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For Information, contact:

ASAE
The Society for engineering in agricultural, food, and biological systems

2950 Niles Road
St Joseph MI 49085-9659 USA
http://asae.org/

Chapter I

Silk

Authors: Zhu Chengyan, Tian Wei, Jin Xiaoke, Li Qizheng, Chen Junjun, Liu Shuangshuang, Hafeezullah Memon, Shao Lingda, Qiu Yingjie, Feng Xuhuang, Wang Quan

祝成炎，田伟，金肖克，李启正，陈俊俊，刘双双，Hafeezullah Memon，邵灵达，裘英杰，冯旭煌，王泉

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1.1. Cocoon, classification, and production

1.1.1. Origin of sericulture and a brief history of silk

As the first country to engage in silkworm rearing, and silk reeling is the great invention of the Chinese people and known as a contribution to the world civilization, which is an important part of Chinese civilization.

French sericultural history scholar Ernest Pariset analyzed the origin of sericulture from the perspective of history and the distribution of natural silkworm in the book *Histoire de la Soie*. He published in upper and lower parts in 1862 and 1865, denied the possibility that sericulture originated in Egypt, India, ancient Greece and other countries with the same long civilization history as China one by one, and got the conclusion that China is the origin place of silkworm and silk in the world. In 1837, the famous scholar Camille Beauvais also pointed out, “No matter how sericulture experts or scholars think about this work, I consider it will always be the hard evidence that the Han people are smarter than any nation in sericulture specific practices, and also the testimony to their amazing achievements.” in his introduction for Sinologist Stanislas Julien’s *Chinese Literature on Sericulture*.

In the records of *Shih Chi*, it is said that “Yellow Emperor decapitated Chiyou and the silkworm goddess presented silk, which was called the work of weaving”. The program of *Outline of General Knowledge* records that “Lei Zu, the daughter of Xiling family, was the imperial concubine Yuan of Yellow Emperor. She began to teach people to raise silkworms and produce silk for clothes. Then there was no frostbite harm in the world, and later generations worshipped her as silkworm goddess.” Records from previous dynasties show that Chinese primitive ancestors began to domesticate wild silkworms in the early period of human society to breed silkworms for human services.

In 1926, a half-cocoon was unearthed at the inhabitant site of Xiyin Village, Xia County, Shanxi Province (about 5,600-6,000 years ago). The cocoon is about 1.36 cm long and 0.71 cm at its widest point. In 1958, some textiles were unearthed at the Qianshanyang site of the Neolithic Age (about 4,700 years ago) in Zhejiang Province. There was silk in these textiles after identification, including the silk piece, thread, and ribbon. The silk piece had not been carbonized completely, appearing in the tawny color, 2.4 cm long, 1 cm wide, which belongs to the filament product. The silk fiber’s cross-sectional area is 40 square microns, the silk fibroin section is triangular, showing that all from the Bombyxmori silkworm family.

In 1977, an ivory cup was unearthed at Hemudu site in Yuyao, Zhejiang Province. This cup is engraved with four peristaltic worm grains, with the body number the same as that of the silkworm, so scholars think this pattern is silkworm grain. Since the 20th century, a series of cultural relics and archaeological achievements in China has confirmed the historical records and myths and legends, which further proves that China is the birthplace of the world sericulture mulberry planting, silkworm rearing, silk reeling, and silk weaving.

In the period of traditional empirical agriculture, the development of sericulture in China has been in the leading stage, with a wealth of knowledge and many books on sericulture science and technology. With the introduction and development of modern experimental agronomy, Chinese sericulture technology has made great achievements after more than one hundred years of exploration.

In ancient China's foreign trade, Silk and Silk goods played a very important role. The famous Silk Road was just the channel through which China exported its silk to the rest of the world. It spread east to Korea, Japan, and other countries, west to central Asia, West Asia, and Europe, and south to southeast Asia, South Asia, and Africa. The related technologies such as mulberry planting, silkworm rearing, silk reeling, and silk weaving were also exported. The Silk Road is the general name of the ancient land transportation line that starts from Xian, China, traverses the Hexi Corridor, the ancient Western Regions, and the whole Asia, then connects north Africa and Europe. This is a national migration corridor, a channel that radiates the four ancient civilization circles of China, India, Persia-Arab and Greece-Roman, connects the three continents of Europe, Asia and Africa, and promotes integration exchange the eastern and western civilizations. This was the road connecting the two largest countries in the world at that time called the eastern Han Empire and the western Roman Empire.

With the development of thousands of years, the traditional Chinese sericulture technology has been evolving and formed its own unique system. In ancient China, many books recorded the knowledge of planting mulberry and raising silkworms, such as *Silkworm Method*, *Silkworm Book*, *Planting Trees and Storing Fruit for Silkworm* were lost in the process of dissemination. Nevertheless, some silkworm books have been saved today, *Book of Si Sheng*, *Sericulture Abstract Qi Min Yao Shu*, *Silkworm Book of Qin Guan*, *On Popularization of Sericulture*, *Wild Silkworm Record*, *Ailanthus Cocoon Spectrum*, are a few examples of them. The knowledge of sericulture recorded in these books is the ancient laborlaboring people's precious experience about sericulture.

1.1.2 Cocoon species and global distribution

Silkworm is a lepidopteran insect. The cocoon is the protective covering of silkworm chrysalis, which contains the pupa body inside. The cocoon layer can be reeled into raw silk, with the frison and waste silk after reeling can be used as raw materials of silk floss and spinning. The species of cocoon depend on the different species of the silkworm, mainly including mulberry cocoon (Figure 1.1), tussah cocoon, castor cocoon and cassava cocoon, coriaria cocoon, yamamai cocoon, amber cocoon, sam cocoon, camphor cocoon, chestnut cocoon, atlas cocoon, tallow cocoon, willow cocoon, etc.

Mulberry silkworm's development temperature is 7 to 40 °C; rearing temperature is 20 to 30 °C, depending on the growth period. It is mainly distributed in temperate, subtropical, and tropical areas. There are eight major silkworm regions in China, including Guangxi, Jiangsu, Zhejiang, Sichuan, Shandong, Guangdong, Chongqing and Anhui, which account for about 80 % of the national total production. Seven secondary silkworm areas include Yunnan, Shanxi, Hubei, Jiangxi, Henan, Shanxi, Hunan, with the cocoon production accounting for about 20 %.

Figure 1.1 Mulberry silkworm cocoon

Tussah silkworm (Figure 1.2), a cocoon-spinning insect that feeds on tussah leaves, belongs to Saturniidae of *Lepidoptera*. The scientific name is *Antheraeapernyi*. Tussah silkworm is originated in China. The development temperature is 8 to 30 °C; the rearing temperature is 11 to 25 °C; the most suitable temperature is 22 to 24 °C. Tussah silkworm is mainly distributed in China and with small distribution in North Korea, South Korea, Russia, Ukraine, India and Japan.

Figure 1.2 Tussah silkworm cocoon

Castor silkworm is one of the cocoon-spinning economic insects that feed on the leaves of castor. Castor silkworm is originated in Assam, northeast India, and spreads out from India in the 18th century. It was introduced to China, United States, Sri Lanka, Malta, Italy, Philippines, Egypt, Japan, and North Korea. A generation of castor silkworm is through the four stages of development including egg, larvae, pupa, and adult. The stage of the egg, larva and pupa is about 10, 20 and 20 days respectively, with the whole generation about 45 to 50 days. The egg is difficult to hatch when it is below 16.5 °C or above 32 °C, and the appropriate temperature is about 25 °C. The larval is kept at about 24 °C. The pupa stage's protection temperature is about 25 °C, and the relative humidity is 75 % to 90 %. The weight can reach about 7g, which is about 5,400 times more than the ant silkworm to the extreme growth. Castor cocoon cannot be reeled, only be used as the raw material for spinning with the result of castor spun silk yarn. When spinning, the castor silk is often blended with waste silk from mulberry, tussah silkworm cocoons, or even with ramie, or chemical fibers.

When the castor silkworm is fed with cassava, it is commonly called as Cassava silkworm. In 1956, cassava leaves were successfully used to raise castor silkworm in Cenxi County, Guangxi Province, then spread to other counties, Guangdong, and Fujian where castor silkworm was called cassava silkworm. Its habits and characteristics are the same as castor silkworm.

Similarly, when the castor silkworm is fed with *Coriaria nepalensis* leaves, it is commonly known as coriaria silkworm. In 1965, castor silkworm was successfully raised by wild coriaria leaves in Tu and Miao Autonomous Prefecture's sericulture experiment station in Hunan Province; therefore, it is known as coriaria silkworm. The growth of the silkworm rearing with coriaria leaves is slower than that with castor leaves, with the whole growing period 2 to 4 days more, but the weight of the cocoon layer is the same, around 0.34 to 0.42 g. Coriaria silkworm is also reared in Hunan, Hubei, Guizhou, Sichuan, Guangxi, Gansu, Shaanxi in China.

Yamamai silkworm, mainly distributed in China, North Korea, South Korea and Japan, is one of the cocoon-spinning economic insects fed with tussah leaves of the genus crustacea. It is a complete metamorphosis insect, whose egg period lasts270 days. It takes about 50 to 60 days for the larval stage from incubation to cocoon formation, 7 to 8 days from cocoon to pupation, and 20 to 30 days for pupae formation and eclosion. The suitable condition of warm eggs is the temperature 18 °C, relative humidity 75-85 %. The optimum temperature for eclosion is 22 to 26 °C. At the extreme of growth, the weight can reach17 to 20 g. The cocoon can be used for silk reeling with the silk beautiful and gentle. For the color of the cocoon is green, the raw silk can keep the natural green color without dyeing and has a unique lustre. Its woven Silk, with gorgeous and beautiful color, belong to a high-grade silk fabric.

Amber silkworm, also known as Assam or Muka silkworm, is one of the cocoon-spinning economic insects fed on Machilus leaves. Amber silkworm is mainly distributed in China, North Korea, South Korea, Japan, with suitable growth conditions of 4 to 25 °C and the relative humidity of 75 to 80 %. The larvae are difficult to survive when the temperature is more than 35 °C, and the relative humidity is less than 65 %. Amber silkworm can eat the leaves of several kinds of plants besides staple food *Machilus* leaves, evergreen leaves like *Rubiaceae*, *Damnacanthus indicus*, and *Michelia Cinnamomum* plant leave. Amber silkworm is polymorphic and can be harvested 4 to 5 times a year. The larval stage generally takes 25 to 35 days from hatching to cocooning, 2 to 3 days for cocooning, 3 to 4 days for laying eggs, 7 to 8 days in summer and 14 to 15 days in winter for egg stage. The cocoon, with golden yellow color, can be reeled. The silk is so tough but with an amber sheen, so called the amber silkworm, and its fabric is used to make expensive garments.

Camphor cocoon is one of the Silk cocoon-spinning economic insects that fed on camphor leaves. Camphor silkworm mainly eats camphor leaves; the silk quality is much better. It also eats maple leaves, willow leaves, wild rose, pear, fan pomegranate, purple shell wood and tanoak leaves, but the silk quality is poor. The main area of camphor silkworm is China, Vietnam, India; however, the largest production is in China's Hainan Island. Camphor silkworm has only one generation every year. The optimum temperature for adult insect eclosion is 16 to 17 °C. There are eight stages of one generation with the whole age about 80 days. At maturity, the female silkworm weighs 16 g and the male silkworm 10 g. Camphor cocoon can also be reeled, about 1000 camphor cocoons can produce 500 g Silk. The silk, in addition to the fishing line, can be refined into the high-quality surgical suture.

Chestnut silkworm, one of the cocoon-spinning economic insects feeding mainly on walnut and chestnut leaves, distributed in China and Japan. It mainly eats the leaves of walnut, chestnut, apricot tree, maple, Pinus, camphor, and elm. The cocoon of eating walnut leaf is heavy, cocoon layer is thick, the silkworm that feeding Kerria Japonica and chestnut leaves are inferior. Chestnut silkworm is mainly distributed in Liaoning, Heilongjiang, Jilin, Jiangxi, Guangxi, with one generation every year and overwintering with eggs. In the case of wild chestnut silkworm's larvae, hatch starts in late May, matures in late June with 4 or 5 sleep, and turns into a cocoon after about 50 days. The cocoon appearance is like a lantern, with different sizes of meshes. It takes about two days to form a cocoon, after 3 to 5 days into pupation. The cocoon can be reeled into raw silk, also can be used as silk spinning raw material with good silk quality. Chestnut silkworm can also take out the silk gland from the abdomen of cooked silkworm and lengthen it for fishing or medical use after soaking in acid.

Ailanthus silkworm, known as small atlas silkworm, is a cocoon-spinning economic insect, feeding on staple food like *Ailanthus altissima* leaves, and leaves of tallow, castor, holly, Michelia, paulownia, Indus and camphor. Ailanthus silkworm is distributed in China, Japan, India. In China, it is distributed in Shandong, Jiangsu, Zhejiang, Jiangxi, Sichuan. There are one, two and even four generations every year, one in a cold region and four in warm areas, like in Taiwan China. Silkworm rearing needs 30 to 40 days. Mature silkworm gathers 2 to 3 leaves to spin silk and form cocoons. The cocoon is greyish-brown, spindle-shaped with holes at the top and slender grips. The cocoon weighs about 3g, the cocoon layer weighs about 0.3 g, and the cocoon shell rate is 10 to 12 %. Ailanthus silkworm in the countryside is generally reeled as soil silk, woven into the fabric known as Ailanthus silk.

Tallow silkworm is one of the economic insects that spin Silk and form cocoon, also known as big atlas silkworm. Tallow silkworm is distributed in China, India, Japan, and Vietnam. In China, it is mainly produced in Guangdong, Guangxi, Fujian. There are 2 or 3 generations every year with pupa state in cold winter. April to November is the breeding season. Tallow silkworm eats coral tree leaves, also tallow leaves, cow-ear maple and holly leaves. The larval stage is sixth or seventh instars. The whole instar in summer is 35 days and in winter 40 days. The cocoon weight is about 6.5 to 10 g, the cocoon layer weight is 0.9 to 1.1 g, and the cocoon shell rate is about 10 %. Tallow silkworm cocoon can be used for spun silk with strong tensile strength.

Willow silkworm, one of the economic insects spinning silk and forming a cocoon, is distributed in China, Japan, and India. There are willow silkworms all over China. Willow silkworm lives two to three generations (rarely four generations) a year, and through the winter with pupa. Willow silkworm mainly eats leaves of willow, maple, tallow, camphor, and paulownia Mature silkworm forms cocoon inside leaves. The cocoon is large, dark brown, and can reel silk more than 300 meters long.

1.1.3 Sericulture and development

- Silkworm rearing technology

（1） Requirements for mulberry leaves

The rearing of parent silkworms requires the contemporary silkworm to be healthy, well-developed, with more eggs and ooplasm and needs to consider the next generation of silkworm to be healthy, easy to raise, disease-free and high yield. Therefore, raising parent silkworms well is the key to obtain high quality and yield silkworm eggs. For first to second instar silkworm rearing, the perforated film should be used to cover the upper and lower to carry out the whole anti-dry breeding. For third instar silkworms only cover the upper side with half-dry breeding, and for fourth to the fifth instar, silkworm rearing is with feeding-tray directly.

The parent silkworm has higher requirements on mulberry leaves, so it is necessary to pay attention to the mulberry garden’s management. The proper mature mulberry leaves must be fed to satisfy all kinds of nutrients needed for normal development of silkworms in all ages. Mulberry leaves are the only nutritional source of silkworms, and the quality of mulberry leaves not only directly affects the constitution, cocoon quality and ooplasm of contemporary silkworms, but also affects the feeding performance of the second generation. The rearing process of silkworms must be with better and adequate mulberry leaves.

First, standards for mulberry leaves need to be strictly controlled. The first instar silkworm needs mulberry leaves with high protein and low sugar, second to third instars with multiprotein sugar-compatible, fourth to fifth instars with suitable protein and high sugar. At the young silkworm stage, leaf color and hand feel are the main factors, combined with the leaf position for selection, mastering the principle of consistent old and young and same leaf color. At the grown silkworm stage, they are mastering the principle of full maturity, large quantity and high quality. Mulberry leaf picking can be twice in the morning and the evening, without insect mouth, yellow, mud and other bad leaves, less loading and fast conveyance to prevent mulberry leaves from fever and wilting.

Next, a good daily plan of feeding mulberry leaves each time and shorten storage time. Mulberry leaves need to soak and disinfect and be used with a reasonable plan to ensure that mulberry leaves can be supplied until the next day at six o’clock. The small leaves are sterilized and cleaned, folded, dried, placed on wet gauze, and then covered with wet gauze for storage. The big leaves were sterilized and dried, stored at low temperature by air conditioning and even distributed.

The nutrition of the 4 to 5 instar parent silkworm determines the number of eggs produced and the ooplasm. Better and adequate mulberry leaves should be ensured. Try to use the larger leaves to reach or slightly exceed the standard, but not too small or too large.

（2） Giving technique of mulberry leaves

Giving technique is an important measure in silkworm rearing, which can affect the growth and development of parent silkworm, quantity and quality of eggs. The key to giving technique is to ensure silkworms full of food and not waste mulberry leaves. Many new hands give too much, leaving a thick layer of mulberry leaves in the silkworm plaque when the second time giving, causing a serious waste, and burying silkworms under mulberry leaves inconvenient excrement removal or causing silkworms lost. It is necessary to master several aspects such as proper time, amount, and methods of giving mulberry leaves in practice. The mulberry cutting in the young silkworm stage depends on the weather, development degree, and other relevant factors, requiring uniform size, square, and consistency. For young silkworm period, the proper time of giving is when mulberry leaves given in the last time is almost finished or a small amount of residual. For the silkworm growing period, giving can be controlled flexibly according to weather, day and night changes. The quantity of giving is determined according to the feeding habit, development stage, temperature, humidity, leaf quality, feeding times, number of residual leaves and silkworm base density. Giving method is summarized as “one sprinkle, two even, three supplements”, to achieve meticulous, gentle, no harm to the silkworm body.

（3） Expansion and area of silkworm seat

After gathering of newly hatched silkworms before giving at each time, seat expansion and uniform are needed. The maximum seating area reaches during the peak feeding period. The second instar parent silkworm starts to be divided into the plaque standardly when giving mulberry leaves after the first feeding. The silkworm seat’s size is determined by different development stages, varieties, number of silkworms, and meteorological conditions. If silkworm seat is too small, silkworms stay crowded, which is easy to cause insufficient feeding and underdeveloped. At the same time, the silkworm is also easy to scratch the body and increase the chance of pathogen infection. When the silkworm seat area is too large, there are often many residual leaves, resulting in poor hygienic conditions, waste of mulberry leaves and high labor consumption.

（4） Silkworm excrement removal

Silkworm excrement removal can keep silkworm seat clean and hygienic, it is an important disease prevention measure in the breeding process. If no removal or not in time, the accumulation of silkworm excrement will be too thick, wet, easy to ferment, steaming heat, and harmful to silkworm health, pathogens are also easy to reproduce.

Therefore, it is necessary to strengthen removal and strictly eliminate the diseased silkworm while breeding.

（5） Moulting process

The silkworm moulting is the transition process of instar enhancement; although the silkworm on the surface is in a static state, the body is actively moulting and sensitive to the external environmental conditions. It is the most important part of feeding technology to treat silkworms in a group. Proper treatment has a significant influence on the growth and development of silkworm. The moulting process includes moulting with satiation, adding the moulting net on time, bed-cleaning before moulting, gathering of undergrown larva, last feeding, Protection during dormancy, first feeding and other technical processing.

（1） Moulting with satiation.

After gluttonous stage for each instar, silkworm eats less gradually, spins a few of silk threads, and its body becomes tensely shining, which is the precursor that the silkworm will enter the moulting stage. At this moment, attention should be paid to guarantee that the silkworm eats enough to prevent hunger, accumulating enough nutrition, and preparing for the energy consumption during the following moulting stage. Deficiency of nibbling mulberry will cause physical weakness, moulting irregularity, and extension of the period. On the contrary, too much mulberry feeding may affect the silkworm's environment, resulting in moulting unevenness, silkworm stealing residual mulberry after moulting. The moulting period of Chinese silkworm is short, so it is necessary to control the amount of mulberry and avoid too much waste. That of Japanese silkworm is long, which needs to pay attention to satiation and achieve a consistent moulting.

（2） Adding the moulting net on time

To ensure the silkworm seat clean and dry, promote silkworm moulting simultaneously, improve the environment, adding a moulting net on time is needed for excrement removal. Adding the net should be on time, if the net is added too early, there will be more silkworm excrement left, the silkworm seat tends to be cold and wet, which are not conducive to silkworm moulting. If too late, there will be too many silkworms under the net and bring trouble to the excrement removal, and silkworms may be easily lost. The suitable period of adding net is determined on the silkworm varieties, body-color and temperature， for instance, the silkworm in the first instar mostly show sparked rice color. The phenomenon of "camel silkworm" Silkworm may be observed in the second instar silkworms, while their body Color may change from bluish-grey to milky white. Silkworms in the third instar may change their color from bluish-grey to milky with their body short and fat. When entering the stage of fourth instar, the color of most silkworms will change from bluish-grey to milky white with their chest shortened and protruded. Usually, the proper time of adding net is determined when most of the silkworms are entered the moulting stage after adding the net and feeding the leaves for two times. It is suggested to add the net earlier for the case of young larval, Chinese silkworm variety and high-temperature seasons, later for the case of elder larval, Japanese silkworm variety, and low-temperature seasons.

（3） Gathering of undergrown larva

When moulting unevenness appears, adding net is needed to separate the later and earlier moulting silkworms, the retarded moulting larva should be taken out and separated to process and moult in separate batches. The undergrown larva will still be reared by dry breeding with better mulberry leaves to make them moulting as soon. Meanwhile, to reduce the development difference between individual silkworm, the retarded moulting larvae needs to be put in a place with higher temperature to promote its moulting. Otherwise, the group development difference will affect the health state of the silkworms, and hence the technical operation in the next step. Generally, gathering of undergrown larvae will be carried out when there is still part of the silkworm larvae not hibernated after bed-cleaning 22 hours. Silkworm larvae that are not hibernated after gathering of undergrown larva for two times should be strictly eliminated.

（4） Protection during dormancy.

After the silkworm is dormant, the silkworm seat should be sprinkled with a thin layer of fresh lime powder to make it dry. The protective temperature during dormancy is adjusted to 0.5 to 1 °C lower than that during each instar, and relative humidity is 75 % in dormancy middle and early stages, and 80 % to 85 % in dormancy middle and late stages. The light should be slightly dim and even to prevent silkworm seats from shining and blowing, in case the silkworms distributed unevenly, making it difficult to molt and feed. In addition, it is needed to keep quiet and adjust humidity at appropriate times.

（5） First feeding in time.

Feeding for the first time after molting is known as first feeding, which mainly decided on the silkworm’s head color and appetite—the head of newly molted silkworm changes from greyish-white to light brown and then dark brown. Early feeding can cause damage to the silkworm’s mouthparts, dyspepsia, and hypoplasia. The suitable time of first feeding is when more than 98 % of the silkworms have moulted and their head have become light brown appearing foraging state. When 1 % of larvae are exuviated, feeding needs to be within 12 hours. When 50 % of larvae are exuviated, feeding needs to be within 6 hours. Mulberry leaves should be fresh, suitable mature and tender at the same time.

（6） Environmental controls

The external conditions affecting the growth and development of silkworm except feeding also include the meteorological environment, namely temperature, humidity, air and light. Four bad climatic conditions should be dealt within the subtropical silkworm zone like low temperature and drying, low temperature and high humidity, high temperature and drying, high temperature, and high humidity. The temperature and humidity of the parent silkworm breeding in each instar should be controlled. In order to reduce the occurrence of non-hibernating eggs, the young silkworm period needs to increase the time of light, requiring 18 hours of light per day (Turning on the light during daytime in the silkworm room), the strong silkworm period needs as far as possible to keep dark, less light (Not turning on the light often).

1.2. Cocoon structure and features

- Mulberry silk

Mulberry silk is a kind of protein fiber, which belongs to structural protein. The spatial structure consists of several different levels, and its corresponding lower level determines each level's characteristics. The primary structure refers to the sequence of amino acids forming the peptide chain, including the number, type, and order of amino acids in the peptide chain. If the primary structure is changed, the secondary structure and its corresponding functions will also be changed. The molecular weight of silk fibroin is about 30,000 to 300,000, and degree of polymerization of each macromolecule varies around 3,000 to 4,000. Silk fibroin is a large complex composed of the heavy chain (H chain), light chain (L chain), and glycoprotein (P25) in a ratio of 6:6:1. Disulfide bonds connect the heavy and light chains to form the H-L complex, and the glycoprotein P25 cannot exist independently from the H-L complex but is non-covalently connected to the H-L complex by strong hydrophobic interaction.

The heavy chain is the core part of silk fibroin. It determines silk's main physical and chemical properties, with a total length of 5,263 amino acids and a molecular weight of 390 kDa. The heavy chain contains the crystal region and the amorphous region. The crystal region accounts for more than 90 % of the whole protein sequence and is mainly composed of GAGAGX (X can be Tyr, Ser, or Val) repeated sequence. The amorphous region consists of the signal peptide of 21 amino acid residues at the N-terminal, 50 amino acid residues at the C-terminal, more than 100 non-repeating amino acid residues, and the spacer region of more than 40 non-repeating amino acid residues. The light chain comprises 262 amino acids with a molecular weight of 26 kDa, and the signal peptide with 18 amino acid residues at the N-terminal. Most of the hydrophilic regions in the light chain are located at the N-terminal, containing three cysteines, of which two cysteines form intramolecular disulfide bonds, and the other cysteine residues form intermolecular disulfide bonds with the heavy chain, which is used to assemble silk fibroin and help to transport the heavy chain from the endoplasmic reticulum to the Golgi. Glycoprotein is composed of 220 amino acids with a molecular weight of 25.7 kDa, usually expressed as P25, and influences the secretion and transport of heavy chain. P25 contains three potential N-carbonylation sites and a signal peptide with 17 amino acid residues at the N-terminal.

Sericin is synthesized and secreted by the silkworm's middle gland and plays a lubricating role in the spinning process. The sericin presence can avoid direct contact between fibroin and the anterior gland's inner membrane and make the silk substance enter the spinning part smoothly. Sericin binds two singles fibers to form silk thread during the spinning, protecting the fibroin in the center. Sericin contains 18 amino acids, in which the primary amino acids are glycine and serine and contain many hydrophobic amino acids with a molecular weight of about 20 to 400 kDa.

The protein's secondary structure is that the polypeptide chain is arranged in periodic curled and folded conformations by the hydrogen bond between the oxygen atom on the carbonyl group and the hydrogen atom on the amino group. This arrangement does not include the relationship between peptide chains and other segments or side chains' conformation. It is based on complex protein spatial conformation, including α-helices, β-strands, β-angle and random coil.

The secondary structure of silk fibroin consists of a crystal region and amorphous region. The molecular chain arrangement of fibroin in the crystalline region is neat and orderly with mainly Silk-II conformation is a priority. Silk-II is antiparallel β-strands conformation, which structure is relatively stable. The content of Silk-I conformation relatively increases in the amorphous region. Silk has two forms, including α-helices and random coil structure. The two kinds of conformation exist simultaneously in silk fibroin, in which the Silk-I conformation is not so stable, but silk is steady and can be transformed into each other under certain conditions. The amorphous area is mainly with large side based amino acids. The steric hindrance of big side base makes it hard for silk protein molecular chain neat arrangement, leading to a loose structure, and more reactive groups on the molecular chain, which is easy to react with chemical reagents or dye, so the reactions between silk and all sorts of chemicals mainly take place in the amorphous region.

Sericin is a water-soluble globular protein with a layered structure. At present, the four-sericin theories put forward by kojiichi Komatsu are widely accepted, which are sericin from its outer layer to inner can be divided into sericin-I, sericin-II, sericin-III, and sericin-IV. The content ratio of the four kinds of sericin is sericin-I: sericin-II: sericin-III: sericin-IV= 41.0:38.6:17.6:3.1. The water-soluble of Sericin-I is the best and diminishes progressively from sericin-I to sericin-IV. After the degumming process, there still exists a small amount of sericin-IV residues on the silk fiber surface.

Mulberry silk is a kind of protein fiber whose structure and composition determine its physical and chemical properties. The protein's sizeable molecular chain contains carboxyl and amino groups, and the side group on the molecular chain contains acid and primary groups, so the protein has the amphoteric character. The amount of primary and acidic amino acids in the protein molecules and the protein solution's pH value determines its charge. When the protein solution is at a specific pH value, the number of positive and negative ions in the protein solution is equal, making the net charge zero and forming facultative ions. Currently, the pH value of the solution is the isoelectric point (pI) of the protein. The isoelectric point of mulberry silk is 3.5 to 5.2. When the protein solution's pH value is less than the isoelectric point, the protein particles are positively charged and negatively charged on the contrary. When the protein solution is at an isoelectric point, the protein particles do not move in the electric field, and the swelling, dissolution, electrophoresis, conductivity, and osmotic pressure of the protein are the lowest. Silk is amphoteric and can react with acid or alkali under certain conditions, which affects the scouring and dyeing effect of silk fabric to some extent. Silk has a specific resistance to acid, but less than wool. Silk is more sensitive to lye, incredibly strong alkali. Protein solutions can also be hydrolytically destroyed by the dilute solutions of strong alkalis at room temperature.

The mechanical properties of mulberry silk are mainly determined by silk fibroin. The crystal region of silk fibroin is dominated by β-strands. The molecular chains are arranged regularly, and the hydrogen bond between adjacent peptide chains is strong. Due to the large side group's steric hindrance, the amorphous mulberry silk region's peptide chain is difficult to arrange appropriately and closely. Therefore, the crystal region gives silk the ability to resist external forces, and the relatively chaotic arrangement of molecular chains in the amorphous region makes silk have good tensile properties. Silk has excellent breaking strength and elongation at break, its breaking strength is four times that of wool fiber, but the breaking elongation is slightly lower, about 15-25 %. Mulberry silk fibers are porous and have hydrophilic and hydrophobic groups on the macromolecular chain, making the hygroscopicity of silk very strong. The conventional moisture regains of silk is 11 %. Under atmospheric conditions, the moisture regain of silk is about 8 % to 9 %. The moisture adsorption-desorption of silk is fast; the moisture regains rate is about 30 % to 35 % when hygroscopicity reaches saturation. Silk releases moisture fast; the water can be quickly discharged to the outside; thus, silk products are comfortable to wear. The cross-section of mulberry silk is like a triangle or semi-elliptic shape, with good luster. Mulberry silk fabric is not comfortable to be pilling and has good antistatic properties.

Mulberry silk has good thermal stability and drying below 110 °C will not damage it. The tyrosine and tryptophan in silk protect the skin from excessive UV radiation through absorption. Excessive ultraviolet irradiation will make silk yellower and brittle because there are a phenolic basis and tyrosine, tryptophan, and phenylalanine with benzene ring structure in silk fiber. Silk's structures will oxidize and turn yellow after absorbing ultraviolet light, reducing the adhesion between molecules, and making the fiber brittle. The amorphous region of mulberry silk is loosely arranged and has amino acid residues of active functional groups, which can react with other inorganic and organic compounds. Therefore, the chemical reaction and dyeing of silk mainly take place in the amorphous region. Direct dyes, acid dyes, and reactive dyes are often used in the dyeing of mulberry silk. Although the direct dyes depend on intermolecular forces and hydrogen bonds and acid dyes rely on intermolecular forces, hydrogen bonds, and ionic bonds; however, the reactive dyes forma covalent bond mulberry silk.

- Tussah silk

Antheraeapernyi belongs to the *Saturniidae* of *Lepidoptera* and is completely a kind of metamorphosis silkworm that feeds on the leaves of edible oak species such as *Quercus mongolica* and sawtooth oak. More than two thousand years ago, China began to use and raise tussah silkworm, the first artificial domestication of wild silkworms in China.

Tussah silk appearance is yellowish-brown with two single silk parallel bonding. Tussah silk is composed of fibroin (70 % to 80 %), sericin (12 % to 13 %), wax (4 %), pigment, inorganic substance, and other impurities. The feel and gloss of the newly reeled silk are a little worse than that of mulberry silk, but the tussah fiber has a high friction factor and strong cohesion. The fibroin is composed of the inner crystalline region and the outer amorphous region. The crystalline region comprises β-strands and α-helices structures, while the β-strands structure is composed of a polyalanine chain. Tussah silk and mulberry silk fibroins both have Silk-I and Silk-II conformations. Compared with mulberry silk, the peptide chain in the tussah silk fibroin molecule has a higher degree of winding and crimping, and the elongation at break is better, which is 27 % to 51 % in general. The line density of tussah silk is higher, reaching about 6.14 dtex, and its breaking strength is 3.34 to 3.48cN/tex. Tussah silk has good moisture absorption and strong resistance to humidity and heat.

Tussah silk fibroin contains many hydrophobic groups, such as carboxyl group, hydroxyl group, making it easy to form hydrogen bonds with other functional groups, to improve the molecular force between tussah silk fibroin molecules. When the tussah silk is subjected to external forces, the molecular conformation can be transformed into a β-strands chain to maintain better mechanical properties. Bowen *et al*. studied the acid and alkali resistance of tussah cocoon, showing that tussah cocoon and silk's acid resistance is better than its alkali resistance. Huanhuan *et al*. using infrared and X-ray diffraction analysis techniques to study the effects of thermal ageing on tussah silk secondary structure, the results show that under specific temperature, β-strands structure content of tussah silk decreased with the increase of thermal ageing time, and the relative content of the random coil structure and α-helices structure increase instead. The higher the temperature of thermal ageing, the more severe damage to the structure of tussah silk, and the more significant decrease in the content of β-strands structure and crystallinity. Wang Fangfang et al. conducted photo-ageing, thermal ageing, and hydrolytic ageing on tussah silk, respectively, resulting in the three factors like light, heat, and hydrolytic have different degrees of damage tussah silk. The fiber after hydrolysis ageing has transverse cracks, and the fiber brittleness is enhanced. Du Shan et al. treated tussah silk and mulberry silk with calcium salt, and the results show that the dissolution rate of tussah silk is lower than that of mulberry silk, the breaking strength of the two kinds of silk is reduced, the breaking elongation rate of tussah silk is increased, while that of mulberry silk decreased. The β-strands structure of the mulberry silk and tussah silk is gradually transformed into the irregular curly conformation and α-helices structure after calcium salt treatment, and the conversion degree of the mulberry silk is high. Chengjie Fu et al. studied the influence of humidity on tussah silk's mechanical properties, finding a linear relationship between the vitreous transformation temperature of tussah silk and the environmental humidity. Increasing humidity and temperature can promote the vitrification of tussah silk.

- Castor silk

The cocoon floss of the castor silkworm is very thick. It accounts for about 1/3 of the cocoon layer. The cocoon layer is soft but lack elasticity and has different cross-sectional bulkiness. The outer layer is fluffy like cotton, and there is no obvious boundary with the cocoon floss, whereas the middle layer is less fluffy, and even the inner layer is dense, there is a rebound sound when pinching it. The Cocoon layer is thin, and there is the obvious stratification as a multilayer cocoon; the outer is slightly fuzzy, the middle is obvious, and the inner is flat. The thickness is also inconsistent; the middle is the thickest, the tail second, the head thinnest, and a small hole for moth out. The floss accounts for 3.6 % in the fresh cocoon weight, the cocoon layer for 10 %, and the pupa body accounts for 86.5 %. Castor cocoons are white but not as bright as mulberry cocoons, cannot be reeled for silk, only be used for the spun silk raw materials. The cross-section of castor silk is like mulberry silk, but it is flatter than mulberry silk. The sericin content of castor silk is about 7 % to 12 %, fibro in about 85 % to 92 %, and impurity about 15 % to 4.0 %. The fineness of castor silk is about 1.65 to 3.3 dtex (1.5 to 3.0 Dan), and its strength is lower than that of mulberry silk, and its breaking elongation and acid resistance are similar, while its alkali resistance is slightly stronger, so it is suitable for 6.25 (160 Nm) spun yarn.

- Yamamai silk

In the wild silkworms, Yamamai silkworm is the second in research and utilization to tussah. The Yamamai cocoon is natural green; the silk section is flat and has the flash effect, known as “diamond fiber”. The color is different in different parts of the cocoon, also the layers; the outer layer is robust; the inner layer is light. Natural fiber makes it difficult to dyeing and color. The elongation of Yamamai Silk (about 41 %) is much higher than that of mulberry silk (15 % to 25 %). After being heated, the color and luster can be changed. After being exposed to sunlight for about a month, the color and luster will change from green to brown. Under ultraviolet ray irradiation, the color is easy to change to yellow. Even if the ultraviolet shielding agent is attached to the silk, the green color also gradually disappears. After finishing with ethyl carbamate and heat treatment, the cocoon color changes little.

Keiji Numata et al. studied the crystal structure and physical properties of Yamamai Silk, finding that tensile deformation does not affect the Yamamai silk molecule’s crystal structure but is beneficial to the orderly arrangement of silk molecules along the axial direction of the fiber in the amorphous region. The silk’s polyalanine sequence can partially crystalline and has little influence on the structure, mechanical property, and thermal property. Xu Shuping et al. treated Yamamai Silk with different acid and alkali concentrations, finding that acid and alkali can destroy the hydrogen bonds between silk molecules, resulting in reduced fiber breaking strength elongation at break, especially after alkali treatment. After acid treatment, recrystallization occurs, and the crystallinity, initial modulus, yield stress, and elongation at break are all increased. Jia Guoxin et al. used calcium salt treatment, and the results show that the calcium salt dissolution rate is increased with the increase of the treatment time, the breaking strength is dropped, the breaking elongation and crystallinity are first decreased and then increased, then the swelling occurs, and the micro-hole structure is enhanced. Wu Yiming et al. used different temperatures to conduct heat treatment on Yamamai Silk, showing that the breaking strength and breaking elongation are gradually decreased, while the initial modulus is changed very little. After heat treatment, the Silk color is gradually changed to yellow, and the crystallinity is first increased and then decreased. Zhang Yangyang *et al*. compared and studied the cocoon structures of mulberry silkworm, castor silkworm, and Yamamai silkworm, finding that Yamamai cocoon has the largest cross-sectional area, but the shape is flat, and the roundness is the smallest. The aggregation structures of castor silk and Yamamai silk are similar, both based on the β-strands structure, and the crystallinity and thermal stability of Yamamai silk are the highest.

➢ Amber silk

Amber silkworms are mainly distributed in Assam of India and some areas of Myanmar, and parts in Yunnan of China. Amber silkworm is more suitable to grow under the Yarlung Zangbo River valley's hilly climate conditions and the eastern Himalayan. In India, the amber silkworm is also known as Assam or Muka silkworm. Amber silkworm overwinters in pupae usually have 5 to 6 generations a year; the generation cycle in summer is about 50 days, the longest in winter up to 150 days. Amber silkworm can eat varieties of food, including *Litsea monopetala*, camphor, Cinnamomum japonicum. Because of feeding difference, amber cocoon color shades are also different, the cocoon color of the amber silkworm feeding with *L. monopetala* is the deepest, and with Cinnamomum, japonicum is the lightest. The Indian amber silkworm feeds on the leaves of the yellow heart tree and *L. monopetala*. When producing cocoon and silk, yellow heart tree leaves are mainly fed, and for autumn cocoon, *L. monopetala* leaves are fed. With the continuous development of artificial domestication technology, the amber silkworm has been semi-domesticated. At feeding time, the newly hatched larva is put on the stems and gathered when it is time for spinning and forming a cocoon. Amber silk is elegant and colorful, not only has natural color and excellent thermal and mechanical properties, but less production, so its commercial value is relatively high. Amber silk is commonly used in high-end products such as saris and belts. Amber Silk is the most potent natural fiber known at present. Its silk products are more durable and washable than ordinary silk products. It also has better moisture absorption and feels comfortable to wear. As the amber silkworm resources are challenging to obtain, India has the leading development and utilization.

Devi *et al.* studied the structure of degummed amber silk, and the results show that the crystalline structure of amber silk contains both β-strands and α-helices structures. The XRD pattern of amber silk shows two sharp contiguous peaks when 2θvalue are 16.81°and 20.20°, while mulberry silk only has a broad peak when 2θvalue is 20.51°. Amber silk is difficult to rinse or dye because the distance between the adjacent α-helices conformations on the molecular chain is 1/4 cell edge. Gogoi *et al.* modified amber silk in an argon atmosphere with plasma to enhance its hydrophobicity and tensile properties.

- Camphor silk

Camphor cocoon is the brown and olive shape, prominent in the middle, small at both ends, and with a hole. Camphor cocoon outer layer is soft; the middle layer is compact; the inner layer is also compact but glossy. The thickness of the cocoon layer is uneven. The sun-facing side of the cocoon layer is thick, but the leaf side is smoother and tighter. This is because the cocoon layer's leaf side has the slow evaporation of water, making the silk bonded more closely. The camphor cocoon floss has a dense structure and no clear boundary with the cocoon layer. The cocoon layer is relatively thin, and the thickness of cocoon floss is about 1/3 of the cocoon layer.

Camphor cocoon is smaller than tussah cocoon and mulberry cocoon, and the cocoon layer is relatively thin. The surface of camphor silk also has nano to micron white calcium crystals like tussah silk. Nitro groups are presented in the sericin of camphor and tussah silk, and the characteristic absorption peak spectrum of (alanine) is presented in both camphor and tussah silk before and after degumming, but not in mulberry silk. Camphor silk has excellent physical properties, like higher breaking strength. In terms of thermal properties, both the initial decomposition and the maximum weight loss rate of camphor silk are higher than those of tussah silk and mulberry silk before and after degumming because camphor silk has high crystallinity.

Camphor silk fibroin can be completely dissolved in acid and alkali; the solution is brown, black. Camphor silk fibroin is insoluble in lithium bromide, ethanol, calcium chloride, water, and ethanol solutions. Nevertheless, camphor silk fiber's dissolution rate is 89.76 % in molten calcium nitrate and 98 % in lithium thiocyanate solution. The camphor silk fibroin prepared with molten calcium nitrate solution can initiate gel phenomenon in the process of dialysis, and the camphor silk fibroin dissolved with lithium thiocyanate solution is relatively straightforward after dialysis with no denaturation, which may be related to the obtained protein molecular weight and the solvent.

2. . Cocoon silk, silk yarns, and their manufacturing

Cocoon silk is derived from silk glands. Once the silkworm and its glands in the body are mature, silkworms are ready to spin silk. The silk fibroin is secreted and pushed forward by the posterior gland with the coelomyarian musculature's contraction. The silk fibroin is surrounded by sericin secreted while crossing the middle silk gland. Silk fibroin and sericin produce a columnar fluid reaching the anterior silk gland. The liquid substance removes part of the water during the process, thus increasing the fluid concentration. The silk fibroin molecules gradually arrange along the fluid flow direction and improve the degree of molecular orientation. The silk fibroin passes through the spinneret's orifice, and the molecular chain stretches and partially crystallizes in shear stress condition.

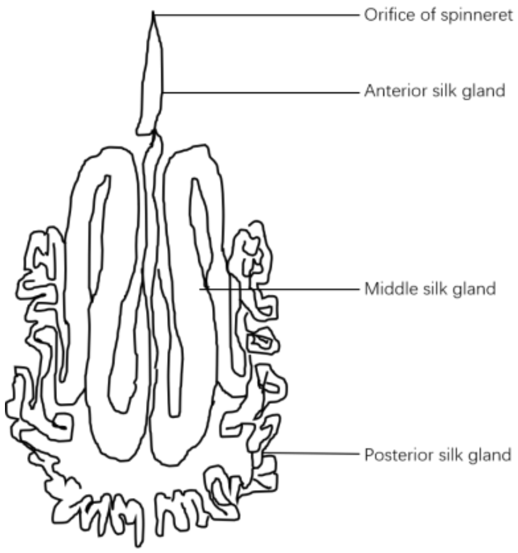


Figure 2.1 Silk gland

The main cocoon and silk-producing countries are China, India, Vietnam, Uzbekistan, and Tajikistan. China accounts for more than 80 % of world production, while India accounts for about 13 %. However, some Indian cocoon varieties cannot be reeled automatically and can only be used for low-end silk blankets, similar to Chinese tussah silkworms. Therefore, the proportion of raw silk produced by China is higher.

The cocoon and silk production industry are China's traditional industry, a "contributing industry" that has made significant contributions to the development of the national economy and an advantageous industry with a monopoly in the international market. At present, China has more than 20 million sericulture farmers and more than 1 million silk workers. More than 70 % of silk products produced are exported, and export trade accounts for about 70 % of the world trade volume, which occupies an important position in the national economy.

China’s cocoon and silk industry has also experienced a course of prosperity, decline, and re-prosperity. In the early Western Han Dynasty and Tang Dynasty, the silk industry was unprecedentedly prosperous, benefiting from the comprehensive national strength. At the end of the Qing Dynasty, the country declined, and the cocoon and silk industries were shrunk. The leading position of cocoon and silk production center was also replaced by Japan, ending thousands of years of glorious history. After founding the People’s Republic of China, China’s cocoon and silk industry started to recover and developed rapidly. Since 1970, China’s cocoon and silk production has returned to first place on the world.

According to the statistics from the China National Bureau of Statistics, in 2017, Chinese silk enterprises produced 141827 tons of raw silk. The main raw silk producing regions, such as Guangxi, Sichuan, Jiangsu, and Zhejiang, produced 50025 tons, 29507 tons, 20353 tons, and 10570 tons, respectively. The raw silk production of Zhejiang has decreased obviously. In addition, the output of raw silk in Guangxi is among the best and still maintains a moderate growth trend.

In 2016, not all the outputs of the main products of Chinese enterprises above the designated size were increased. The outputs of raw silk, spun silk, silk fabrics, and silk quilts were 158400 ton, 8987 ton, 667.56 million meter and 20.74 million pieces, with the year-on-year change ratios 0.51 %, -6.89 5.82 %, -14.62 %, respectively.

In 2017, almost all the outputs of main products of Chinese enterprises above designated size were decreased slightly. The output of raw silk was 141800 tons, which decreased by 1.86 % from the previous year. Spun silk output was 7618 tons, which decreased 11.62 % from the previous year. The output of silk fabrics was 600.7 million meters, which decreased by 2.7 % from the previous year. The silk quilt output was 19.22 million, which decreased by 4.23 % from the previous year. The output of raw silk in the western and central regions accounted for 66.6 % and 9.6 % of the total production, increasing by 1.6 % and 0.4 %, respectively. From the regional output perspective, the output of silk fabrics in the eastern and central regions accounted for 47.6 % and 10.6 %, decreasing 0.7 % and 2.7 % respectively compared with the same period last year. The data mentioned above shows the tendency that raw silk and silk fabric production are gathering in the central and western regions in China.

Table 2.1 Raw silk output of different regions of China in 2016 and 2017

	Area	2016 output (tons)	2017 output (tons)
1	Guangxi	47568	50025
2	Sichuan	33289	29507
3	Jiangsu	25333	20353
4	Zhejiang	14000	10570
5	Jiangxi	7244	6023
6	Shanxi	6327	6082
7	Anhui	6069	5142

8	Chongqing	5051	3458
9	Yunnan	4656	4383
10	Guangdong	2240	964
11	Shandong	1903	781
12	Liaoning	1509	1066
13	Henan	1293	1386
14	Hubei	1077	1101
15	Guizhou	772	985

According to the analysis of the export amount of the leading export countries and regions, the structure of China's silk exports to the top ten traditional world markets had changed significantly, as shown in Table 2-2. Export earnings of the United States, Hong Kong China, and Pakistan declined 6.35 %、13.48 %和 19.97 % respectively in 2017. However, export earnings from seven countries, India, Nigeria, Saudi Arabia, Italy, Ethiopia, Japan, and the United Kingdom, had increased in varying degrees. Among them, the exports to Nigeria, Saudi Arabia, and Ethiopia increased substantially by 135.64 %, 198.4 %, and 256.5 %, respectively, compared with the same period last year.

Table 2.2 Export statistics of the main markets of silk goods in 2017

	Country and region	Amount / ten thousand US dollars	Year-on-year increase rate/ %
1	America	39665.82	-6.35
2	India	31042.19	5.41
3	Nigeria	26425.52	135.64
4	Saudi Arabia	25327.18	198.40
5	Italy	21460.20	1.03
6	Ethiopia	20929.08	256.50
7	Hong Kong, China	17184.77	-13.48
8	Japan	16857.85	5.70
9	England	16426.84	30.93
10	Pakistan	13914.55	-19.97

2.1 Production process of cocoon silk

Cocoon silk production refers to the whole process from collecting cocoon to packaging for transportation and sale.

The technological process is as follows: cocoon mixing, cocoon peeling, cocoon sorting, cocoon cooking, silk reeling, re-reeling, skein-finishing and inspection. The first four steps are the processing of silkworm cocoons, while the rest four are the processing of the silk threads.

2.1.1 Cocoon mixing

The process of evenly mixing cocoons from two or more lots according to the proportion required is called cocoon mixing. The mixed cocoons are generally seen as from one cocoon batch for reeling.

As cocoons' qualities from different lots vary, there will be quality differences in the mixed cocoons if they are not evenly mixed, which will cause production fluctuation and unstable product quality. Proper cocoon mixing is also helpful to reduce the fluctuation of the number of ends dropping. Overall, cocoon mixing aims to minimize cocoon quality differences and stabilize production, thus unifying reeled silk quality. Also, the cocoon shell cannot be damaged after mixing.

The cocoons can be mixed with or without the floss. The cocoon shell's damage is smaller in mixing with floss, but it is hard to mix evenly. Whereas mixing cocoons without floss may break the cocoon shells and obtain a uniform mixing effect. For this reason, silk reeling enterprises generally choose the first way to mix cocoons.

WA212 cocoon mixer is a two-stage umbrella-shaped machine. The production capacity of each machine is 1500kg/h. The precise units are shown in Figure 2.2.

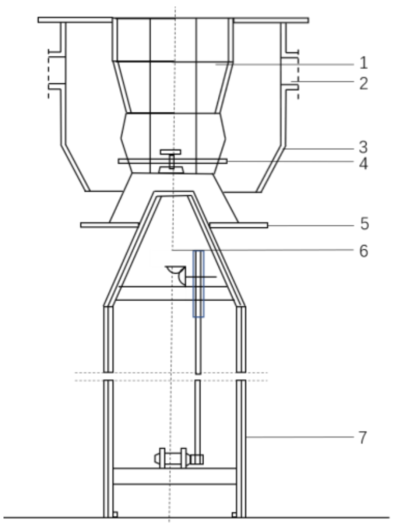


Figure 2.2 WA212 cocoon mixer. 1. cocoon bucket 2. suction duct 3. casing 4. first stage mixing "umbrella" 5. second stage mixing "umbrella" 6. drive spindle 7. rack.

2.1.2 Cocoon peeling

Cocoon peeling is to peel off the loose hairy cocoon shell clothing outside the cocoon called floss.

Because of that the sericin content of cocoon floss is more than 30 %, floss is fragile, and the fibers within floss are distributing irregularly, which makes floss cannot be reeled and usually be used as raw material for silk-spinning. Peeling off the floss before cocoon selection benefits each process's normal operation, including cooking and reeling, and making improvements in the quality of raw silk.

In general, spring cocoons' floss weight accounts for about 2 % of the total weight, while autumn cocoons account for about 1.8 %.

2.1.3 Cocoon sorting

The individual physical differences of silkworms and cocooning environment lead to the diversity of cocoon shape size, cocoon shell thickness, color, and luster. Besides, cocoon collection, cocoon drying, transportation, and other factors also affect the cocoon quality to varying degrees. Consequently, raw cocoons should be selected and sorted according to process requirements. The defective cocoons not able to reel should be removed. If meticulous selection is necessary, further sorting could be carried out to the relabel cocoons. Overall, the purpose of cocoon selection is to eliminate the cocoons that cannot be reeled to meet the requirements of raw silk grades needed.

2.1.4 Cocoon cooking

The sericin on the cocoon silk periphery glues them in sequence, so the cocoon silk is tight and uncluttered. For a cocoon, there are more than 1 million sticking points. Because of the uneven adhesion of glue points and sericin's existing in the form of dry glue, which leads to the difficulty in finding the thread head, it is suitable to reel directly. The cocoon shell's sericin must be properly expanded and softened to weaken the adhesion between the cocoon shells to dissociate the cocoon silk sequentially.

The purpose of cocoon cooking is to make the outer sericin of cocoon silk properly expand and dissolve by the action of water, heat, and auxiliaries. The adhesion between the cocoons shells and cocoon threads is weakened so that the cocoons can be sequentially dissociated during silk reeling.

2.2 Silk reeling

Silk reeling is a process in which several cocoon threads are sequentially dissociated from the cocoon shell and held into raw silk according to raw silk specifications. The current technological process of silk reeling is shown in Figure 2.3.

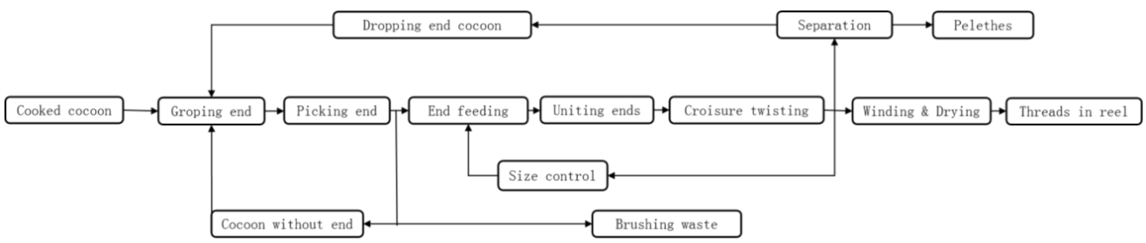


Figure 2.3 technological process of silk reeling

The raw material of silk reeling is cooked cocoon, the finished product is silk in the reel, and the by-products are brushing waste and pelettes of the cocoon.

Silk reeling generally uses dry cocoons as raw materials to facilitate the storage and transportation of silkworm cocoons, and the reeled silk is called dried cocoon raw silk.

In recent years, under the background of rising labor, coal, and other energy costs, increasing pressure on environmental protection, and rising prices of fresh silkworm pupae, the cost of silk reeling is rising day by day. Many enterprises in Guangxi, Shandong, and other places began to reel fresh cocoons. Fresh cocoon reeling refers to collecting cocoons, putting them in the freezer to kill pupae and store, taking them out in batches, and process them in modern silk reeling machine. The silk produced is called fresh cocoon raw silk.

Silk reeling is the primary process in the silk-producing process. The fibers of several cooked cocoons are dissociated and merged into raw silk. There are many methods of silk reeling.

According to the cocoon floating state during silk reeling, it can be divided into three types, i.e., floating reeling, half-sunk reeling, and sunk reeling. As types of silk reeling machinery, it can be divided into multi-end reeling and automatic reeling. According to the different perception types of automatic silk reeling machine, it can be divided into two types, i.e., automatic reeling with a fixed number of cocoons and fixed size.

Since the “11th Five-Year Plan” period, China implemented and accelerated the “Mulberry Transfer from East to West” project. The cocoon and silk industry has become a new agricultural, industrial and trade industry with strong development momentum and significant market potential in Guangxi. During the “12th Five-Year Plan” period, China’s cocoon and silk industry deepened the reform of the integration of trade, industry, and agriculture and achieved the goals set. Remarkable achievements have been made in structural adjustment, scientific and technological progress, brand building, cultural inheritance, and so on. In these five years, the total direct income of silkworm farmers reached 111.54 billion yuan, the output value of enterprises above designated size reached 641.3 billion yuan, and the export of real silk commodities totaled 16.6 billion US dollars. During the 12th Five-Year Plan period, the scale of cocoon and silk production is stable. The fluctuation range of production and demand is much smaller than that of the “11th Five-Year Plan” period, showing a steady operation trend. According to the statistics of the Ministry of Commerce and the National Bureau of Statistics, at the end of 2015, the area of mulberry gardens was 12.32 million mu (a Chinese unit of area, equals to 0.0667 hectares), with an annual output of 628000 tons of silkworm cocoons and 172000 tons of raw silk, of which the change rates are 2.5 %, -2.6 % and 3.4 % respectively over 2010. With the accelerated pace of industrialization and urbanization in the eastern coastal areas, the cocoon and silk industry has moved from east to west. In 2015, cocoon production and silk production in the central and western regions accounted for 79.3 % and 71.4 % of the national output, respectively, 11.0 % and 12.8 % higher than at the end of the "11th Five-Year Plan". Industrial clusters with their characteristics have been formed in the eastern, central, and western regions, and the layout has been continuously optimized.

The silk industry in Guangxi has gradually developed and grown. Driven by the project of "Mulberry Transfer from East to West" of China, industrialization has been further improved by attracting investment and actively accepting transferred enterprises. The autonomous region and the municipal governments have implemented preferential policies in terms of land, funds, and the purchase of fresh cocoons; silk industrial parks have also been established in Luzhai, Yizhou, and Hengxian, respectively.

Guangxi Guihe Group is the largest silk reeling enterprise in China's silk raw material production industry worldwide. At present, the group has four branches in Lingshan, Pubei, and Binyang, with 70 sets of automatic silk reeling machine (28000 ends), producing more than 2000 tons of raw silk per year. The owned Lingshanb Guihe Silk Industry limited company has 30 sets of automatic silk reeling machines with a total of 12000 ends, the largest silk reeling factory in the world.

The popularization rate of automatic silk reeling machines in Guangxi has already reached 100 %. Most of the machines are Feiyu 2000-2008 automatic silk reeling machines. A total number of 11 key technologies of these machines have attained national patents, has been awarded the second prize of national scientific and technological progress award, national key new products, national key torch plan project, second prize of scientific and technological progress of China textile industry, famous brand products of Zhejiang province, the first prize of scientific and technological progress of Zhejiang province, and so on.

So far, only China produces automatic silk reeling machines in the world. Chinese equipment is of low price and good quality. Other silk-producing countries such as India (developing rapidly in silk production), Uzbekistan, North Korea, and Vietnam use Feiyu series automatic silk reeling machines made by Chinese Hangzhou Textile Machinery Company. Besides relying on the unique advantages of Indian silk, India's silk production has developed rapidly in recent years.

Figure 2-4 Feiyu 2008 automatic silk reeling machine

2.2.1 Groping-picking ends

Before silk reeling, cooked cocoons and dropping end cocoons must be brushed, end groped, and picked to make them become correct-end cocoons, of which the cocoon threads can be continuously dissociated. This process is mainly completed by the groping-picking ends mechanism of the automatic silk reeling machine.

The brushing cocoon and groping ends from the cocoon's surface, cocoon without end, and dropping end cocoons is called groping ends. If the brush is too soft to overcome the adhesion between the cocoon shells, it is difficult to draw out the ends. If the brush is too hard or the surface is too rough, it will scratch the cocoon shells.

In the actual production, various factors affect the efficiency of groping-picking ends comprehensively, as shown in Table 2.3.

Table 2-3 Factors affecting groping efficiency and the attained ends volume

Influence factor		Groping efficiency		amount of brushing waste		General range
		Increase	Decrease	Decrease	Increase	
brush	Quantity	Many	Less	Indefinite	Indefinite	6~9
	Position	Low	High	Indefinite	Indefinite	About 70 mm into water
	Old / New	New	Old	Old	New	—
	Size	Big	Small	Small	Big	—
Brusher	Quantity	—	—	—	—	8~10
	Rotational speed(r/min)	Quick	Slow	Slow	Quick	—
	Swing angle（°）	Big	Small	Small	Big	126~242
	Swing frequency	More	Less	Less	More	40~50
Number of cocoons		Appropriate	Inappropriate	Appropriate	Inappropriate	400~600
Decoction	Temperature	High	Low	Low	High	82~92
	PH	High	Low	—	—	6.8~7.8
	Soup quantity	Appropriate	Inappropriate	Indefinite	Indefinite	About 60~70 mm into water

2.2.2 End feeding

During the reeling process, because of the dropping of ends and the size reduction of the cocoon thread from the outer cocoon shell to the inner cocoon shell, the size of reeled silk may decrease as well. When it reaches the limitation, the cocoon thread from the correct-end cocoon should be supplied to ensure the raw silk size meets the specified requirement.

After size decreasing, supplying cocoon is carried out with two steps. Firstly, the groped end cocoons should be added to the reeling part, which is called “end supplying”. Secondly, the end added should be hand over to threads under reeling and attached, called “end attaching”.

For automatic reeling, the “end supplying” process is further divided to “cocoon supplying” and “end feeding” procedures. The act of feeding the correct-end cocoon into the reeling part is called “cocoon supplying”, and the act of giving the cocoon threads to the size decreasing threads is called “end feeding”.

2.2.3 Integrating ends and twisting croisure

The threads strips through the end feeding process cannot be wound directed. The main results are as follows:

(1) The cohesion between the cocoon threads is too weak to make them embrace tightly, thus causing the weakness in strength and easy to split.

(2) As the existence of much moisture in silk threads, it is difficult to dry them, and the silk color is also affected, but the sericin is glued to each other to form a hard rubber strip if the threads are directly wound. Besides, the thread is not easy to unwind when re-reeling, which is easy to cause the breaking down of threads.

(3) Various slubs inevitably appear on the thread; these naps should be removed before winding as much as possible. For this reason, the threads should be under the function of button and croisure before winding.

The integrating ends unit (also called as porcelain eye) is made of porcelain and round with a small hole in the center, as shown in Figure 2.5. Its role is to integrate cocoon filaments, prevent slub occurring, reduce silk moisture, and fix the position of the croisure. The croisure is to dissipate moisture, enhance cohesion, and get rid of part of the s. It is shown in Figure 2.6.

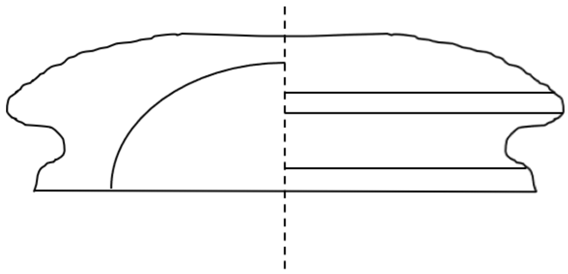


Figure 2.5 Cross-section of porcelain eye

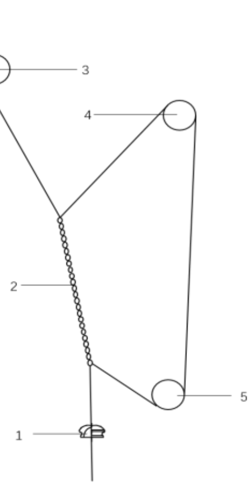


Figure 2.6 Croisure. 1-Button 2-Croisure 3-Positioning drum wheel 4-Upper drum wheel 5-Lower drum wheel

2.2.4 Winding and drying

The formed silk thread still contains much moisture after cocoon threads dissociation, end feeding, end attaching, integrating, and croisure twisting. In order to meet the requirements of unwinding and other processes, proper drying should be carried out, and then the silk thread should be wound in a particular form in an orderly and reasonable manner with the reeling machine. The quality of winding and drying has direct effects on the processability and quality of raw silk.

2.2.5 Collection, transportation, and separation of end dropped cocoons

If the end dropped cocoons and pelettes produced during silk reeling is not discharged in time, the cocoon shell in the reeling slot will fester and the pupal acid will leak, resulting in turbid reeling liquid, affecting the quality of raw silk and the consumption of raw materials. Therefore, the end dropped cocoons must be discharged from the reeling slot in time, and separated with pelettes, and collected for other by-products application.

2.2.6 Re-reeling and skein-finishing

The reel threads need to be processed into skein or bobbin silk byre-reeling and finishing before they can be shipped in batches. At present, most silk reeling enterprises choose to make them into skein silk, while a small number of enterprises choose the form of the bobbin.

Re-reeling is the process of reeling the silk threads from the reel to the grant reel or bobbin. After re-reeling, the process of finishing makes the silk threads in grant reel or bobbin form well, reduce defects, unify the silk color and quality, prevent threads fracture, and facilitate transportation and storage.

2.2.7 Quality inspection and technical design of raw silk production

Raw silk is the primary raw material of silk fabric production enterprises. The quality of raw silk directly affects the weaving processing and the quality of the fabric. The main requirements for raw silk quality to ensure the quality of silk fabrics are shown as follows.

(1) The size of raw silk should be uniform

The size specification of raw silk greatly influences the length, weight, width, warp, and weft density of fabrics. In the case of large size deviation, it will produce defects such as warp, weft bar, and uneven thickness of fabrics, even if the average size indicator meets the standard.

(2) The neatness of raw silk

When raw silk's neatness is not good, there will be slubs on the threads, causing the breaking down and work efficiency reduction in the weaving process. Moreover, the fabric's surface is easy to fluff and lose the silk fabric's inherent smoothness and luster, which will cause uneven dyeing.

(3) Other quality indexes of raw silk

If the strength and elongation of raw silk are good, there will be less breakage, high work efficiency, and less raw material consumption in the process of silk weaving and knitting. The appearance quality and fastness of the fabric are also affected by these two indicators.

(4) Appearance quality of raw silk

Raw silk with various appearance defects will also affect the fabric's appearance quality, such as color strips and color bars.

Silk process design refers to the design of process procedures and parameters according to raw cocoons' performance or production requirements. The production can be carried out through the silk production process design by the best procedures and conditions. Therefore, silk reeling process design is the most important related with the production activities of silk enterprises. The specific requirements mentioned above include the following aspects.

(1) Accuracy

Only when the process design is accurate can it play an organizational role in the production and play a guiding role in technology.

(2) Comprehensiveness

The content of the process design must be comprehensive. In terms of indicators, quality, output, and consumption should be included. In terms of the production process, cocoon mixing, peeling, sorting, cooking, reeling, re-reeling, and finishing should all be included. Besides, the relationship between each process index and the producing process should be fully considered.

(3) Timeliness

The process design must be carried out before production; otherwise, it will cause the production to be disjointed.

2.2.8 ISO 15625-2014 Silk - Electronic Test Method for Defects and Evenness of Raw Silk

The test of cleanness and neatness or evenness variation for raw silk has been currently made through eye-check on seriplane panels. The test is carried out in an inspection room with a special lighting system. Due to the difference of the coverage area of the threads on the board, and the penetration and reflection of the light, the evenness or stripes, cleanness, and neatness can be visually judged by comparing the Seriplane boards with the standard photos.

However, there are many problems existed, such as maintaining the objectivity of inspection, training of inspectors, require many technicians for this testing etc. On the other hand, the alternative means with electronics technology has been required for the improvement on this kind of test. For example, semiconductor laser sensor has been used for the test of cleanness and neatness, and the device with CCD line sensor has been worked out for the test of evenness variation. The probability of turning to practical use on those devices was obtained through comparing the new method to the current test method (eye-check on seriplane panels) with repeat of needed experiments.

Since the end of last century, China's silk industry has carried out a lot of research work on the electronic detection equipment and test methods of raw silk. According to the characteristics of raw silk, the "optical + capacitive" multi spindle electronic detection technology route was established, and the raw silk electronic detection laboratory was established. A large number of raw silk inspection and various comparative tests were carried out, which laid a technical foundation for the formulation of the new standard.

In October 2009, China put forward a proposal to ISO (the International Organization for Standardization) to establish an international standard "test methods for electronic detection of raw silk", which was approved by the vote of 23 member countries of ISO / TC38 / SC23 (ISO / TC38, *Textiles*, Subcommittee SC 23, *Fibers and yarns*).

Since it was officially approved by ISO in May 2010, with the concern and strong support of national standardization management committee, cocoon and silk Office of Ministry of Commerce and other ministries or relevant departments, led by China Silk Association, the international standard development project was implemented by the National Silk Standardization Technical Committee. Experts from the silk testing center of Zhejiang import & export inspection and Quarantine Bureau, Zhejiang kaixiya International Co., Ltd., Zhejiang Silk Technology Co., Ltd., Suzhou University and other scientific research institutes and testing units formed the China project working group. They worked with Italy, Switzerland, France, South Korea, India, Japan, Germany, Kenya and other eight countries to solve the key problems involved.

On May 1, 2014, ISO 15625-2014 "Silk - Electronic Test Method for Defects and Evenness of Raw Silk" led by China was finally released and implemented. This is the first international standard of China's silk industry.

Basic Information of the standard is followed:

Standard Number：ISO 15625-2014

Name：Silk - Electronic Test Method For Defects And Evenness Of Raw Silk

State：effective

Replace the following standards：ISO DIS 15625-2012; ISO FDIS 15625-2014

Publishing unit：International Organization for Standardization (ISO)

Date： 2014-05-01

Scope

This International Standard specifies a test method for defects and evenness of raw silk by capacitive and optical electronic testers. This International Standard is applicable to raw silk with the yarn size between 13.3 dtex and 76.7 dtex or 12 denier and 69denier, whether in skein or on cone, soaked or unsoaked.

2.3 Spun silk

Many waste cocoons cannot be used as raw materials for raw silk production, and a certain amount of wasted threads will be produced in the process of silk production and silk weaving production. All these materials also have excellent natural silk characteristics, and they are processed into various specifications of silk yarn through a series of processes. This kind of silk yarn is called spun silk. The silk yarn made from the waste material is spun by the spinning processing, which is called silk-spinning. Spun silk products have the luster of natural silk fibers and, meanwhile, have the characteristics of staple yarn products. It has been welcomed by consumers for a long time.

2.3.1 Raw materials for spun silk

Raw materials for spun silk come from a wide range of origins with complex types. The raw materials for silk-spinning include floss, pelettes, defective cocoon, waste silk threads, etc. In China, the raw materials for mulberry silk-spinning are mainly produced in Jiangsu and Zhejiang, followed by Sichuan, Guangdong, Shandong, Anhui, Hunan, Hubei and Shaanxi and for tussah silk-spinning are mainly from Liaoning, Sichuan, and Shanxi.

Spun silk material is a valuable textile material that can be spun into a spun silk of 3.3~4.1 tex linear density by the silk-spinning process. Spun silk has the characteristics of compact structure, uniform evenness, clean appearance, and good luster and is suitable for weaving light and thin high-grade silk fabrics. Silk noil produced in silk-spinning can be made into thick spun yarns with 33~100 tex linear density, which can be used to produce underwears with soft feeling and good warmth.

2.3.2 Production of spun silk

The process of silk-spinning includes three steps: scouring, draft making, and spinning.

The purpose of scouring is to remove most of the sericin, grease, and other pollutants from the raw materials to benefit the following spinning and finishing. Scouring determines the quality of silk fiber and the difficulty of further processing. The technological process is shown as follows: sorting and cleaning, scouring, washing, dehydrating, and drying.

(1) Sorting and impurity removal

The sorting process is carried out according to the types of raw material, gum content, oil content, color, strength, cocoon shell thickness, etc. Impurity removal uses manual or mechanical methods to hit the raw materials to make impurities fall, or useschemical methods to carbonize plant impurities. If the raw material is a cocoon, then, itshould be cut by the cocoon cutter and remove the pupa.

(2) Scouring

Scouring is the process of putting the raw materials into the scouring tank or machine for degumming, degreasing, and dirt removal with chemicals and auxiliaries. There are two methods of scouring: the biochemical method and the chemical method.

(3) Washing, dehydrating, and drying

After the raw material is scoured, there are many impurities, such as solution and scum on the silk fiber, which need to be washed away with clean and warm water in the washing machine, dehydrated by a centrifugal dehydrator, and finally dried by hot air in the dryer and made into refined waste silk.

The purpose of fine drafting is to make refined waste silk into the fine draft that meets the technical requirements through the functions of sorting, mixing, loosening, impurity removal, dressing, and so on. The technical route is shown below (Figure 2.7).

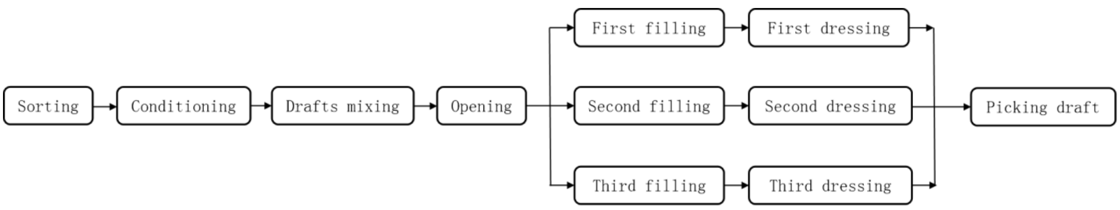


Figure 2.7 Technical route of fine draft making

(1) Sorting

There are non-clean and uneven refined products in the scoured raw materials, fibers entangled into clusters or impurities. The raw materials and impurities with the poor degumming need to be picked out and loosened to prepare fine draft making.

(2) Wetting

The moisture regains rate of refined waste silk does not meet the requirements of dressing. Therefore, the wetting solution should be used to wet the fiber before opening to improve the fiber's softness, reduce the friction between the fibers and the fiber's damage, eliminate the static phenomenon, help to comb the fiber, and improve the production rate.

(3) Drafts mixing

According to spun silk production requirements, all kinds of refined waste silk are mixed in a certain proportion to form a mixed lap with a stable comprehensive index. Usually, several kinds of raw materials are mixed into 400g to 500g lap according to a certain proportion, with a small amount mixing method.

(4) Opening

The process is to use the waste silk opener to loosen, mix the refined waste silks, and remove the impurities inside so that the fibers can be initially straightened and made into uniform pieces with a specific size and weight. Then they are manually wound into a lap. The waste silk opener is composed of conveyor lattice (1), feeding licker-in (2), knife rail (3), cylinder (4), work roller (5), brush roller (6), and stripping roller, as shown in Figure 2.8.

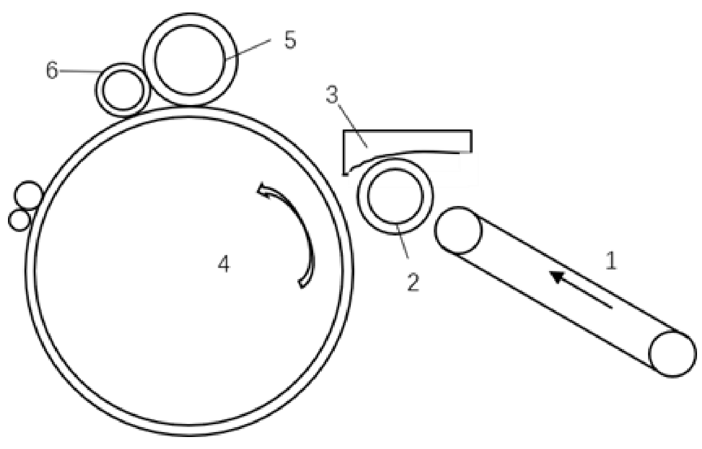


Figure 2-8 Waste silk opener

The silk fiber in the opened cocoon is so long that it must be cut off before spinning. The function of the filling process is to cut off, loosen, comb, and mix the fibers with impurities removing at the same time. The filling process is carried out with the filling machine, and the semi-finished product is a fringe of silk. The filling machine is composed of a conveying lattice (1), feeding roller (2), feeding licker-in (3), cylinder (4), brush roller (5), and automatic stop device with a fixed length, as shown in Figure 2.9. When the fed waste silk reaches a certain length, the fixed-length automatic stop device stops the feeding motion. The fiber is then cut off at a fixed length by hand, and the fiber is rolled up with a wooden rod to make a fringe of silk.

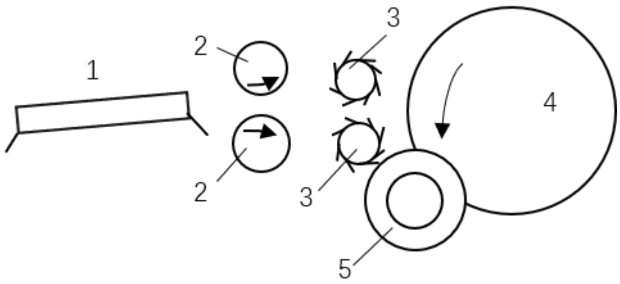


Figure 2.9 Filling machine

(6) Combing

The purpose of combing is to comb the bundle-like or bulk-like fibers into a single fiber state to be further straightened equally. The short fibers and impurities trapped in the fibers could be thoroughly removed at the same time. The combing is generally carried out with a circular combing machine. Furthermore, the draft is made into a combed draft after being combed up and down four times.

The quality of the combed draft has a significant influence on the quality of spun silk. The dressing process is the key process of spun silk production.

(7) Picking draft

Picking the draft is mainly to remove impurities, uncombed fibers, and knots. Furthermore, the combed draft needs to be pulled into small pieces of a certain weight and folded into a specified width for the following spinning processing to meet the spreading machine's processing requirements.

Spinning is the complete process of joining the silk fibers and finally processing them into silk yarns that meet the specified quality indicators. Firstly, the draft is merged, drawn, combed, and processed to roving with equal fiber straightness and evenness. Secondly, they are spun into yarn with a certain linear density, considerable strength, and proper twist by the spinning machine. At last, the spun silk as the final product can be obtained after the process of doubling, twisting, and singeing,

The entire technical process of silk-spinning is as follows:

(1) Mixing of refined waste silk

According to the spun silk's designed linear density, the combed drafts are mixed with a certain proportion to reduce the quality fluctuation and maintain production stability.

(2) Spreading

The bundle's draft strips are fed into the spreading machine piece by piece with a certain lap length. It is wound on a wooden drum after carding and drafting. When all the bundle drafts are wound, the drafts are pulled apart by hand and wound onto the shape of a ball. The spreading process is usually carried out two times to align the fibers and remix them.

(3) Sliver making

The Sliver making process makes the draft strips processed by spreading into continuous sliver with fixed weight and length. It can improve the evenness of the sliver and play a mixing role.

(4) Drawing

The drawing process is to make thick and uneven sliver to thinner sliver with significantly evenness improvement by the processes of combining and drawing.

(5) First roving

In the case of a roving machine using a pin roller to draft sliver, because the drafting force of this device is weak, a first roving process is necessary for the purpose of sharing part of the drafting task, dispersing the bundled fibers, and combining the slivers to improve the weight evenness. In the case of using an apron to draft sliver, the first roving process is unnecessary because the drafting force of the apron is strong enough. However, the apron drafting has no carding effect and cannot reduce surface defects on the sliver.

(6) Roving

The purpose of roving is to spin sliver into roving required. In addition to a certain linear density, the roving also needs to have an appropriate twist and be wound into a particular shape as other spinning material. As shown in figure 2-10, the roving frame is composed of can (1), supporting plate (2), iron pressing roller (3), collector (4), supporting roller (5), pin roller (6), pressing roller (7), front roller (8) and spindle (9).

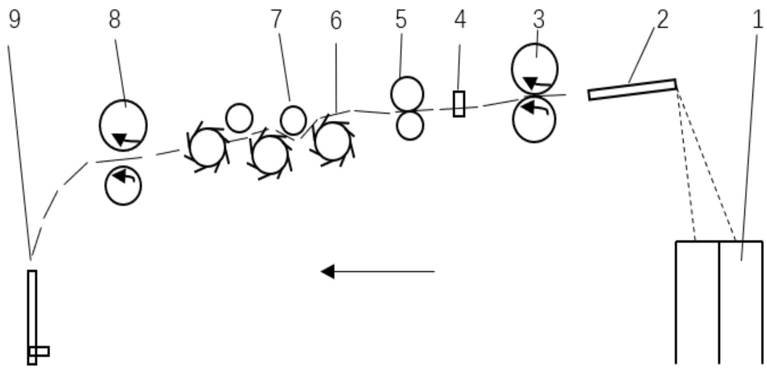


Figure 2.10 Schematic of DJ441 roving frame

(7) Spinning

The purpose of spinning is to lengthen and fine-draw the roving with the spinning machine. The roving is spun with a certain twist to form a spun yarn with a specified linear density. This process is the key process of silk-spinning.

(8) Doubling and twisting

Doubling refers to the merging of two or more spun silk yarns by the doubling machine. Generally speaking, two spun yarns with the same linear density are preferred. After doubling, the yarn is twisted with the twisting machine to improve the strength, evenness, elasticity, and luster of the spun silk.

(9) Winding

Spun silk products are required to have a smooth surface, good evenness, and no defects such as nep, rough knots, impurities, flyings, and so on. Therefore, the spun silk still has to go through the electronic yarn cleaner in the winder to remove the spun silk defects and be wound to increase the package capacity improving the production efficiency of the back-end singeing process.

(10) Singeing

The purpose of singeing is to remove the hairs, knots, and other impurities from the spun silk's surface and increase the spun silk's cleanness and luster.

(11) Skein reeling

In order to facilitate dyeing or sale, the spun silk wound in the singeing cheese is reeled in the form of a skein with a circular length of 1.25m and a weight of 100g per skein.

(12) Skein-finishing

Skein-finishing refers to the removal of defects by manual inspection. Workers check each skein of spun silk on the frame to remove knots on the silk, pick out silk yarns with serious quality problems, distinguish the silk's color and luster, and determine whether the specification of spun silk is correct, which is the final procedure to guarantee the right specification before leaving the factory.

(13) Packing

In order to facilitate transportation, every 50 skeins of spun silk are packed into one packet, each packet weighs 5kg, and every ten packets are packaged into one bale. At present, spun silk wound in bobbin is becoming more become.

2.4 Silk production on the world and development of new cocoon silk Fibers

2.4.1 Silk production on the world

Since 1951, the output of cocoons and raw silk over the years on the world are increased steadily, although it keeps stable in recent 10 years. The great increase of production of cocoons and raw silk are largely determined by the rapid increase of the production in China. From following figures (Figure 2.11 and 2.12), the world production of cocoon and raw silk is mainly contributed by China. At about 1970s, China replaced Japan and became the largest country of cocoon and raw silk production. A very important fact is that India is always increase its production in recent 50 years and has become second largest country of the production of cocoon and raw silk.

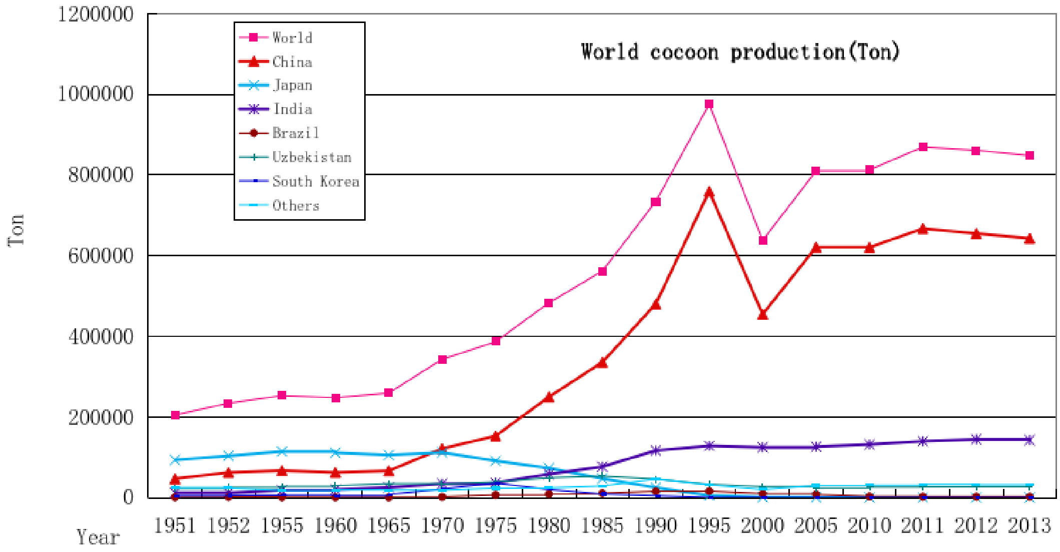


Figure 2.11 World cocoon production

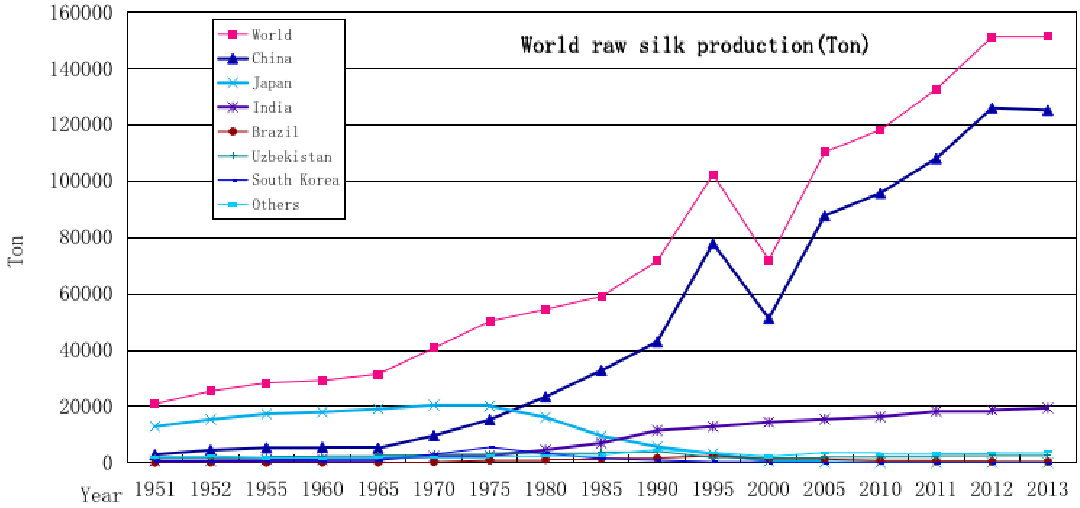


Figure 2-.2 World raw silk production

2.4.2 Development of new cocoon silk Fibers

For many years, lots of achievements have been made in the research and development of silk and silk products especially in China.

The research and developments on silkworm varieties and silk production technology in China are mainly focused on the improvement of the quality, production and productivity of silk and silk products.

Up to today, the cocoon silk, especially the fineness of the cocoon silk (usually 2.5 ~ 3 denier), does not change much and the main properties of the silk and silk products almost remain the same, which results in that the further development of the silk products so as to widen the application areas is restricted.

To improve the present situation, lots of research have been made to develop special varieties of the silkworms including: （1）Natural colored cocoon silk; （2）Thick denier cocoon silk; （3）Fine denier cocoon silk; and （4）Male silkworm cocoon silk.

(1) Natural colored cocoon silk

Use the natural color genes in the colored silkworms (Figure 2.13) existed in nature to create new silkworm varieties. The color cocoon breed now includes red, yellow (orange to brown), green and pink, etc., althoughthe largest production of colored cocoons in China is yellow cocoons and yellow cocoon silk, as shown in Figure 2.14 and 2.15.

Figure 2.13 Colored and normal Silkworms

Figure 2.14 Colored cocoons

Figure 2.15 Normal and yellow colored cocoon silk

(2) Thick Denier Cocoon Silk

In China today, the most majority of the raw silk is produced from common cocoons with the cocoon silk size 2.5 ~ 3 denier/filament. The silk fabrics made from 20/22 denier raw silk are usually light in weight and are mainly used for lady's dresses, especially for the summer dresses. Meanwhile, the silk fabrics are apt to be crease, contract, which adds difficulties to the maintenance of the silk products.

Because of the low stiffness of the common silk yarns, the silk products to be too soft to keep their shapes and as a result, the silk fabrics are not widely used in man's wears and other similar areas where the product needs to keep the shape well.

More than ten-year's research in China has cultivated a new and special silkworm variety, "Xingmiao×Mingri", a thick denier silk. The size of the thick denier cocoon is much larger than that of the usual cocoons (shown in Figure 2.16), and the distribution of the cocoon silk in the shell is also different, as shown in Figure 2.17.

Figure 2.16 Normal and thick denier cocoons

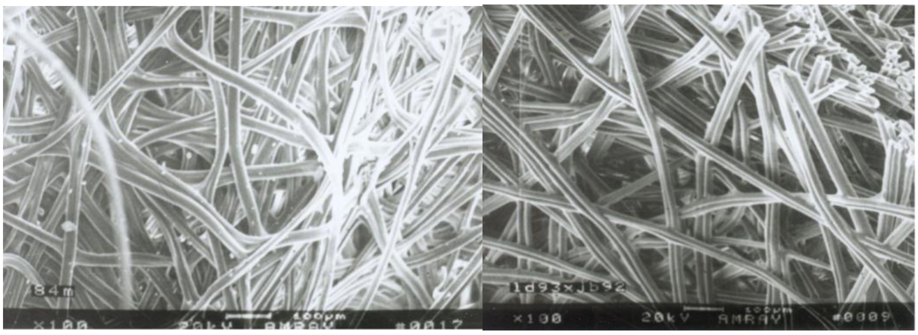


Figure 2.17 Cocoon silk distribution in the shell of cocoons.

(a) Normal cocoon (b)Thick denier cocoon

As commonly known, the fineness of normal cocoon silk is in the range of 2.5 to 3 denier. Many tests show that the average fineness of the "Xingmiao×Mingri" cocoon silk is over 4 deniers, and the maximum average fineness over 4.7 denier. The thick cocoon silk is at least one denier thicker than common cocoon silk. One test shows that the average size of the thick cocoon silk reaches 4.29 denier, as shown in Table 2.4.

Table 2.4 Test result of the fineness (Denier) of the raw silk reeled from fixed 10 thick denier cocoons

Item	Raw silk	Single cocoon silk
Average Fineness (Denier)	42.896	4.29
Coefficient of Variation (%)	6.08	6.08
Max. Fineness Difference (Denier)	6.272	0.63

The silk denier variation from outer layer to inner layer of the cocoon shell is significant to silk reeling and the evenness of the raw silk. Fineness tests of the single thick denier cocoon silk show that the fineness of the cocoon silk does not change greatly within the first 700 meters, but after that the fineness becomes too small so as to affect the evenness of the reeled raw silk (as shown in Figure 2.18).

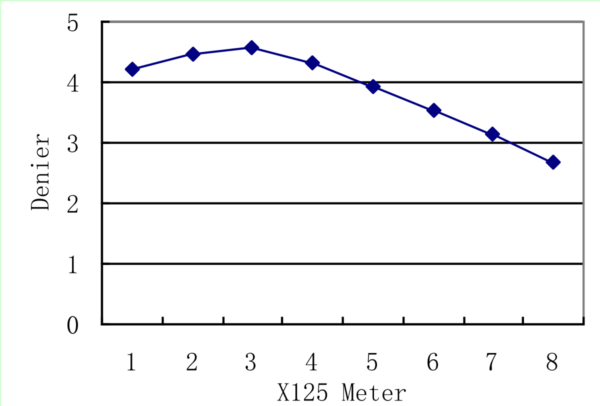


Figure 2.18 Average fineness (denier) variation of the thick denier cocoon silk from outer to inner layer of the cocoon shell

(3) Fine denier cocoon silk

Beginning from more than 20 years ago, the fine denier cocoon is spun by the silkworm molting 3 times (reduced 1time). Typical silkworm breeds and the cocoon filament, in China, are:

1） The Sericultural Research Institute, Chinese Academy of Agricultural Sciences, 853 白(Bai), 543B, filament denier: 1.63-2.65d;

2）Shandong Sericultural Research Institute, Qianchun (芊春) and Zhiri) (知日, filament denier: 1.63-2.20d. The crossbreed: 1.86-2.85d. Note: Filament denier of common cocoon silk: 2.5 ~ 3d.

Application of the Fine denier cocoon silk may be used to produce fine denier raw silk, for sheer woven (habutai, insulating taffeta etc.) and knitted (underwear, silk stocking, etc.) fabrics, or combined with synthesized fibers to form core-spun filament yarns to develop very sheer and fine fabrics.

（4） Male silkworm cocoon silk

From 1996, The Sericultural Research Institute, Zhejiang Academy of Agricultural Sciences, began to research on the male silkworm and cocoon silk. The percentage of the male cocoon reaches 99.8 %. The practical feeding and silk reeling test show that the male silkworm variety is successful now. The main production of the male silkworm cocoon is Zhejiang, Yunnan, Shandong, Guangxi province, etc.

Some features of the male silkworm and its cocoon silk include:

1) Easier to breed, higher efficiency of the mulberry leaves and lower the food price;
2) Higher raw silk percentage of cocoon, smaller filament denier (2.2-2.49d),

better cleanness, abrasion property and elasticity, higher grade of the raw silk, etc.

3) Fewer dissimilar threads in raw silk, the silk quality improved greatly. This may be the main reason of the research and production of male silkworm and cocoons.

3. Silk textiles and their production

3.1 Introduction

Silk textiles, as one of textile varieties, can be produced with raw silk or spun silk, synthetic or artificial fibers, etc. In ancient times, silk was the fabric woven by silk (mainly including mulberry silk, and a small amount of tussah silk and cassava silk). Due to the expansion of textile raw materials, any fabric woven with man-made or natural filament fibers may be called silk (according to the general classification of silk fabrics). But silk fabrics woven with pure mulberry silk are called “pure silk” especially.

Silk is a special local product of China. It is the Chinese working people in ancient time who invented the silk technology and produced silk products on a large scale and opened the first large-scale trade exchange between the East and the West of the world which is called the “silk road” in history. Since the Western Han Dynasty, Chinese silk has been shipped abroad in large quantities and has become a world-famous product. At that time, the road from China to the Western countries was called “Silk Road” by Europeans, and China was also called “Seres”, meaning silk producing county. Silk culture has become a sign representing the Chinese culture.

3.1.1 Silk Products and Development

There are many different versions on the time of silk’s origin. According to historical references, there are two common views or sayings, the first one is that since Fuxi (伏羲), people began to weave mulberry cocoon filaments into silks. The other one is that during the period of the Yellow Emperor (皇帝), Leizu (嫘祖) invented the method of breeding mulberry and the technology of rearing silkworms.

For the above two statements, there are many records in writing, but without any physical confirmation. It can be thought of that the first one referring to the naturally growing silkworm, and the other to the domesticating silkworm. Meanwhile, the time of the occurring of these two versions are different, which means that these two views or sayings are reasonable, existing no contradiction. Fuxi and Yellow Emperor are the ancestors of Chinese culture and the common ancestors of all Chinese people.

Before the Xia Dynasty (more than 2100 BC), silk production was in its early stage. People began to use cocoons to draw silk and weave silk into fabrics. From the Xia Dynasty to the end of the Warring States Period (2100-221 BC), silk production entered its development period. Silk weaving technology had made outstanding progress, and it had been able to use a variety of weaving patterns and colored silk to weave very exquisite silk fabrics.

From the Qin Dynasty to the Daoguang period of the Qing Dynasty (221 BC-1840 AD), it is the mature period of silk production. During this period, various processes were increasingly improved, hand-operated silk machines were also promoted and become more popular. A complete agricultural, industrial, and commercial system of silk production was formed then.

Especially since the Han and Tang Dynasties, from the world-famous "silk road", a lot of silk fabric and raw silk were exported to Central Asia, West Asia, the Mediterranean, and Europe, which were widely popular with all countries and promoted the exchange of trade, culture, and technology between the East and the West.

From the beginning of 1804, China's silk industry began to move towards modernization. Until the founding of the people's Republic of China, China's silk industry developed more rapidly, and a relatively complete silk industry system was established. Now silk products of China have been sold to more than 100 countries and regions in the world. Under the new reform and opening situation, the traditional silk industry of China is blooming and walking to a splendid future.

For China, silk is the symbol of ancient culture. For the world, it also makes an indelible contribution to the development of human civilization. Because of its excellent quality, exquisite designs, and rich cultural connotations, Chinese silk is famous worldwide. Thousands of years ago, along the silk road, silk was spread from Chang'an to Europe, which took not only beautiful clothes and ornaments but also the ancient and splendid civilization of the East. From then on, silk almost became the disseminator and symbol of oriental civilization.

In China's silk culture, the most famous are 'Silk Road', 'four famous embroideries', 'three famous brocades' and 'imperial costumes', and so on.

(1) Silk Road

The name of "Silk Road" is the "invention" of German scholars. In ancient, the basic connotation of the Silk Road was that it was the land channel of trade communication from China, through Central Asia, to South Asia, West Asia, Europe, and North Africa. In his book *China*, German geographer Richthofen mentioned, "Hexi Corridor is the main road of the silk road".

The starting point of the silk road was Chang'an, the ancient capital of China. It got to the Mediterranean Sea through Afghanistan, Iran, Iraq, and Syria, and ends in Rome; the total length was about 6440 km.

The real formation of the silk road originated from Zhang Qian of the Western Han Dynasty, and the official spread of silk to the West began at that time when the Western Han Dynasty began to connect with the western regions.

Qian Zhang (164 BC-114 BC) lived in the period of Emperor Wu of the Han Dynasty. Qian Zhang was the Silk Road pioneer, who was known as "the first Chinese to open his eyes to see the world". He spread the Central Plains civilization to the Western regions and introduced sweaty horses, grapes, alfalfa, pomegranates, flax, and other species from the Western regions to the Central Plains, which promoted the exchange of civilizations between the East and the West.

As time goes by, the Silk Road has become the generic name of all the political, economic, and cultural channels between ancient China and the West. They included an official channel to the Western regions named "North-West silk road" opened by

Qian Zhang in the Western Han Dynasty, “Grassland Silk Road” of Central Asia, which faced the Mongolian Plateau in the north and then moved westward to the northern foot of Tianshan Mountains to enter Central Asia, “Southwest Silk Road” which was from Chang’an to Chengdu and then to India. They also included the “maritime Silk Road” for maritime trade, which started from Guangzhou, Quanzhou, Hangzhou, Yangzhou, and other coastal cities, from the South Ocean to the Arabian Sea, and even as far as the east coast of Africa, etc.

(2) Four famous embroideries

Suzhou embroidery is the general name of embroidery products which are produced in Jiangsu Province with Suzhou City as the centre. Suzhou embroidery originated in Wu County, Suzhou City. With a mild climate, Wu County is close to Taihu Lake and rich in silk, local women have a tradition of being good at embroidery. Superior geographical environment and rich brocade create favourable conditions for the development of Suzhou embroidery. In the long historical development process, Suzhou embroidery is known as the “Oriental Pearl” and has formed a local style with beautiful patterns, harmonious colors, clear lines, lively stitches, and fine embroidery.

Figure 3-1 Su embroidery

Shu embroidery, also named “Sichuan embroidery”, is the general name of embroidery products produced in Sichuan Province with Chengdu City as the centre. Shu embroidery has a long history. Using soft satin and colored silk as the main raw materials, Shu embroidery gave full play to hand embroidery advantages and formed a robust local style with a wide variety of needling techniques. The themes of Shu embroidery usually are flowers and birds, animals, mountains and rivers, insects and fish, and figures, etc. Besides a pure appreciation of the embroidery screen, there are quilt cover, pillowcase, clothes, shoes, cushion, tablecloth, headscarf, handkerchief, painting screen, and other products. There are a large strip screen and a small pocket; Shu embroidery is a fine art with both ornamental and practical value.

Figure 3-2 Shu embroidery

Xiang embroidery is the general name of embroidery products produced in Hunan Province with Changsha City as the center. Xiang embroidery won the best award in the Torino world fair in Italy in 1912 and the first award in the Panama world fair in 1933. Xiang embroidery is known abroad as the ideal embroidery. The characteristic of Xiang embroidery is to embroider with velvety thread (untwisted yarn). The velvety thread used to be dealt with in the special solution to prevent pilling. Local people called this kind of embroidery as “fine wool embroidery”. Mostly, Xiang embroidery takes traditional Chinese painting as the theme, with vivid forms and unrestrained style. For this kind of product, Xiang embroidery colors are mainly dark or light grey, black and white; the style is simple and elegant as ink painting. However, if used for daily necessities, Xiang embroidery products were colorful and decorative.

Figure 3-3 Xiang embroidery

Yue embroidery is the general name of Guangdong embroidery art, including two schools named “Guangxiu”, centred on Guangzhou and “Chaoxiu” represented by Chaozhou. Previously, most embroidery workers were men from Guangzhou and Chaozhou, which were rare in the world. Yue embroidery first appeared in the Tang

Dynasty, and its characteristics were formed in the middle and late Ming Dynasty. In the Qing Dynasty, it was exported from Guangzhou port and became famous abroad. Yue embroidery shows special features including exquisite skills, decorative design, flourishing and fresh brilliant colors, smooth and bright embroidery piles, distinctive textures and natural embroidery streaks.

Figure 3-4 Yue embroidery

(3) Three famous brocades

Yun Brocade refers to a kind of jacquard silk woven handicraft produced in Nanjing City, with fine weaving, exquisite patterns, and gorgeous brocade patterns. Yun Brocade collects the great achievements of silk weaving technology in the past dynasties and integrates the valuable experience of other silk weaving techniques. It has reached the peak of silk weaving technology of its time. The main feature of brocade is different flowers with different colors, if observed from a different direction, the flowers on the fabric will show different colors. The history of Yun brocade can be traced back to the Song Dynasty because of its brilliant color and looking like clouds in the sky, so it is named Yun (meaning clouds in the sky in Chinese) brocade. Yun brocade was popular in the Ming and Qing Dynasties and was a tribute for the royal family in Yuan, Ming, and Qing Dynasties. Yun Brocade is known as the last milestone in the history of Chinese ancient brocade craft.

Figure 3-5 Yun brocade

Originally, *Shu brocade* referred to the colorful brocade produced in Sichuan, but later it became the general name of brocade produced in various places with a weaving method same as Sichuan. Shu Brocade is usually made of dyed bright silk thread, and it is the warp thread that is woven into flowered. It uses color stripe to make color or add flower and is woven by the combination of geometric pattern organization and pattern decoration. The patterns of Shu brocade are drawn from a wide range of materials, such as myths and legends, historical stories, inscriptions, landscape, figures, flowers, birds, animals and so on. The name of "Jinguan town" located in Chengdu city was given in the period of Qin and Han Dynasties, and from Qin and Han Dynasties to Sui and Tang Dynasties, almost all brocades are Shu brocade. Shu Brocade was one of the main trading products on the Silk Road and was also the predecessor of Kyoto Xizhen weaving, a national treasure of Japan.

Figure 3-6 Shu brocade

Song brocade originated in the late Song Dynasty and its main producing area in Suzhou. Song brocade was developed based on Shu Brocade in Tang Dynasty with features of precise and delicate pattern design, firm and soft texture, symmetrical, rigorous and varied, rich and smooth patterns, gorgeous but not hot, complicated but not chaotic colors. The main feature of Song brocade is that both warp and weft together are woven into pattern designs. Song brocade is very practical, soft, and strong in texture, exquisite in design, wear-resistant and can be washed repeatedly so that it can be used widely.

Figure 3-7 Song brocade

(4) Imperial costumes

China is an ancient country with historic etiquette and age-long tradition in the clothes and hat. To a certain extent, the development of Chinese silk is also a miniature of the splendid ritual system. It can be said that ancient Chinese costumes are one of the etiquette systems tools of "distinguishing the superior from the humble" and the materialization of the feudal and patriarchal system. The costumes worn by ancient emperors had special marks, which need to be regulated by a set of formal dress system and must be strictly implemented. They were all related to etiquette, from the shape and color of clothes to the silk thread's length and material. Therefore, the Emperor's dress was the criterion and cornerstone of the whole dress system.

Figure 3-8 Imperial costumes

3.1.2 Classification of silk fabrics

There are generally two kinds of silk classification, including 14 major categories and 35 small categories.

According to the fabric structure, warp and weft combination, processing technology, and the surface shape of the silk fabrics, they are divided into 14 categories, including plain habutai, crepe, satin, ghatpot, gauze, leno, velvet, sheer silk, brocade, crepons, poplin grosgrain, bengaline, taffeta, silk.

Thirty-five small categories are mainly divided according to the performance of silk surface, including crepe de Chine, Qiaoqi, Bi crepe, shunsu, taff, electric spinning, thin spinning, silk spinning, Mian silk, doupioni, pimple, star pattern, rib, thread, stripe, lattice, cool, yarn-dyed, double-sided, concave-convex, mountain-shaped, flower, trimming, glossy, dull, flash, bright, raw, special dyeing, warp printing, flanging, velvet, kimono, large Tiao and Kesi.

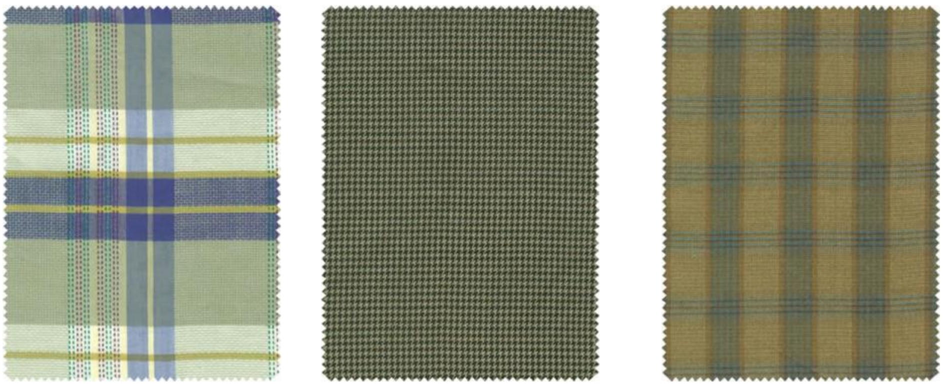
Typical silk fabrics are shown in Figure 2-10.

(a) 11206 Silk habutai (b) Yarn-dyed Silk habutai

(c) Silk georgertte (d) Silk crepe de chine

(e) Yarn-dyed dupionisilk (Douppioni or Dupion)

(f) Pure or mixed silk satins

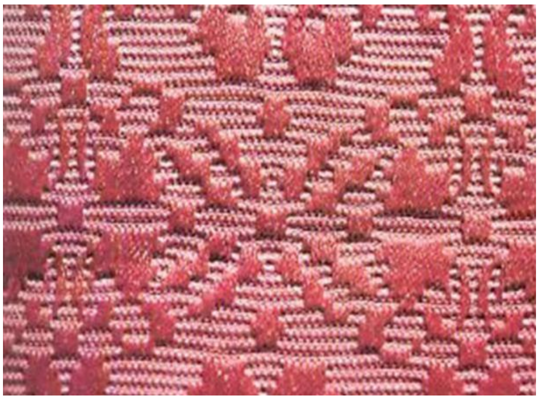


(g) Spun silks (laffis)

(h) Jacquard ghatpot

(i) Jacquard leno

(j) Silk voile (chiffon)



(k) Wenshang Poplin silk

(l) Burnout velvet (m) Plain velvet

(n) Bengaline quilt cover

(o) Suiting silk

(p) Suzhou Brocade (q) Brocade satins

Figure 3-9 14 major categories of silk fabrics

3.2 Silk woven fabrics

3.2.1 Introduction

Woven fabrics are formed by interlacing two mutually perpendicular sets of yarns, also known as shuttle fabric. Two sets of yarns are called warp and weft yarns, respectively.

The interlacing pattern of the warp and weft is known as the *weave*. Two kinds of interlacing are possible. The first one is that the warpis over the weft called warp overlap, and the second is that the weft over the warp called weft overlap.

Among the woven fabrics, the most basic weave is the elementary weave, and other weaves can be evolved on this basis. The elementary weaves include plain, twill, and satin weaves, respectively.

(a) Plain weave (b) Twill weave (c) Satin Weave

Figure 3-10 Elementary weaves

Plain weaves are the simplest weave. In this weave, the threads interlace in alternate order, i.e., the first warp thread cross over the first weft thread and pass under the second weft thread; and the second warp thread passes under the first weft thread and cross over the second one, and so on. The plain weave ensures the simplest form of interlacement of two sets of yarns so that the yarns interlace each other at right angles. The plain weave produces an equal number of warp and weft floats in a weave repeat.

Twill weaves produce diagonal lines on the cloth. These weaves are employed for ornamentation, making cloth heavier by higher yarn density, and better drapability that can be produced with the same yarns and the density in plain weave.

In pure satin weaves, the cloth's surface consists almost entirely of warp or weft floats, as in the repeat of weave, each thread of weft (or warp) passes overall and under one thread of warp (or weft). The interlacing points are so arranged to allow the floating threads to slip and cover the binding point of one thread by the float of another, which results in the production of fabric with a maximum degree of smoothness and lustre without any prominent weave features.

3.2.2 Yarn preparation

Because the package forms and specifications of various silk raw materials cannot meet the requirements of weaving, so, the warp and weft yarns before weaving need to be pre-treated to meet the weaving requirements; these pre-treatment processes are called yarn preparation processes.

The preparation processes before weaving are also different, which depends on the warp and weft yarns. But most of them include the following preparation steps: raw material inspection, impregnation, winding, doubling, twisting, heat setting, warping, drawing-in and warp tying.

(1) Raw material inspection

In a silk weaving factory, the raw material inspection generally refers to the sampling inspection of various raw materials entering the factory.

Its contents mainly include the inspection of physical and mechanical properties, color absorption performance, appearance, handle, and the degree of unevenness level, etc. The inspection results are the basis for the rational use of raw materials

(2) Impregnating

Before winding, raw silk should be impregnated to be soften and lubricated, improve its wear resistance and anti-static performance.

Silk is mainly composed of sericin and silk fibroin. Sericin is coated on the surface of silk fibroin, which protects the silk fibroin and increases the strength as well as the cohesion of silk. However, sericin is unevenly distributed on the surface of silk fibroin, and its characteristics are brittle and hard. During processing, the filament might lack softness that might cause broken ends. Especially in the twisting process, twist cutting is easily occurred and the number of broken ends may be increased. Hence, it is necessary to impregnate before winding to improve the weaving performance of mulberry silk.

(3) Winding

Winding is to change the package form of the silk thread, e.g., the raw silk or the silk in the big package is wound into the bobbin with or without fringes, so that the raw material can obtain suitable winding form and length as required as the next processing step.

For the winding process, there are the following requirements:

1) In order to facilitate the subsequent processing and improve the production efficiency, the silk thread should have a certain tension and packing form;

2) The silk slubs should be removed while winding to improve silk quality;

3) The bobbin’s winding structure should meet the requirements of unwinding in the next processing step as far as possible to obtain high-speed winding;

4) During winding, the yarn’s original physical and mechanical properties should be kept to the best, such as elasticity, strength, elongation, etc.

(4) Doubling

Doubling is to combine two or more threads, some of which are twisted simultaneously to form a strand. The purpose and requirements of doubling are as followed:

1) According to the combination of warp and weft yarns in the fabric specification, the combined silk thread should meet certain thickness requirements after doubling.

2) By doubling, the uniformity of the linear density of silk thread is improved.

3) The defects such as coarse slubs and uneven tension on the raw silk should be removed, the strength will be increased, and the quality of the filament will be improved.

4) A small amount of twist can also be obtained in the winding process, to make it easier for the next processing step.

In general, most of the yarns that need to be twisted have to go through the doubling process, while those without twisting can be doubled directly in the warping process. Sometimes the twisted threads have to be doubled again.

Doubling can be divided into doubling with and without twists. For the doubling with twist, a certain twist is added to the yarn during the process. On the contrary, doubling without twist combines the threads without the addition of any twist during the process.

(5) Twisting

Twisting is to add a proper twist to monofilament or combined strands to enhance its strength, wear-resistance, and elasticity to meet fabric design requirements. In other words, twisting is the process of twisting single or stranded yarn to obtain the required twist.

The purposes of twisting are as follows:

1) Increasing the strength and wear resistance of the silk thread, reducing the fuzzing and breakage, and improving the fabric fastness. For the natural silk used for dyeing, the cohesion force before dyeing can be increased.

2) Making the silk thread had a certain shape or style, and making the fabric obtained the appearance effect such as refraction, wrinkle, loops, or knots, etc.

3) Increasing the elasticity of silk thread, improving the fabric's anti-crease ability, and making it had a cool feeling when wearing.

For different silk fabric, according to the requirements in appearance, internal quality, and product applications, some warp or weft yarns need to be twisted, some do not, some are twisted for the single filament, some are first doubled and then twisted, and some are doubled and twisted at the same time. From the raw silk twisted, there are raw silks with or without same thickness to be doubled and then twisted.

In terms of twisting methods, there are dry twisting and wet twisting. And according to the twisted yarn varieties, there are ordinary and fancy twisted yarns.

As to the twist range, the twist can be divided into three kinds: weak twist (less than 1000 twists/m), medium twist (1000-2000 twists/m), and strong twist (more than 2000 twists/m).

The direction of the twist can be classified intoS-direction and Z-direction, as shown in Figure 3-11. If the twisting direction before and after doubling of the raw silk is different, then it will be called counter twisting. On the contrary, it will be called a co-directional twisting. In order to balance the torsion stress between the single raw silk and the doubled raw silk, they are always twisted in different directions.

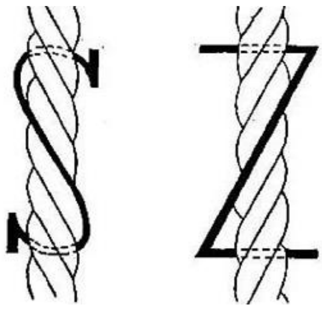


Figure 3-11 S-direction and Z-direction twist

(6) Setting

The setting, commonly known as to fix the twisting, is a necessary process after the silk thread twisted. The setting is a heat treatment for the twisted silk thread, especially for the high twisted silk thread, to stabilize the twist and eliminate the liveliness or prevent back twisting and rolling of the twisted silk threads.

In the twisting process, the filament is subjected to external force, making its long-chain molecules twist in the twisting direction. Before twisting, the molecules in the filament are in a state of equilibrium. During twisting, the external force will cause the filament to stretch and twist, resulting in stress and an unbalanced couple inside the molecule.

When the twisted yarn is in the natural state, under the action of its elasticity, it produces untwisting and twisting shrinkage, which is not conducive to the normal operation for the following processes, and also affects the product quality.

Therefore, in order to stabilize their twist, setting is carried out for all the yarn being twisted. During the setting process, it is required that the physical and mechanical properties of the silk thread should not be affected, especially its strength, elongation, and elasticity should not be damaged. At the same time, convenient operation, time and energy saving also should be considered.

The setting principle of twisted yarn is to speed up the relaxation process of fiber by heating and humidifying to achieve the stabilizing twist. The setting methods can be divided into a natural setting, wet setting, heating setting, and damp heat setting method.

(7) Warping

Warping refers to the silk thread's parallel winding from the rimmed and endless bobbins onto a warp or weaving shaft according to the total number, width, and length required by the fabric specifications for sizing or weaving.

In the warping process, every warp yarn should maintain constant tension of the same size and should not be subjected to excessive friction and tension during winding to avoid damaging the strength and elasticity.

In order to avoid wide and sharp warp in the next process, the surface of the warp shaft should be cylindrical, and all warp lines should be parallel. It should be ensured that the warp wire wound on the warp beam reaches the specified warping length.

When any single warp is broken in the warping process, the warping machine should be able to stop immediately without any missing warp or broken ends around the warping frame.

(8) Warp drawing-in and tying-in

Warp draw-in refers to the work of passing the warp through the heald, reed, and stop wire when the beam is put on the loom. Warp tying-in connects the thread ends of the new weaving shaft and the end of the old weaving shaft by twisting or knotting to replace the draw-in process. Warp drawing-in or tying-in is the last step of warp yarn preparation.

3.2.3 Weaving

Weaving is the process of interlacing of two systems of yarns, warp and weft yarns, in perpendicular angle, on the loom. The warp must be interwoven with the weft according to a certain rule, or pattern, so as to weave a complete fabric. Warp yarns are put into healds and reeds, driven up and down by loom shedding mechanism, and interwoven with weft yarn to form the fabric. The formation of the fabric on the loom is mainly accomplished by the cooperative movement of the following mechanisms: shedding, weft insertion, beating-up, take-up and let-off.

(1) Shedding

According to the fabric weave, the warp yarns follow the rising and falling motion of the heald frame, resulting in regular ups and downs; a certain space formed between the upper and lower layers of warp yarns is known as the shed. The opening mechanism is called the shedding mechanism, which can be divided into three categories: cam and linkage mechanism, dobby shedding mechanism, and jacquard shedding mechanism.

The cam and linkage mechanism controls the movement of the heald frame by a cam or connecting rod, which is suitable for simple three primary structures, such as plain weave, twill weave, and satin weave; The dobby shedding mechanism is controlled by the pattern card, which is suitable for changing structure, joint structure, and small jacquard structure; In the jacquard shedding mechanism, there uses harness cords, not heald frame, to form the shed. The jacquard mechanism controls the lifting and lowering of warp yarns according to fabric structure, suitable for weaving jacquard fabric with large weave repeat.

(2) Weft insertion

After the shed is formed, the weft is introduced into the shed through a weft insertion device to realize warp and weft’s interweaving. Weft insertion can be divided into shuttle insertion and shuttleless insertion. For shuttle insertion, the weft is pulled through the shuttle’s shed to complete the weft insertion with smooth fabric selvedge, but the output is relatively low, and weaving defects are more frequently happen than the shuttleless insertion.

The shuttleless insertion can be divided into rapier, projectile, air-jet and water-jet weft insertion. Shuttleless weft insertion is relatively more advanced, with higher productivity. Modern large-scale textile enterprises usually use shuttleless weft insertion.

(3) Beating-up

The process of pushing the weft into the fabric-fell and interlacing with the warp to form a fabric with specified weft density is called beating-up motion. The mechanism to complete this motion is called the beating-up mechanism.

(4) Let-off

Let-off refers to sending quantitative warp yarn from the weaving shaft to meet the weaving requirements and maintain warp tension during weaving.

(5) Take-up

Take-up refers to leading the formed fabric away from the cloth-fell in time and winding it onto the cloth roller. It can be divided into intermittent take-up mechanism and continuous take-up mechanism.

3.3 Silk knitted fabrics

3.3.1 Introduction

Silk knitted fabric is made of pure silk or pure silk composite yarns. The yarn is looped by knitting needles, and then the loops have connected each other in series to form the knitted fabrics.

Silk knitted fabric, as a kind of high-grade textile products, was begun and gradually developed in the 1970s, and has made remarkable progress in varieties, quality and knitting technology through gradual development for many years. There are a series of silk knitted products, including warp knitted, weft knitted, and stockings, etc.

The raw materials used in silk knitting have also expanded from the original silk to spun silk, tussah silk, and various new differential fibers, composite fibers and functional fibers. The fabrics also ranged from white scouring to dyeing, printing, and finishing, and have formed a series of deep-processed products, with the characteristics of soft touch, comfortable wearing, gorgeous and luxurious looks, which are favoured by consumers around the world.

Silk knitted fabrics have developed a variety of fabrics, which have obvious advantages compared with ordinary knitted fabrics, with some examples introduced bellow.

Pure silk pineapple silk: pure silk pineapple silk has a grid concave-convex effect on the face and diamond-shaped grid effect on the back by complex knitting of looping and multiple rows of doubling stitch and is deeply loved by consumers.

Silk bead ground fabric: silk bead ground belongs to the large circular weft knitted fabric, the surface of the fabric shows sparse holes with honeycomb shape, and has better moisture absorption and breathability, comparing with ordinary knitted fabrics.

Silk loop velvet: the series of silk loop velvet products have characteristics of light weight, good softness and excellent warmth, which are used as high-quality fabrics for warm clothing, scarves and bedding in autumn and winter. Silk knitted loop velvet products not only have the characteristics of moisture absorption, permeability and lightness, but also have better elasticity than woven silk fabrics, and are becoming more favored by consumers.

Silk knitted fabrics are mainly used in the field of clothing, mostly as close-fitting clothing and are deeply loved by people because of its softness, smoothness, elasticity and good air permeability, comfortable to wear and good sanitary function.

Silk knitted underwear has now entered the development stage of multi-function and ecological health care with various texture effects. Those functions include body shaping, flame retardant, antibacterial, anti-odor, anti-static and temperature regulation functions, bringing unprecedented sensory effect and skin care effect to knitted underwear.

Silk warp knitted products are one of the best fabrics for summer T-shirts. They are stiffer and well-dressed than ordinary knitted fabrics and are not easy to snag, which are suitable for high-grade men's clothing, and are also shown a fashion trend of women's knitted fashion in the future.

3.3.2 Yarn preparation for silk knitted fabrics

The requirements for knitting and weaving are different. Traditional silk knitting raw materials include raw silk, spun silk, noil silk, tussah silk and so on. At present, most silk knitting varieties and processes (including warp knitting, flat knitting) still need to go through steps including raw material selection, softening(impregnating) treatment, winding, twisting and setting before knitting, which is quite similar with the preparation for silk weaving.

In the warp knitting process, the requirements for the softness of raw silk are relatively higher. Because the softness of raw silk is relatively lower, the raw silk must undergo the softening process before knitting.

The warp knitting preparation process for silk mainly includes raw material selection, softening treatment, winding and warping.

3.3.3 Silk knitting

Silk knitting can be divided into two categories, weft knitting and warp knitting, about 70 % of the silk knitted products belong to weft knitted, while warp knitted, crocheted and other products account for a small proportion.

At present, most of the knitting machines can be used for silk knitting. There are crochet, tongue needle and grooved needle (composite needle) knitting machines. Different knitted products are produced by different type of machines, different knitting needles and different processing routes with different technical treatment methods.

Weft knitted fabric refers to the knitted fabric in which one or more yarns are drawn out from the bobbin and placed on the corresponding knitting needles of the weft knitting machine in order along the weft direction to form a loop, which is interloped with each other in the longitudinal direction, as shown in figure 3-12.

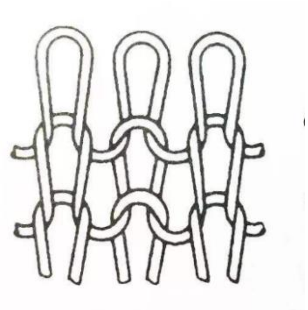


Figure 3-12 Loop forming principle of weft knitted fabric

Same to the weft knitted fabrics, the basic structural unit of warp knitted fabrics also is the loop.

In general, the loops on each yarn of weft knitted fabric are distributed along the transverse direction, while the loops on each yarn in the warp knitted fabric are distributed along the longitudinal direction; each row of weft knitted fabric is composed of one or several yarn coils, while each loop row of warp-knitted fabric is composed of a group (a row) or several groups (several rows) of yarn delivered from the warp beam, as shown in figure 3-13.

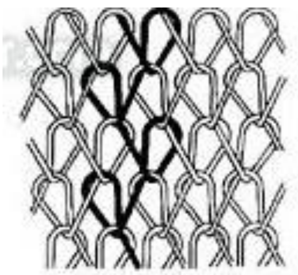


Figure 3-13 Loop forming principle of warp-knitted fabric

3.4 Other silk products

It is true that most of the silk knitted products is in the form of knitted fabrics for T-shirt, tight clothes, sportswear, swimsuits, dancing clothes and socks, pantyhose and gloves, silk masks, etc. In recent years, there is a tendency that more cocoon silk is used as the quilt filler, called silk wadding. Usually, silk wadding quilt refers to bedding items containing more than 50 % mulberry silk (tussah silk) as the filler.

Silk wadding is deeply favoured by consumers because of its special performance, such as, no static electricity, mothproof, mildew proof, light weight, warm keeping, etc. As a material of natural animal protein fibers, silk wadding quilt has good compatibility with human body, can promote sleep, improve sleep quality, reduce insomnia and enhance human vitality, after long-term using of Silk wadding quilt.

Figure 3-14 Silk wadding quilt

4. Modern silk education

4.1 Introduction

China's textile industry has a long history, and the development of corresponding silk professional talents training is explicit. Take Zhejiang Province as an example, the training of silk professional talents can be divided into three periods, i.e., the ancient family “apprenticeship mode” training period before the founding of the Sericulture Academy, the modern industrialized "vocation mode" training period after the founding of the Sericulture Academy , and the modern professional "specialization mode" training period after the foundation of the People's Republic of China.

4.2 Modern silk education

The silk industry is a classic historical industry in Zhejiang Province. At present, silk professionals' training is an important factor to ensure the transformation and upgrading of the silk industry. However, due to the historical changes in the training of silk professionals in Zhejiang Province, the talents in today's silk industry in Zhejiang Province are facing a situation where they are out of touch. In order to solve this problem, the people's Government of Zhejiang Province proposes to attach great importance to the training of silk professionals and focus on supporting Zhejiang Sci-Tech University to resume professional silk education.

With the development of the silk industry, the industrial chain of modern silk products continues to add new contents, from the initial planting of mulberry, sericulture, silk reeling, silk weaving, silk printing, newly added dyeing, machinery, automation, design, marketing, and other necessary industrial chain links. At the same time, during the training period of the "professional system", Chinese universities also experienced several major adjustments; each adjustment had a great impact on the talent training of silk major.

Zhejiang silk "professional" professional talents cultivation period can be divided into three stages, namely "education as the core for silk professional talent training" stage (before 1998 silk professional cancel silk professional rapid development), "to the silk textile education as the core" of talent cultivation stage by 2017 after the cancellation of professional silk (silk set professional resume before enrollment), and the 2017 silk recovery after the admission of contemporary design and engineering to a new stage of inheritance and innovation.

In 1998, with the implementation of the new edition of The Catalogue of Specialties of Institutions of Higher Learning, the Ministry of Education officially established the management at the central and provincial levels. Under the macro-management system with the provincial government's overall planning as the main, the adjustment of specialties of colleges and universities throughout the country continued to deepen, and the Zhejiang silk industry was ignored by Zhejiang province its limited scale. With the integration of the silk engineering major into the textile engineering major, silk professionals' cultivation has entered the stage of talent cultivation. The silk major has been completely abolished, that is, silk professionals' cultivation with "textile education as the core".

Silk industry development has reached a critical period of transformation of the mode of growth, only face to the world, from the supply side of the silk industry and silk products based on the demand side, the industry development of the pulse in the terminal of the silk consumption market, analysis of consumption characteristics and future trends of contemporary silk, silk products innovation and improve product quality to increase the added value of silk products, so as to the recasting brilliant silk industry in Zhejiang province. This is the basis for the orientation of silk professional personnel training.

History combed to illuminate the future, the Sericulture Academy founded in 1897 by Lin Qi, the governor of Hangzhou, developed into today's Zhejiang Sci-Tech University, the dominant characteristic of silk subject ushered in the historical opportunity of characteristic development. The “Sericulture Academy” to “Zhejiang Sci-Tech University” has a long history, rich experience, and remarkable training results.

4.3 Programs of modern silk education in ZSTU

The College of Textile Science & Engineering (International Silk College) in ZSTU, shown in Figure 4-1, was developed on the basis of the Sericulture Academy founded in 1897, shown in Figure 4-2. It has a college history of more than 120 years, which is a college with long history, strong faculty, and obvious disciplinary characteristics. It was founded by merging the departments of Silk Engineering and Textile Chemical Engineering and named as the College of Fiber Engineering in December 1994, which later renamed as the College of Textile Science & Engineering (International Silk College) in June 2019. Adhering to the University’s spirit of “Seek Truth from Facts”, and University’s Motto - “Rich in Virtue, Farsightedness, Broadness in Knowledge and Act Sincerely”, the college is always keeping on finding its own innovative way and making progress step by step. With years of sustained development, CTSE & ISC gradually grows into a prestigious college with distinctive educational characteristics, particularly in silk and fashion technology, novel fiber materials, modern textile, green dyeing, and finishing technology. Textile Science & Engineering in ZSTU has been among the top subjects of Textile Science & Engineering in China.

Figure 4-1 Photo of the front gate of Zhejiang Sci-Tech University (ZSTU)

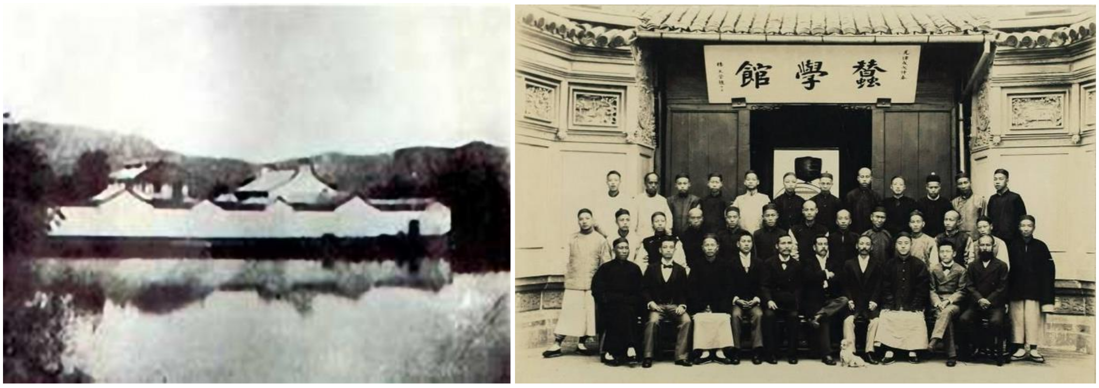


Figure 4-2 Sericulture Academy founded in 1897

The college offers versatile and excellent educational programs of all levels, including bachelors, masters, doctoral programs and post-doctoral research program, including Textile Engineering, Light Chemical Engineering, Non-woven Materials & Engineering and Silk Fashion Design & Engineering. In particular, Textile Engineering and Light Chemical Engineering are 2 National-level Characteristic Professional Subjects, which were listed in Elite Engineering Training Programs by the Ministry of Education (MOE). Textile engineering is one of the first batch of national-level comprehensive reform pilot majors in local colleges and universities.

The college, in ZSTU, has rich experience and a large number of senior professionals related with international communication and training. In recent years, the University has organized three receptions and lecture assignments on the theme of Chinese Silk Culture and Textile Industry Tour for visiting groups from the University of Manchester, United Kingdom, Kansas State University, United States and Education and Training Center of the Ministry of Industry, Indonesia. In 2016, under the guidance of the support by the Ministry of Science and Technology and the provincial department, ZSTU undertook the 2016 International Training Program Processing Technology and Innovation Design of Modern Silk Products for the first time and provided training for the 16 students from Poland, Vietnam, Thailand, Cambodia, India, and Mongolia. From 2017 to 2019, ZSTU successfully undertook three sessions of the Modern Silk Production Processing And Innovation Design Technical Training Course, which 59 students participated in, from 12 countries such as Thailand, Cambodia, India, Mongolia, Myanmar, Bangladesh, Mauritius, Egypt, Ghana, Sudan, Uzbekistan, and Laos, shown in Figure 4-3.

（a）Field visiting of the trainees

（b）Opening ceremony of the program

Figure 4-3 2016 International Training Program Processing Technology and Innovation Design of Modern Silk Products

Based on the background of the in-depth research in the silk industry for more than 120 years, giving full play to the characteristic advantages, inheriting and developing brocade intangible cultural heritage， ZSTU College of Textile science and engineering (International Institute of Silk) has successfully held eight Chinese intangible cultural heritage inheritance population training plan hosted by the Ministry of Culture and Tourism—Training Program on Art & Technique Heritage and Creative Design of Brocades，which more than 120 people attend, including Song brocade, brocade preface, Zhuang brocade， Hangzhou brocade, k'o-ssu and so on， for the further inheritance of Chinese traditional silk skill, carrying forward the Chinese silk culture, improving the level of intangible cultural heritage protection, shown in Figure 4-4.

Figure 4-4 Trainees of the program

In addition to theoretical analysis and practical teaching, creation design, product development, and brand marketing are all ZSTU characteristics and advantages of intangible Cultural Heritage research and training. From silk brocade to intangible cultural heritage research, from boosting poverty alleviation to promoting multi-cooperation, ZSTU has reached a lot of achievements on heritage protection work, has set up the bridge to academic, art, design, production and market for traditional brocade technique, has formed a friend circle among brocade traditional craftsmen, creative designers, modern production processors, and professional market vendors, forms a working mode on intangible research—complementary and school union joint school, and solves some platform of the existence and development of intangible cultural heritage.

The sentence, Cultivate the brocade field, create a benchmark for innovation, enhance the industry's strength and boost poverty alleviation, can summarize the work of ZSTU on the protection of intangible cultural heritage in recent years. The training course has further expanded its influence at home and abroad and has gradually become an essential platform for information exchange and technology promotion between the domestic silk industry and its counterparts in Asian countries.

5. Summary

Silk has a history of about five thousand years in China. The Chinese ancestors invented silk and brought Chinese culture to the world through silk and has made it become one of the special products of China. The ancient Chinese working people produced silk products and opened the first large-scale trade exchange between the East and the West in the world's history called the Silk Road. Since the Western Han Dynasty, Chinese silk has been shipped abroad in large quantities and has become a world-famous product. China is also known as the "Seres", meaning "Silk producing country".

As an independent culture, silk culture is closely related to ancient Chinese culture's occurrence and development. Silk culture originated in China, developed in China, extended to all parts of the world, and promoted the exchange and development of politics, economy, culture, science, and technology between China and other countries in the world. Silk has an indelible contribution to the promotion of human civilization.

Silk culture plays an essential role in promoting the international textile industry. Silk culture reacts to the textile industry, making it carry out a series of innovations and reforms on the original basis, thus improving labor production efficiency, creating new fabric types, and further enriching silk culture. Foreign silk culture plays a more critical role in the development and innovation of the local textile industry. After the Chinese silk entered the European countries, the monarchs of various countries established and developed their silk industry one after another; in this process, the spread of silk culture is not a simple similar, but continuous improvement and fullness. After the formation of foreign silk culture, it was fed back to China, which played an essential role in promoting China's textile industry's development and progress.

Silk culture promotes the development of the Chinese language and literature. Silk culture has played an essential role in the emergence and development of Chinese characters. There are many words related to Silk in Chinese. In addition, many literary works also describe sericulture and silk to express feelings or reflect social reality. Poems and songs related to silk culture appear in the corners of literary works of all dynasties.

Finally, silk culture promotes the exchange and integration of world cultures. As one of the great inventions in ancient China, Silk contributes a lot to world civilization through the ancient Silk Road. Simultaneously, foreign culture also entered China through the Silk Road, making the local culture more flourishing and more colorful. Countries take silk trade or the exchange of silk goods as a breakthrough to strengthen ties between countries and maintain peaceful and stable international relations, thus providing good conditions and environment for the progress and development of world civilization.

Chinese silk culture with long history has made an outstanding contribution to Chinese civilization and even the world civilization and has had a far-reaching impact on world society’s development. In the process of increasingly frequent cultural exchanges, how to enrich cultural connotations and integrate into the spring tide of global cultural competition, to make silk have more vitality and influence, and play a more positive role in social development is the direction of efforts for all the people related with silk.

References

[1] Li Guodong. Research on the integration and innovation of subtropical silkworm eggs incubation technology [D]. Jiangsu University of Science and Technology, 2018.

[2] Zhang Qing. Research on the evolution and optimization of Chinese silkworm spatial pattern [D]. Chinese Academy of Agricultural Sciences, 2018.

[3] Huang Yangyu. Research on the characteristics and breeding technology of subtropical silkworm original species[D]. Guangxi University, 2018.

[4] Yang Yingying, Zhang Minshuang, Tian Wei, Zhu Chengyan. Process optimization and performance analysis of natural cassava silk degumming[J]. Modern Textile Technology, 2017, 25(05): 47-51.

[5] Edited by Li Wenzhi. "Data on Modern Chinese Agricultural History" First Series 1840-1911[M]. Beijing: Published by Sanlian Bookstore, first edition in December 1957.

[6] Deng Tingting. Research on the structure and properties of silkworm silk, wild mulberry silk and amber silk [D]. Southwest University, 2017.

[7] Jia Xuefeng. Research on the industrial development of castor silkworm (cassava silkworm) in Guangxi [D]. Guangxi University, 2017.

[8] Silk Production and Export Management[M]. New Delhi;A.P.H. Publishing Corporation, 2001

[9] Li Jianqin, Zhou Yuxian, Gu Guoda. Analysis of changes in the spatial distribution of silkworm cocoon production and influencing factors in my country[J]. Sericulture Science, 2014, 40(05): 902-910.

[10] Zhou Yuxian. Analysis of changes in the spatial distribution of silkworm cocoon production in China and influencing factors[D]. Zhejiang University, 2014.

[11] Yao Jia, Luo Qianqian, Zhu Chengyan, Kou Yongqi, Yu Dan. Cocoon cooking process of natural green cocoons[J]. Textile Journal, 2013, 34(10): 35-38.

[12] Qi Henan. Research on "Italian Silkworm Book"[D]. University of Science and Technology of China, 2011.

[13] Fu Chengjie. In-depth study on the structure and mechanical properties of tussah silk[D]. Fudan University, 2010.

[14] Li Fuqiang. Research on the Inheritance Mode and Evolution of Chinese Sericulture Technology [D]. Southwest University, 2010.

[15] Li Long. Research on the Development of Sericulture in India[D]. Southwest University, 2008.

[16] Han Yifei. Technical research on exporting Chinese silkworm species to Southeast Asian countries[D]. Soochow University, 2002.

[17] Xu Shiqing, Lu Xiaoping, Shen Weide, Chen Xilin, Han Yifei, Zheng Biping. Research on the technical plan for exporting Chinese silkworm varieties to Southeast Asian countries[J]. Chinese Agricultural Science Bulletin, 2000(04): 30-31+34.

[18] QU Da-cai, SONG Gui-rong,LIJun,etal.Development and Forecast of Semitropical Silk Industry in Guangxi Province[J].Asian Agricultural Research,2009,1 (4) 36-40.

[19] Long Dan. The properties of camphor silk and the preparation and research of silk fibroin microspheres[D]. Wuhan Textile University, 2016.

[20] Vincenzo Count Dandolo.The art of rearing silkworm[M]. London: Northumberland-court,1825.

[21] Yang Yingying, Lv Zhining, Tian Wei, Zhu Chengyan. Characterization of structure and properties of cassava silk[J]. Journal of Textile Research, 2017, 38(06): 1-5.

[22] Zhu Xinyu, editor in chief. "Chinese Silk History" [M]. Beijing: Textile Industry Press, first edition in February 1992.

[23] Luo Lianqing. Adjust the cocoon selection plan to meet the needs of the raw silk market[J]. Guangdong Sericulture, 2006(01): 16-18.

[24] Chengdu Textile Industry School. Silk Making Technology [M]. Beijing: Textile Industry Press, 1986.

[25] Wang Xiaoying. New Weaving Silk [M]. Beijing: China Textile Publishing House, 2001.

[26] Zhejiang Silk Company. Silk Making Handbook [M]. Beijing: Textile Industry Press, 1988.

[27] Hangzhou Textile Machinery Factory, Hangzhou Xinhua Silk Factory. Theory and Management of Automatic Silk Reeling Machine [M]. Textile Industry Press, 1985.

[28] Xu Hui. Real silk knitting production technology [M]. Beijing: China Textile Publishing House, 1996.

[29] Huang Guorui. Cocoon and Silk Science[M]. Beijing: Agriculture Press, 1996.

[30] Suzhou Institute of Silk Technology, Zhejiang Institute of Silk Technology. Silk Making Chemistry [M]. 2 Edition. Beijing: China Textile Publishing House, 1996.

[31] Sajib Kumar Paul, Zhang Luyan, Liu Jiali, Liang Mingjin, Tian Wei, Zhu Chengyan. Research on the automated weaving of Jamdani sari[J]. Silk, 2019, 56(07): 65-69.

[32] The First Editorial Office of China Standard Press. China Textile Standards Compilation: cotton roll; wool, linen, silk roll; chemical fiber roll [M]. Beijing; China Standard Press, 2002.

[33] Product Department of China Textile Industry Association. Ecological Textile Standard [M]. Beijing: China Textile Press, 2003.

[34] Yu Shurong, Wang Jinqian, Zhou Xiaohong, Wu Ziying, Zhu Chengyan. Development and research of spun silk elastic fabric[J]. Silk, 2001(07): 30-32+0.

[35]Yang Yingying, Shoushuangshuang, Ouyang Weiwei, Shi Kangni, Tian Wei, Zhu Chengyan. Research on the properties of fresh cocoon silk and dry cocoon silk fabrics[J]. Silk, 2017, 54(09): 1-6.

[36] Zhang Xia. Comparative study on domestic production equipment for cocoon cooking and silk reeling [D]. Soochow University, 2007.

[37] Yang Herong. Research on the development of my country's cocoon and silk industry [D]. Southwest Agricultural University, 2005.

[38] Yao Mu. Textile Materials Science [M]. Beijing: China Textile Press, 2015.

[39] Yu Chongwen. Spinning [M]. Beijing: China Textile Publishing House, 2009.

[40] Jiang Yaoxing, Guo Yalin. Textile Inspection[M]. Beijing: China Textile Publishing House, 2001.

[41] Chen Wenxing, Fu Yaqin. Silk processing engineering [M]. Beijing: China Textile Publishing House, 2015.

[42] Luo Lianqing, Zeng Ruiwen, Deng Xiaozuan. The effect of dry cocoon moisturizing treatment on silk reeling quality and silk yield[J]. Guangdong Sericulture, 2001(01): 26-30.

[43] Fei Wanchun. Theoretical model describing the titer sequence of cocoon silk[J]. Silk, 2007(02): 19-21.

[44] Zhang Qichao, Jiang Wenbin, Fu Yaqin. Study on the difference of structure and performance between fresh cocoon raw silk and dry cocoon raw silk[J]. Modern Textile Technology, 2015, 23(01): 1-5.

[45] Zhang Guobing. Research and discussion on the direct silk reeling process of fresh cocoons[J]. Light Textile Industry and Technology, 2011, 40(04): 7-8.

[46] Luo Wenzheng, Feng Yunfang. New rapid scouring agent for real silk and its application process [J], Journal of Zhejiang Institute of Silk Technology, 1990, 7 (2): 52

[47] Liu Yongcheng, Shao Zhengzhong, Sun Yuyu, Yu Tongyin. The structure and function of silk protein[J], Polymer Bulletin, 1998

[48] Wang Sansan. Silk Trade: Origin and Characteristics[J], Academic Research, 2019

[49] Silk Culture and Products Compilation Group. Silk History and Culture (1): The Origin of the Silk Road[J], Modern Silk Science and Technology, 2017

[50] "Historical Records: The Benji of the Five Emperors": "The Yellow Emperor lived on the hills of Xuanyuan, and married the daughter of Xiling, he was the ancestor of Lei."

[51] "Tongjian Waiji": "Xiling family persuaded silkworms to harvest, and silkworms started here.

[52] Shen Xianmin. The development trend of the international silk industry and our countermeasures[J], Silk, 2001, 07

[53] Yuan Xuanping, Zhao Feng. "The History of Chinese Silk Culture", Shandong Fine Arts Publishing House

[54] Wang Xuanyu, Zhao Kai, Gao Huiju, Mou Zhimei. Silk culture and its role in social development [J], China Sericulture, 2011, 32(02): 83-87

[55] Feng Yan. On the connotation and industrial significance of silk culture [J], Foreign Silk, 2005, (6): 33-38

[56] Li Bing. Research progress on the origin of silkworm and wild mulberry[J], China Sericulture, 2008, 29 (2): 11-13

[57] Chen Youshan. On Huzhou Silk Culture[J], Journal of Huzhou Teachers College, 1999, (4): 64-68

[58] Li Ronghua, Chen Ping. Introduction to Chinese Silk Culture[J], Sericulture Bulletin, 1997, 17 (3): 28- 32

[59] Zhang Shaohua. On the cultural significance of the Silk Road [J], Theory and Observation, 2005, (6): 74-75

[60] Zhu Chengyan, Zhou Xiaohong. "Modern Weaving Principles and Applications", China Textile Press, 2017

[61] Zhou Jiao. Analysis of the variety and aesthetic characteristics of the three famous brocades in ancient China, Silk, 2018

[62] Qian Xiaoping. Research and Inheritance of Song Jin, Silk, 2015

[63] Zhou Li. Four Famous Chinese Shows, Old Friends, 2015

[64] Wu Lili, Zhan Yuting, Chen Junjun, Lu Jialiang, Zhu Chengyan. The inheritance and application of Zhang satin in modern apparel design[J], Silk, 2020

[65] Liu Shuangshuang, Luo Qianqian, Wang Ling, Tian Wei, Li Qizheng, Zhu Chengyan. Research on the relationship between natural yellow silk fabric degumming process and color difference[J], Silk, 2014

[66] "Silk Origin and History", Shandong Silk Textile Vocational College Library, 2017

[67] Chang Liliang, Research on the Design of Color in Traditional Embroidery[J], Popular Literature and Art, 2019

[68] Long Hairu. Knitting [M]. China Textile Publishing House, 2004.

[69] Chen Weilai. Silk knitting production technology and new product development [M]. China Textile Press, 2010.

[70] Xu Hui, Chen Weilai. Real silk knitting production technology [M]. Beijing: China Textile Publishing House, 1996.

[71] Wang Xiao. Production technology of real silk warp knitted fabrics[J]. Jiangsu Silk, 2002(04): 17-18.

[72] Liu Yunqing, Zhu Yuxiu. Mechanical and physical test of dry knitting yarn[J]. Silk, 1984(02): 39-42.

[73] Qian Hao. Talking about the pre-treatment and dyeing processing technology of silk knitted fabrics [J]. Shanghai Silk, 2012, 000(004): 7-13.

[74] Li Yiyou. Research on the production of silk knitted fabrics by trolley knitting method [C] National Silk Innovation and Product Development Forum. 2003.

[75] Li Yiyou, Cheng Bin. Discussion on the Dyeing and Finishing Process and Equipment of Real Silk Knitted Silk [J]. Silk, 1993.

[76] Chen Weilai. Analysis of the status quo and technological characteristics of silk knitting[J]. Silk, 2001(05): 38-40.

[77] Wang Shuisheng. Scouring and dyeing and finishing of silk knitwear[J]. Silk, 1986(10): 38-39.

[78] Feng Xining. Current status and development of scouring technology for silk knitted fabrics [J]. Knitting Industry, 1989(01): 7+50-52.

[79] Wang Xiao. Discussion on the knitting technology of silk-covered cotton knitted fabric[J]. Modern Textile Technology, 2003(04): 24-25.

[80] Geng Qinyu. Comfortability and performance improvement of real silk[J]. Liaoning Silk, 2000(04): 16-20.

[81] Tian Tian. One-step scouring process of urinary oxygen for silk knitted fabrics[J]. Printing and Dyeing, 1997(09): 8-11+3.

[82] Yang Yang. Selection, products and structure of real silk warp knitting equipment[J]. Silk, 1995(02): 38-40+5.

[83] Li Yiyou, Pan Zhiyu. Discussion on the production technology of real silk weft knitted fabrics[J]. Knitting Industry, 1995(01): 47-51+4.

[84] Wang Fengyun. Analysis on the Dyeing Process of Silk Knitted Fabrics[J]. Silk Technology, 1995(02): 18-19+29.

[1]李国栋. 亚热带蚕种孵化技术集成与创新研究[D].江苏科技大学,2018.

[2]张晴. 中国桑蚕空间格局演变及其优化研究[D].中国农业科学院,2018.

[3]黄扬玉. 亚热带桑蚕原种特点及繁育技术研究[D].广西大学,2018.

[4]杨莹莹,张旻爽,田伟,祝成炎.天然木薯蚕丝脱胶工艺优化与性能分析[J].现代纺织技术,2017,25(05):47-51.

[5]李文治编.《中国近代农业史资料》第一辑 1840-1911[M].北京:三联书店出版， 1957年 12 月第一版.

[6]邓婷婷. 家蚕丝、野桑蚕丝及琥珀蚕丝的结构和性能研究[D].西南大学,2017.

[7]贾雪峰. 广西蓖麻蚕（木薯蚕）产业发展研究[D].广西大学,2017.

[8]Silk Production and Export Management[M]. New Delhi;A.P.H. Publishing Corporation, 2001

[9]李建琴,周育仙,顾国达.我国蚕茧生产空间布局变迁及影响因素分析[J].蚕业科学,2014,40(05):902-910.

[10]周育仙. 中国蚕茧生产空间布局变迁及影响因素分析[D].浙江大学,2014.

[11]姚佳,骆倩倩,祝成炎,寇勇琦,俞丹.天然绿色茧的煮茧工艺[J].纺织学报,2013,34(10):35-38.

[12]齐赫男. 《意大利蚕书》研究[D].中国科学技术大学,2011.

[13]付诚杰. 柞蚕丝结构和力学性能的深入研究[D].复旦大学,2010.

[14]李富强. 中国蚕桑科技传承模式及其演变研究[D].西南大学,2010.

[15]李龙. 印度蚕业发展研究[D].西南大学,2008.

[16]韩益飞. 中国蚕品种输出东南亚国家技术研究[D].苏州大学,2002.

[17]徐世清,陆小平,沈卫德,陈息林,韩益飞,郑必平.中国蚕品种输出东南亚国家技术方案研究[J].中国农学通报,2000(04):30-31+34.

[18]QU Da-cai, SONG Gui-rong,LIJun,etal.Development and Forecast of Semitropical Silk Industry in Guangxi Province[J].Asian Agricultural Research,2009,1 (4) 36-40.

[19]龙丹. 樟蚕丝的性质及其丝素微球的制备与研究[D].武汉纺织大学,2016.

[20]Vincenzo Count Dandolo.The art of rearing silkworm[M].London: Northumberland-court,1825.

[21]杨莹莹,吕智宁,田伟,祝成炎.木薯蚕丝结构与性能表征[J].纺织学报,2017,38(06):1-5.

[22]朱新予主编.《中国丝绸史》[M].北京:纺织工业出版社，1992 年2月第一版.

[23]骆莲清.调整选茧方案,适应生丝市场需求[J].广东蚕业,2006(01):16-18.

[24]成都纺织工业学校.制丝工艺学[M].北京：纺织工业出版社,1986.

[25]王小英.新编制丝学[M].北京：中国纺织出版社,2001.

[26] 浙江省丝绸公司.制丝手册[M]. 北京：纺织工业出版社,1988.

[27] 杭州纺织机械厂,杭州新华丝厂.自动缫丝机理论与管理[M]. 纺织工业出版社,1985.

[28] 徐辉.真丝针织生产技术[M].北京：中国纺织出版社,1996.

[29] 黄国瑞.茧丝学[M]. 北京：农业出版社,1996.

[30] 苏州丝绸工学院,浙江丝绸工学院.制丝化学[M].2版. 北京：中国纺织出版社,1996.

[31] Sajib Kumar Paul, 张鲁燕,刘珈利,梁明进,田伟,祝成炎.Jamdani纱丽的自动化织造研究[J].丝绸,2019,56(07):65-69.

[32] 中国标准出版社第一编辑室. 中国纺织标准汇编：棉卷；毛、麻、丝卷；化纤卷[M].北京；中国标准出成社，2002.

[33] 中国纺织工业协会产品部. 生态纺织品标准[M].北京：中国纺织出版社,2003.

[34] 虞树荣, 汪进前,周小红,吴子婴,祝成炎.绢丝弹性织物的开发研究[J].丝绸,2001(07):30-32+0.

[35] 杨莹莹, 寿霜霜,欧阳微微,侍康妮,田伟,祝成炎.鲜茧丝与干茧丝织物性能研究[J].丝绸,2017,54(09):1-6.

[36] 张夏. 国产煮茧、缫丝生产设备的比较研究[D].苏州大学,2007.

[37] 杨和荣. 我国茧丝绸业发展问题研究[D].西南农业大学,2005.

[38] 姚穆. 纺织材料学[M].北京：中国纺织出版社,2015.

[39] 郁崇文. 纺纱学[M].北京：中国纺织出版社,2009.

[40] 蒋耀兴, 郭雅琳.纺织品检验学[M].北京：中国纺织出版社,2001.

[41] 陈文兴, 傅雅琴.蚕丝加工工程[M].北京：中国纺织出版社,2015.

[42] 骆莲清, 曾瑞雯,邓小钻.干茧补湿处理对缫丝品质和出丝率的影响[J].广东蚕业,2001(01):26-30.

[43] 费万春. 描述茧丝纤度序列的理论模型[J].丝绸,2007(02):19-21.

[44] 章琪超, 江文斌,傅雅琴.鲜茧生丝与干茧生丝的结构性能差异研究[J].现代纺织技术,2015,23(01):1-5.

[45] 张国兵. 鲜茧直接缫丝工艺的研究与探讨[J].轻纺工业与技术,2011,40(04):7-8.

[46] 骆文正, 封云芳. 真丝绸新型快速精练剂与应用工艺[J], 浙江丝绸工学院学报, 1990, 7 (2) : 52

[47] 刘永成, 邵正中, 孙玉宇, 于同隐. 蚕丝蛋白的结构和功能[J], 高分子通报, 1998

[48] 王三三. 丝绸贸易:起源与特征[J], 学术研究, 2019

[49] 丝绸文化与产品编写组. 丝绸历史与文化(1):丝绸之路的起源[J], 现代丝绸科学与技术, 2017

[50] 《史记·五帝本纪》：“黄帝居轩辕之丘，而娶于西陵之女，是为嫘祖。”

[51] 《通鉴外纪》：“西陵氏劝蚕稼，亲蚕始于此。

[52] 沈宪民. 国际丝绸业的发展趋势和我们的对策[J], 丝绸, 2001, 07

[53] 袁宣萍, 赵丰. 《中国丝绸文化史》,山东美术出版社

[54] 王玄瑜, 赵凯, 高绘菊, 牟志美. 丝绸文化及在社会发展中的作用[J], 中国蚕业, 2011, 32(02):83-87

[55] 冯雁. 浅谈丝绸文化的内涵及产业意义[J], 国外丝绸, 2005, (6): 33 - 38

[56] 李兵. 家蚕和野桑蚕的起源研究进展[J], 中国蚕业, 2008, 29 (2): 11 - 13

[57] 陈友善. 论湖州丝绸文化[J], 湖州师专学报, 1999, (4): 64- 68

[58] 李荣华, 陈萍. 中国蚕丝文化概论[J], 蚕学通报, 1997, 17 (3): 28- 32

[59] 张少华. 试论丝绸之路的文化意义[J], 理论与观察, 2005, (6): 74 - 75

[60] 祝成炎, 周小红. 《现代织造原理与应用》, 中国纺织出版社, 2017

[61] 周纠. 中国古代三大名锦的品种梳理及美学特征分析, 丝绸, 2018

[62] 钱小萍. 宋锦的研究与传承, 丝绸, 2015

[63] 周丽. 中国四大名秀, 老友, 2015

[64] 吴丽丽, 詹宇婷, 陈俊俊, 鲁佳亮, 祝成炎. 漳缎在现代服饰设计中的传承应用[J], 丝绸, 2020

[65] 刘双双, 骆倩倩, 王伶, 田伟, 李启正, 祝成炎. 天然黄色蚕丝织物脱胶工艺与色差之间的关系研究[J], 丝绸, 2014

[66] 《丝绸起源与历史》, 山东丝绸纺织职业学院图书馆, 2017

[67] 畅丽亮, 色彩在传统刺绣中的设计研究[J], 大众文艺, 2019

[68] 龙海如. 针织学[M]. 中国纺织出版社, 2004.

[69] 陈慰来. 丝针织生产技术与新产品开发[M]. 中国纺织出版社, 2010.

[70] 徐辉，陈慰来. 真丝针织生产技术[M].北京:中国纺织出版社，1996.

[71] 王晓. 真丝经编面料的生产技术[J].江苏丝绸,2002(04):17-18.

[72] 柳云青，朱毓秀. 干法针织用丝的机械物理试验[J]. 丝绸, 1984(02):39-42.

[73] 钱灏. 浅谈真丝针织物的前处理和染色加工技术[J]. 上海丝绸, 2012, 000(004):7-13.

[74] 李义有. 台车编织法生产真丝针织物的研究[C] 全国丝绸创新及产品开发论坛. 2003.

[75] 李义有，承斌. 真丝针织绸染整工艺与设备的探讨[J]. 丝绸, 1993.

[76] 陈慰来. 真丝针织的现状和工艺技术特征分析[J]. 丝绸, 2001(05):38-40.

[77] 王水生. 真丝针织品精练和染整工艺[J]. 丝绸, 1986(10):38-39.

[78] 冯西宁. 真丝针织物精练技术的现状及发展[J]. 针织工业, 1989(01):7+50-52.

[79] 王晓. 真丝丝盖棉针织物编织工艺探讨[J].现代纺织技术,2003(04):24-25.

[80] 耿琴玉. 真丝绸的舒适性及其性能改良[J].辽宁丝绸,2000(04):16-20.

[81] 田恬.真丝针织物尿氧一步法精练工艺[J].印染,1997(09):8-11+3.

[82] 杨阳.真丝经编设备的选型及产品和结构[J].丝绸,1995(02):38-40+5.

[83] 李义有,潘知愚.真丝纬编面料生产工艺探讨[J].针织工业,1995(01):47-51+4.

[84] 汪凤云.真丝针织物染色工艺浅析[J].丝绸技术,1995(02):18-19+29.