Research progress of polyolefin fibrillating fiber

Shu Hu[1,a],Hui Guo[1,2,b] ,Xiangchao Chen[1,c] and Peng Li[1,d]

[1]Science and Technology Innovation Center,Shenzhen Selen Science & Technology Co., Ltd, Shenzhen 518132,China.

[2]Shenzhen Selen Advanced Material Technology Research Institute Ltd, Shenzhen 518052, China.

E-mail: [a]Corresponding author:hushu@szselen.com, [b]guohui@szselen.com, [c]chenxiangchao@szselen.com, [d]lipeng@szselen.com

Abstract： The properties and producing methods of polyolefin fibrillating fiber were introduced in this paper. The research progress of polyolefin fibrillating fiber and the fibrillating device were reviewed. At the same time, the disparity of fibrillating device at home and abroad was discussed. The problems existing in the domestic polyolefin fibrillating fiber were pointed out, and the development trend of f polyolefin fibrillating fiber was discussed.

1. Introduction

The fibrillating fiber is a new type of synthetic fiber which has developed rapidly in 1870s. At present, the most widely studied and used industrial applications are mainly polytetrafluoroethylene fibrillating fiber and polypropylene as typical polyolefin fibrillating fiber. The PTFE material has excellent thermal stability and chemical resistance, but its raw materials and processing equipment are expensive. Considering the complex processing technology and difficult melt processing, large shrinkage of products and relatively low production efficiency, the PTFE materials are only used in some special occasions [1]. With lighter in density, lower price and material requirement, simple process and high automation of equipments, high in tensile strength and resistant to chemical corrosion, the polyolefin fibrillating fiber is more suitable for industrial production and application[2]. The section of fibrillating fiber is in a flat shape. It contains a lot of superfine fiber, which has high degree of fibrillation, high specific surface area, and strong adsorbing ability. It can be used as the main fiber filter material, as well as small amount of "large size fiber"-skeleton to support network. When made into non-woven air filter materials, it has a fluffy structure, high filtration efficiency and large dust holding capacity but very low air resistance[3]. When polarized with high voltage, the filtration efficiency is further improved, which make it a appropriate material for high efficiency and low resistance air filter production.

2. Process for producing polyolefin fibrillating fiber

The fibrillating fiber is made from polyolefin material with high crystallization and low liquidity. First, the polyolefin is prepared into a thin film. Through full longitudinal stretching and orienting, the longitudinal strength of film is greatly increased, correspondingly the transverse strength is extremely low. Thus the film has a tendency to burst into slim fiber along the longitudinal. After thermal forming and fibrillation process, the polyolefin fibrillating fiber can be obtained as long fiber, or cut into a certain length of short fiber[4].

Long fiber: mixing, extrusion granulation, feeding, extrusion molding, Film preparation, thermal

stretching (orienting), heat-setting, fibrillating (fibrils collection/twisting), and rolling.

Short fiber: mixing, extrusion granulation, feeding, extrusion molding, film preparation, thermal stretching (orienting), heat-setting, fibrillating, ibrils collection, (traction-threading, steam heating, drag, curl), short cut, pack spare.

The manufacturing methods of polyolefin fibrillating fiber are mainly composed of three core technologies:

(1) Preparation of the polyolefin film

Blown film process has advantages of low price of production equipment, high film production, comfortable hand feel of the product, which is mainly used for low-end products such as reticular fibrillated fiber substrate in buildings, bind rope, packaging bags, carpet and decorative fabric etc. As the higher requirements of fibrillated fiber products on quality and stability, the large foreign equipments for flat wire and fibrillation fiber are mainly based on flat film method. For example, the Supertex production line (as shown in figure 1)designed by Farley Brothers company , can produce fibrillation fiber used as lining materials in bulk container, low shrinkage fibrillated fiber used in carpet base cloth and high strength fibrillated fiber used in weaving geotextile. The Supertex production line can produce 300-3300dtex fibrillated fiber, meeting kinds of specific requirements[5].

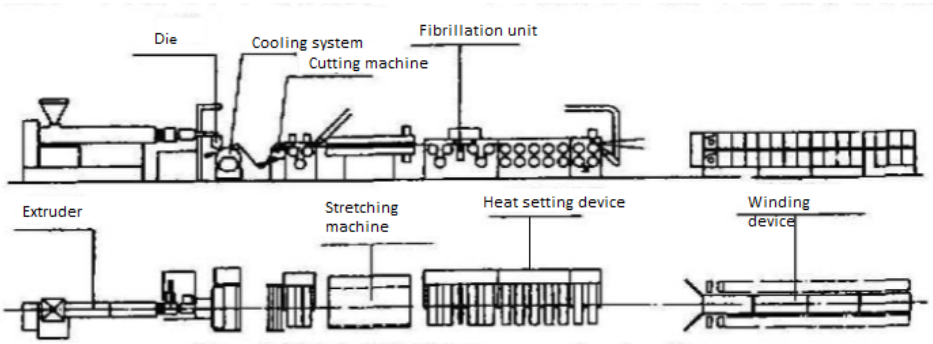

FIGURE 1. Supertex extrusion line for high strength fibrillating fiber.

（2）Film drawing

After decades of application in production, in order to get more fine fiber, after film forming the film is usually sliced into 5 ~ 30 mm ribbon online for hot drawing. Besides, cutting back materials can be recycled.

Cutting usually adopts coaxial blade cutting method. The cutter can be square, diamond, long hole type and can also be a sharp alien blade. The blade material can choose stainless steel, tungsten steel, hard alloy and etc. In order to prolong the service life of blade, coating process is usually used. The ideal thickness of the blade is 0.12 ~ 0.25 mm. According to the requirement of denier of the fiber, a variety of different spacing specifications are formed.

In order to precisely cut, the cutting device should be installed in the position where the film is in tension (as shown in figure 2 and figure 3).

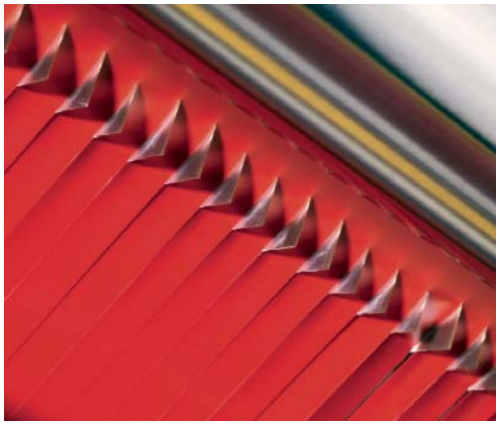

FIGURE 2. The Cutting unit of Starlinger Corp in Austria.

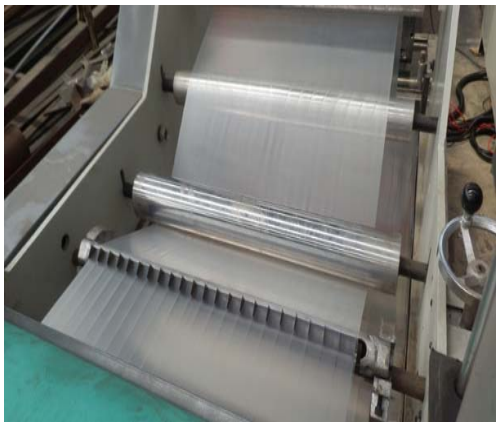

FIGURE 3. The Cutting unit for polyolefin network fiber production line

Thermal film drafting device generally adopts five and seven stretching rollers, making a ideal stretching ratio, as well as finer fibers. The heating methods for stretching mainly divided into electric heating and steam heating and oil heating. Steam heating uses too much energy and is eliminated at this stage. Electric heating mostly uses far-infrared electric thermal roasting, which saves electricity and is convenient for automatic control.

The oil heating is heated by the double helix connecten with the stainless steel multi-layer high pressure hose in the drawing roll, and the temperature of the roller is controlled by thermal oil with high boiling point.

In order to prevent the film from non-uniform heating and fast cooling, the preheating and heat insulation device can be added before stretching roller or between two stretching rollers.

Preheating device/insulation device can be divided into three kinds-hot water (steam) tank, contact device (arched plate) and hot oven. The hot air circulation device with heating oven are mainly used abroad. How to maintain uniform temperature distribution inside the oven without impacting the flatness of the narrow strip needs special attention.

Thermal setting device generally adopts the same as the draft process, but the setting temperature is slightly a little higher than the drawing temperature about 5~ 10℃technically.

(3) Fibrillation of film[6]

Film fibrillating is the core process in fibrillating fiber production. By highly uniaxial tensile (8 ~ 13 times), the longitudinal strength of the film reaches high, while transverse strength reduces to the limit. Through mechanical fibrillation or chemical methods, the film stretches and forms a mesh, then breaks up into fiber, winds for spare. The fibrillation method can be summarized into three categories: the random mechanical fibrillation, the chemical mechanical fibrillation and the adjustable mechanism.

Because the fiber produced by the first two methods is uneven structurally, and the fiber diameter and denier are uncontrolled, random mechanical method and chemical mechanical method is not applied to textile fibers.

Adjustable mechanical method uses mechanical means such as knifing and embossing to fabricate regular fibrillating fiber (reticular fiber) in early times. It develops later that one or two specially designed high-speed roller (as shown in figure 4 and 5) is used. After stretching along the longitude, the banded film passes through the roller fixed with blade or steel needles, and is cut into uniform fibrous mesh.

FIGURE 4. Fibrillation device of Taian Haidai Rope Machinery Science Technology Co.,Ltd.

FIGURE 5. Stretching machine and fibrillation for tape systems fb9 of oerlikon corporate.

Until the 1990s, due to the limited processing capacity and precision of the mechanical equipment, the film thickness of the flat fabrication method is not as thin as the blown method's, which cannot meet the processing requirements of the superfine fiber. With development of electrical automation, mechanical instrument system, precision mold processing and plastic modification, the use of cooling water and cooling roller in flat method come out. This makes flat method better than blown method in film thickness, hand feeling and production efficiency. Film prepared with flat method is more uniform and stable in size, which contributes to film fabrication. Besides, it needs less floor space. Since the mass production at home and abroad in 1890s, the single screw extruder is used, with the screw diameter Φ90~120mm and the draw ratio 30. For example, SJ-L starEX 800 /TM and starEX 1500/TM from starlinger company (see figure 6), with ultimate melting capacity 330kg/h and 600 kg/h, maximum production rate 420m/min and 420kg/min respectively, is mainly used for bag, FIBC weaving cloth, geotextile and agricultural cloth, carpet yarn, man-made lawn film crack silk back etc[7]. Oerlikon company[8] has similar plastic film Tape systems FB9 series extrusion line (as shown in figure 7). Flat wire machine or film line equipped with transverse adjustable high-precision fibrillating device can be used for producing superfine fibrillating fiber as the air filter material.

FIGURE 6. Flat wire drawing machine of oerlikon corporate.

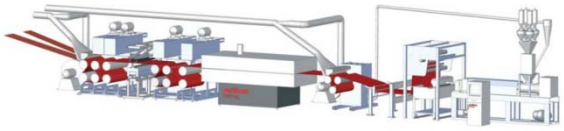

FIGURE 7. Schematic diagram of ape systems FB production line of oerlikon corporate.

3. Research progress of polyyolefin fibrillating fiber

The study of polyolefin fibrillating fiber abroad started earlier. In the 1830s, the Germans Heinrich Jaeque[9] discovered the potential of tape yarn(Slit) and fibrillating fiber (Split) production in the study of tensile phenomenon of polyvinyl chloride (PVC) and polystyrene membrane. Most of the early studies were confined to the laboratory, with no practical value. In the 1860s, with the industrialization of the polypropylene, it opened a world for thermoplastic polyolefins fibrillating fiber. Our country has been researching on the slitting tape yarn and film fibrillating since the 1970s. In domestic Beijing Plastics Factory pioneered the use of cutting tools on the pilot and expanded production of polypropylene fibrillating fiber. They made detail trial test and theoretical analysis on the fibrillation device, technological conditions and the influence factors of fibrillation, especially on basis of forming fibrillated network, average length, denier of the fiber and uniformity, and the cause of broken filament[10]. The fibrillation fiber was first applied to filter material in cigarette. At that time the cigarette filter materials acetate mainly depended on import, thus general attention had been paid on polypropylene fibrillation fibers,for its bonded mesh structure,not easy to loose hair, hardness, and high rate of mouth and so on.

Guojun Liu and others[11] blended PP with LDPE and HDPE respectively in extrusion and blow tube membrane as the filter material of cigarette. LDPE has good film forming stability, and is more soft than PP, for which the wrinkling problem of membrane in the herringbone plate can be solved. However, HDPE and PP have significant difference in characteristics of thermal fluidity, and the thickness contribution of the film is heterogeneous, which is not favorable to thermal stretch and fibrillation. When titanium dioxide (TiO_2) is added in the polyolefin as nucleating agent, the crystallinity and orientation degree of membrane increased. It not only benefits preparation of fibrillating fibers, but also improves whiteness of the product[12]. Haitao Wang and Huanfang Zhang[13~14] respectively used two-step grafting method and high energy electron beam radiation to graft the surface of polypropylene fiber, fabricating polypropylene filter with high absorption. The intercept efficiency of filter fiber after grafting modified was significantly increased, considering total particle phase of mainstream smoke, nicotine and tar content of phenolic compounds.

The raw material for preparing polyolefin fibrillating film requires low liquidity, high tensile strength and high elongation at break. Hence in the practice PP needs to be modified to increase its strength and toughness, in order to improve the effect of fibrillation. Shu Hu and others[15] combined

the surface graft modification of hyperbranched polymer nano powder with POE to improve PP. The fibrillating fiber they prepared has characteristics of high fibrillation degree, high fracture strength and initial modulus. Crystalline ethylene chain segments in POE have good compatibility with PP, so it's easy to get smaller dispersed phase particle and narrow particle size distribution in PP matrix. The compatibility and dispersity of hyperbranched modified polymer nano powder in the polymer base material are obviously improved, which to a certain extent expands and reinforces the PP/POE. This not only improves the tensile strength and toughness of fibrillating fiber, but also plays an important role in reducing breakage in the production process[16]. After curled up and short cut, the film fibrillating fiber can be made into air filtration material with high efficiency and low resistance by means of non-spinning needle-strengthening and high voltage polarization.

4. Progress in research on polyolefin fibrillation equipment

In the 1870s, Yazawa Masahide and others[17] set small regular interval protrusions in the surface of the rotating device, in which the high oriented undirectional film slits itsself into fibrillating fiber. The shell company[18] adopts tube membrane method to prepare the polypropylene film. The film is stretched along longitudinal direction in a hot oven, and then goes through a roller with more than one circular needle. The top of the needle is higher than the roller's surface, and the needle has greater linear velocity than the film has. The rotating direction of needle roller accords with the film movement, while the needles tilts towards the opposite direction of the film movement in a certain angle. When the thermoplastic oriented film goes through the needle roller surface, the film fibrillation appears under the tension of needle line, which forms reticular fiber of average size 10 d. After further processing and it can be made into fabric yarn for the carpet backing, and decorative fabric.

CB Olson and others[19] found that the folding of the membrane leads to vibration during the stretching process and jagged fissures during the cutting period. By locating the serrated roller and pressure roller on the parallel surface of the cylinder, and seperating each other, foldings can be avoided. 3M Company[20~21] treated the oriented film with fluid energy such as ultrasound, high-presssure jet of water organic solvent liquid, air or nitrogen or carbon dioxide, to make its microporous surface fibrillated, and get the fibrillation products with minimal diameter, high strength and high modulus. 3M Company was the first company who applied fibrillation fiber in air filtration material with high efficiency and low resistance. They charged polymer film with static electricity, polarized the fibrillation fiber, and then sticked them together by ultrasonic as non-woven filter. By these means the filtration efficiency and dust capacity of the filter material improved significantly, and the air resistance loweredat the same time[22]. Oricon company[23~24] coated PTFE composite between battens of fibrillation roller surface to reduce friction, ensuring smooth pass of the fiber on fibrillating godet. Xueyue Zhao and others[25] installed triangular blades on the connecting parts, and fixed the connecting parts in dovetail groove of fibrillation roller. However the preblem is it took a lot of time to replace and install the blade. Burckhardt Company[26] fixed the needles on a special needle holder, which simplified the installation of the needles on the needle bed and greatly reduces cost of material and time in replacing the fibrillating mechanism. Chunfeng Liang and others[27] holded that net-like stripes bump in the surface of roller between needle roller, combined with flower pattern in the outer surface, can increase the friction between the fiber bundle and peripheral surface of roller. It made the ribbon or fibrillated film wind on the fibrillation godet in a whole, and could prevent the fiber bundle or film deviating from fibrillation or roller in the process of movement.

At present, the gap in fibrillation device between domestic and foreigner is mainly on needle roller and the needle materials, materials processing, and processing precision, etc.

Specific reasons exist in the following aspects:

(1) Inferior equipment in processing.

In order to save the cost, inferior bits are used, leading to uneven hole size in the needle roller. The aperture is different in size, and the hole is a wave. Poor precision of drilling machine, perpendicular hole and vibrating machine, causing nonuniform hole size and even supression deformation.

(2) Unreasonable materials chosen.

The domestic needle roller is mainly made of brass pipe and Japanese bronze pipe. The pipe is too hard to force uniformly in compression moulding and the needle roller is easy to distort. Fiber roll steel plated hard chrome is mainly used abroad, which is durable and not easy to rust.

(3)The precision of domestic fibrillaring needle is rather poor, and the material and heat treatment are not qualified, causing not enough hardness, easy deformation of long use. While the hardness of imported steel needle exceeds the HRC60. Jiangsu Textile Equipment Research Institute the LTD co. owns the fibrillar mechanism with the highest rows of needle roller and needle density in domestic, which can achieve 10 single needle/cm. India BASANT Company and Sitaram Products Company also achieve the same level, while India Rktexparts Company can make 16 needle/cm in single row.

At present, the world's top level is Switzerland Burckhardt, 25 needle/cm single row, while in stagger way of multi line distribution the needle density can reach 100 cm/row needle, or even 125 needle/cm. This attributes to the needle with minimum diameter 1.4 mm, the accuracy about 0.3 mm, needlepoint exceeding 2 mm in domestic. While imports needle can make minimum diameter 0.3 ~ 0.4 mm, accuracy 0.1 mm, needlepoint exceed 0.5 mm.

(4) The tessellation (assembly) of the fibrillation needle is a delicate work, for the deformation of needle tip caused in installation is irreparable. The needle roller manufacturer uses the internal polish to make repair of the inner diameter, but it is of little effect. To circular polishing inside the roller, it actually aggravates the decentration situation between the needle tip diameter Ds and installing diameter d. For the brass has been suppressed with deformation, it is difficult to find concentric point, to lacate the jig. The inner polishing turns to produce the speaker hole, one side loose and the other tight in assembling, leading the pinpoint of diffrerent height, and seriously affecting the quality of the fibrillation roller. Special craft has been used in needle roller products abroad. It is no need to polish the inner side repeatedly, and batch of needle roller can keep the needlepoint beating degrees within 0.1 mm, 0.03 mm within d size error in the installation. Assembling standard shaft with needle roller, all is sliding bearing assembly effect, not too loose and not too tight. It’s no need to polish the inner hole repeatedly, with high coaxial degree and easy assembly.

(5)According to the experience of foreign companies, there should be strict requirements for dynamic balance and radial vibration during the manufacture and installation of fibrillation equipment. The spacing of needles should be identical. The axis of needle must be perpendicular to the needle roller when installation. It cannot tilt, and the tip height should be consistent. In order to improve the service life of equipment, hard chromium is usually coated in the roll surface, which makes it more difficult to deal with the needles.

5. Summary and prospect

With the rapid growth of economy, China’s chemical fiber industry has kept nearly 20% of high-speed increase for seven years in a row under the rapidly expansive demand of textile market at home and abroad. However, for a long time, there has been a large gap between domestic and foreign manufacturers in plastic film extrusion mould, processing precision, stretching equipment and stability of the cooling system. The fact is that no fibrillating rollers and needles is specially designed for producing superfine fibrillating fiber. Although domestic film fiber production is very high, they are only used in plastic woven bag, jumbo bag, rope, membrane crack yarn, concrete reinfocing fiber in construction and other low-end products. But it is never seen in high-end field, which has more qualification in denier and evenness of fibrillating fiber.

In recent years, the chemical fiber industry in China is still developing at high speed, along with the increasing production. What’s more, the special fiber is one of the key points of the 13th Five-year Plan. Although the polyolefin film fibrillating fiber and its products have many advantages, there is a large gap between China and overseas in polyolefin film fibrillating fiber at present, from the product categories and functionality, stitch density of fibrillating roller, the accuracy of machanism and process stability. It restricts the applications of polyolefin film fibrillating fiber in our country and its special use of air filtration material.

First of all we should study advanced foreign technology of related areas, absorb the core

knowledge of equipment and process, and the essence of design idea. Especially we should upgrade the equipment and technology of fibrillation, enrich the theory of fiber preparation, solve the problem of nonuniform denier, fiber broken, and improve the stability of our products and production efficiency. Secondly according to the practical application, through modifying raw materials, we need to take a active part in developing high functional fibrillating fiber, such as antibacterial, green flame retardant, resistance to ultraviolet, far-infrared modification, electret masterbatch, etc. Last but not least, update its variety and quality level to meet the needs of the market, in order to expand its application range. For the nationwide haze presents currently and gets worse and worse, it is hard to solve this problem effectively in the short term. In this aspect, it is urgent to break the foreign monopoly of film fibrillating fiber technology in the field of air filtration material. The research on film fibrillation fiber in the use of air filtration material with high efficiency and low resistance, can not only satisfy the the increasingly stringent requirements to air filter material and equipment, but also provide more effective protection for public health. Besides, it is also in accord with the national industrial policy, energy saving and emission reduction.

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Corresponding Author: Shu Hu, Mainly engaged in conductive/antistatic polymer composite materials and functional fiber research, E-mail:hushu@szselen.com. Mobile phone: +86 18682350972.

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