Study on the Impact Resistance of Protective Cycling Apparel Fabrics

Haoying Li
Jiaxing Vocational and Technical College, Jiaxing, China

Abstract: With the growing awareness of safety and the rapid increase in the number of automobiles, the riding environment for motorcyclists has become increasingly hazardous, posing significant threats to their safety. Consequently, the protective role of clothing for riders has gained greater importance. This paper employs methods such as market research and experimental analysis to study the impact resistance of fabrics made from nylon-spandex and polyester-spandex blends. The research focuses on fabrics with varying raw materials, structures, and densities. Experimental results indicate that the impact resistance of nylon-spandex fabrics exceeds that of polyester-spandex fabrics. Rib knit fabrics show superior impact resistance compared to plain knit fabrics, and the thicker the fabric, the stronger its impact resistance. These findings provide valuable insights and references for the production of impact-resistant apparel.

Keywords: Protective Cycling Apparel; Structure; Density; Breathability; Abrasion Resistance; Impact Resistance

1. Background and Significance

In the latter part of the 1990s, motorcycles emerged as a popular means of transportation in the Chinese landscape, particularly gaining traction in small to medium-sized cities and rural areas. As urban areas faced challenges such as congestion, parking constraints, and a resurgence in the younger generation's quest for individuality and freedom, motorcycles began to permeate society with a growing momentum.[1] The attire worn by riders, enveloping their entire physique, plays a pivotal role in shielding them from potential impacts, thus underscoring the critical importance of investigating the protective capabilities of protective motorcycle apparel fabrics. The *2024 Outdoor Market Research Report* published by Magic Mirror Insights points to a substantial growth potential within China's outdoor sports market compared to the market saturation levels observed in European and American regions.[2-3] Market studies suggest that motorcycle garment fabrics predominantly consist of knitted materials known for their exceptional elasticity, softness, moisture-wicking properties, and breathability. Notably, fabrics used in motorcycle riding attire predominantly comprise blends of nylon-spandex and polyester-spandex—materials renowned for their quick-drying attributes, comfort, and the aesthetic appeal resembling combed cotton, rendering them favored choices for crafting athletic wear. Moreover, spandex features prominently in these fabrics due to its superior elasticity and shape retention, aligning perfectly with the demands imposed by high-intensity physical activities. Commonly employed fabric structures include plain knit and ribbed variations, both of which represent prevalent configurations in the realm of knitted textiles.

In the realm of functions, protective performance stands out as particularly crucial. [4] Consequently, this study employs a blend of nylon-spandex and polyester-spandex, varying textile parameters to weave a total of eight experimental fabrics. Through examining these textiles for properties such as impact resistance, durability, and breathability, the research aims to furnish a solid theoretical foundation and practical reference for the design of impact-resistant fabrics in the future.

2. Research Content, Approach, and Methodology

2.1 Research Content

This study involved the selection of nylon-polyester and polyester-spandex blended yarns, utilizing diverse textile parameters to produce eight experimental fabrics. The investigation focused on the fabrics' impact resistance, abrasion resistance, breathability, and other functional properties. The specific research content encompassed the following four aspects:

(1) Survey Analysis. By conducting surveys, insights were gathered regarding current consumer evaluations of protective motorcycle apparel and riding gear available in the market, pinpointing areas for potential improvement.

(2) Market Research. Primary research was conducted on professional protective motorcycle apparel and riding gear available in the market. This aimed to grasp the organizational structures, fiber compositions, blending ratios, and other essential aspects of protective motorcycle apparel or specialized riding gear fabrics, thereby laying the groundwork for formulating experimental protocols.

(3) Sample Design Strategy. Drawing upon actual weaving conditions in factories and controlled variable factors (including blending materials, fabric density, and structural compositions), designs for weaving nylon-spandex and polyester-spandex blended fabrics were tailored. Collaborative efforts with factories were initiated to commence the weaving processes.

(4) Impact Resistance Testing and Fundamental Performance Trials. Comprehensive tests were conducted to evaluate the fundamental qualities of the fabrics, encompassing basic attributes such as breathability and abrasion resistance, as well as protective characteristics like impact resistance.

2.2 Research Approach and Methodology

2.2.1 Market research and survey analysis

Through an in-depth study of the protective motorcycle apparel and riding gear available in the market, the primary fabric compositions, structural designs, and yarn blending ratios of such garments were examined. Additionally, a questionnaire survey was conducted among motorcycle riders to gather insights into consumer feedback on the available protective motorcycle apparel, identifying areas of dissatisfaction and aspects they wish to see improved.

2.2.2 Experimental analysis

The basic properties and impact resistance of the fabrics were tested, followed by a detailed experimental analysis of the obtained data.

3. Survey Analysis

3.1 Questionnaire Survey

The primary survey location for this questionnaire study was the Hangzhou region. The sample size consisted of 50 respondents, with 50 valid questionnaires collected. Upon statistical analysis of the raw survey data, it was discovered that all participants in this study were frequent motorcycle riders or professional cyclists, with a gender distribution of 66% male and 34% female. These participants exhibited a substantial understanding of protective motorcycle apparel and cycling gear, possessed specific preferences, and provided targeted and valuable feedback.

3.2 Research Findings Analysis

In terms of the performance aspects of protective motorcycle apparel, a likert scale was employed in the survey design, ranging from 1 to 5. Here, 1 indicated extreme dissatisfaction, 2 denoted dissatisfaction, 3 represented neutrality, 4 signified satisfaction, and 5 indicated great satisfaction. The survey primarily aimed to gauge consumer preferences for protective motorcycle apparel and riding gear, while also exploring the existing deficiencies in the market offerings. Insights gleaned from the survey revealed that consumers expressed some dissatisfaction with the moisture-wicking and breathability properties, as well as impact protection, among other functions of current motorcycle and protective cycling apparel available in the market. The overall evaluation of the garments' performance, as indicated in Figure 1, highlighted various areas for improvement:

Consumer evaluations of the performance of motorcycle or protective cycling apparel, as depicted in Figure 1, revealed that respondents were particularly critical of the garments' moisture-wicking capabilities, elasticity without constraint, windproofing, antimicrobial properties, and style aesthetics. Conversely, respondents indicated relative satisfaction with the garments' durability, fabric resilience, and design aesthetics. It is evident that current market offerings fall short of meeting consumers' ideal standards in various performance aspects.

The performance features that consumers expect from motorcycle or protective cycling apparel are primarily reflected in the following aspects, as illustrated in Figure 2 consumer-desired apparel performance.

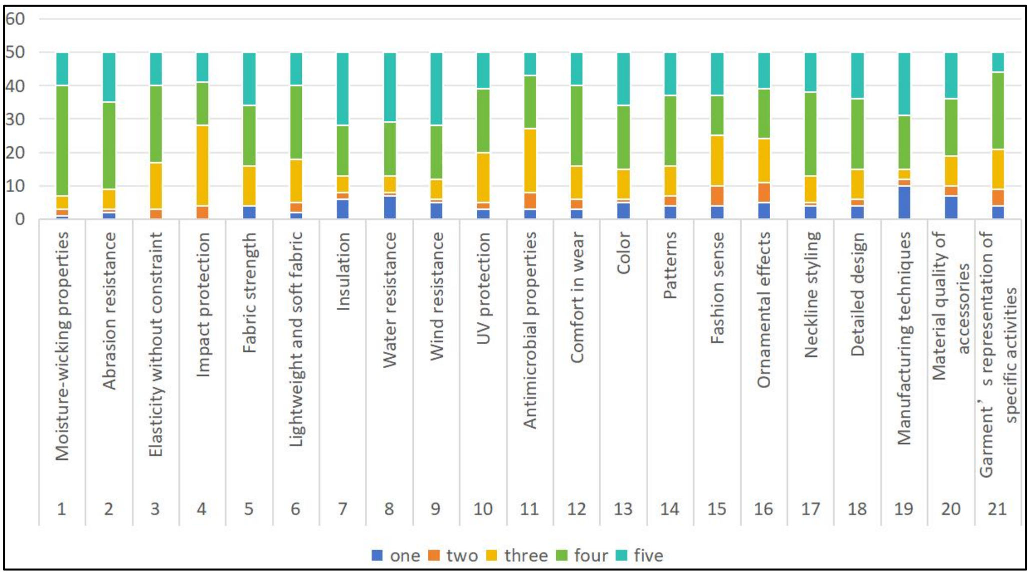

Figure 1. Consumer Evaluation of the Performance of Protective Motorcycle Apparel

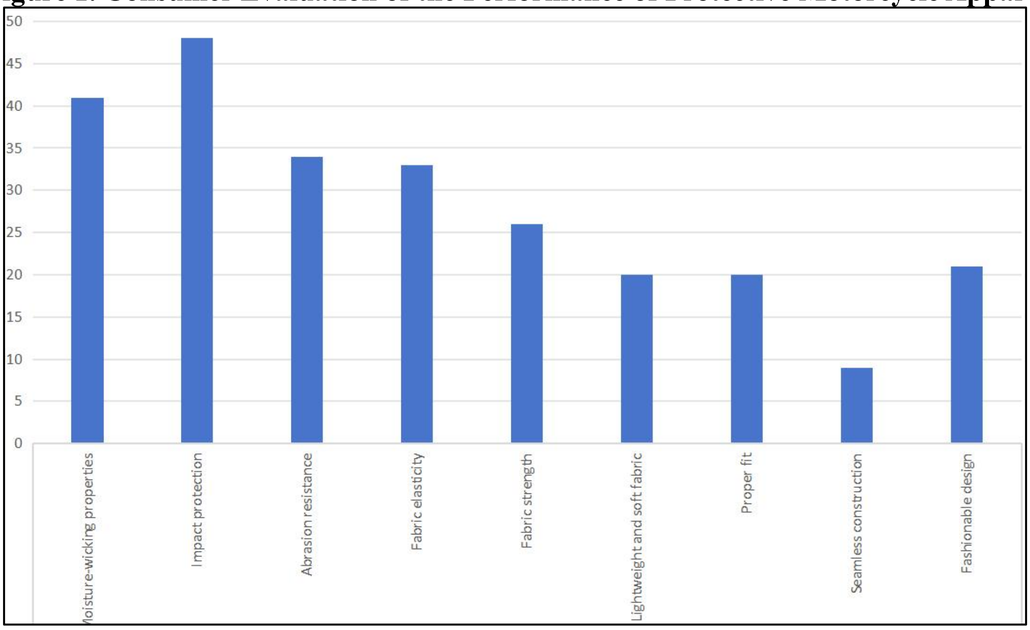

Figure 2. Consumer-Desired Apparel Performance

From Figure 2, it is clear that consumer expectations for garment performance are heavily focused on impact protection and moisture-wicking properties. These two factors also represent the areas where consumers expressed the most dissatisfaction with the current market offerings. Therefore, this study focuses on impact protection as its primary research subject, aiming to propose improvements to market apparel based on these needs.

4. Experiment and Data Analysis

4.1 Sample Design and Experimental Conditions

Based on the survey findings, the experimental design for this study involved the use of circular plain knit fabrics produced using seamless production technology. Two types of materials were selected—polyester/spandex and nylon/spandex—each with two different structures (plain knit and rib knit). One of the structures was produced with two different process densities adjusted by the production machinery (where process density here refers to the density adjusted by the circular knitting machine in the seamless production process at the cooperating factory, resulting in fabrics with varying degrees of tightness). The gradients of density adjustment were +0 and +10,[5] resulting in a total of eight fabric samples. The threads used in the production of these fabrics of the same material had identical fineness, with a spandex content of 10%. The eight fabrics were numbered as follows, as shown in Table 1:

Table 1. Sample Selection

Sample Number	Material	Blend Ratio	Structure	Density Adjustment Gradient
#1	Nylon/Spandex	90/10	Plain knit	+0
#2	Nylon/Spandex	90/10	Plain knit	+10
#3	Nylon/Spandex	90/10	Rib knit	+0
#4	Nylon/Spandex	90/10	Rib knit	+10
#5	Polyester/Spandex	90/10	Plain knit	+0
#6	Polyester/Spandex	90/10	Plain knit	+10
#7	Polyester/Spandex	90/10	Rib knit	+0
#8	Polyester/Spandex	90/10	Rib knit	+10

Based on the selection of these samples, the variables for this experiment included the material, structure, and process density.

According to the regulations outlined in the Chinese standard GB/T.6529-2008 *Standard Atmosphere for Conditioning and Testing of Textiles*, all experimental samples were placed under standard atmospheric pressure conditions with a temperature of 20±2°C and a relative humidity of 65%±5% for 24 hours before experimentation. The external conditions in the laboratory were set to a standard atmospheric pressure of 20±2°C and a relative humidity of 65%±5%.

4.2 Sample Structure and Specification Experiment

4.2.1 Impact resistance of fabric

Definition and Benefits of Impact Resistance:

Impact resistance refers to the ability of a sample to withstand impact loads.

A fabric with impact resistance can effectively resist external shocks, protecting the human body from injury caused by external forces.

Principle and Improvement Methods for Fabric Impact Resistance:

When an external force impacts a fabric, part of the force is reflected, and part is absorbed by the human body. Typically, when the external force is small, the human body can withstand the shock. However, when the external force becomes too large, the human body will not be able to resist it, leading to injury.

The force acting on the human body will generate an impact. From the perspective of textiles, to reduce the harm caused by external forces to the body, it is essential to minimize the amount of force that penetrates the fabric. This can be achieved by increasing the rebound and absorption capacity of the fabric to external forces. The better the fabric's capacity for rebound and absorption, the better its impact resistance and protective performance, ultimately reducing the risk of injury to the body.

Due to the fact that the energy absorption capacity of knitted fabrics remains at the cutting edge of technology and no clear standards currently exist to guide experiments and quantitatively analyze such fabrics[6], this study investigated the energy absorption performance of knitted fabrics with the ultimate goal of developing protective motorcycle apparel with impact protection capabilities. Therefore, this research referred to the commonly used European standards for testing the impact resistance of protective gear. In Europe, the EN1621-1:2012 and EN1621-1:2013 standards specify requirements for impact resistance in protective gear for areas such as the shoulders, elbows, knees, and back[7], providing clear guidelines.

However, these two standards apply specifically to protective gear designed for extreme sports. The protective motorcycle textiles studied in this paper have not yet reached the rigorous requirements of extreme sports protective gear. As a result, during the testing process, the testing methods outlined in these standards were referenced, but the initial conditions must be adjusted according to the actual circumstances. The initial energy should be set within the fabric's current maximum tolerance range, allowing for a comparative performance analysis of fabrics with different surface structures and raw materials.

(1) Impact Resistance Testing Method

The drop hammer test apparatus can authentically replicate common instances of falling impact, providing a superior method for assessing the impact resistance of materials. Moreover, variables such as the shape, size, boundary conditions, and impact speed of the impact head can be flexibly adjusted according to experimental design requirements. Thus, considering the demands of the research topic and practical constraints, this paper opted for the use of a drop hammer impact tester to investigate the impact resistance of protective motorcycle fabrics.

The drop hammer impact head adopted a conical shape, with a mass of 10kg. Various height conditions were set, meaning different drop heights were established under unchanged circumstances. According to the principle of conservation of energy, the instantaneous initial impact energy of the drop hammer,[8] i.e., the maximum impact kinetic energy, is calculated as:

$Q=mv^2/2=mgh$

Experimental Equipment: As shown in Figure 3, the RCL-300 Drop Hammer Impact Testing Machine

Experimental Sample: Size: 40mm*40mm

Number of Experiments: 5 trials

Figure 3. RCL-300 Drop Hammer Impact Testing Machine

(2) Experimental Results and Analysis

The results were analyzed and compared based on the mean values. The raw data can be found in the appendix, and the average values for fabric impact resistance are presented in Table 2:

Table 2. Fabric Impact Resistance

Fabric Number	1	2	3	4	5	6	7	8
Penetration Force/N	19.60	17.64	22.54	20.58	17.64	16.66	18.62	17.64

Figure 4 is plotted according to Table 2 Fabric Impact Resistance:

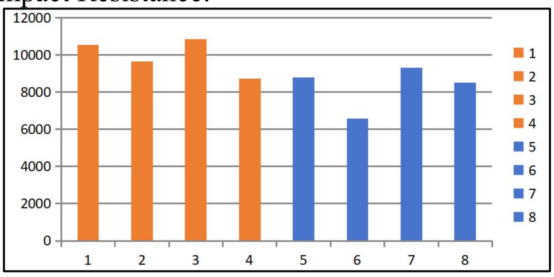

Figure 4. Fabric Impact Resistance

1). The impact penetration force of nylon-spandex fabrics exceeds that of polyester-spandex fabrics.

2). When comparing fabrics of the same material, fabrics with higher density exhibit greater impact penetration resistance than fabrics with lower density.

3). For fabrics of the same material, rib knit fabrics demonstrate higher impact penetration resistance than plain knit fabrics.

4.2.2 Fabric abrasion resistance

Due to the diverse forms of wear encountered during daily clothing use, the testing methods are relatively complex. This study primarily employed flat abrasion testing.

(1) Testing Method

The aim was to simulate the wear experienced in areas such as the cuffs, hips, and soles of socks during regular wear. The wear mechanism typically follows this sequence: abrasion — fiber fracture — fiber detachment — fabric thinning — weight reduction — structural damage — hole formation.

Sample: Circular fabric specimens with a diameter of 12 cm

Equipment and Tools: As shown in Figure 5, the Y522 Fabric Abrasion Testing Machine

Testing Indicator: Abrasion Resistance

Number of Tests: 3 trials

Figure 5. Y522 Fabric Abrasion Testing Machine

(2) Test Results and Analysis

The results were analyzed and compared based on the average values. The raw data can be found in the appendix, and the average values are shown in Table 3:

Table 3. Fabric Abrasion Resistance

Sample Number	1	2	3	4	5	6	7	8
Number of Revolutions	10542	9655	10836	8720	8790	6584	9305	8518

Figure 6 Fabric Abrasion Resistance is plotted according to Table 3:

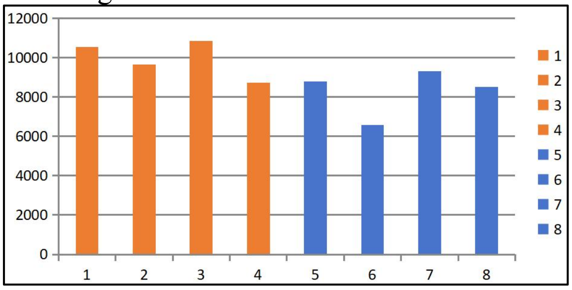

Figure 6. Fabric Abrasion Resistance

From Figure 6, it can be observed that nylon-spandex-blend fabrics exhibit superior abrasion resistance compared to polyester-spandex blends. However, in comparison to other fabrics, both nylon-spandex and polyester-spandex blends perform relatively well in terms of abrasion resistance. For protective cycling apparel, where the hips frequently come into contact with the saddle, superior abrasion resistance is essential. This fabric meets the requirements for outdoor protective cycling apparel,[9] making it suitable for outdoor garments as well.

4.2.3 Fabric air permeability

In addition to providing aesthetic appeal, the primary purpose of clothing is to maintain a balance of energy exchange between the human body and the surrounding environment. When environmental conditions change, adjusting the amount of clothing helps regulate the energy balance, ensuring that the skin temperature remains constant. [10] The ability of air to pass through fabric is referred to as fabric air permeability. This directly impacts the wearability of the fabric.[11] The air passes through the gaps between yarns and fibers, and the fabric's permeability is influenced by the shape and structure of the fibers as well as the fabric's weave structure.

(1) Testing Method

Air is passed vertically through the fabric, creating a pressure difference between the fabric's front and back sides. The volume of air passing through the fabric per unit time at a specific pressure difference is defined as the fabric's air permeability.[12] This experiment followed the standard GBT 5453-1997 *Determination of Air Permeability of Fabrics*.

Sample: 200 mm × 200 mm

Equipment and Tools: YG(B)461D-II Digital Fabric Air Permeability Tester, as shown in Figure 7

Testing Parameters: Sample pressure difference: 100 Pa

Testing Indicator: Air Permeability (R, in mm/s)

Number of Tests: 10 trials

Figure 7. YG(B)461D-II Digital Fabric Air Permeability Tester

(2) Test Results and Analysis

The results were compared and analyzed based on the average values. The raw data can be found in the appendix, and the average values are shown in Table 4: Fabric Air Permeability

Table 4. Fabric Air Permeability

Sample Number	1	2	3	4	5	6	7	8
Air Permeability R (mm/s)	139.55	150.37	112.55	129.48	168.55	176.47	150.18	173.38

From Table 4, Figure 8 illustrates the fabric air permeability among the samples.

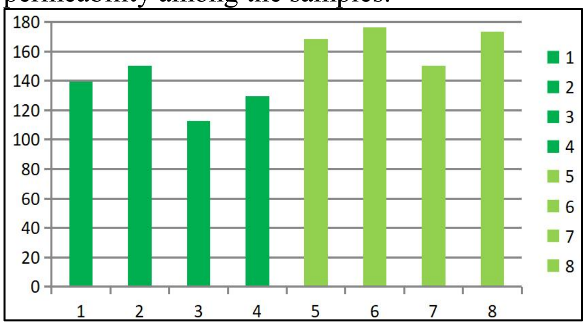

Figure 8. Fabric Air Permeability

According to Figure 8, the air permeability of the samples ranges between 110 mm/s and 180 mm/s. In terms of air permeability ranking from good to poor: polyester-spandex fabric performs better than nylon-spandex fabric. Therefore, the air permeability of polyester-spandex fabric surpasses that of nylon fabric.

This experiment further explored the relationship between fabric air permeability and fabric structure in Figure 9. Additionally, the relationship between fabric air permeability and fabric density is illustrated in Figure 10:

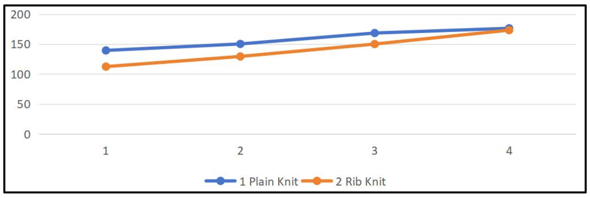

Figure 9. Comparison of Air Permeability between Plain Knit and Rib Knit Structures

As depicted in Figure 10, fabrics with lower densities exhibit superior air permeability. Figure 9 indicates that the air permeability of a plain knit fabric outweighs that of a rib knit fabric. While rib knits possess larger gaps than plain knits, both structures are influenced by various factors affecting air permeability. Despite rib knits having larger gaps, their thickness can impact air permeability significantly, making it challenging to easily determine the influence of rib knits or plain knits on fabric air permeability.

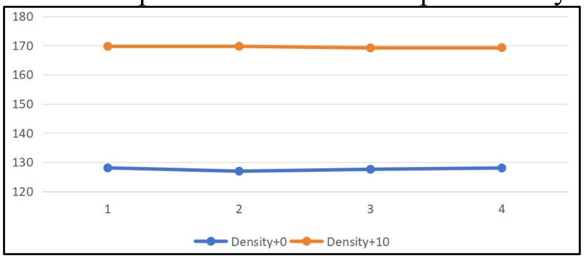

Figure 10. Impact of Different Fabric Densities on Air Permeability

5. Conclusion

Nylon-spandex and polyester-spandex blended fabrics are now commonly adopted in outdoor apparel due to their exceptional durability. This paper presents the following conclusions regarding the performance of nylon-spandex and polyester-spandex fabrics:

(1) Through experimental testing on fabric impact resistance, the results show that nylon-spandex fabric outperforms polyester-spandex fabric, and rib knit fabric surpasses plain knit fabric. Generally, fabrics with greater thickness exhibit stronger impact resistance.

(2) Evaluation of fabric abrasion resistance reveals that nylon-spandex fabric surpasses polyester-spandex fabric in this aspect. Both fabrics exhibit favorable abrasion resistance.

(3) Assessment of fabric moisture permeability demonstrates that polyester-spandex fabric excels over nylon-spandex fabric in terms of breathability. Fabrics with lower densities showcase superior moisture permeability.

Due to constraints in experimental conditions and time limitations, further in-depth research and improvements are required in the investigation of impact resistance of nylon-spandex and polyester-spandex blended fabrics. Research and development in impact resistance of flexible fabrics are still in their nascent stages. While this paper has explored and analyzed the fundamental properties of nylon and polyester fabrics, the study on novel fabrics lacks depth due to constraints in time, resources, and experimental conditions. Further research is necessary to delve into other aspects of fabric performance, such as antibacterial properties, sun resistance, and wash durability. As the samples in this study had the same blend ratio, the impact of blending ratios on fabric wearability was not explored. Moreover, the study only focused on plain and rib knit structures, lacking investigation into warp-knit structures, which may impact wearability. These limitations call for further comprehensive research in the future.

Acknowledgments

This work was financially supported by the Research Project of Jiaxing Vocational & Technical College in 2025 (Project Number: jzyz202507) and 2024 Domestic Visiting Engineer "University-Enterprise Cooperation Project" in Higher Education Institutions (Project Number: FG2024324).

References

[1] Zhao Jing, Yang Xiandong, Wang Gaoyuan, Xu Fan, et al. Market A market investigation on motorcycling clothes industry. Shanghai Textile Science & Technology, 2010(07): 13-16.
[2] Tian Hui. Towards “Deep” Yet “Light” Fashion. China Apparel, 2025(06): 32-33.
[3] Zhang Xuan, Shao Xinyan. Research on the Design of Motorcycle Riding Apparel Based on the KJ Method and Kano Model. Fashion Designer, 2024: 106-111.
[4] Deng Xiaolei, Zhang Tao. Analysis of the Research Status of Airbag Motorcycle Riding Apparel. Light Textile Industry and Technology, 2024(05): 130-133.
[5] He Ling. Research on Impact-Resistant Seamless Knitted Fabric Performance and Development of Protective Sportswear. Zhejiang Sci-Tech University, 2015.
[6] Zhao Yanyan. Development of Protective Fabric for Jacquard Warp Knitted Fabrics and Related Protective Performance Studies.

Donghua University, 2011.
[7] Yang Hui, Tian Yuanfei. Optimization of Bicycle Riding Apparel Design Based on Safety Protection Needs. Journal of Beijing Institute of Clothing Technology (Natural Science Edition), 2025(01): 11-17.
[8] Yu Xiaokun, Guan Juanjuan, Luo Yang. Design and Development of Anti-impact Hip Protection Pants for Elderly Female. Journal of Donghua University (Natural Science Edition), 2020(05): 733-739.
[9] Wu Xueyuan, He Guoying, Pei Xianglin. Development of High-Elastic Velvet Nylon Outdoor protective cycling apparel Fabrics. Knitting Technology, 2021(09): 5-7.
[10] Chen Kequan. Properties of PTT filament and development of the knitted fabrics. Knitting Industries, 2005(09): 23-25.
[11] Zhang Lijuan, Xing Lihong. The performance researching of fractal cross-twist polyester yarn fabric. Textile Reports, 2016: 41-44.
[12] Zhang Jianxiang, Wang Guizhi, Cui Jinde, Tian Lili, Huang Yanhua. Breathability Testing of Textiles. Printing and Dyeing, 2009(23): 38-40.

