Research on Innovation and Application of Thermoplastic Polyurethane Elastomer Bionic Leather Fabric from the Perspective of Sustainable Design

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Abstract. With the improvement of consumers' awareness of environmental protection and the continuous improvement of consumer demand, the leather industry is developing in the direction of environmental sustainability and functional diversity. This article takes thermoplastic polyurethane elastomer yarn as the research object. From the perspective of sustainable design, the woven process is used to weave the thermoplastic polyurethane elastomer yarn and the traditional yarn, and the new fabric obtained after weaving is tested and analyzed. Analyzing and discussing the results of multiple experiments, and expounding the functions and characteristics of the new fabric, weaving a new type of leather fabric that is different from traditional leather-thermoplastic polyurethane bionic leather fabric. The fabric has better gloss, water resistance, abrasion resistance and leather texture, and also has a bionic texture that traditional leather does not have. The research results of this article verify the innovative ideas and design directions in the process, provide more possibilities for the design and development of future luggage products, and make the design of luggage products more diverse.

Keywords: Sustainable design; woven process; thermoplastic polyurethane elastomer yarn; bionic leather fabric.

1. Introduction

With the rapid growth of population and the continuous improvement of national economy, the demand for leather is increasing exponentially, but the natural leather can't meet people's needs, and the appearance and development of synthetic leather make up for the shortage of natural leather quantity[1], widely used in clothing, luggage, shoes, furniture and automobiles. However, the traditional leather industry has high consumption and serious pollution, and the public's attention to environmental issues has brought severe challenges to the leather industry[2]. In this paper, based on the visual threshold of sustainable design, based on the research object of thermoplastic polyurethane elastomer yarn, from the point of view of sustainable design, we try to weave the new material thermoplastic polyurethane elastomer yarn and traditional yarn by shuttle weaving process. The experimental analysis of thermoplastic polyurethane elastomer imitation leather fabric after weaving is carried out, and the functions and characteristics of the new leather fabric are expounded. More sustainable thinking is incorporated into the redesign process. Through the use of new materials in woven technology, consumers' cognition of traditional materials and technical limitations of luggage is
broken, and more possibilities are given to sustainable luggage materials. To make the leather industry towards sustainable ecological development and functional diversity.

2. Research Status and Trends at Home and Abroad

2.1. Current Status and Trends of Thermoplastic Polyurethane Elastomer Materials

Thermoplastic polyurethane elastomer (TPU for short) is a kind of polyurethane rubber, it has better wear resistance and high elasticity than polyurethane PVC, it is the most ideal material to replace PVC and PU. This material is widely used in the automobile industry and is distributed in the whole structure part of the automobile. For example, Roleez Wheels Inc. in the United States used TPU as raw material. Good strength and toughness, abrasion resistance, squeezing impact and not afraid of puncture, suitable for various terrains on the earth, also known as ROLEEZ all-terrain tires. In addition to the advantages of high wear resistance, good safety, high comfort and low resistance, a new type of composite tire has been successfully developed by South China University of Technology at home and abroad; TPU materials have also contributed greatly to the biomedical process and have gradually replaced PVC.

In recent years, due to the development of TPU materials, the application field of this material has been broadened and its popularization value has been increased. TPU film is a new type of high-tech fabric developed from TPU raw materials. Foreign research on TPU film mainly focuses on performance, such as Frick Achim and Spadaro Marcel think that it has high strength and wear resistance. TPU film is a kind of green material. Because of its excellent properties and environmental protection, it is becoming more and more widely used, so it has a good market prospect. Fabrics with waterproof and moisture permeable function are the main characteristics of textile functional clothing product development in various countries, the TPU film has a good waterproof and moisture-permeable function and has become a necessary material for major textile companies to develop waterproof and moisture-permeable fabrics. As a new type of material with stable performance and good environmental protection, TPU film has a wide range of applications, mainly in footwear, waterproof and moisture-permeable fabrics. Most of these products are daily necessities, such as Nike, Adidas, Lv, Gucci, Coach, Crocs, Li Ning Anta and other brands are loyal users.

2.2. Current Status and Trends of Luggage Materials in the Context of Sustainable Design

Sustainable design has become the most popular design method, designers have begun to think deeply about the environmental protection of luggage products. Many brands at home and abroad are actively committed to the development and design of environmental protection materials. Innovation breakthrough in material technology. Freitag brand in Switzerland is recycled from recycled truck tarpaulins, Each bag is not repeated modelling; American Samsonite brand through recyclable materials launched more than 50 green eco-environmental series; Compared with China, there are few research results on the sustainable application of luggage in China. The company's awareness of sustainability is not enough, and the research and development capabilities are relatively weak. The more successful case belongs to the designer Wei Minghui through recycling plastic bags and advertising cloth for reuse design. It can be seen that the development of new materials and technologies has become the trend of sustainable luggage development in the future. It conveys the personalized characteristics of luggage under sustainable design, so that sustainable luggage design can create luggage that is more in line with consumer and environmental needs, so that it can be better based on future luggage in the industry.

3. Setting of Experimental Goals

3.1 Applications of Thermoplastic Polyurethane Elastomers

The most common form of thermoplastic polyurethane elastomer (TPU) material is applied in the form of film in the industrial and civilian fields. TPU film has the excellent characteristics of other plastics
and rubbers, which makes TPU film widely used in footwear, clothing, medical, automotive, electronics and other fields\textsuperscript{[13]}. (Table 1)

Table 1. TPU Types of films.

| Category          | Function                                                                 | Distribution area                                                                 |
|-------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Shoes             | TPU film and shoe base cloth composite, made of waterproof and breathable fabric with good cushioning performance, light, wear-resistant, anti-slip, recyclable and other advantages. | Such as Nike, Adidas, Converse, Li Ning, Anta and Well-known sports brands at home and abroad are in use. |
| Clothing          | TPU film can be combined with textiles to make composite fabrics with high elasticity, high strength, good toughness, antistatic and waterproof and moisture permeability. | Windbreaker, Raincoat, Wetsuit, Women's underwear and other waterproof and moisture-proof clothing. |
| Automotive industry | A repair material with elastic memory, which can automatically repair scratches when scratched, and has super stretchability and ductility. It can be used in a variety of parts in the car body. | Surgical clothing biological protective clothing, lifejackets and other protective clothing. |

All in all, the application field of TPU film is more and more extensive, and it has developed rapidly at home and abroad, and has broad application prospects in textiles, footwear, medical, automotive and other industries. At present, with the development of science and technology, the domestic manufacturing technology of TPU film and its composite products has made great breakthroughs, creating favorable conditions for domestic TPU film and its composite products.

3.2 Selection of Luggage Materials in the Context of Sustainable Design

Sustainability is the most important theme at the moment, and it occupies the mainstream development trend. The environmental protection materials used on luggage are also increasing, gradually replacing natural materials and chemical materials. The characteristics and materials of TPU material belong to a kind of environmentally friendly materials. At the same time, it has good performance, so it can replace the traditional soft PVC material to meet the environmental protection requirements of more and more fields.

The TPU yarn is made of TPU materials and various textile fibers. This new yarn is wrapped in high performance TPU materials (see figure 1), adding many properties that the original fiber does not have, TPU yarn obtained in this way still ensures that it is also environmentally friendly. However, it is more likely to widen the scope of application to new boundaries, a new attempt on TPU materials.

Figure 1. TPU Experimental Yarn.

4. The Design Experiment Process of Thermoplastic Polyurethane Elastomer Bionic Leather Fabric

4.1. Experimental Methods Based on Woven Process

TPU the material is more prone to problems in processing, the requirements for its production process are more stringent, otherwise it is easy because of the production environment and technical parameters of a little fluctuation will lead to product quality problems, But with the rapid development of technology and mechanical equipment, the preparation process of TPU materials has been greatly optimized, the proportion of TPU raw materials is becoming more and more accurate, and each step of
the experimental process is more rigorous. Make the characteristics of TPU materials more and more stable, increase more performance, bring more possibilities products.

![Figure 2. Preparation of TPU Materials in 2018.](image)

**Image Source.** A brief introduction to the TPU preparation process wuquancal1119 Baidu Library

Under the preparation process of raw materials, raw materials and fibers are processed into TPU yarns, and then woven technology is used as the carrier of TPU bionic leather fabric research to break the previous production mode. The advantage of using woven technology is that the woven fabric is not only made of TPU yarn, but combined with a variety of textile fibers, it makes the fabric more rich and design, and then applies it to the product. It is no longer a modular product. (Figure 3)

![Figure 3. TPU Material post-processing process.](image)

### 4.2. Experimental Design

#### 4.2.1 Experiment on knitting different yarns and TPU yarns

1. **Intertwined cotton yarn with TPU yarn**

   The toughness of TPU yarn can not be used as warp because of technical reasons, so polyester yarn with high toughness strength is used as warp, TPU yarn and cotton yarn are the main weft for interweaving. The double-layer texture and single-layer texture are mainly selected for collocation weaving. Double layer texture, the tactile feeling of this kind of fabric is thicker than that of single layer. The organization mode adopts the design form of "double-single-double" (figure 4) for circular weaving. This pattern can better reflect the difference between the two yarns, but in order to make the fabric come out of the effect is obviously different, double-layer texture with TPU yarn, one side with cotton yarn, two different yarns intertwined up and down at the same time. After hot pressing, the fabric will show that the front of weaving with TPU yarn will show a lustrous leather fabric, and the opposite side will still maintain the texture of the yarn, forming two different touch effects.

   ![Figure 4. “Double-single-double” organization chart loop pattern.](image)

2. **Combination of metal and TPU yarns**

   Weaving with metal yarn and TPU yarn, this time the whole fabric is made of double-layer texture (figure 5), using partition distribution, the sample is divided into two parts for comparison before and after hot pressing, because the tensile force of metal yarn and TPU yarn is different.

   ![Figure 5. Effect before hot pressing. Effect of hot pressing.](image)

   From this we can see that the tension of yarn is different, the effect is different, the tension of cotton thread is the same as that of TPU yarn, so the interwoven fabric is not too elastic, and the metal yarn is just the opposite, so there is such a big contrast. Therefore, the choice of yarn tension is different yarn weaving, will make the fabric the best effect.

3. **Combination of copper wire and TPU yarn**
Another kind of plastic copper wire and TPU yarn were used to interweave the experiment. The single-layer texture was tissue structure. After using copper wire, the fabric could be shaped. Three ways of matching are designed to use single-layer texture (Table 2).

Table 2. Three experimental methods.

| Category | Description |
|----------|-------------|
| Category 1 | TPU yarn is the majority, the copper wire is added with local small strip to achieve the combination of soft and hard effect, and the leveling effect of the fabric is obtained after hot pressing. |
| Category 2 | Copper wire and TPU yarn are interwoven back and forth, but during the weaving process, the copper wire will bend and break, and the removed fabric will naturally curl up, which increases the trouble of hot pressing. After hot pressing, the copper wire will be deformed. |
| Category 3 | By adding copper wire to some local areas, the fabric can change shape freely. |

From this we can see that the first method is more stable. In TPU yarn weaving, copper wire is woven with local small strips to make the fabric more straight and easy to deform, so as to achieve the effect of both hard and soft. The first method is more stable than the second and third methods.

(4) Combination of elastic rope and TPU yarn
Select and TPU different materials elastic rope with the same characteristics to try different effects, interweave with rubber elastic rope and traditional yarn, and use "double + single layer pattern "(figure 9) to design two experimental schemes. First scheme is naturally intertwined back and forth, but the elasticity of elastic rope is much stronger than that of TPU yarn. In the process of weaving, the fabric will gradually narrow, which cannot guarantee that the final fabric is the same width. Before hot pressing, the fabric texture is strong and the handle is rough. After hot pressing, the rubber elastic rope will not be completely melted, but there will be some adhesion to become transparent fabric (figure 10).

Figure 9. Double + single layer pattern weave. Figure 10. Effect before hot pressing—Effect after.

The second solution is to press two hooks on each side of the machine during the knitting process. Every time the elastic rope goes back and forth, it will be hooked by the hooks on both sides. To prevent it from shrinking, tighten the elastic rope so that the fabric has Obvious wrinkle effect. When I finally took it down, I found that the effect of shirring was more obvious than the previous piece of fabric. At the same time, there were some pattern deformations (Figure 11), and the most important point was that the fabric could not be hot pressed does not reflect the characteristics of TPU yarn. And most importantly, the fabric can’t be hot pressed to reflect the characteristics of the TPU yarn. This shows that the second scheme has no good effect, the fabric can’t be hot pressed, TPU the yarn does not play any role, plus the fabric is very easy to deform, the data results are easy to make mistakes, can’t have a stable data analysis, and the first scheme has good effect.

(5) Summary of the experiment
The first group and the second group belong to the experiment of traditional yarn and TPU yarn weaving, the third group and the fourth group belong to the experiment of non-traditional yarn and
TPU yarn weaving. The first and second groups of fabrics are more stable in performance and integrity than the third and fourth groups. (Table 3)

Table 3. Experimental Comparison between Traditional Yarn and Non-traditional Yarn and TPU Yarn.

| Distinction | Results analysis |
|-------------|------------------|
| Conventional yarn | From this, when traditional yarn and TPU yarn are woven, they are not limited by material properties, have a variety of structure patterns, can be fused with each other, and the effect of fabric is the best. Therefore, the first group and the second group of experimental schemes are selected, and the effect is the best. |
| TPU yarn | |
| Group I | Cotton yarn texture soft, and TPU yarn weaving, fabric both soft and leather texture, pattern structure can have a lot. |
| Group II | Because of the characteristics of metal yarns, the fabric woven with TPU yarns also has a certain elasticity, increasing the possibility. |
| Group III | Copper wire and TPU yarn toughness is different, pattern structure will be limited, fabric success probability is low. |
| Group IV | The elasticity of elastic rope is strong, it is difficult to control in the process of compilation, and the probability of success is low. |

4.2.2 Hot pressing experiment of changing hot pressing variable. According to the previous knitting experiment, it is finally determined to select traditional yarn and fabric woven by TPU yarn for hot pressing experiment. The performance of the yarn is analyzed by using the controlled variable method for multiple hot-pressing experiments, mainly by changing the hot-pressing temperature and hot-pressing time to obtain the best hot-pressing effect of the fabric. The first one is to change the hot pressing temperature, and compare it with a double single-layer structure under the knitting of cotton yarn and TPU yarn. (Table 4)

Table 4. Comparison of Two Tissue Changes in Hot Press Temperature.

| Serial number | Single layer | Double layer | Hot press times | Hot press time | Hot pressing temperature | Change | Single layer | Double layer |
|---------------|--------------|--------------|----------------|---------------|--------------------------|--------|--------------|--------------|
| 1             | 1            | 1            | 2 Times        | 20 second     | 30 degrees               | No change | No change    | No change    |
| 2             | 1            | 1            | 2 Times        | 20 second     | 60 degrees               | No change | No change    | Start melting |
| 3             | 1            | 1            | 2 Times        | 20 second     | 100 degrees              | Melt half | Two thirds melt, good film formation |
| 4             | 1            | 1            | 2 Times        | 20 second     | 145 degrees              | Full melting, weak film forming effect | Fully melted, good film texture |
| 5             | 1            | 1            | 2 Times        | 20 second     | 170 degrees              | Excessive melting, fabric deformation | No more dissolution |
| 6             | 1            | 1            | 2 Times        | 20 second     | 190 degrees              | No longer melts, the gloss of the fabric will decrease | No change |
| 7             | 1            | 1            | 2 Times        | 20 second     | 210 degrees              | The surface of the fabric is dark | No change |

Figure 12. Comparison of two kinds of tissues changing the hot pressing temperature.
It can be seen from the above data chart that when the number and time of hot pressing are constant, and the temperature of hot pressing is 170 degrees, the double-layer texture fabric has the best effect, the temperature continues to rise, and the fabric no longer changes. The single-layer pattern is because the structure is too thin and overheated, the surface of the fabric will be burned, and the pattern will become black paste.

The second is to change the hot press time, compare the difference between the two tissue structures in changing the hot press time through multiple sets of data, and analyze and compare which tissue structure is relatively stable.

| Serial number | Single layer | Double layer | Hot press times | Hot press temperature | Change Single layer | Change Double layer |
|---------------|--------------|--------------|-----------------|----------------------|---------------------|---------------------|
| 1             | 1            | 1            | 2 Times 5 second | 170 degrees         | More than half melt | Half melt           |
| 2             | 1            | 1            | 2 Times 10 second | 170 degrees         | Fully melted, fully formed | Full melting, good film formation |
| 3             | 1            | 1            | 2 Times 15 second | 170 degrees         | The fabric begins to deform | The best film forming condition |
| 4             | 1            | 1            | 2 Times 20 second | 170 degrees         | Fabric deformation | No reaction         |
| 5             | 1            | 1            | 2 Times 25 second | 170 degrees         | The fabric is badly deformed and the pattern is disordered | The pattern starts to darken and become mushy |
| 6             | 1            | 1            | 2 Times 30 second | 170 degrees         | The overall fabric has completely changed | The pattern has become a black paste |

Figure 13. Comparison of Two Tissue Changes of Hot Press Temperature.

As shown in the above data chart, when the hot pressing times and hot pressing temperature remain constant, the hot pressing time is 15 seconds each time, and the fabric effect is the best.

4.2.3 Waterproof testing of fabrics. This piece of fabric must not only have a sense of imitation leather, wear resistance and wind resistance, but also must have a certain degree of water resistance. Started to conduct waterproof test on fabrics. According to GB/T 4745-2012 "Determination of Moisture Resistance of Textile Fabric Surface Wetting Test", a water wetting test to determine the surface moisture resistance of various fabrics with or without water-resistant or water-repellent finishing method. The fabrics with single-layer weave and double-layer weave were tested at the same time, and the wetness of the fabric was rated according to the description of water-soaking phenomenon in Table 1.
Table 6. Water level description.

| Water level | Description of water contamination |
|-------------|-----------------------------------|
| Level 0     | Complete wetting of the entire test surface; |
| Level 1     | Completely wetted surface; |
| Level 1-2   | The surface of the specimen is wetted beyond the spray point and the wetting area is more than half of the sprayed surface; |
| Level 2     | The surface of the sample is wetted beyond the spray point, and the wetting area is about half of the surface; |
| Level 2-3   | The surface of the specimen is wetted beyond the spray point and the wetting area is less than half of the drenched surface; |
| Level 3     | Sample surface spray point wetting; |
| Level 3-4   | Wetting at spray points equal to or less than half of the sample surface; |
| Level 4     | Wetting at sporadic spray points on sample surface; |
| Level 4-5   | The surface is not wet, there are a few water drops; |
| Level 5     | No water droplets or wetting on the surface; |

Waterproof performance standard: Grade 0-1, no moisture resistance; Grade 1-2, poor moisture resistance; Grade 2-3, poor moisture resistance; Grade 3, with anti-wetness; Grade 3-4, with good anti-wetness; Grade 4, with good anti-wetness; Grade 4-5, excellent moisture resistance;

Figure 14. Waterproof effect.

According to the test results, it is found that the fabric with single layer texture is wetted, the waterproof grade belongs to grade 1, and the fabric with double layer texture is wetted by spray point equal to or less than half, and the waterproof grade belongs to 3-4 grade.

4.2.4 Experimental results.

Table 7. Experimental results.

| Experimental programme     | Experimental results                                                                 |
|-----------------------------|---------------------------------------------------------------------------------------|
| Weaving experiments        | The four sets of knitting experiments show that the first and second sets of solutions are more suitable for weaving with TPU yarns, and the fabric performance and integrity are the most stable. |
| Hot pressing experiment    | According to experiments, the double-layer texture structure is selected, and the fabric effect is the best when the hot pressing time is 20 seconds and the hot pressing temperature is 170 degrees. |
| Waterproofing experiment   | Through experiments, we know that the double-layered structure is used to woven fabrics with better waterproof performance. |

From the above three experiments, it can be seen that the fabric is the most stable TPU the interweaving of yarn and traditional yarn, whether from the integrity of the fabric or the weaving process, it is the most suitable. Using single and double structure for weaving, through the comparison and analysis of hot pressing test and waterproof test, it is concluded that when the hot pressing time is 20 seconds and the hot pressing temperature is 170 degrees, the effect is the best and the waterproof effect is better.

5. Innovation and Application of Thermal Plastic Polyurethane Elastomer-like Leather Fabric

TPU bionic leather fabric has excellent characteristics such as cold resistance, aging resistance, environmental protection, non-toxicity, and degradability. It also has waterproof performance. It can
be better used in clothing and luggage to solve the environmental pollution caused by the leather industry and replace the existing Artificial leather and natural leather.

5.1. Process Innovation
This experimental design is to make TPU yarn from TPU material and fiber spinning, and choose woven technology as weaving method. Before this, it is a bold attempt to combine TPU few materials with woven technology. It can not only guarantee that there will be no pollution in weaving process, but also subjectively make yarn more design in weaving process, not limited to the traditional batch mechanical production mode.

5.2. TPU Innovation of Biomimetic Leather Fabrics in Bags
From the selection of raw materials-the use of craftsmanship-to the final product design of TPU imitation leather fabrics, there is no pollution, which greatly changes the previous leather production mode and brings more favorable promotion to the future luggage industry. In addition, this fabric also has the characteristics of waterproof, windproof and leather feeling, which meets the necessary characteristics of leather. This design, driven by the concept of sustainability, is a bionic leather fabric woven with environmentally friendly TPU yarns. The current fashion trends are combined to carry out color and style transformations to achieve the integration of practicality and fashion. The author designed four different bags with fabrics made of TPU yarns to enhance the beauty and practicality of the fabrics, combined with color trends, and integrated fashionable color matching techniques to create a fresh and natural atmosphere. As shown in (Figure 15)

6. Conclusions and Outlook
Based on the concept of global sustainable development, this paper uses the innovative design of new materials TPU yarns under woven technology, and tests the fabrics with various experiments to improve the diversity of leather fabrics. It breaks the limitation of the original material and remold the new leather fabric which is different from natural leather and artificial leather. At the same time, considering the practicability of the design fabric, the designed fabric is successfully applied to the product, which highlights the value of the fabric. In the future, the fabric can also gradually replace artificial leather fabrics, thus reducing resource consumption and environmental pollution, and promoting the sustainable design of luggage industry.

Acknowledgement
1 Special funds for the construction of high-level teachers of Beijing Institute of Fashion Technology.
2 Open project of Beijing Apparel Industry Digital Engineering Technology Research Center.

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