84 g	108.76 g

It can be observed from the Table 8 that there is significant reduction in weight of E-glass reinforced cotton gloves after 10 as well as 20 repeated washes. The cotton fibres do not have high strength to with stand repeated laundering therefore significant weight reduction of gloves occurred due to lost in broken cotton fibre from surface of knitted gloves.

Experimental testing according to the EN and 308:2003 standard

The cut resistance properties in terms of abrasion resistance, blade cut resistance and tear resistance of E-glass reinforced cotton gloves were determined after repeated laundering and use in various industries as shown in Table 9.

Table 9 : Performance level achieved by the E-glass reinforced cotton gloves before and after washing as well as before and after industrial use.

Sr. No.	Test Parameter	Unit	Test results before wash and use		Test results after 10 washes	Test results after 20 washes	Test results after user 1	Test results after user 2	Test results after user 3	Test results after user 4
			Test results	Level achieved	Level achieved	Level achieved	Level achieved	Level achieved	Level achieved	Level achieved
1.	Abrasion resistance:	No. of cycles	Breakdown observed upto 250 rubs	1	1	1	1	1	1	-
2.	Blade cut resistance	Index	18.33	4	4	4	4	3	3	-
3.	Tear resistance across width	New ton	>75	4	3	3	3	3	3	-
	Tear resistance across width		>75	4	3	3	3	3	3	-

User 1 - Carpenter workshop; User 2 - Floor construction; User 3 - Tin industry; User 4 - General handling

It can be observed from Table 9 that the achieved level of abrasion resistance of E-glass reinforced cotton fibre is only 1 which is not suitable where high abrasion resistance is required. Although gloves retain this level of abrasion resistance even after 10 and 20 repeated washing as well as after continual use in various industries. The gloves have high blade cut resistance and tear strength of level 4. This may be due to superior covering of E-glass filaments owing to the short staple cotton fibres. The level of blade cut resistance not reduced even after repeated 10 and 20 laundering cycles. Although, slight reduction in blade cut resistance from level 4 to level 3 was observed after use of gloves in floor construction and tin industry. This is due to the fracture of E-glass during end user trial. The level of tear strength of E-glass reinforced cotton was slightly reduced from level 4 to level 3 after repeated laundering as well as continual use in various industries. It is worthwhile to mention that owing to the presence of cotton fibres, these gloves are more suitable for various coating treatments such as latex, nitrile for better performance. These coatings would improve the abrasion resistant of these gloves along with superior oil and water repellency required while working in the wet conditions.

Comparative observations of gloves

It can be analysed that abrasion resistance of E-glass reinforced HPPE (7 gauge) gloves is of level 4, whereas E-glass reinforced HPPE (10 gauge) gloves is of level 2. The E-glass reinforced HPPE gloves of 7 gauge provide better abrasion resistance than that of E-glass reinforced HPPE gloves of 10 gauge. This is mainly due to heavier weight of Gauge 7 liners. In case of E-glass reinforced cotton gloves abrasion resistance is only of level 1.

The achieved abrasion resistance of these gloves is in following order

E-glass reinforced HPPE (7 Gauge) of level 4 > E-glass reinforced with HPPE (10 Gauge) of level 2 >E-glass reinforced cotton of level 1.

In case of blade cut resistance performance, E-glass

reinforced with HPPE (7 gauge) and E-glass reinforced with HPPE (10gauge) gloves shows better results of level 5 than E-glass reinforced cotton gloves of level 4. In case of tear resistance E-glass reinforced HPPE (7 gauge), E-glass reinforced HPPE (10 gauge) and E-glass reinforced cotton shows similar level 4 of performance.

In overall comparative study, it was found that E-glass reinforced HPPE (7 gauge) gloves shows best whereas E-glass reinforced cotton gloves shows least durability in cut resistant performance of gloves in repeated laundering as well as application in various industries.

Conclusion

The results of the study show that E-glass reinforced HPPE (10 gauge) gloves and E-glass reinforced cotton gloves can be used efficiently for cut protection as per EN308:2003 standard in various industries. These gloves exhibit cut protection properties even after repeated laundering up to 20 cycles as well as continual use in various industries. The comparative study shows that the cut resistance performance and durability of E-glass reinforced HPPE (7 gauge) gloves was found best in comparison to E-glass reinforced HPPE (10 gauge) gloves and least was shown by E-glass reinforced cotton gloves. There are only some bearable changes in aesthetic properties such as change in colour, soiling and slight increase in fuzziness on surface of all these gloves after repeated laundering as well as continual use. It may be concluded that being cost effective, the use of E-glass reinforced HPPE and cotton gloves can be explored further on the basis of performance in cut protective clothing applications.

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