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Fabric Composition and Wearability Analysis of Zhuanghua

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Abstract
Zhuanghua is a representative variety of Nanjing Yun brocade, symbolising the highest achievement of ancient Chinese textile technology. It has been widely used as a clothing fabric since its appearance. This paper firstly explored the characteristics of weaving materials, fabric weaves, and fabric weaving of Zhuanghua based on a literature review, manufactory visiting, and a market survey. To preserve the textile application, the permeability, shape preservation property, and appearance preservation property of fabric were tested for wearability. Specifically, six pieces of Zhuanghua satin were selected as the primary samples, along with six pieces of customised plain satin as the matching samples. Influenced by the *Zhuangzhi* technique, the Zhuanghua satin presented the following features. The thickness and air permeability of the Zhuanghua satin varied between patterned and non-patterned parts. The Zhuanghua satin in the weft direction showed higher tensile strength, stronger stiffness, and weak crease recovery ability. The average weft elongation at break of Zhuanghua satin increased by 25% and the weft flexural rigidity by 3-8 times, while the average weft crease recovery angle decreased by nearly 30°. The performance of anti-fuzzing and anti-pilling was improved, and the grades increased by 1 and 2, respectively. The study is conducive to a more scientific understanding and development of Yun brocade.

Keywords
Zhuanghua, Zhuanghua satin, *Zhuangzhi* technique, wearability, Yun brocade.

Introduction

As a complex multicolored weft jacquard fabric, Nanjing Yun brocade is woven on a dedicated drawloom [1]. It is made of valuable materials, such as silk threads, metal threads and peacock feather threads [2]. The majority of scholars in Yun brocade, including Xu [3] and Jin [4], believed that Yun brocade originated from the Yuan Dynasty (1271-1368 CE) and flourished in the Ming Dynasty (1368-1644 CE) and Qing Dynasty (1636-1912 CE). In the Yuan Dynasty (1271-1368 CE), Nasich, a kind of brocade woven with gold thread, was the embryonic prototype of Zhijin (one category of Yun brocade) [5]. The weaving technique of Yun brocade became increasingly sophisticated in the Ming Dynasty (1368-1644 CE), when the most prominent achievement was the *Zhuangzhi* technique, invented by silk handicraftsmen in Nanjing. Known as one of the "Three Famous Brocade" (Yun brocade [6], Shu brocade [7], and Song brocade [8]) in China, Yun brocade ranks first [9] because its technique draws on the advantages of silk weaving technology of past dynasties. Furthermore, the combination of metal threads and the *Zhuangzhi* technique gave Yun brocade unique local characteristics [10]. Yun brocade developed rapidly and prospered in the Qing Dynasty (1636-1912 CE). More than 300,000 people devoted themselves to Yun brocade weaving, making Nanjing the hand-made silk hub of the country. In 2009, the *Zhuangzhi* technique of Yun brocade was included in UNESCO's "List of Representative Works of Human Intangible Cultural Heritage."

Yun brocade is divided into four categories, namely, Kuduan, Kujin, Zhijin, and Zhuanghua. Zhuanghua is the most representative one. It is a weft-faced textile with a regional scooped pattern produced with multiple coloured brocading wefts by coiled weaving in sections, layers, and groups [11]. In the same weft direction of the fabric, more than a dozen patterns with different colours can be seen. It combines traditional Chinese tapestry weaving technology and the *Zhuangzhi* technique, making it possible to change brocading wefts to those of different colours flexibly during weaving. According to the ground weave, Zhuanghua can be divided into Zhuanghua satin, Zhuanghua gauze, Zhuanghua velvet, Zhuanghua chou, Zhuanghua leno, and Jinbaodi (***Figure 1***). Traditionally, Zhuanghua is applied to making costumes or decorating palaces and temples, such as official garments [12], sutra quilts, canopies, and *Thang-ga*. In China's feudal era, ancient Chinese rulers deeply favoured the Zhuanghua because it symbolised status, social identity, and power. With its deep historical and cultural value, it was seen as precious gold.

Textile is considered the primary carrier of Zhuanghua, especially Zhuanghua satin, which has lasted for generations. Zhuanghua satin is a weft-faced textile, the patterns of which are woven with the *Zhuangzhi* technique. In the past, Zhuanghua satin was often used to make clothing for royal families, such as the Emperor's dragon robe and Empress's phoenix robe (***Figure 2***). It was also

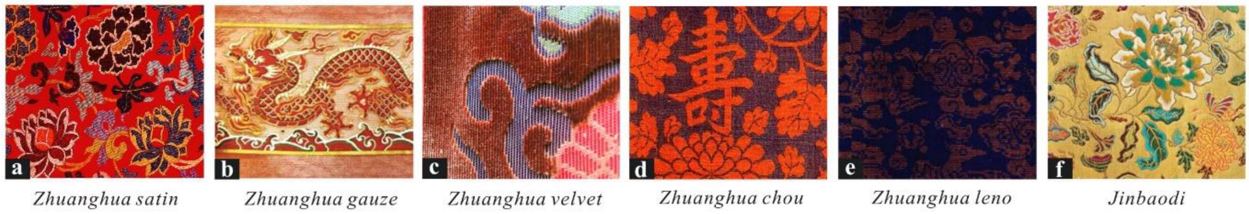

Fig. 1. Schematic diagrams of subdivided varieties of Zhaunghua. Figures (a), (b) and (f) are in the collection of the Nanjing Yun Brocade Research Institute, Nanjing 210000, China. Figures (d) and (e) are in the collection of the Palace Museum, Beijing 100000, China. Figure (c) is a reproduction from the book Nanjing Yun Brocade (Dai J, 2009)

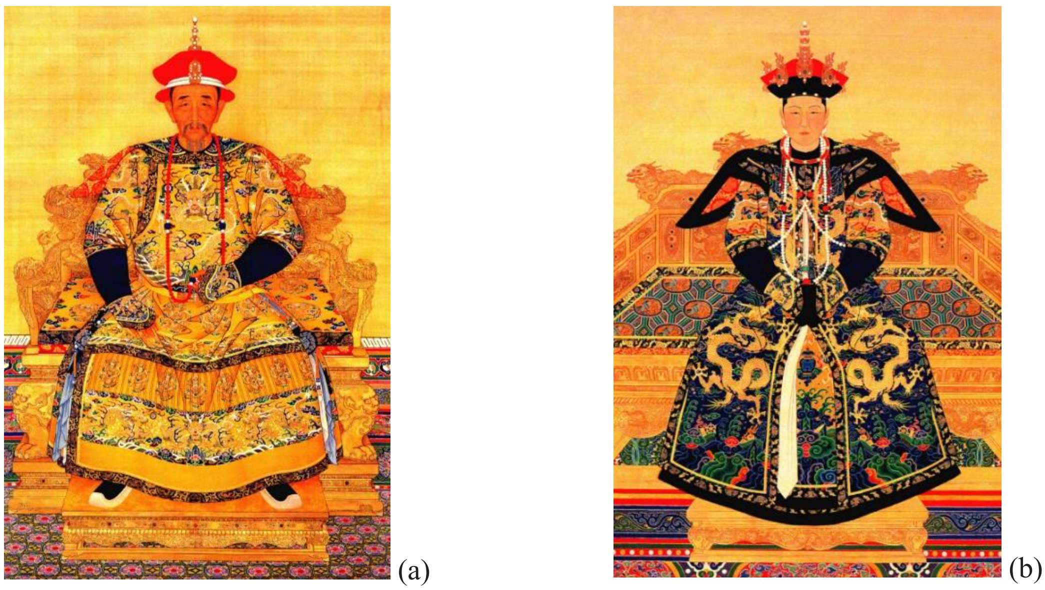

Fig. 2. (a) Portrait of Emperor Kangxi of the Qing Dynasty in Zhuanghua satin, (b) portrait of Empress Xiaocheng, wife of emperor Kangxi, in Zhuanghua satin. Source: The Palace Museum, Beijing 100000, China

given to meritorious officials as a reward or foreign envoys as a gift [13].

While in modern times, it is generally used to make haute couture clothing [14], such as costumes and wedding dresses, Zhuanghua, even Yun brocade in clothing, is not as popular as other brocade. The current study on Zhuanghua mainly focuses on the history, patterns, and craftsmanship [15-20]; few articles study the fabric composition and wearability of Zhuanghua in terms of the weaving technique. The shortcomings of related research makes it difficult to understand and evaluate Zhuanghua scientifically, which further hinders its innovative design and development of modern Yun brocade costumes. Thus, it was of great necessity to conduct this research to explore the typical characteristics of the fabric composition and wearability of Zhuanghua.

In this paper, the fabric composition of Zhuanghua is first introduced by reviewing literature and presenting substantial first-hand information from experts in Yun brocade. Specifically, the characteristics of weaving materials, fabric weaves, and fabric weaving are discussed. This can provide a clearer understanding of Zhuanghua for readers. Then, we selected six pieces of Zhuanghua satin as the primary samples and six pieces of customised plain satin as the matching samples. We used modern textile testing devices to test air permeability, moisture permeability, stretch resilience, the crease recovery property, stiffness, and propensity to surface fuzzing and pilling. By contrasting two groups of samples, we explored the effects of the *Zhuangzhi* technique on fabric wearability. Significantly, this paper achieved the first success in providing specific fabric wearability parameters of Zhuanghua satin. The results can be used as a reference for the costume design of Yun brocade and facilitate development in other fields.

1. Fabric composition of Zhuanghua

1.1. Weaving materials

1.1.1. Silk thread

As the primary material, the dyed silk thread used for Zhuanghua is mulberry silk [21]. Raw silk or degummed silk should be selected during the weaving process according to the fabric structure, function and technique. The warps require certain strength and wear resistance conditions, thus it is better to choose dyed monofilament with a higher degumming rate. The ground weft can only be seen on

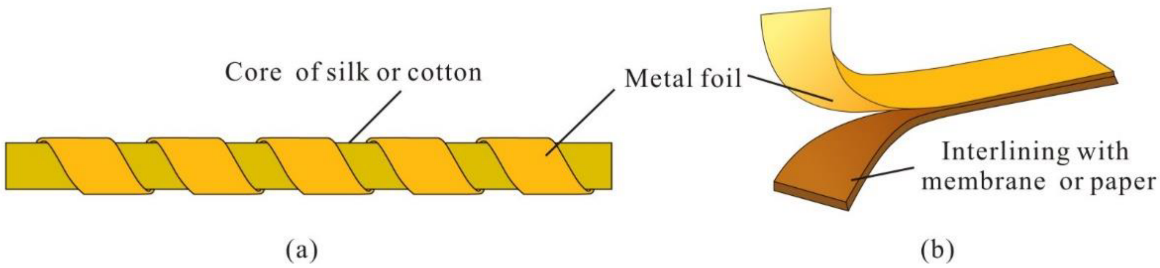

Fig. 3. (a) structural model of lamella, (b) structural model of filé

the back of the fabric. Therefore, during the golden age of Yun brocade, dyed plied degummed silk was chosen for the ground weft of high-grade Yun brocade garments. In contrast, dyed raw silk or silk with a low degumming rate was used for brocade produced in folk workshops or for palace decoration. The body motifs of the brocade are created with brocading weft threads, among which the most widely used is *Sirong*, which is a dyed degummed silk with a unique pressing process. In this way, good fluffiness can be achieved. With the development of textile materials, some synthetic fibers have also been applied to the weaving of Zhuanghua. Since around 2010, *Sirong* has been partly replaced by viscose rayon in the current Yun brocade market since products made of the two materials look similar.

1.1.2. Metal thread

Metal thread composed partly or entirely of gold, silver, or metallic materials is the typical yarn of Zhuanghua. According to shape, the metal thread can be divided into several types, among which the more common ones are lamella and filé, shown in ***Figure 3***.

The filé is a wrapped thread composed of a lamella wound around a dyed multifilament silk or cotton core. The lamella can be a narrow strip (0.3-0.6mm wide) made of precious or base metal or produced from metal foil to whose back side interlining made of membrane or paper is adhered, which is used for thread. The membrane interlining used for Zhuanghua is generally of animal skin or animal-gut membrane [22], such as parchment. The paper interlining made from bamboo or mulberry bark has two types: *two-layer paper* and *seven-layer paper*, created by pressing two and seven pieces of paper together, respectively. The *seven-layer paper* is thicker, primarily used for interlining of the filé, while the *two-layer paper* is soft, generally used for the interlining of the lamella. The preparation process of the *two-layer paper* and *seven-layer paper* is complicated. To simplify the production process, they have been widely replaced by a material similar to kraft paper since the early 21st century [23]. It is worth noting that there was an adhesive, *Yujiao*, made from colleseed oil, bone glue, etc.,used to bond metal foils and interlining. Later, it was also replaced by chemical glue. However, the metal foil easily falls off in a hygroscopic state.

In terms of metal strips or foil composition, the standard metal threads for Zhuanghua are gilt and silvered membrane (paper) lamella (filé). In the Ming Dynasty (1368-1644 CE) and Qing Dynasty (1636-1912 CE), most Zhuanghua fabrics applied *potion gold thread* [2]. The thread is actually pure silvered lamella or filé, whose golden appearance is smoked by burning sulfur and Aucklandia lappa Decne; however, this is rare now. By the end of the Qing Dynasty (1840-1912 CE), metal threads made of alloys began to be widely used in Zhuanghua fabrics. We have collected common Zhuanghua satin woven with several typical metal threads through market research, shown in ***Figure 4***.

Figures 4a & b show gilt paper lamella and gilt paper filé, whose gold-inclusive rate of gold foil is 99%. ***Figure 4c*** displays alloyed paper lamella, and a filé composed of a lamella of polyester material is demonstrated in ***Figure 4d***. There are significant differences between the four pieces in appearance. The gilt paper lamella is slightly narrower than the alloyed paper lamella. The filé made of polyester without an interlining is relatively finer than the gilt paper filé, hence two threads of it are used together when weaving. The colour of brocade woven with metallic lamella or filé is light yellow, which cannot achieve the golden and gorgeous appearance of brocade woven with the gilt variety.

1.1.3. Peacock feather thread

Peacock feather thread (***Figure 5a***) is the most distinctive yarn of Zhuanghua. Its raw material is selected from freshly fallen peacock tail feathers. A manual twisting method is employed to spiral fine down feathers onto silk thread. Usually, the feathers are in ideal shapes and similar sizes. The twisted peacock feather thread must also be steamed and shaped at a high temperature to smoothly unwind during weaving. Meanwhile, it helps to achieve sterilisation and mothproofing.

An enlarged image of peacock feather thread is shown in ***Figure 5b***. It illustrates that there are regular horizontal stripes distributed on the surface of a single fiber of the fine down feather. Thus, the colour of peacock feather thread is not decided by pigments but by the interaction between natural light and wavelength-similar structures [24]. The surface of the down feather is shiny like metal, with dark and bright sides. When the light shines on it directly, its unique photonic crystal structure will change its colour. Consequently, when observing the peacock feather thread from different angles, we can see various colours, such as brown, purple, blue, green, and black [25]. The fine down feathers of the thread

Fig. 4. (a) Zhuanghua satin woven with gilt paper lamella (gold-inclusive rate of gold foil is 99%). (b) Zhuanghua satin woven with gilt paper filé (gold-inclusive rate of gold foil is 99%). (c) Zhuanghua satin woven with alloyed paper lamella. (d) Zhuanghua satin woven with filé composed of a lamella of polyester material. Source: Nanjing Shengshijinxiu Brocade Weaving Limited Company, Nanjing 210049, China

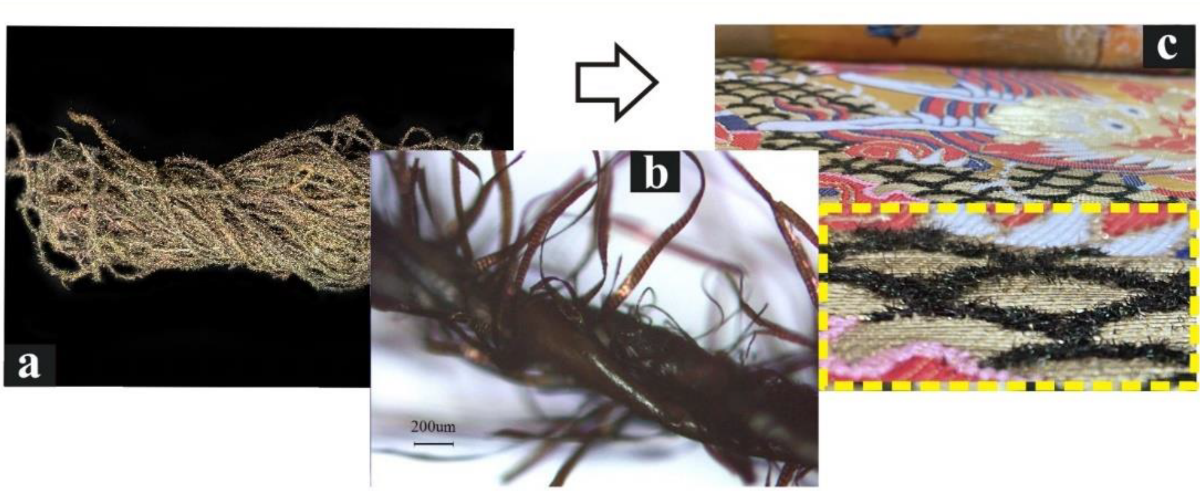

Fig. 5. (a) physical image of peacock feather thread, (b) enlarged image of peacock feather thread, (c) Zhuanghua satin with peacock feather thread. Source: Nanjing Shengshijinxiu Brocade Weaving Limited Company, Nanjing 210049, China

are irregularly tortile in shape due to the manual twisting, making the yarn curly and fluffy. Meanwhile, Zhuanghua woven with peacock feather thread has a noticeable relief effect (***Figure 5c***).

1.2. Fabric weaves

Zhuanghua is woven in a weft-faced compound weave. Take Zhuanghua satin as an example its representative ground weaves are 5-end, 7-end or 8-end satin, while its flower weave is 5-end, 7-end or 8-end satin, respectively. It is worth noting that the coloured brocading wefts of the flower weave can be changed freely as required during weaving. That is why Zhuanghua is still required to be woven by hand on special looms, while other types of Yun brocade can be made with modern power looms. Typical weaves of the four varieties of Yun brocade [26] are shown in ***Figure 6***.

If the ground of Kuduan is a satin weave, the pattern of which is also a satin weave. ***Figure 6a*** depicts Kuduan with 8/5 satin as the ground weave. Kujin generally takes satin and twill as the ground weave, while the number of brocading wefts varies from 2 to 6. Zhijin is usually woven with additional metal threads based upon the weave of Kuduan or Kujin. ***Figure 6b*** shows Zhijin based upon the Kuduan weave, which uses 8/5 satin as the ground weave, and the proportion of brocading weft to the ground weft is 1:2. ***Figure 6c***

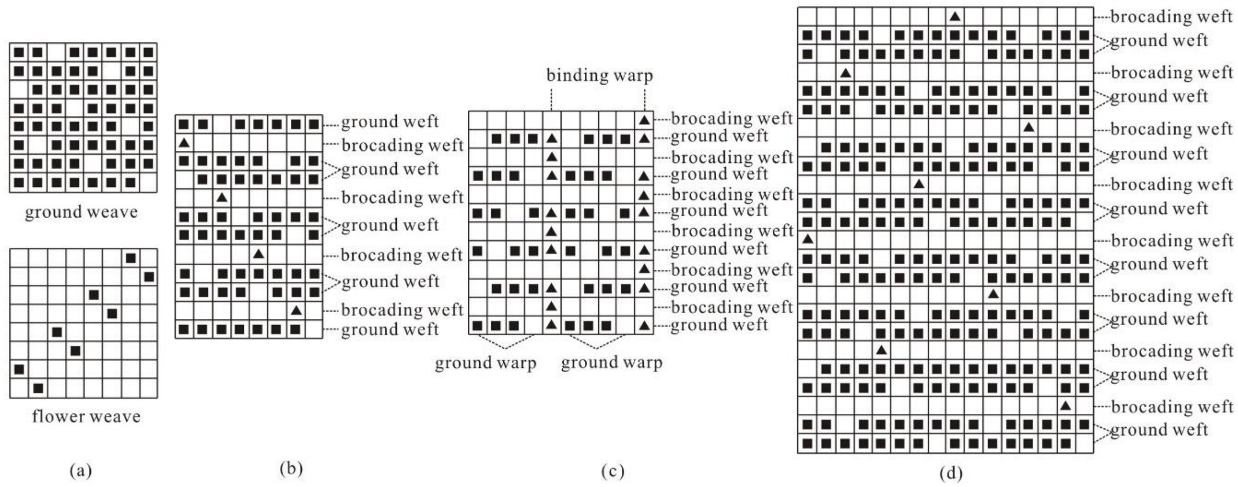

Fig. 6. (a) Fabric weave of Kuduan, (b) fabric weave of Zhijin & Kuduan, (c) fabric weave of Zhijin & Kujin, (d) fabric weave of Zhuanghua satin
□: Weft interlacing point. ■: Warp interlacing point. ▲: Binding warp interlacing point

shows Zhijin based upon Kujin weave, which uses 3/1↗ twill as the ground weave, and the proportion of brocading weft to the ground weft is 1:1. It has two groups of warps, and the proportion of the ground warp to the binding warp is 4:1. A fabric weave of Zhuanghua satin is given in ***Figure 6d***. The ground weave is 8/3 satin and the flower weave - 8/3 satin. Sixteen heddles interfilar points control the floats of the brocading weft, and the proportion of the brocading weft to the ground weft is 1:2.

1.3. Fabric weaving

1.3.1. Weaving looms

Yun brocade was generally woven on a drawloom (*Hualou*), which is a handloom equipped with a figure harness composed of leashes that control all warp ends to form the pattern. There are two types of drawlooms: small and large. They are installed and built according to the type of Yun brocade and are different in selecting and pulling cords, the weaving technique, and other aspects. The mechanism of the small drawloom is relatively simple, and it is suitable for brocade with simple motifs, such as Kuduan. In the weaving process, completing a piece of brocade requires the tacit cooperation of the drawboy and the weaver [27], as shown in ***Figure 7a***. The drawboy pulls the lashes on the drawloom to control the warp ends that must be raised. The weaver needs to raise or lower shafts by treading the foot pedal of the loom to produce sheds for the passage of the weft, which enables shuttles to be thrown in the required place. ***Figure 7b*** shows a large drawloom with more than 1,000 components [28]. It is a particular loom for weaving Zhuanghua with a body length of 560 cm, height of 400 cm, and width of 140 cm. It is a significant invention in brocade weaving and even in the silk weaving industry, showing the wisdom of ancient Chinese craftsmen [29].

1.3.2. Weaving technique

There are dozens of traditional Zhuanghua weaving processes, which require joint effort and meticulous workmanship from design to production. The processes [2] include pattern and motif design, pattern grid drawing, the cross-stitch plain-knit procedure, yarn preparation, loom loading, final weaving, etc. Among them, the following three techniques are essential: The first is drawing the pattern grid, which is to draw the required patterns on squared paper. Each vertical grid represents a group of warp yarns, while the horizontal one represents a brocading weft (one colour represents one specification of the brocading weft). The second is the cross-stitch plain-knit procedure [30], a bridge for the pattern from the sketch to the fabric. It uses the old way of knotting notes to store colour and pattern information according to the pattern grid. Then a "program," just like a computer program, is obtained and then placed on the drawloom to guide the operation of the drawboy. The last is the *Zhuangzhi* weaving process, which is the core weaving technique of Yun brocade. With the *Zhuangzhi* technique, the patterns and motifs are created by the small brocading shuttles wrapped with brocading weft threads, and the number of brocading wefts can reach nearly 30 in the same weft direction. In addition, brocading weft threads of different colours can be flexibly changed in any position of the required pattern. This technique is also known as *warp-through and weft-back*. Unlike the *warp-through and weft-broken* of Chinese *Kesi*, the *weft-back* of Zhuanghua is connected at the other end, and its patterns and motifs are produced by *weft-back* brocading wefts [31].

2. Experimental work

Zhuanghua satin was selected as the primary sample to test and analyse its wearability. In order to explore the influence of the *Zhuangzhi* technique on the wearability of fabrics, it was necessary to customise matching samples of plain satin. The permeability (including air and

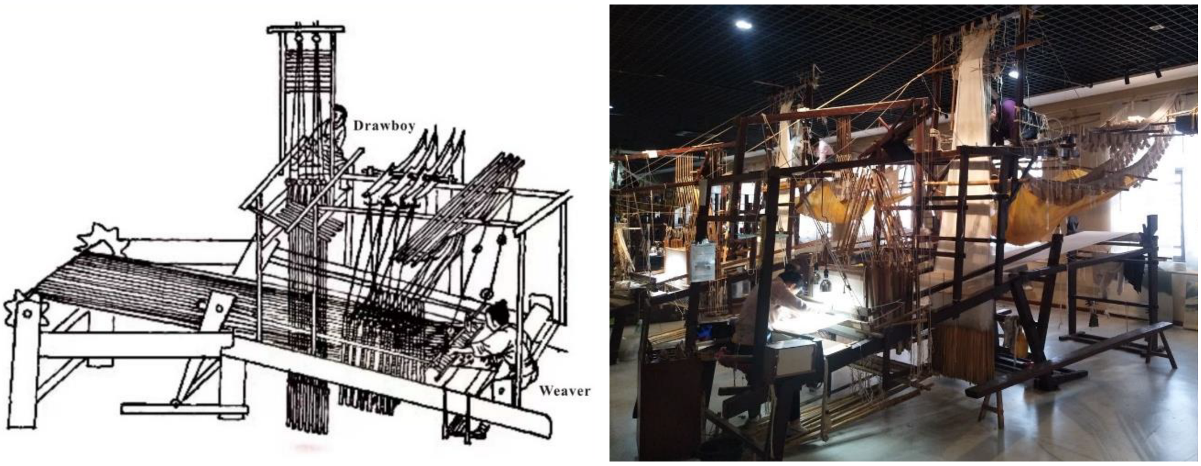

Fig. 7. (a) Schematic diagrams of small drawloom, Source: Tiangong Kaiwu, Ming dynasty, 1368–1644 AD (Song YX, 1637), (b) large drawloom, Source: The Nanjing Yun Brocade Research Institute, Nanjing 210000, China

Sample code	Measured yarn fineness/tex			
	Warp	**Ground weft**	**Brocading weft/*Sirong***	**Brocading weft/gilt paper filé**
A1	3.5	29.5 (7)	41±0.5	56 (2)
A2	3.5	29.5 (7)	41±0.5	56 (2)
A3	3.5	29.5 (7)	41±0.5	56 (2)
B1	3.5	18.2 (5)	41±0.5	56 (2)
B2	3.5	18.2 (5)	41±0.5	56 (2)
B3	3.5	18.2 (5)	41±0.5	56 (2)
a1	3.5	29.5 (7)	/	
a2	3.5	29.5 (7)	/	
a3	3.5	29.5 (7)	/	
b1	3.5	18.2 (5)	/	
b2	3.5	18.2 (5)	/	
b3	3.5	18.2 (5)	/	

Table 1. Detailed Parameters of Yarns

moisture), shape preservation property (including crease recovery and stretch resilience), and appearance preservation property (including stiffness and propensity to surface fuzzing and pilling) of the fabric were tested. The experiment aimed to explore whether Zhuanghua meets the design requirements of modern clothing and try to seek better applications based on physical parameters.

2.1. Samples

Two different specifications of Zhuanghua satin were selected as the primary samples, including three samples for each specification, respectively. Samples A1, A2, and A3 represented Zhuanghua satin with 140/10 cm brocading weft density, and Samples B1, B2, and B3 represented Zhuanghua satin with 160/10 cm brocading weft density. Plain satin for matching samples was customised according to the primary samples' specifications. The matching samples of A1, A2, and A3 were denoted as a1, a2, and a3, respectively. They were made of the same material and specifications but without patterns or motifs. The matching samples B1, B2, and B3 correspond to b1, b2, and b3 respectively. The twelve samples woven on a large drawloom were provided by Nanjing Shengshijinxiu Brocade Weaving Limited Company (Nanjing, China).

2.1.1. Materials

Compared with plain satin, the fabric composition of the Zhuanghua satin was more complicated. It consisted of warp, ground weft, and brocading weft (including *Sirong* and gilt paper filé). The warp thread was monofilament silk after degumming, while the ground weft thread, made from cooked silk with little twists, was plied yarn. There were a dozen colours of *Sirong* made from degummed multifilament silk without a twist. The specific yarn parameters are shown in ***Table 1.***

2.1.2. Fabrication of samples

As shown in ***Figure 8a***, the plain satin was 7/4 warp-faced satin, and the ground weave of the Zhuanghua satin was consistent with it, while the flower weave of the Zhuanghua satin was 7/2 satin. It can be seen from ***Figure 8(b)*** that the floats of the *Sirong* and gilt paper filé were controlled by fourteen heddles interfilar points. And the proportion of the brocading weft to the ground weft was 1:2.

Table 2 gives detailed parameters of the yarns in the selected samples. The density of the brocading wefts (*Sirong*) of A1-A3 (149/10 cm) and B1-B3(155/10 cm) measured was found to be different from the ideal data (140/10 cm and 160/10 cm, respectively). This is likely to be an error caused by hand weaving, which

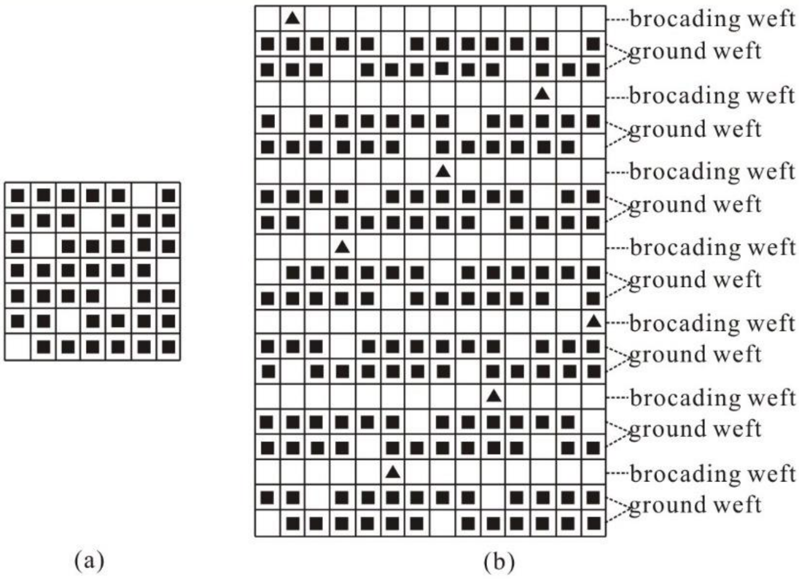

Fig. 8. (a) Fabric weave of plain satin, (b) fabric weave of Zhuanghua satin

Sample code	Measured warp and weft density (·10 cm^{-1})			
	Warp	Ground weft	Brocading weft/*Sirong*	Brocading weft/gilt paper filé
A1	1420	295.0	150.0	147.0
A2	1420	290.0.	148.5	146.5
A3	1420	302.0	149.0	147.5
B1	1420	315.0	155.5	156.0
B2	1420	310.0	152.5	153.5
B3	1420	320.0	157.5	156.5
a1	1420	304.0	/	
a2	1420	299.0	/	
a3	1420	307.0	/	
b1	1420	333.5	/	
b2	1420	322.5	/	
b3	1420	335.0	/	

Table 2. Detailed parameters of yarns for samples

Sample code	Weight of fabric (g m^{-2})	Thickness (mm)
A1	241.8	0.41±0.12
A2	238.2	0.39±0.10
A3	243.6	0.42±0.13
B1	292.7	0.57±0.37
B2	288.3	0.52±0.31
B3	295.1	0.58±0.35
a1	134.6	0.35
a2	132.1	0.34
a3	135.2	0.36
b1	116.9	0.22
b2	113.8	0.22
b3	117.3	0.23

Table 3. Detailed parameters of samples

explained why the ratio of the ground weft density to the brocading weft density of the Zhuanghua satin was close to 2:1 rather than 1:1.

Detailed parameters of the 12 samples are shown in ***Table 3***. Since the Zhuanghua satin was decorated with supplementary brocading wefts on the plain satin base, the grammage of the Zhuanghua satin was heavier than the matching sample.

Combined with the fabric weave characteristics of the Zhuanghua satin (***Figure 8b***), we found that the thickness of the Zhuanghua satin was uneven, and it was thicker than plain satin overall. This is because the brocading weft floats of varying lengths were stacked on the back of the Zhuanghua satin when applying the *Zhuangzhi* technique. The more brocading weft floats stacked, the heavier the fabric would be.

2.2. Test equipment and methods

The measurement was carried out under standard external environmental conditions, with a temperature of 20±2°C and humidity of 65±5%.

2.2.1. Evaluation of air permeability

The fabric's air permeability was tested by an FX3300 textile air permeability tester (Wenzhou, China) according to the standard GB/T 5453-1997 [32]. The evaluation index was the mean air permeability (mm/s), and the pressure difference was 10Pa. Each fabric was tested ten times, and the average was taken as the final result.

2.2.2. Evaluation of moisture permeability

The fabric's moisture permeability was tested by a YG(B)216 textile moisture permeability tester (Wenzhou, China) according to the standard GB/T 12704.1-2009 [33]. Three samples with a diameter of 70 mm were selected for each fabric.

The measurement was performed with an oven (heating temperature of 160°C, humidifying temperature of 38±2°C, and relative humidity of 90±2%. The evaluation index was the water-vapour transmission rate [g/(m^2·d)]. Each fabric was tested three times, and the average was taken as the final result (accurate to 0.001 g).

2.2.3. Evaluation of stretch resilience

The fabric's stretch resilience was tested by a YG026PC-250 textile electronic tensile strength tester (Wenzhou, China) according to the standard GB/T 3923.1-2013 [34]. Five rectangular samples with a size of 50×320 mm were selected for each fabric in the warp and weft directions. The interval length of the fabric test was set to 200 mm, and the stretching speed was 20 mm/min. The evaluation indexes were the breaking force (N) and elongation at break (%). Each fabric was tested five times, and the average was taken as the final result.

2.2.4. Evaluation of crease recovery property

The fabric's crease recovery property was tested by a YG541E automatic textile wrinkle elasticity tester (Wenzhou, China) according to the standard GB/T 3819-1997 [35]. Five "T"-shaped samples were selected for each fabric in the warp and weft directions. The evaluation index was the crease recovery angle (°). Each fabric was tested five times in the warp and weft directions, and the average was taken as the final result.

2.2.5. Evaluation of stiffness

The fabric's stiffness was tested by a YG(B)022D automatic textile stiffness tester (Wenzhou, China) according to the standard GB/T 18318-2001 [36]. Six rectangular samples with a size of 25×250 mm were selected for each fabric in the warp and weft directions. The evaluation index was flexural rigidity. Each fabric was tested six times in the warp and weft directions, and the average was taken as the final result.

Sample code	Air permeability	Moisture permeability
	Mean air permeability (mm/s)	Water-vapour transmission rate [g/(m^2·d)]
A1	321.50±98.5	10780
A2	327.50±101.5	10480
A3	323.50±91.5	11270
B1	122.40±57.6	11170
B2	129.55±62.45	10180
B3	115.25±53.75	11220
a1	150	11910
a2	154	11040
a3	143	12270
b1	137	11840
b2	143	10670
b3	134	12570

Table 4. Test results of permeability

2.2.6. Evaluation of fabric propensity to surface fuzzing and pilling

The fabric's propensity to surface fuzzing and pilling was tested by a YG502 textile fuzzing and pilling tester (Wenzhou, China) according to the standard GB/T 4802.1-2008 [37]. Five samples with a 113±0.5 mm diameter were selected for each fabric. The test pressure was 590 cN, and the number of fuzzing and pilling was 50. The evaluation index was the grade of anti-fuzzing and anti-pilling, which was evaluated by comparing the woven fabric fuzzing and pilling grade sample card (Suzhou Silk Research Institute) of woven fabrics. Each fabric was tested five times, and the average was taken as the final result.

3. Results and Discussion

3.1. Permeability

The permeability of fabric mainly includes air permeability and moisture permeability, which is an essential indicator of clothing comfort. ***Table 4*** shows the mean air permeability and water-vapour transmission rate. Compared with plain satin, the air permeability of patterned and non-patterned parts on the same Zhuanghua satin was different, and the maximum difference of air permeability of one fabric can even reach 203 mm/s (***Figure 9***).

The gilt paper filé, with superior three-dimensionality, enlarged the space between yarns and increased the air permeability. Thus, the maximum air permeability of plain satin was observed to be always smaller than that of Zhuanghua satin. The mean air permeability of samples A1-A3 was found to be larger than that of samples B1-B3. This was because the latter's brocading weft (*Sirong*) was denser than the former's - the denser the brocading weft (*Sirong*) is, the less air permeable it is. Regarding the moisture permeability of the samples, the water-vapour transmission rate was about 11,000 g/(m^2·d), and there was no significant difference between types or samples (***Figure 9***). This can be attributed to the sample's primary weaving material: mulberry silk, a hydrophilic fiber with excellent hygroscopicity. Gaseous water molecules can adhere to the fiber's surface and hydrate with the hydrophilic groups inside it. Thus, it will timely absorb the sweat produced by the human metabolism [38].

In general, while the moisture permeability of Zhuanghua satin is

Samples code	Stretch resilience				Crease recovery property	
	Breaking force (N)		Elongation at break (%)		Crease recovery angle (°)	
	Warp direction	Weft direction	Warp direction	Weft direction	Warp direction	Weft direction
A1	954.3	1628.4	20.0	14.7	114.8	79.2
A2	946.2	1623.7	20.5	12.2	111.8	71.4
A3	974.5	1644.0	20.1	13.9	116.7	82.5
B1	965.2	1721.2	20.2	10.3	97.8	89.2
B2	936.8	1718.3	19.9	12.5	91.0	87.0
B3	984.9	1759.7	21.1	9.9	96.8	91.4
a1	1021.3	1860.2	22.9	7.7	91.2	108.8
a2	1003.4	1821.1	23.8	10.0	87.4	107.6
a3	1063.6	1871.4	24.5	10.8	93.8	114.0
b1	1019.7	1738.7	22.4	9.4	93.5	113.8
b2	996.9	1711.4	21.4	9.5	92.7	111.9
b3	1025.4	1744.6	23.1	11.0	93.5	119.9

Table 5. Test results of shape preservation property

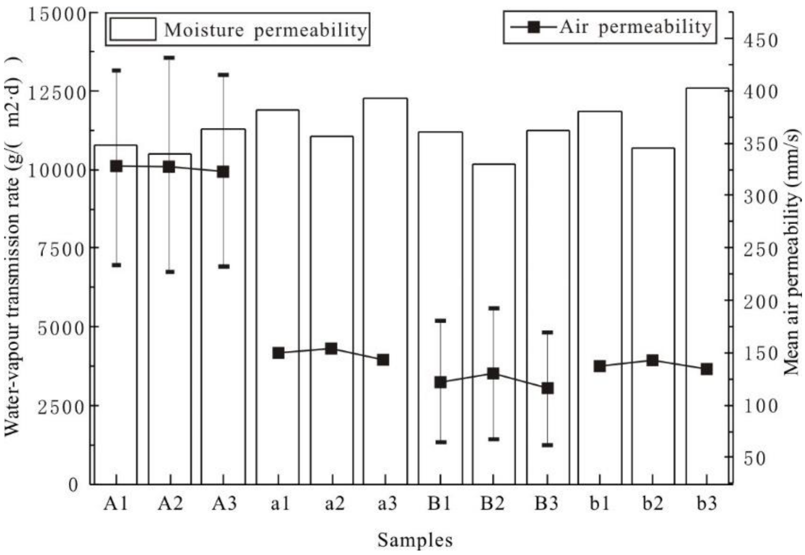

Fig. 9. Moisture permeability and air permeability of samples

good, the air permeability is unevenly distributed. Therefore, during the design and production process of Yun brocade clothing, it is necessary to consider the characteristics of human sweat distribution [39]. This is to form a suitable microclimate between the human body, clothing, and environment, making it more comfortable.

3.2. Shape preservation property

The stretching resilience and crease recovery property are important indicators for evaluating the intrinsic quality of apparel fabrics. They can reflect the ability of fabrics to resist damage from external forces and preserve shape. As shown in ***Table 5*** and ***Figure 10 a*** and ***b***, all the samples' weft breaking force (over 1,600 N) was more significant than the warp.

This was related to the thread fineness and warp and weft density of the fabric, demonstrating that the fabric could withstand greater weft external forces. The elongation at break refers to the elongation deformability when a fiber breaks. We discovered that the warp elongation at the break of the 12 samples was greater than that of the weft, because the softness and elasticity of the warp thread were better than those of the brocading weft thread. This may also be one of the reasons why all samples have warp crimping properties. Meanwhile, compared with plain satin (9.7%), the average weft elongation at break of Zhuanghua satin (12.25%) increased by 25%. Excellent crease recovery can reduce the wear caused by wrinkles and maintain the functionality and durability of garments. The anti-crease ability of the fabric improves as the crease recovery angle increases. As shown in ***Figure 10 c***, the weft crease recovery angle of Zhuanghua satin was generally smaller than that of the warp, while plain satin was the opposite. Moreover, the weft recovery angle of Zhuanghua satin was obviously smaller than that of plain satin, which was caused by the supplementary metal thread. When the fabric is folded, it is difficult for the metal thread to recover in a short time after being distorted by external force due to the significant bending rigidity and poor flexibility of the metal foil. Therefore, the average weft crease recovery angle of Zhuanghua satin (83.5°) was nearly 30° smaller than that of plain satin (112.7°). In addition, the warp crease recovery angles of samples A1-A3 were larger because of the warp crimping property.

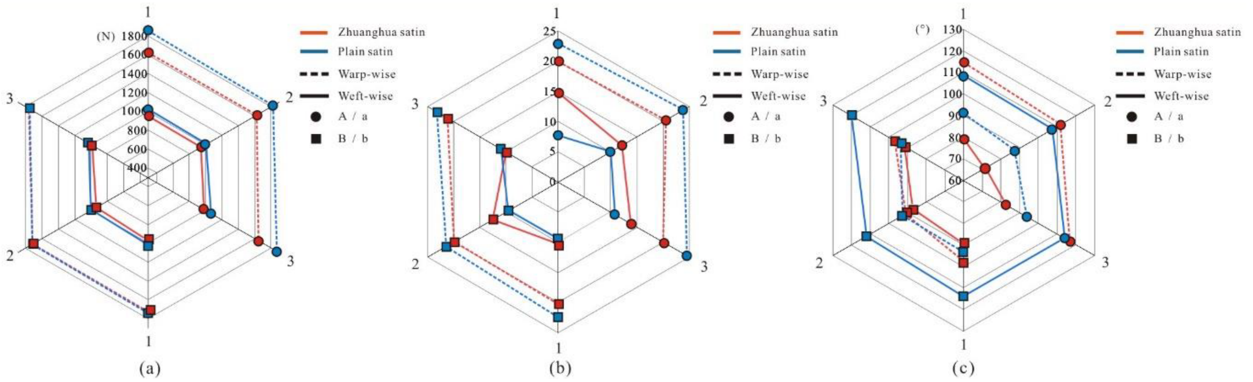

Fig.10. Stretching resilience and crease recovery property of samples, (a) breaking force of samples, (b) elongation at break of samples, (c) crease recovery angle of samples

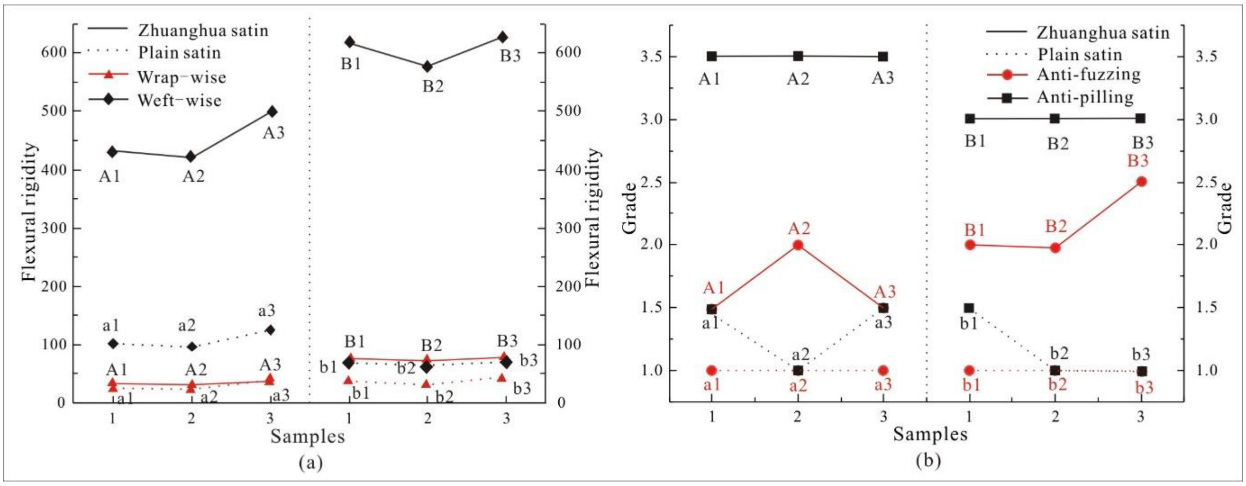

Fig. 11. Stiffness, anti-fuzzing property and anti-pilling property of samples. (a) flexural rigidity of samples, (b) grade of anti- fuzzing and anti-pilling

Generally, Zhuanghua satin has superior tensile resistance but poor crease recovery in the weft direction. In the design of garment patterns, it is suggested that Zhuanghua satin should be used as a designer fabric for splicing clothing. However, to extend the service life of the garment, it is best not to use it in garment parts that are easily wrinkled by human body movement, such as elbows, knee joints, etc.

3.3. Appearance preservation property

The anti-fuzzing property, anti-pilling property, and softness of fabric are fundamental to the appearance and aesthetics of clothing. Fabrics with excessive stiffness will increase the difficulty of making garments, while fuzzing and pilling will hurt the appearance of the garments. As demonstrated in ***Figure 11a***, the warp flexural rigidity of Zhuanghua satin was found to be similar to the matching samples, but the differences in the weft direction were considerable.

In ***Table 6***, the weft flexural rigidity of samples A1-A3 was four times that of samples a1-a3, and that of samples B1-B3 was nine times that of samples b1-b4 because abundant and thick brocading weft threads were added in the weft direction of the Zhuanghua satin, improving the weft stiffness of the fabric. The weft stiffness of B1-B3 appeared to be greater than that of samples A1-A3 because the fabric weft density was more significant than the former. The anti-fuzzing ability of the plain satin was inferior due to the fine silk thread with few or no twists, which was easy to snag and break. Fortunately, we found an increase in the anti-fuzzing ability of the Zhuanghua satin (***Figure 11b***), representing a grade up by about 1. This result was supported by the *Sirong* used as the brocading weft of the Zhuanghua satin, with a higher fabric weft density. Observing the samples after repeated rubbing, we found fewer fluffs formed on the surface of the Zhuanghua satin, as the grade of the anti-pilling (3-3.5) had increased by 2, recorded in ***Table 6***.

Therefore, Zhuanghua satin is not very soft. Hence, it is good to use it as a partial fabric to support the garment and maintain its shapes, such as stand-up collars, lapel collar bands, and waistbands. It is not wise to use Zhuanghua satin as a fabric for cuffs, practical pockets, or underarm side patterns, where the brocade will fluff or pill due to frequent rubbing.

Samples code	Bending behaviour		Anti-fuzzing and anti-pilling resistance	
	Flexural rigidity		Anti-fuzzing grade	Anti-pilling grade
	Warp direction	Weft direction		
A1	32.8	432	1.5	3.5
A2	31.0	421	2.0	3.5
A3	37.0	498	1.5	3.5
B1	77.0	616	2.0	3.0
B2	72.0	577	2.0	3.0
B3	79.0	629	2.5	3.0
a1	26.0	102	1.0	1.5
a2	24.0	97	1.0	1.0
a3	39.0	125	1.0	1.5
b1	37.0	68	1.0	1.5
b2	31.0	65	1.0	1.0
b3	45.0	70	1.0	1.0

Table 6. Test results of appearance preservation property

4. Conclusion

Zhuanghua, a representative variety of Nanjing Yun brocade, is a gem of ancient Chinese culture and silk weaving skills. In order to preserve and develop this world intangible cultural heritage, Zhuanghua was analysed from the aspects of weaving material, fabric weave, and fabric weaving through a literature review, market research, and interviews with experts on Yun brocade. Zhuanghua satin most commonly used for clothing was selected as samples. Six items were tested with respect to permeability, the shape preservation property, and appearance preservation property. Through the analysis of the results, we found the following:

Influenced by the *Zhaungzhi* technique, the thickness of Zhuanghua satin showed differences between patterned and non-patterned parts. Regarding fabric permeability, the water-vapour transmission rate of Zhuanghua satin was similar to plain satin, and the moisture permeability of all samples was good. Nevertheless, its air permeability was not as stable as plain satin's due to the three-dimensional metal thread and brocading weft density. When designing the garment pattern, it is necessary to apply the Zhuanghua satin according to the distribution of human sweating to guarantee thermal and moisture comfort for the human body. With a weft breaking force of Zhuanghua satin over 1600 N, its average weft elongation at the break increased by 25%, while the average weft crease recovery angle decreased by nearly 30°, compared with plain satin. As regards the fabric shape preservation property, Zhuanghua satin was of superior resistance to external damage nut with a weakened weft crease recovery property on account of the metal threads as the brocading weft. Thus, it is not recommended to use it in garment parts that are easily wrinkled by human body movement. For the fabric appearance preservation property, Zhuanghua satin showed stronger weft stiffness, and the performance of anti-fuzzing and anti-pilling improved. The weft flexural rigidity of Zhuanghua satin was approximately 4-9 times that of the matching samples; the grades of anti-fuzzing and anti-pilling increased by about 1 and 2, respectively. Consequently, Zhuanghua satin can be a part that supports the garment. It is wise to use it for garment parts that are less rubbed to maintain an elegant and beautiful appearance.

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References

1. Jin Y.S. Study on the inheritance of Nanjing Brocade. History of science and technology, Nanjing University of Information Science&Technology. 2016.
2. Dai J. Nanjing Yun Brocade. Suzhou: Soochow University Press; 2009.
3. Xu Z.J. The History of Nanjing Brocade. Nanjing: Jiangsu Science and Technology Publishing House; 1985.
4. Jin W. Nanjing Brocade. Nanjing: Jiangsu People's Publishing House; 2009.
5. Xu Z.J. Nanjing Yun brocade. Nanjing: Jiangsu Science and Technology Publishing House, Nangjing Press; 2002.
6. Lu L. Inheritance and Innovation of Chinese Intangible Cultural Heritage in Modern Designs: A Case Study of Nanjing Cloud-Pattern Brocade. *Journal of Landscape Research*. 2015; 7(02), 29-30+34.
7. Ma D.K, Cheng M, Zheng D, Fan X.M, Wang W.J, Fang J. Development of Sichuan Brocade with Imitating Embroidery Effect Based on Free-Floats Interlacing Weave. *Journal of Textile Science and Technology*. 2020; 06(01), 2739-1543.
8. Sun Y.Q. Song Brocade: a Rare Treasure. *China & the World Cultural Exchange*. 2013; (09):18-20.
9. Miu H, Wang G.H. Analysis and research of three famous brocade and innovation design of Song Brocade. *Modern Silk*

Science & Technology. 2016; 31(6): 201-204.

10. Guan J. Research on the inheritance and development of Nanjing Yunjin Brocade. Fashion Design and Engineering, Suzhou University. 2018.
11. Lu J.L, Chen X.F, Fan L.X, Zhang S.C, Han Y.J. Imitation of different flowers in different colors effect of Nanjing brocade. *Journal of Silk*. 2012; 49(03), 34-37+44.
12. Du H.M, Jiang J.J, Xie J.Y. Research on modern design application of visual elements of Yunjin Buzi patterns in Qing Dynasty. *Packaging Engineering*. 2020; 41(16), 266-273.
13. Zhang R, Liu Q. The Latest Progress of the Research and Exhibition on the Digitization of Nanjing Yun brocade Colors. *TBIS Textile Bioengineering and Informatics Symposium Proceedings.* 2020; 481-487.
14. Kuang C.Y, Wang J.H, Zhang H.C. Study on the Application of Yun Brocade in Modern Design. *Proceedings of 2012 2nd International Conference on Applied Social Science (ICASS 2012) Volume 3*. 2012; 319-323.
15. Guan J. Research on the inheritance and development of Nanjing Yunjin Brocade. Fashion Design and Engineering, Suzhou University. 2018.
16. Li B, Liu A.D, Li Q. Study on the Qrigins of the Nanjing Brocade. *Journal of Silk*. 2014; 51(08): 1-6.
17. Qian X.P. Analysis on characteristics of Shu brocade, Song Brocade and Yun brocade. *Journal of Silk*. 2011; 48(05): 1-6.
18. Liu L, Cui R.R. Development and inheritance of Nanjing Brocade. *Journal of Clothing Research*. 2018; 3(05): 445-447+451.
19. Ying X.H, Yu SL. The pattern of Nanjing Brocade is analyzed from morphological semantics. *Art Education Research*. 2018; (22): 20-22.
20. Wang Q, Li Z. Nanjing brocade pattern and its application in “new Chinese” clothing design. *Journal of Silk.* 2019; 56(05): 60-65.
21. Zhou J. Analysis on variety and aesthetics of three famous brocades in ancient China. *Journal of Silk*. 2018; 55(04): 93-105.
22. Burnham D.K. Warp and Weft. Toronto: Royal Ontario Museum; 1980.
23. Lu Z.Y, Hu R, Han S.M. Technical analysis and comparative study of three groups of decorative twisted gold threads of fabrics in Ming and Qing dynasties. *Sciences of Conservation and Archaeology*. 2017; 29(04):36-44.
24. Wang Y.L, Fang H.J, Yin A.N, Chen Y. The manufacturing process of “Peacock Lucky Robe” from the Palace Museum-Application of 3D Video Microscope. *Palace Museum Journal*. 2009; (04),149-154+163.
25. Zhang Q.Y, Lv H, Zhao Q.L, Wang X. Color Analysis of different color zones of peacock feather. *Spectroscopy and Spectral Analysis*. 2013; 33(03),632-635.
26. Dai J. Study on Yunjin’s fabric structure. *Journal of Silk*. 2004; (4): 47-50.
27. Song Y.X. The exploitation of the works of nature. Beijing: China Science and Technology Publishing House; 1637.
28. Zhang R, Liu Q. The Latest Progress of the Research and Exhibition on the Digitization of Nanjing Yun Brocade Colors. *Textile Bioengineering and Informatics Symposium Proceedings (TBIS 2020)*. 2020; 481-487.
29. Xu B.W. Research on the design of Nanjing Yun brocade loom. Nanjing University of the Arts. 2005.
30. Zhang D.Y. Nanjing Yun Brocade. Nanjing: Yilin Press; 2013.
31. Chai J, Cui R.R, Niu L. Study on the Technological Process and Artistic Characteristics of Ancient Chinese Zhuanghua Silk Fabric. *Fibres & Textiles in Eastern Europe*. 2021; 29(4), 105-111.
32. GB/T 5453: Textiles—Determination of the permeability of fabrics to air. China National Textile Council, Beijing, China. 1997.
33. GB/T 12704.1: Textiles—Test method for water-vapour transmission of fabrics—Part 1:Desiccant method. China Textile Industry Association. Beijing, China. 2009.
34. GB/T 3923.1. Textiles—Tensile properties of fabrics—Part 1: Determination of maximum force and elongation at maximum force using the strip. China National Textile and Apparel Council. Beijing, China. 2013.
35. GB/T 3819. Textile fabrics-Determination of the recovery from creasing of a folded specimen by measuring the angle of recovery. China National Textile Council. Beijing, China. 1997.
36. GB/T 18318. Textiles—Determination of bending length of fabrics. State Bureau of Textile Industry of China. Beijing, China. 2001.
37. GB/T 4802.1. Textiles—Determination of fabric propensity to surface fuzzing and to pilling—Part 1: Circular locus method. China National Textile and Apparel Council. Beijing, China. 2008.
38. Dai J.Y, Xu B.J, Zhang H, He W.H, Xu R.L, Liu X.J. Wearability test and analysis of viscose silk-like fabric. *Journal of Silk*. 2017; 54(01), 9-14.
39. Raccuglia M, Hodder S, Havenith G. Human wetness perception in relation to textile water absorption parameters under static skin contact. *TEXTILE RESEARCH JOURNAL*. 2016; 87(20), 2449-2463.