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A study on the spinning of combined spinneret holes with various cross-sections

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Abstract: In this paper, a method of direct spinning is proposed for direct spinning of heterogeneous spun wire-blown holes standard parts and the motherboard mounted on the spin board assemblies. The standardization of the spinneret hole was conducive to improving the machining accuracy and efficiency of the pores, and the spinneret holes could be replaced in time when a hole in the spinneret fails. Moreover; on the other hand, according to the needs of the process of spinning, the spinnerets with various cross-sections were combined and installed on the same motherboard for spinning, and the spinning obtained different bionic new functional products. Based on the results, a finite element model of the standard part of the spinneret hole was developed, and the spinnability of the combinable spinnable spinneret board was verified by simulating the melt flow in the spinneret channel through POLYFLOW software. Further, by the processing of the spinneret, the motherboard was installed into a combined spinneret, and the spinneret assembly was installed on the spinning machine for the experiments. Furthermore, the tow section was observed using a microscope, and the results showed the feasibility of the proposed method.

Keywords: Special-shaped spinneret holes, Spinning, Spinnerets, Fluid simulation,

1. Introduction

The fabric that is obtained by processing the special-shaped cross-section fiber has characteristic luster, fluffiness, breathability. And stain resistance, etc., and is widely used in the fields of clothing, decoration, and technical textiles. Presently, for a particular spinneret, all the special-shaped cross-sections on the spinneret are of the same shape and size. If one of the spinneret holes does not work due to failure, it is necessary to replace it with a new or repaired spinneret for re-spinning. Losing or repairing a spinneret plate due to a spinneret hole failure is very expensive and time-consuming, and therefore it affects the production efficiency of the enterprise.

The unevenness of the natural fibers provides a good feel and performance, whereas the chemical fibers have a unified fiber cross-section and mechanical properties, which can enrich the varieties and properties of the chemical fibers using various processing technologies. Further, polyisofibrous fibers with different cross-sections or different line densities have the characteristics of excellent differences in natural fibers. The blended fiber wire formally combines the two, and the controllable bionic fiber products are obtained through the blended fiber spinning. Due to the complexity of the process and the lengthening of the production process in this method, the production efficiency is reduced and the production cost is increased.

In order to improve the spinning efficiency and reduce the production cost, a combined spinning method of spinneret and motherboard that was installed with spinneret was proposed in this work. The shape and size of the spinneret and the cross-section of the spinneret hole were determined according to the spinning process and made into standard parts. These were the corresponding mounting holes on the motherboard. Further, it could be combined according to the process needs. If one of the spinneret holes was found to be faulty, then the spinneret hole was replaced.

The physical properties of the silk threads are related to the shape and size of their formed section. Generally, industrial melt spinning adopts the method of circular hole spinning [1], but the cross-section of the natural long silk thread is non-circular or irregular [2-4]. Kim et al [5] prepared microporous polypropylene hollow fiber membrane by melt-spinning and cold-drawing. The molecular orientation was affected by the melt draw ratio and spinning temperature, and the crystallinity of hollow fiber was affected by melt-draw ratio and annealing temperature. Takarada et al[6]. Developed a numerical analysis program of flat hollow fiber high-speed melt-spinning. By comparing the numerical solution simulation analysis results with the experimental test results, the correctness and effectiveness of the method proposed in this work were verified.

The tow obtained using the direct spinning method of the spinneret composed of the same cross-sectional shape with different cross-sectional shapes and sizes acts as the function of the natural fiber. Further, it has the characteristics of high production efficiency and relatively short process flow. However, the spinning of the spinnerets with different cross-section shapes and sizes has differences such as shrinkage and inconsistent cooling time, which brings great challenges to the spinning of many kinds of different cross-section shapes. Wang et al. [7] theoretically analyzed the possibility of producing blended yarn with a single spinneret and studied the difference of melt-flow with different diameter nozzles under the same spinning pressure. At present, there are relatively many studies on multi-component blending [8-10], however, there is no public report on the method of direct spinning of the spinneret plate assembly composed of many kinds of different cross-section spinneret standard parts.

This paper presents a combined spinning method of the spinneret and motherboard installed with the spinneret. The FEM of the spinneret is established, and the dynamic characteristics of the special-shaped section spinneret hole in the process of spinneret are simulated and analyzed. Based on the processed spinnerets, the spinnerets with different hole shapes, cross-sections, and sizes were installed on the motherboard for the spinning experiments. Further, the spinnability and effectiveness of the proposed method are verified by simulation and experimental results.

2. Combined spinneret with different cross-sections

The modeling of the spinneret and Spinneret of combined multi-class spinneret holes with various cross-sections are discussed below.

2.1 Spinneret

In order to facilitate the replacement of the faulty spinneret holes, a spinneret plate combined with spinneret hole parts and the motherboard for installing the spinneret hole parts was developed in this work. The standardization of the spinneret hole is beneficial in order to improve the accuracy of the micropores and reduce the production cost. At the same time, it is easy to replace it during failures. On the other hand, the spinnerets with various special-shaped sections can be installed on the same motherboard for spinning in order to meet the requirements of the special functional filaments.

This paper proposes for the first time a combination of spinnerets hole standardization and the design of the spinneret schematic diagram. The physical diagram is shown in Fig.1, where the end of the standard part and the corresponding interface on the matrix is easy to pick up.

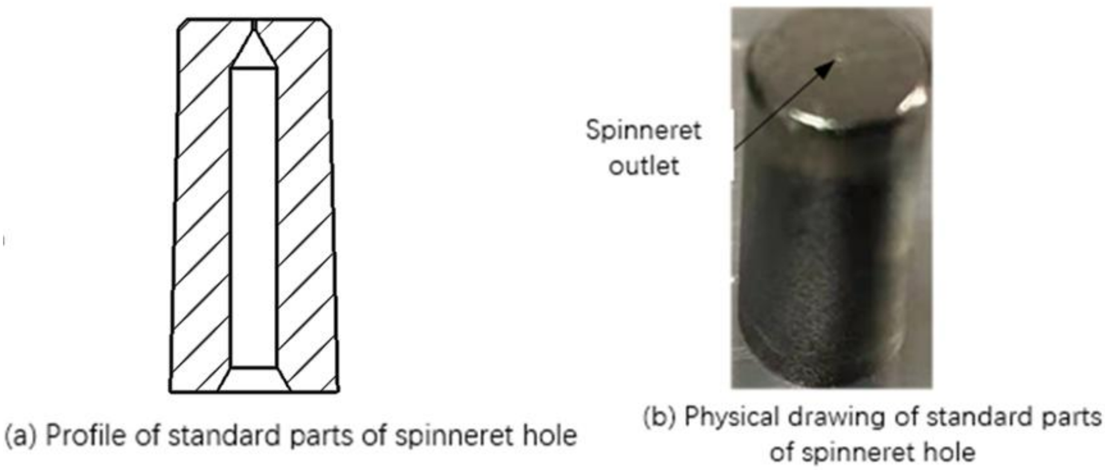

Fig. 1 Design standard parts of spinneret hole and actual processing drawing

In Fig. 1, the spinneret is a circular platform, and the taper adopts the Morse taper of the international standard, which is used for static fit for accurate positioning. As the taper is very small, a certain torque is transmitted by using the principle of friction, and as it is a taper fit, it can be easily disassembled. Within a certain range of the same taper, the workpiece can be disassembled and assembled freely, and the use effect will not be affected during the operation. For example, if the taper shank drill for the drilling has to be disassembled for grinding during its use, it will not affect the central position of the drill after the disassembly.

2.2 Spinneret of combined multi-class spinneret holes with different cross-sections

The spinneret standard parts and the master parts with special-shaped cross-sections were obtained through machining process. As different types of spinneret standard parts with special-shaped cross-sections and the master board could be exchanged, the spinnerets with different cross-section shapes and sizes could be installed on the master according to the spinning process requirements in order to obtain the spinneret assembly, as shown in Fig. 2 (a). It could be compared with the existing industrial spinneret (Figure 2 (b)).

(a) The spinneret hole standard parts are matched with the matrix to install the spinneret plate assembly

(b) Industrial spinneret

Fig. 2 Comparison between the industrial spinneret and spinneret assembly designed in this paper

When compared with the existing industrial spinneret, the machining requirements are found to be high, and the verticality of the micropores and the spinneret surface is difficult to guarantee. Further, the failure of the spinneret hole repair cycle is either long or the replacement cost is high. Therefore, the spinneret assembly proposed in this work is easy to replace the spinneret head, the maintenance is easy and safe. Furthermore, it also develops a new functional product through the combination of the standard parts with various cross-sectional shapes and sizes of the spinneret holes.

3. Simulation analysis of the special-shaped spinneret hole

The simulation analysis of the special-shaped spinneret hole includes the simulation conditions of different types of spinneret holes and the simulation results and analysis. They are briefly discussed below.

3.1 Simulation conditions of different types of spinneret holes

In order to study the spinnability of the spinneret standard parts proposed in this paper, the polypropylene melt flow of spinnerets with different hole shapes was simulated using the POLYFLOW software. The simulation parameters were set as follows:

1) melt inlet conditions: The inlet flow Q was 5.23×10^{-9} m^3/s, and the inlet temperature was 295℃.
2) Channel wall conditions: The slip between the melt and the component channel wall was ignored.
3) Melt outlet conditions: The melt was considered as an incompressible non-Newtonian fluid.

The influence of the inertial force and gravity on the dynamic performance of solution flow was ignored during the simulation. The spinning process parameters used in the simulation are shown in Table 1.

Table 1 Parameters for POLYFLOW software simulation

Type	Numeric_value	Unit
Melt non Newtonian index	0.33	/
Relaxation time	0.0033	s
density	900	kg/m³
Specific heat capacity	1900	J/(kg·K)
Zero shear viscosity	114	Pa·s
Extreme shear viscosity	50	Pa·s

The bird model was used to set the boundary conditions. As the polymer melt was a non-Newtonian fluid and had pseudo plastic behavior at high shear rate γ, the constitutive equation that was selected for the numerical simulation was the bird Carreau model, whose expression is shown in Eq. (1).

$$\eta = \eta_\infty + \frac{\eta_0 - \eta_\infty}{[1+(\lambda\dot{\gamma})^{\frac{1-n}{2}}]} \qquad (1)$$

In Eq. (1), η refers to the shear viscosity of the melt, η_∞ refers to the shear viscosity of the melt. η_0 refers to the shear viscosity of the melt. λ refers to the shear viscosity of the melt, and n refers to the shear viscosity of the melt.

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In the numerical solutions, the viscosity was iterated using the Pi-card algorithm, and the pressure and stress were iterated using the linear algorithm. Further, the velocity was iterated using Mini-element.

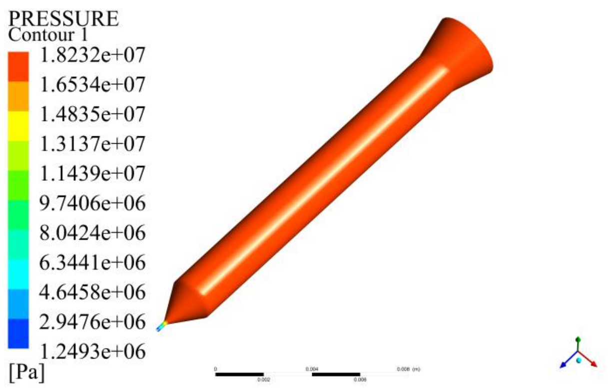
3.2 Simulation results and analyses

The key structural dimension parameters and the process parameters of the spinneret during simulation are shown in Table 2.

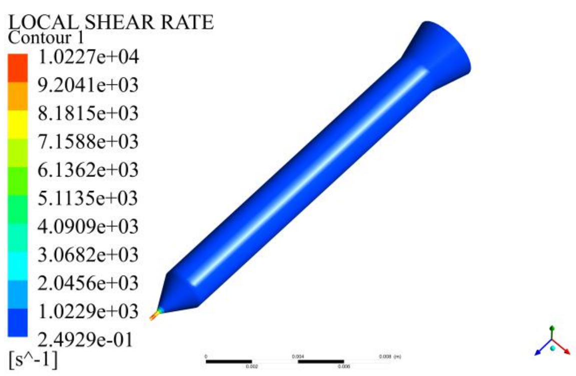
Table 2 key dimensional parameters and inlet flow parameters of spinneret

Section shape of spinneret outlet	Microporous size(mm)	Microchannel depth(mm)
Circular	0.16	0.48
Circular	0.18	0.54
Trifoliary shaped	0.1*0.25	0.5

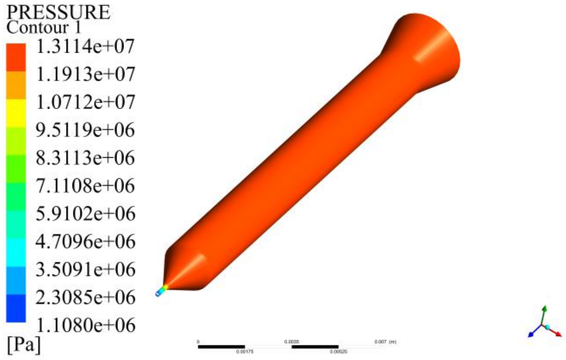
The pressure distribution and the shear rate distribution in the melt channel were obtained by simulating the extrusion of the spinnerets with different cross-section shapes, as shown in Fig. 3.



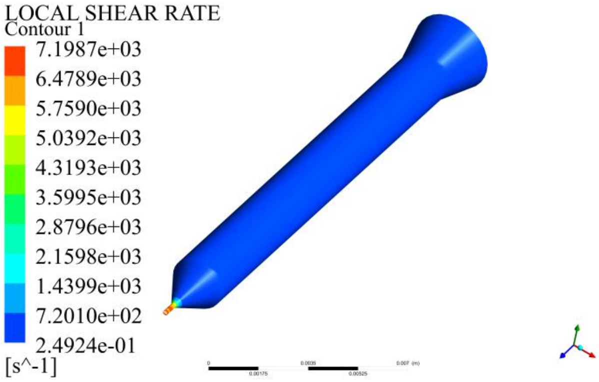
(a) Pressure distribution of circular hole with a diameter of 0.16mm



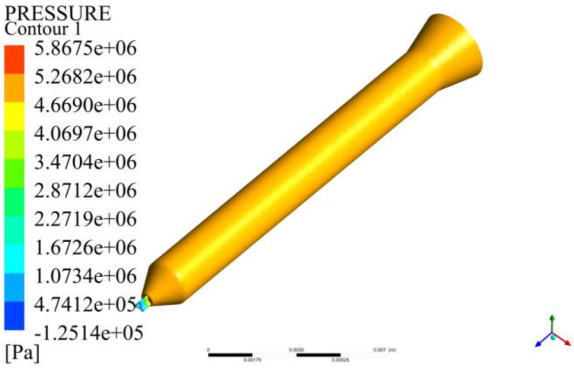
(b) Section shear rate distribution of circular hole with diameter of 0.16mm



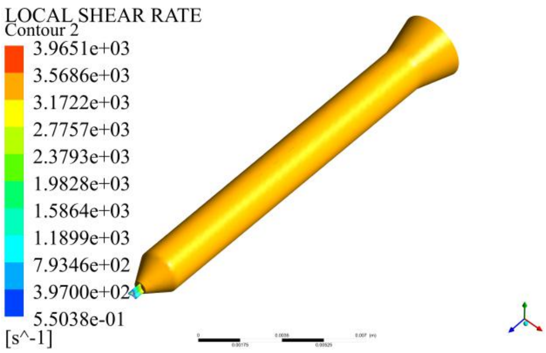
(c) **Pressure distribution of circular hole with a diameter of 0.18mm**



(d) **Shear rate distribution of circular hole with a diameter of 0.18mm**



(e) Dissect the trifoliary 0.1*0.25mm pressure distribution



（f）Dissect the trilobite 0.1*0.25mm shear rate distribution

Fig.3 Simulation study on Spinnability of special section spinneret

From the simulation results of the pressure distribution (a), (c), and (E) in Figure 3, it is observed that the pressure reduction trend of the melt in the spinneret channel along the section direction is the same, and the pressure decreases with the axis. Further, it is found that the pressure drop drops sharply during the transition from the pilot hole to the micropore, and the change is found to be the largest in the spinneret micropore, and the pressure change laws of the three shapes are observed to be the same.

Further, it is observed from the shear rate distribution at the outlets of (b), (d), and (f) in Figure 3 that the shear rate reaches the maximum at the exit of micropores, and it is calculated according to the formula proposed by Miller to convert the size of special-shaped holes into the equivalent diameter of circular holes, 0.10x0.25. The equivalent diameter of the trilobal shape was 0.20mm. Under the same flow rate, the shear rate is found to decrease with the increase of the diameter.

4. Spinning experiment of the combined spinneret with different cross-sections

The materials that were selected for this experiment was the filament grade PP slice from HY Petrochemical Co., Ltd. This experiment was carried out under the condition of the standard ambient temperature of 25 °C and relative humidity of 30%. The spinning process parameters during the spinning experiment are shown in Table 3.

Table 3 Spinning process parameters

Type	Numeric value	Unit
Screw zone I temperature	230	℃
Screw zone II temperature	232	℃
Screw zone Ⅲ temperature	232	℃
Screw four zone temperature	235	℃
Component temperature	240	℃
Side blow speed	0.4	m/s
Side blow air temperature	25±0.5	℃
Distance between the air outlet and spray board surface	100	mm
Blow length	1000	mm
Pump supply	36	g/min

In this work, the spinneret with spinneret hole structure in Table 2 was used for the experimental spinning. The 18 spinneret parts were combined with the motherboard in order to form the spinneret assembly for the spinning, and the three-component composite spinning system of Donghua University was used for spinning, as shown in Figure 4.

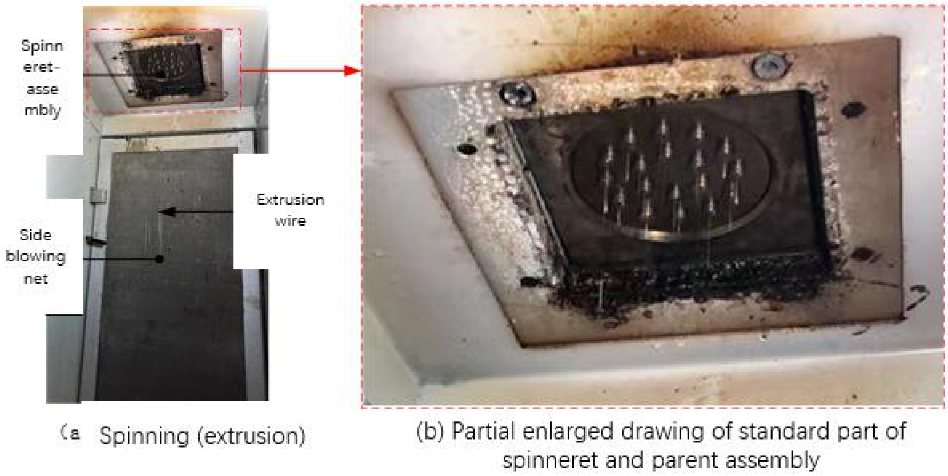


Figure 4: spinning experiment of spinneret composed of spinneret holes with multiple types of special-shaped sections

In order to facilitate the slicing and subsequent observation, a tow with high linear density was obtained by merging. Y172 fiber slicer was used to cut the formed wire with a multi special-shaped cross-section with a thickness of 20um. The fiber cross-section shape was observed under BA210LED biological microscope, and a clear image of the interface was obtained. The fiber cross-section is shown in Figure 5.

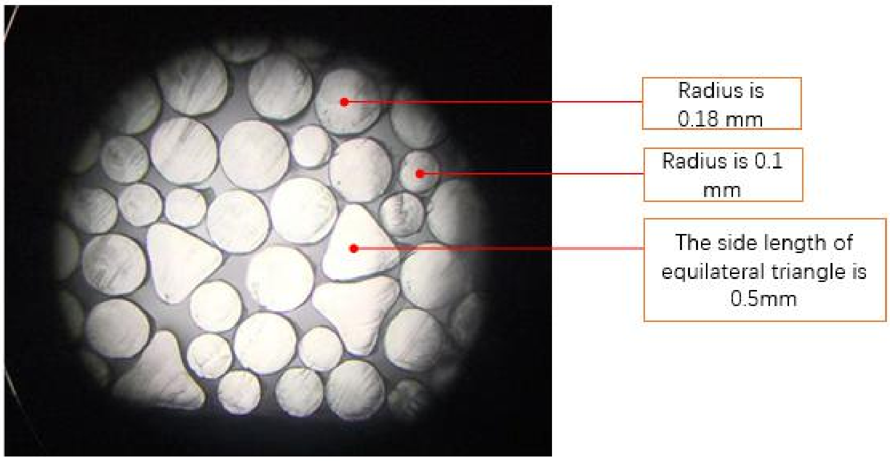


Figure 5: enlarged cross-section of spinning forming tow (100X)

5.Conclusions

In this work, a combined spinning method of the standard spinneret components and motherboard that was installed with the spinneret component was presented. The finite element model of the standard spinneret holes was established, and the dynamic characteristics of the special-shaped section spinneret holes in the process of spinneret were simulated and analyzed. Based on the processed standard spinnerets, the standard spinnerets with different cross-section shapes and sizes were installed on the motherboard for the spinning experiments. The spinnability and effectiveness of the proposed method were verified using the simulation and experimental results.

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References

[1] Happey Y. Applied fiber science[M]. Academic Press, 1978.

[2] Awiszus B. Metal spinning of non-circular hollow parts[C]. Proceedings of the 8th International Conference on Technology of Plasticity, 2005-10. 2005: 353-354.

[3] Awiszus B, Härtel S. Numerical simulation of non-circular spinning: a rotationally non-symmetric spinning process[J]. Production Engineering, 2011, 5(6): 605-612.

[4] Xia Q, Xiao G, Long H, et al. A review of process advancement of novel metal spinning[J]. International Journal of Machine Tools and Manufacture, 2014, 85: 100-121.

[5] Kim J J, Jang T S, Kwon Y D, et al. Structural study of microporous polypropylene hollow fiber membranes made by the melt-spinning and cold-stretching method[J]. Journal of Membrane Science, 1994, 93(3): 209-215.

[6] Takarada W, Ito H, Kikutani T, et al. Studies on high-speed melt spinning of noncircular cross-section fibers. III. Modeling of melt spinning process incorporating change in cross-sectional shape[J]. Journal of applied polymer science, 2001, 80(9): 1589-1600.

[7] Wang N, Zhang J, Kan L, et al. Theoretic analysis on the manufacture of blended yarn by one spinneret[J]. Fibers and Polymers, 2007, 8(3):284-288.

[8] Rave H, Schemken M, Beck A. et al. State of the Art of Bicomponent Staple Fiber Production[J]. Melliand-china, 2002, 52:58-61.

[9] Levin M. Handbook of fiber science and technology[M]. Chemical Processing of Fibers and Fabrics, 1984.

[10] Calhoun P H, Medlock C I, Smith R C. Multi-component fiber including elastic elements[P].

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US.7238423B2. 2007-07-03.