Design, Development and Preparation of Pouched Scuba-Knitting Spaced Fabric

Kuang Liyun¹, WU Liwei²
Tianjin University of Technology, Tianjin 300387, China
² zhangnan@tju.edu.cn

Abstract: Objective To improve the protection of human joints and avoid the injury caused by falls in the elderly. By testing and evaluating the wearability and mechanical properties of the pouched scuba-knitting fabric with no filling material, filled with EPS and POM, this paper provides a theoretical basis for the development of the protection products for the elderly. Methodology Using nylon filament and spandex stretch yarn as raw materials, two kinds of cushioning materials, EPS and POM, are respectively filled into pouched scuba-knitting weft-knitted structure. Results Due to the limit of 3mm spacing between front and rear needle beds of the computerized flat knitting machine, among all kinds of samples tested, the air permeability of EPS is stronger than that of POM with the increase of EPS sphere diameter. Because EPS spheres are more easily attached to water, the moisture permeability is shown to be the best. The mass loss of non-filled fabric is the greatest in the wear resistance test. Due to the characteristics of weft-knitted fabrics, there is no obvious difference among the three kinds of knitted fabrics in the tests of bursting, stretch recovery, pilling. Conclusion The pouched scuba-knitting structure filled with EPS is more suitable for the design and production of the protective fabric for the elderly afterwards.

Along with an ageing population increasingly grim in China, the fracture caused by falling down of old people and a series of additional issues, such as illness and family financial burden, etc. have attracted extensive attention of global medical world and people in other fields[1]. Awareness of raising the life quality of the elderly is increasing year by year in the whole of society, and also how to avoid injuries caused by falling of the elderly becomes an urgent problem to be solved at present [2], so research and design of care products for the elderly has attracted much attention.

As early as 1983, Palumbo P proposed a device to protect and support the knee[3]; Zhang Tong et al. tested the buffer performance of sponge materials, that obtains the best method for femur protection[4]. Fu Chunlin's research and development on ceramic far-infrared thermal-preservation and health-care knitted fabrics[5]; In the 10th Symposium on functional Textiles and Nanotechnology application, Xu Xuejuan et al. proposed the research and prospect of ceramic far-infrared fabrics[6]. Li Yong et al. studied the impact resistance of woven plain cloth and Warp knitted biaxial laminated material[7]. In addition, protection content is also introduced in <Application Prospects of Spacer Fabrics> translated by Liang Chunjin[8]. To sum up, for the research on falling protective knee pads, currently more researchers focus on three aspects including filler of protective knee pads, biaxial-shaped composite fabric and three-dimensional spacer fabric, while the research and design of functional protection products should consider human factors, product factors and market factors[9]. Therefore, it is necessary for wearable protective products of elders to have a certain buffering function[10]. In addition, protecting the bones from damage, it is also necessary to have a certain comfort and ability to
respond to seasonal needs\cite{11}. Secondly, the wearable protective products should be with flexibility of weaving, easy to produce and conducive to improvement\cite{12}.

According to the design requirements of functional wearable protection products\cite{13}, this paper proposes to develop and produce knee-protection fabrics based on weft-knitted scuba-knitting spaced structure. From the aspects of breathability, moisture permeability, bursting, tensile recovery, pilling and wear resistance, the wearability and mechanical properties of the three kinds of protective fabrics with no filler, EPS and POM were comprehensively compared and evaluated. That provides data reference for the development of protective products for the elderly.

1. Experimental Research

1.1 Selection of experimental materials
The weft-knitted scuba-knitting spaced fabric will eventually be used as a protective product for the elderly, which needs to be elastic, comfortable and wear-resistant for human wear. Therefore, the raw material chooses the black double 100-denier polyamide filament\cite{14} with excellent fracture strength, elongation and resilience (Produced by Huili Spandex Products Factory in Zhuji City). At the same time, the single 30/75 black spandex stretch yarn\cite{15} produced by Junrong Knitting Raw Material Sales Department in Zhuji city was added to improve the overall elasticity of the product and the ability to cover the filler. Using YG(B-0)021DL electronic single yarn strength tester, the breaking strength of double-ply nylon filament and spandex stretch yarn was tested in the standard guided by GB/T3916-1997\cite{16}. The basic parameters obtained are shown in Table 1. According to the data in the table, it can be seen that the average strength of polyamide yarn is 960.10cN, and its coefficient of variation (CV) is 6.02%. The average strength of spandex is 319.18cN, and its CV is 3.56%. The strength of the two yarns was relatively stable.

| Description        | Yarn number (Tex) | Breaking strength (cN) | Breaking elongation (%) | Tensile modulus (GPa) | Manufacturer                                      |
|--------------------|------------------|------------------------|-------------------------|-----------------------|---------------------------------------------------|
| Spandex Stretch Yarn | 12               | 319.18                 | 61.23                   | 0.5                   | Huili Spandex Products Factory in Zhuji City       |
| Nylon Filament      | 27               | 960.10                 | 93.26                   | 1.4                   | Junrong Knitting Raw Material Sales Department in Zhuji city |

1.2 Preparation of fabric samples
The main fabric structure is composed of rib scuba-knitting and double knit structure arranged one by one, both of which are double-sided fabric structure, which can make the final product keep the surface smooth and avoid the generation of folds. In order to make use of the hollow characteristics of the scuba-knitting fabric, the two kinds of fabric are arranged one by one to improve the pressing elasticity of the fabric to a certain extent\cite{17}. In the main structure of the fabric, two schemes of filling a POM sphere\cite{19} with a diameter of 3mm and a density of 1.42 in the scuba knitting\cite{18} and a EPS sphere\cite{20} with a diameter of 5mm will be adopted\cite{21}, as shown in Figure 1. The scuba knitting is evenly distributed. Each small scuba knitting is designed as a square "pocket" with five needles and ten horizontal rows, as shown in Figure 2 and Figure 3.
The LXC-252SCV computer flat knitting machine produced by Jiangsu Jinlong Technology Co., LTD is used to fabricate the product samples. From the space between the front and back needle beds, the filler slides into the scuba knitting "pocket" woven (Fig 4). After the filling action is completed, start the machine and repeat this action until all scuba knitting are filled. As shown in Fig. 5, the density mirror was used to observe the fabric and record the data. See Table 2 for the results.

![Polystyrene foam balls](image1)

![Filling distribution map in scuba](image2)

![Weave pattern of Bag-shape scuba structure](image3)

![Diagram of Bag-shape scuba and EPS filling](image4)

**Tab.2 The horizontal and vertical density of samples**

| Structure               | Rib  | Double Needle | Fill with scuba knitting |
|-------------------------|------|---------------|--------------------------|
| Horizontal density      | 74   | 72            | 72                       |
| /(column /10cm)         |      |               |                          |
| Vertical density        | 130  | 114           | 187                      |
| /(row /10cm)            |      |               |                          |
In this paper, the air permeability, moisture permeability, bursting, tensile recovery, wear resistance and pilling performance of the fabric were tested for 5 times respectively for A (scuba knitting fabric without fillings), B (scuba knitting fabric filled with EPS) and C (scuba knitting fabric filled with POM). With GB/T 5453-1997 as guidance standard, use YG (B) 461 d - II digital fabric air permeability instrument (produced by Changzhou First Textile Equipment co., LTD,) to test fabric air permeability. Fabric moisture permeability test use Wenzhou Daiei Textile Instrument co., LTD production of YG (B), 216 - type II fabric moisture transmission device, in GB/T 12704.2 2009 as guidance standards; YG065C bursting strength tester produced by Laizhou Electronic Instrument Co., LTD is used for fabric bursting test, and GB/T7742-2005 is the guiding standard. The fabric tensile recovery test takes FZ/T70006-2004 as the guiding standard, using YG065C bursting strength tester manufactured by Laizhou Electronic Instrument Co., LTD. The wear resistance of the fabric is tested for 200 times under the condition of grinding wheel rotation speed of 60r/min and pressure of two grinding wheels of 250cN. The YG (B) 522 type fabric wear-resistant instrument manufactured by Wenzhou Darong Textile Instrument Co., LTD is used. The pilling performance test of fabric is based on GB/T4802.8-2008 as the guiding standard. The M511 double-head fabric pilling tester manufactured by Qingdao Shanfang Instrument Co., LTD is used.

2 Results and discussion
The purpose of this paper is to provide strong theoretical data support for the research and development of protective products in the later stage. Therefore, the categories, structure and weaving process of protective products for the elderly are not discussed in detail here. At the present stage, only three kinds of fabric (A, B, C) of the elderly protection products are used for the comparison of wearability and mechanical properties, and the differences are evaluated and studied, so as to find out which kind of fabric is most suitable for the design and use of the elderly protection products.

2.1 Analysis of fabric breathability test
Fig. 6 is a comparison of the average permeability of ABC fabrics. Under the sample pressure of 100/(Pa), the permeability and heat removal performance is enhanced with the increase of the value. The experimental data shows that the average permeability of the scuba knitting structure with fillings is much higher than that of the scuba knitting structure without fillings (233.54mm /s), and the coefficient of variation is 7.31%. The average permeability of scuba knitting structure filled with EPS (455.42mm /s) and the coefficient of variation is 4.49%, which was greater than the CV value of 10.86% that the average permeability of scuba knitting structure filled with POM (429.50mm /s). Through the analysis of the results, it is preliminarily judged that the pore diameter of the fabric increases after the scuba knitting structure is opened by the filler, so compared with the fabric without the filler, the...
increase of the filler diameter is directly proportional to the improvement of the permeability of the fabric.

Fig.6 Comparison of average permeability

2.2 Analysis of fabric moisture permeability test

In accordance with GB/T8170, the experimental test results can be applied to the calculation after the average is calculated. According to the calculated formula WVT=(Δ m-Δm ')/A·t, the average value of mass change before and after moisture permeability of the three fabric samples of ABC is obtained, as shown in Fig.7: A is 1.345g, B is 1.356g, and C is 1.348g. The mean values of the moisture permeability of the three fabrics are: A, 11406.361 g/(㎡·24h), B, 11501.767/(㎡·24h), C, 11431.802/(㎡·24h), as shown in Fig.8. It can be found from the comparison experiment that group B samples have the highest moisture permeability, followed by group C and group A samples. According to the fact analysis, the reason for this phenomenon is that EPS spheres in group B are more likely to adhere to water, while POM in group C has less adhesion to water than EPS, so there will be such a difference in moisture permeability. According to the measured average moisture permeability value of the three kinds of fabrics, all are larger than 10000, which is enough to show that the moisture permeability of the three fabrics is good.

2.3 Analysis of fabric bursting test

Fig.8 shows the comparison of bursting tests of A and B fabrics. As shown in the figure, the average bursting value of A is 1445.20N, and the coefficient of variation is 3.29; The average bursting value of B is 1448N, and the coefficient of variation is 8.03. The difference of average bursting value between the two is 2.80N, and the difference of bursting deformation rate is 0.09%. As shown in Fig. 9, the deviation of the average value of the two fabrics is within the acceptable range of the experimental
deviation, and both fabrics have good bursting resistance. According to the data analysis, the main reason for the great variation of bursting value is the inner filled with EPS sphere. The POM sample was not tested in the experiment, but it can be considered that the presence or absence of filler has no effect on the bursting performance of the fabric. The bursting state of the experimental sample is shown in Fig.10.

Fig.9 Comparison of fabric bursting test data

Fig.10 The experimental sample was in a state of bursting

2.4 Analysis of fabric tensile resilience test

Fig. 11 and Fig. 12 are the comparison of the average value of the tensile resilience, in the horizontal and vertical directions respectively (the actual stretch of 75mm in the horizontal direction and 50mm in the vertical direction), of the samples of ABC with different fillers. As shown in Fig. 13, the experimental data shows that horizontal tensile deformation is 7.03mm in group A, 7.03mm in group B and 7.05mm in group C; Vertical tensile deformation is 6.36mm in group A, 6.48mm in group B and 6.37mm in group C. The horizontal and vertical plastic deformation rate, rapid projectile deformation rate, slow projectile deformation rate, elastic recovery rate and the stress relaxation rate of the three groups are almost the same. Therefore, it can be preliminarily concluded that the existence of filler in the scuba knitting fabric and different type of filler has no influence on the tensile resilience of the fabric. The states before and after stretching are shown in Fig.14.
2.5 Analysis of fabric wear resistance test
Comparison of experimental data of weight loss per unit area of sample slices is shown in Fig 15. The average mass loss before and after wear of group A is the largest among the three groups, $2.47 \times 10^{-3}$ g/c m$^2$, and the coefficient of variation is 6.50%; Group B is followed by $1.83 \times 10^{-3}$ g/c m$^2$, and the coefficient of variation is 7.12%; The lowest mass loss is $1.73 \times 10^{-3}$ g/ C m$^2$ in Group C, and the coefficient of variation is 4.383%. According to the analysis, the differences between filling EPS and
filling POM, is caused by the characteristics of the filler, because EPS is a kind of soft material, in the process of experiment, fabric sample will produce a certain deformation from the influence of the grinding wheel weight (compressed to a certain extent). In comparison with filling hard POM (not happen deformation), filling EPS will result in the increase the contact area with the grinding wheel, so mass loss of the sample filled with EPS is bigger, as shown in fig.16.

2.6 Analysis of fabric pilling test

As shown in Table 3, after comparing and rating each sample, the final rating of the three groups are all level 4. The pilling resistance of all samples are excellent, which is due to the suitable yarn selection and weaving method and proves that the pilling resistance of the product is good.

| Tab.3 | Data of pilling and results |
|-------|----------------------------|
| Sample | No filler | With EPS | With POM |
| 1      | 4          | 4         | 3        |
| 2      | 4          | 4         | 4        |
| 3      | 3          | 3         | 4        |
| Rate   | 4          | 4         |          |

3 Conclusion

In this paper, the wearability and mechanical properties on three kinds of pouched scuba-knitting fabric with no filling material, EPS and POM are compared, and the differences are evaluated and studied. The experimental results are as follows:

1) The combination of black double-ply 100-denier nylon filament and 30/75 spandex stretch yarn, after weaving and testing of wearability and mechanical properties, has been clearly shown the reasonableness. Two-ply polyamide yarns have greater strength than single yarns and increase the thickness of the fabric. Due to the characteristics of weft knitted double-sided fabric, the filling material can be tightly wrapped in the fabric during daily use, not easy to expose and slip out. After adding a single spandex filament to improve the overall elasticity, that can make the finished product flatter and tighter.

2) Abrasion resistance test of mechanical properties shows that the mass loss of non-filled fabric is the largest; There are no significant difference about the fluff pilling and tensile recovery among three kinds of tested samples.

3) Wearability test data shows that the larger the diameter of the filling material, the stronger the permeability. Because EPS spheres are easier to adhere to the water, so the moisture permeability is better.
By analyzing and comparing the above experimental results, it is concluded that, due to the limitation of 3mm spacing between front and rear needle beds of computerized flat knitting machine, the pouched scuba-knitting fabric filled with EPS is the best one, which is more suitable for the design and production of knitted protective fabric for the elderly afterwards. At the same time, this paper has a certain prospect for the future. The scuba-knitting spaced fabric filled with EPS is suitable for the design and development of a variety of elderly protection products, such as knee joint, hip joint, shoulder joint, elbow joint, etc. At the same time, in the weaving process, if the computer flat knitting machine installs an automatic material-inputting device, the scuba-knitting spaced fabric filled with fillers will be able to achieve large-scale mass production.

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Author Brief:
1. Kuang Liyun (1979—) Female, Shandong province, Master, Lecturer, Tianjin University of Technology, mainly engaged in knitting product design research
2. Wu Liwei(1984—), Male, Tianjin city, PHD, Lecturer, Tianjin University of Technology, Textile composites (Department of Knitting and Knitting Clothing, College of Textile Science and Engineering, Tianjin University of Technology,300387, 18630969603, zhangnan@tju.edu.cn)

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