Comparative study of cut and abrasion resistance performance of gloves made from high-performance composite yarns

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Abstract

Cut resistant gloves are generally made from different types of high-performance composite yarns. To achieve a certain level of cut resistance, material type, material composition, and yarn linear density are changed which however make it sometimes difficult to decide the most suitable combination of the materials. In this work, eighteen seamless gloves were made by using core and sheath friction-spun yarns of various linear densities and core types, and their cut resistance performances were compared. For this purpose, eighteen composite yarns with three linear densities i.e. 118 tex (Ne 5), 98 tex (Ne 6) and 84 tex (Ne 7) were made on a friction spinning machine by using 5.55tex (50 denier), 11.11 tex (100 denier), 16.66 tex (150 denier), 33.33 tex (300 denier) multifilament glass yarns, and 89 denier (40 micron) and 139 denier (50 micron) monofilament steel yarn as core and Kevlar®29 staple fiber as sheath. Mechanical tests of the yarns showed that the tensile strength and tenacity of yarns increased as the linear density of glass yarns increased, whereas elongation at break and time to break increased with an increase of linear density of steel monofilament yarn. The coefficient of friction of all the yarns did not show any significant trend. Abrasion and cut resistance of the gloves made from 118 tex (Ne 5) composite yarn with 5.55tex (50 denier) glass yarn as core showed the best results, whereas no significant difference was seen in the dexterity of all the gloves.

Key Words: Cut resistance, Composite yarns, Protective gloves

Introduction

Cut resistant gloves are used to protect the wearer's hands from cuts while working with sharp tools or edges in workplaces such as edible meat processing units, glass producing, and processing works, the metal sheet processing plants, etc. Gloves made of steel wire mesh and leather are the conventional means of protection against hand injuries [1]. However, they do not meet the required level of comfort because the steel gloves are heavy and rigid while leather gloves have more thickness. The thicker leather gloves sometimes do not provide the required protection and even increase the risk of injury [2]. To reduce weight and thickness and to improve the dexterity and protection from cut injury, gloves are now being made from high-performance fibers. These fibers have a higher strength to weight ratios as compared to steel and alloys [3, 4].

Cut resistance is the ability of a material to resist damage or failure when challenged with a moving sharp-edged object [5]. In a cutting process, the normal and frictional forces are involved. The normal force is applied at the point of contact of blade and material, and the frictional force develops when the blade penetrates and slides the material. The cutting force is the resultant vector of these two forces. During cutting, the frictional force of some materials is much higher than the normal force as in case of some rubber materials, whereas in case of some high performance fibers such as para-aramids and ultra-high density polyethylene, the normal force is higher than the frictional force. As the coefficient of friction between the blade and material increases, cut resistance of material may increase or decrease depending on the thickness, modulus and the microstructure of the material [6]. The total energy required to propagate a cut strongly depends on two components: lost energy dissipated by the gripping force exerted by the material on the blade sides; and essential cutting energy at the tip of the blade. These two energies have opposite effects on the cut resistance of a material. The greater is the work required to deform the material in transverse compression, the higher is the energy dissipated which implies better-cut resistance of the material. Conversely, an increase in the frictional force at the edge of the blade increases cutting energy and reduces the cut resistance of the material. Thus an increase in the coefficient of friction increases both energies and can result in two opposite effects on cut resistance performance of the material [7].

As stated earlier to reduce the hand fatigue and improve dexterity at the required cut protection level. The cut resistant gloves are being made from various types of high-performance composite yarns with different combinations of core and sheath materials. Many types of high-performance multifilament yarns such as glass, polyethylene, polyamide, and monofilament stainless steel are used in the core of the composite yarns, whereas para-aramids and blends of high-performance synthetic fibers are used as sheath materials for these composite yarns. Gloves made from such yarns have different cut resistance levels and to enhance the cut resistance performance, types and blend ratio of core and sheath materials, and linear yarn densities are changed [8]. Hence it becomes difficult to select an adequate core and sheath combination of a composite yarn to achieve the desired cut resistance performance gloves.

Materials and Methods

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Du Pont's para-aramid fiber Kevlar® 29 has excellent mechanical properties which make it suitable for cut resistance applications. Kevlar® 29 staple fiber of 1.5 denier, and 38 mm length was used as the sheath and two types of materials, i.e., E-glass in the form of multifilament yarn and stainless steel in the form of monofilament yarn were used as a core for making all composite yarns used in this research work. The physical and mechanical properties of Kevlar®29 are given in Table 1. Four levels of E-glass multifilament yarn i.e. 50 denier (5.55 tex), 100 denier (11.11 tex), 150 denier (16.66) and 300 denier (33.33 tex) and two levels of monofilament stainless steel i.e. 40 micron (89 denier) and 50 micron (139 denier) were used to make eighteen composite yarns on a friction spinning machine. The physical and mechanical properties of the core yarns determined as per ISO 3341:2000 are given in Tables 2 and 3.

Table 1: Physical and Mechanical Properties of Kevlar®

S. No.	Parameter	Value
1	Staple length (mm)	38
2	Fineness (denier)	1.5
3	Tenacity (g/denier)	23
4	Tensile strength (GPa)	2.9
5	Tensile modulus (GPa)	60
6	Elongation at break (%)	4
7	Moisture regain (%)	4.3
8	Density (g/cm^3)	1.44

Table 2: Physical and Chemical Properties of E-glass Multifilament yarn

Sr. No	Parameter	Yarn Linear Density			
		5.55tex (50 den)	11.11tex (100 den)	16.66tex (150 den)	33.33tex (300 den)
1	No. of filaments per yarn	102	204	350	988
2	Twist (TPI)	1.0	1.0	1.0	1.0
3	Tensile strength (GPa)	2.7	5.8	8.9	17.8
4	Tensile modulus (GPa)	72	72	72	72
5	Density (g/cm^3)	2.6	2.6	2.6	2.6
6	Elongation at break (%)	4.8	4.8	4.8	4.8

Table 3: Physical and Mechanical Properties of Stainless Steel Monofilament

Sr. No.	Parameter	Value
1	Tensile strength (GPa)	1.77
2	Tensile modulus (GPa)	200
3	Elongation at break (%)	11
4	Density (g/ cm^3)	7.86

Table 4: Yarn Coding

Sample No.	Sample Code	Composite Yarn Count (Ne/tex)	Core Type/denier
1	5G50	5/118	Glass/50
2	5G100	5/118	Glass/100
3	5G150	5/118	Glass/150
4	5G300	5/118	Glass/300
5	6G50	6/98	Glass/50
6	6G100	6/98	Glass/100

7	6G150	6/98	Glass/150
8	6G300	6/98	Glass/300
9	7G50	7/84	Glass/50
10	7G100	7/84	Glass/100
11	7G150	7/84	Glass/150
12	7G300	7/84	Glass/300
13	5S89	5/118	S.S/89
14	5S139	5/118	S.S/139
15	6S89	6/98	S.S/89
16	6S139	6/98	S.S/139
17	7S89	7/84	S.S/89
18	7S139	7/84	S.S/139

For preparing the sheath material for the composite yarns, para-aramid staple fibers were manually opened and fed to the fine opener of a blow-room line. The rotational speed of the opener was kept as 700 rpm to open the fiber flocks gently and to avoid fiber breakage by the spikes of the opener. The relative humidity and temperature of the blow-room were kept at 55% and 30^o C, respectively. The opened material was fed to the carding machine in the form of a batt. The rotational speeds of the first, second and third taker-in were kept at 700, 1100 and 1500 rpm, respectively. The gauge between the feed plate and the first taker-in was set at 0.052 inches. The cylinder and the top set speeds were set at 450 rpm and 4 inches per minute, respectively. The gauges between the top-set and the cylinder were set at 0.013 inches at the back and 0.011 inches at the front. The sliver of 60 grains per yard (4.44 ktex) was produced at the delivery speed of 80 m/min with a running efficiency of about 90%. The relative humidity and temperature of the carding department were set at 56% and 29^o C, respectively. Six carded slivers were then fed to breaker draw frame and fifty grains/yard (3.54 ktex) drawn sliver was produced at the delivery speed of 300 m/min with a running efficiency of about 80%. Again, six drawn slivers delivered by the breaker draw frame were fed to the finisher draw frame and a forty-five grains/yard (3.19 ktex) finisher drawn slivers were produced at the delivery speed of 350 m/min with a running efficiency of about 80%. The relative humidity and temperature of the drawing department were kept the same as in the carding department. Each of the finisher drawn slivers was fed to the friction spinning machine with varying core types, sizes, and drafts to produce resultant counts of Ne 5 (118 tex), Ne 6 (98 tex) and Ne 7 (84 tex).

Three sheath slivers were fed to the opening zone of the friction machine consisted of a carding drum with saw tooth wire. These sheath slivers formed the outer cover of the composite yarns. One core sliver was passed through the drafting zone to form the bottom cover over the core yarns. Both core and sheath slivers formed the sheath portion of the composite yarns. E-glass multifilament yarns and stainless steel monofilament yarns were fed from below to form the core of the composite yarns. Four counts of E-glass and two counts of stainless steel materials were used in the core of composite yarns of linear densities of Ne 5 (118 tex), Ne 6 (98 tex) and Ne 7 (84 tex), which resulted in eighteen composite yarns with varying core types and linear densities. All the spun yarns were coded, which are enlisted in Table 4.

All the yarns were used for making gloves, each in dimensions of 240 mm x 100 mm, on a 7 gauge gloves knitting machine by feeding 2 ends at constant input speed to obtain 7x7 wales and courses per inch. The areal density of each glove is given in Table 5.

Table 5: Areal Densities of Gloves

Sr. No.	Glove Code	Glove Size (mm) length x width	WPI/ CPI	Areal Density (g/m^2)
1	5G50	240 x 100	7 / 7	483
2	5G100	240 x 100	7 / 7	485
3	5G150	240 x 100	7 / 7	488
4	5G300	240 x 100	7 / 7	480
5	6G50	240 x 100	7 / 7	405
6	6G100	240 x 100	7 / 7	406
7	6G150	240 x 100	7 / 7	403
8	6G300	240 x 100	7 / 7	401
9	7G50	240 x 100	7 / 7	353
10	7G100	240 x 100	7 / 7	352
11	7G150	240 x 100	7 / 7	352
12	7G300	240 x 100	7 / 7	348
13	5S89	240 x 100	7 / 7	483
14	5S139	240 x 100	7 / 7	480
15	6S89	240 x 100	7 / 7	405
16	6S139	240 x 100	7 / 7	403
17	7S89	240 x 100	7 / 7	352
18	7S139	240 x 100	7 / 7	354

Results and Discussion

- Effect of yarn core type and count on composite yarn properties

The mechanical properties of composite yarns were determined as per ISO 3341:2000 while frictional properties of yarns against solids were studied using ASTM D 3412-01. It was found that the mechanical properties of composite yarns for same yarn count changed with the change in the core type. Similarly, these properties were also changed with composite yarn count for a specific core type. Greater values of breaking force and tenacity were observed for coarser cores with same material type in case of E-glass, while lesser values were obtained in case of stainless steel cores. Moreover, cores of E-glass when compared with cores of stainless steel of the same composite yarn count gave greater breaking force and tenacity. The coarser composite yarns made from the same type and size of core yarn yielded mixed results. Similarly, the coefficient of friction of composite yarn, which also depends on the sheath material, also yielded mixed results. Similarly, the elongation at break and time to break in case of E-glass core increased with increase in the count of composite yarns while keeping the count of the core constant. But the results did not show a significant trend in case of glass cores. The mechanical properties and coefficient of friction of yarns are given in Table 6.

- ***Effect of composite yarns on the abrasion resistance of gloves***

The abrasion resistance of gloves was determined as per EN388:2003. In this method, circular cut specimens of glove fabric were rubbed against the standard abrasive material, and a number of cycles to abrade was counted. Gloves made from coarser composite yarns with same core count showed greater resistance to abrasion due to greater mass per unit area which also meant contribution of a greater number of para-aramid sheath fibers, which proved good abrasion resistance of para-aramid fibers. Another reason for these results was the fact that the presence of greater number of sheath fibers resulted into greater contribution during twisting around filament core, hence firmer binding resulted into lesser slippage. That resulted in greater resistance to fibers getting out of the twisted mass of yarn while abrading. Similar results were obtained for both E-glass and stainless steel cores while the trends were not clear when cores of E-glass and stainless steel were compared. In fact, composite yarns of Ne 5 (118 tex) with E-glass cores showed more resistance to abrasion compared to stainless steel cores, while the abrasion resistance was on lower side for E-glass core compared to stainless steel core when composite yarns of Ne 7 (84 tex) and Ne 6 (98 tex) were compared. That was due to the lesser contribution of sheath fibers towards total abrasion resistance and better abrasion resistance of stainless steel core filaments compared to E-glass.

Maximum resistance to abrasion was obtained by using composite yarns of Ne 5 (118 tex) having E-glass core of 50 denier count, while minimum strength was obtained by using composite yarns of Ne 7 (84 tex) with 300 denier E-glass core. This also proved the excellent abrasion resistance properties of para-aramid fiber which was used as a sheath material. The results of the abrasion test are graphically explained in Figure 1.

Table 6: Properties of composite yarns

Code of Yarn Sample	Breaking Force		Elongation at Break	Tenacity		Time to Break (s)	COF (μ)
	cN	CV%	%	cN/tex	CV%		
7G50	946	5.34	1.65	11.22	5.34	3.4	0.273
6G50	766	5.17	1.54	7.79	5.17	3.2	0.265
5G50	837	4.53	2.16	7.09	4.53	5.4	0.275
7G100	1095	5.12	2.02	12.89	5.12	4.2	0.281
6G100	1082	4.86	2.09	11	4.86	4.3	0.263
5G100	1270	4.69	2.14	10.76	4.69	5.4	0.28
7G150	1435	4.85	1.99	16.61	4.85	4.1	0.273
6G150	1271	4.25	2.04	12.91	4.25	4.2	0.278
5G150	1662	4.12	2.48	14.08	4.12	6.2	0.265
7G300	1501	4.96	1.78	17.85	4.96	3.7	0.264
6G300	1544	3.25	2.09	15.69	3.25	4.3	0.266
5G300	2259	5.23	2.23	19.13	5.23	4.6	0.272
7S89	444	5.27	1.6	5.26	5.27	3.3	0.266
6S89	629	3.87	2.21	6.39	3.87	4.6	0.276
5S89	621	4.88	1.55	5.26	4.88	3.2	0.283
7S139	320	4.63	3.33	3.79	4.63	6.9	0.278
6S139	431	3.89	3.67	4.38	3.89	7.6	0.269
5S139	556	2.56	2.68	4.7	2.56	5.5	0.287

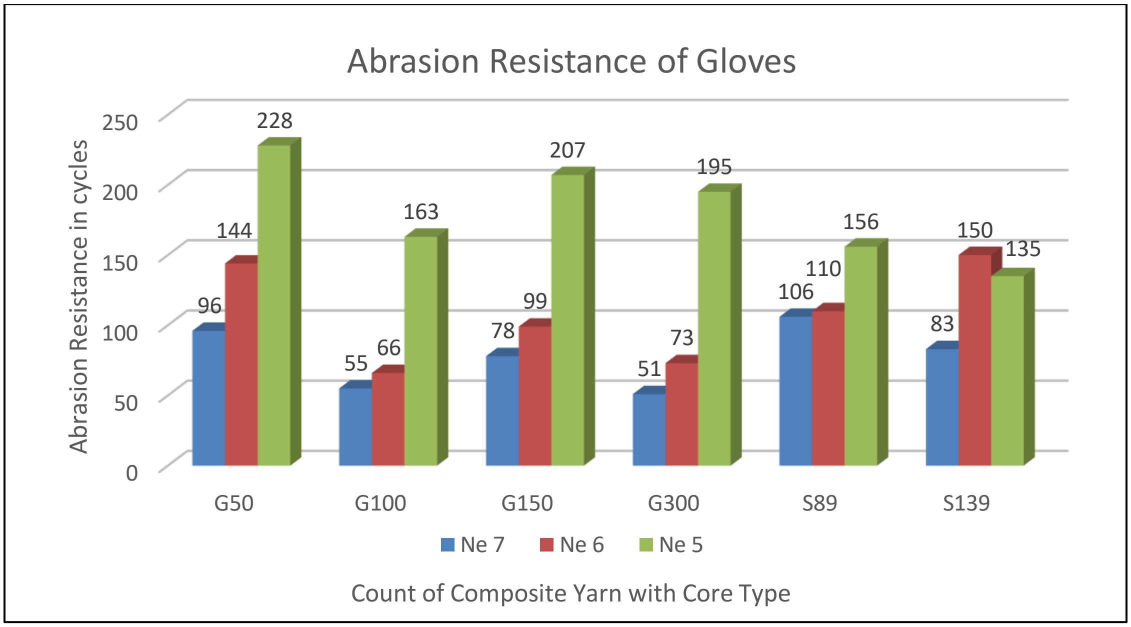

Figure 1: Abrasion Resistance of Gloves

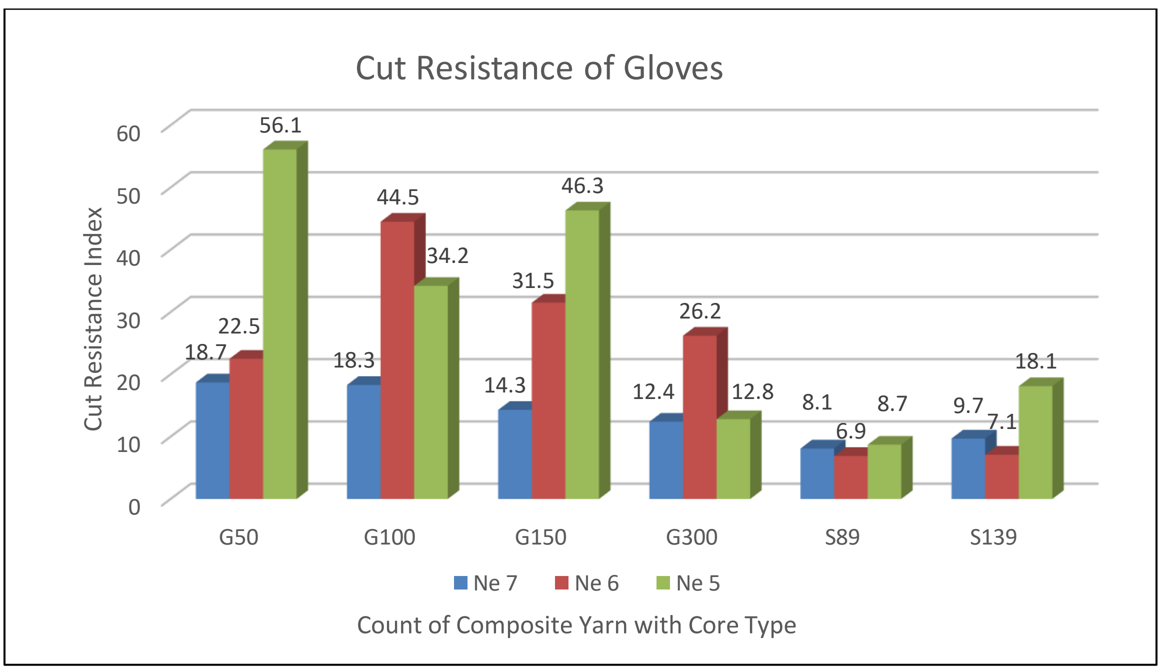

Figure 2: Cut Resistance of Gloves

- ***Effect of composite yarns on cut resistance of gloves***

The cut resistance of gloves was determined according to EN 388:2003. In EN388 blade cut resistance method which is based on Coup Test, a circular blade with 5N load was used to cut the glove specimen by moving back and forth on it. The number of cycles of blade to cut the fabric were noted; the higher the number of cycles, greater the cutting resistance [9] The results showed that greater cut resistance was achieved for gloves made from coarser composite yarns with same core as compared to finer yarns due to more mass per unit area of material offering resistance to cut. Maximum cut resistance was achieved for gloves with a maximum mass per unit area made from Ne 5 (118 tex) composite yarns, while minimum cut resistance was achieved for gloves with a minimum mass per unit area made from Ne 7 (84 tex) composite yarns. Similar results were obtained for both core types. Also, the cut resistance decreased for the same count of composite yarns made with coarser cores as compared to yarns made with finer cores. That showed an increase in cut resistance with an increase in the number of para-aramid fibers used as the sheath of composite yarns, which also showed the better cut resistance of para-aramid fibers as compared to E-glass fibers. Moreover, it showed better grip of sheath fibers around the filament core in case of finer cores when compared to coarser cores.

It was also found by the analysis of experimental data that cut resistance offered by composite yarns made from E-glass core was greater than that offered by composite yarns made from the stainless steel core. The higher cut resistance of E-glass can be attributed to its higher tensile strength and bulkiness compared to stainless steel. Due to the same reason, the cut resistance of coarser composite yarns with stainless steel core was less than the cut resistance of finer composite yarns with E-glass core. The results of cut resistance test are graphically presented in Figure 2.

The data showed that maximum cut resistance was achieved for gloves made from coarsest composite yarns and finest core. That combination gave cut resistance index value of 56.1 that was well above the minimum required cut index value of 20.0 which is equivalent to cut the level of 5. The reason behind that result was maximum contribution of the thickest sheath of Kevlar® fibers towards cut resistance which were firmly held together and around thinnest cores. That particular yarn, on analysis, gave a maximum proportion of Kevlar® sheath fibers in the composite yarn which was 95.3% which helped in achieving best cut index values.

The gloves made from stainless steel cores could not achieve a cut level of 5 (cut resistance index of 20 or greater). The maximum cut resistance level of 4 (equivalent to cut resistance index from 10 to less than 20) was achieved for composite yarn of Ne 5 made from the core of diameter 50 microns stainless steel. All other composite yarn samples made from stainless steel cores could perform to cut the level of 3 (equivalent to cut resistance index from 5 to less than 10). The lower values of cut resistance for gloves made from composite yarns of stainless steel cores can also be attributed to monofilament nature of cores, in addition to low tensile strength. In comparison to stainless steel, all samples of gloves made with composite yarns having E-glass cores gave minimum cut resistance level of 4 or higher, which shows better characteristics of E-glass towards cut resistance. Use of multifilament core of E-glass can also be the reason behind more cut resistance. The lowest value of cut resistance index of 12.4 from composite yarns made from E-glass core was still higher than all except one value obtained by using stainless steel core.

Composite yarns made by using E-glass as core material were softer and bulkier in feel than yarns made from stainless steel cores. The reason behind it was the use of multifilament cores of E-glass compared to mono-filament cores of stainless steel. The bulkiness was due to the less specific gravity of E-glass compared to stainless steel. That softness and bulk resulted into the contribution of more sheath fibers and core filaments towards resistance to cutting force. That combination resulted into greater resistance to fiber slippage, hence resulting into dissipation of portion of energy exerted by cutting force at right angles in trying to move the fibers laterally, while lesser portion available for cutting the yarns.

- ***Effect of composite yarns on gloves dexterity***

The dexterity of gloves was determined according to EN 420:2003. Gloves finger dexterity was measured by picking steel pins of varying diameters from 5mm to 11 mm within the time duration of 30 seconds. All samples passed the maximum level of dexterity test. Hence no effect of the count of composite yarn, type of core, or diameter of the core could be found on the dexterity of gloves.

Conclusions:

The study revealed that increase in diameter of glass core resulted into increase in tensile strength and tenacity of composite yarns for all counts, whereas an increase in diameter of stainless steel core resulted into a decrease in tensile strength and tenacity of composite yarns of same counts. Similarly, composite yarns with glass cores offered greater tensile strength and tenacity as compared to composite yarns with stainless steel cores for same counts. The effect of change of the diameter of glass core on breaking elongation and time to break was not significant, while the effect of such change for stainless steel core yarns had a direct relationship with breaking elongation and time to break. The coefficient of friction of all yarn samples was almost the same showing almost no contribution of core material towards coefficient of friction.

The tests for abrasion resistance showed a positive correlation between abrasion resistance and count of composite yarns with glass cores, while its correlation was negative with core diameters. On the other hand, for finer counts, composite yarns with stainless steel cores showed better abrasion resistance than yarns with glass cores.

The tests for cut resistance showed a positive relationship between cut resistance and diameter of composite yarn keeping core the same. Similar results were obtained by reducing the core size for the same yarn counts. These results showed the effective role of Kevlar® sheath fibers towards cut resistance. The yarns with glass core showed better-cut resistance when compared to yarns with stainless steel cores. That was partly due to the higher tensile strength of E-glass compared to stainless steel and partly due to using multifilament glass fibers in comparison to monofilament stainless steel fibers. Even the lowest cut resistance from composite yarns made of glass core was higher than most values of cut resistance from composite yarns made of the stainless steel core. None of the gloves made from composite yarns using stainless steel cores could achieve cut resistance level of 5.

No relationship could be found between the dexterity of the gloves and the count of composite yarn, type of core, and core diameter as all samples passed the test to the maximum level.

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