COMPACT SPINNING WITH DIFFERENT FIBRE TYPES: AN EXPERIMENTAL INVESTIGATION ON YARN PROPERTIES IN THE CONDENSING ZONE WITH 3D-PRINTED GUIDING DEVICE

Malik Yonis Hassan Saty1,2,3, Ibrahim Abdalla2,4, Ahmed Elhassan5, Amjad Farooq5, Bismark Sarkodie5, Yong Wang2,6,7, Zhenzhen Xu2*, Jinmei Du1*

1 College of Textiles and Clothing, Qingdao University, Qingdao, 266071, China
2 College of Textiles and Garments, Anhui Polytechnic University, Wuhu, 241000, China
3 College of Engineering Technology of Industries, Sudan University of Science and Technology, Khartoum, 11111, Sudan
4 Shanghai Key Laboratory for Development and Application of Metal Functional Materials, School of Materials Science & Engineering, Tongji University, Shanghai, 201804, China
5 State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, College of Materials Science and Engineering, Donghua University, Shanghai 201620, China
6 Advanced Fiber Materials Engineering Research Center of Anhui Province, Anhui Polytechnic University, Wuhu, 241000, China
7 Anhui Province College Key Laboratory of Textile Fabrics, Anhui Polytechnic University, Wuhu, 241000, China

*Corresponding author. E-mail: xuzhenzhen@ahpu.edu.cn, jinmei_du@qdu.edu.cn

Abstract:

The lattice apron-based compact spinning system is a form of pneumatic compact spinning that employs airflow to condense fibres into a bundle, enhancing the yarn’s attributes. To explore the airflow dynamics in pneumatic compact spinning, researchers primarily employ traditional theoretical approaches, experimental measurement techniques, and computational fluid dynamics (CFD) methods. In our previous research, we utilized CFD to observe the airflow patterns in pneumatic compact spinning. In this study, we implemented experimental measurement techniques to assess the impact of a 3D-printed guiding device (B-type) on yarn properties. We tested different fibre types in the condensing zone of the compact spinning system with a lattice apron. We used three types of roving to spin the yarn: pure cotton, cotton/polyester (80/20), and polyester/viscose (65/35). The findings revealed that yarns spun using the guiding device exhibited superior strength, hairiness, and evenness compared to those spun without the device.

Keywords:

Compact spinning with lattice apron, airflow, yarn properties, 3D guiding device, experimental investigation

1. Introduction

Compact technology is a modified ring-spinning method that can be applied to both short and long staple fibres and provides unique benefits [1,2]. By expanding the capabilities of ring spinning, compact spinning improves the quality of the textiles produced [3–5]. This technique is widely recognized as one of the most progressive in the field of ring spinning [1,6–12]. Because of this, the technology has drawn a lot of interest since it was first shown to the market at ITMA-Paris in 1999. Since then, many spinning mills all around the world have adopted these tools as standard equipment [1]. The yarn formation has set new criteria by the technology of compact spinning [13–19]. Because of the elimination of the spinning triangle, the assembly of the yarn created by the compact technic is dissimilar from using conventional ring spinning. The novel perspectives led by the technology of compact spinning have shown their value in textile operations, from producing yarns to the ultimate steps [20–25]. The goal of compact spinning, as a new spinning mechanism, is to create outstanding yarns [26–31].

Compact spinning condenses the fibres pneumatically or mechanically. Pneumatic compact spinning is dominant nowadays due to the yarns produced from it having the best quality compared to mechanical compact spinning [32]. Pneumatic compact spinning is generally categorized into two types: roller type and lattice apron type [33]. Currently, the most popular compact spinning system is the one that uses a lattice apron; it contributes to up to 95% of the spinning market. As a result, both industry and academic research have shown a great deal of interest in and attention to compact spinning with a lattice apron [34]. Research endeavours aimed at delving deeper into the compact spinning system have concentrated on understanding the airflow domain, which is thought to be crucial in characterizing the yarn manufacturing process [26,34,35]. In order to investigate the flow field in pneumatic compact spinning, researchers mainly focus on traditional theoretical methods, experimental measurement methods, and computational fluid dynamics (CFD) methods [11,31,36]. Experimental investigations were conducted by Altas and Kadoğlu [22] to compare the physical properties of spun yarns and knitted textiles produced using both a mechanical compact spinning machine and the traditional ring spinning system. The analysis examined and compared the characteristics of yarns created through mechanical compaction, pneumatic compaction, and conventional ring spinning techniques. Based on the findings, it was determined that yarns produced by the pneumatic compact spinning method exhibited the highest quality. Yilmaz and Usal [28] conducted a study to examine the characteristics of yarns produced by various spinning methods.
The study utilized traditional ring, compact, and compact jet spinning devices. The investigation revealed that yarns manufactured using the compact jet system had improved property values in comparison to those produced by the conventional ring and compact systems. Cheng and Yu [21] compared the characteristics of cotton yarns made with a traditional ring spinning machine and a Rieter ComforSpin® K40 compact spinning machine. The objective of their investigation was to comprehend the structural variations and underlying principles of the two approaches. The results showed that yarns spun with the compact spinning process were of higher quality with respect to evenness, hairiness, and tensile strength.

In current years, the use of CFD to solve flow-related problems in the textile industry is steadily increasing [37]. Previous studies have utilized CFD methods to analyse and investigate pneumatic compact spinning processes [38,39]. Han et al. [40,41] concentrated on examining the condensation impacts of three different suction slot designs: V-shaped, parallel-shaped, and obliquely parallel-shaped. Utilizing simulations, the researchers investigated the fibre trajectories and flow field within the condensing zone of a compact Siro spinning machine fitted with a lattice apron.

The findings suggested that the optimization of the slot shape could lead to a significant improvement in the possessions of compact spun yarn. Liu and Liu [42] conducted an examination of the 3D flow field characteristics across four different pneumatic compact spinning system configurations. To accomplish this, they utilized AutoCAD software to construct 3D models of the numerous condensing zones and conducted numerical simulations to evaluate the flow field within these zones. The study findings revealed that the type of roller lattice apron utilized has a principal influence on the spreading of the flow field, which in turn significantly impacts the properties of the yarn within the condensing zone. In our previous work [34], three unique guiding devices (A-type, B-type, and C-type) were created to explore the impact of guiding devices on airflow characteristics and yarn properties within the condensing zone of compact spinning using a lattice apron. Through numerical flow field simulations, the underlying concept for designing the guiding device was identified as minimizing negative pressure dispersion and enhancing the efficiency of airflow utilization. Furthermore, the utilization of a guiding device demonstrates a substantial enhancement in the condensing zone’s active range of air velocity, leading to considerable benefits in fibre condensing when compared to the absence of such a device. The analysis of airflow revealed a significant negative pressure in the air-suction flume area, while the central zone exhibited high velocity on its centreline. According to the results obtained, the B-type guide device demonstrated optimal performance in terms of achieving the best quality outcomes for tensile strength, hairiness, and yarn evenness.

The use of 3D printing to fabricate the guiding device provides several advantages over traditional manufacturing methods. The design flexibility of additive manufacturing enables highly customized geometries and material selection, allowing for an optimized form factor with a reduced size. Furthermore, the customized geometry can improve ergonomics and user comfort compared to standard designs. Depending on production volumes, 3D printing may also result in lower manufacturing costs. Additionally, the 3D-printed guiding device offers enhanced customizability, miniaturization, ergonomics, and potential cost savings over conventional approaches. In this study, we investigated the effect of a 3D-printed guiding device (B-type) on yarn properties using experimental measurement methodologies. To achieve this, diverse fibre varieties were spun within the condensing zone of a compact spinning system equipped with a lattice apron. The sections that follow describe the experimental procedures for spinning, yarn spinning, yarn testing, and yarn analysis. In conclusion, the study draws a comprehensive conclusion based on the obtained results.

2. Materials and method

2.1. Materials

The objective of this study was to determine the impact that a 3D-printed guiding device (B-type) has on yarn qualities in the condensing zone of a compact spinning frame with a lattice apron when spinning different fibre types. This was accomplished by spinning the yarn from a combination of three distinct rovings: (a) 100% cotton roving, (b) a blend of cotton and polyester fibre (80/20), and (c) a blend of polyester and viscose (65/35). The linear density of the polyester/viscose blend roving was 538 tex, whereas the pure cotton and cotton/polyester fibre blend rovings weighed 535 tex.

2.2. Method

This section examines the use of a compact spinning system with a lattice apron to produce yarns, with the goal of investigating the effects of a guiding device on diverse fibre types. The top view of the drafting system for the compact spinning system with a lattice apron, which was utilized in this experimental work, is depicted in Figure 1. The specific B-type prototypes, chosen based on the simulation findings, were then 3D printed to enable further experimental evaluation, as shown in Figure 2(a).

Figure 1. Top-down view of the drafting system in the compact spinning system equipped with a lattice apron.
3. Results and discussion

The following testing process was used to evaluate the spun yarns. To get accurate results, we conditioned five bobbins of yarn for at least 48 h under our lab’s regular conditions (65% RH and 20.2% C). Spun yarns were then evaluated based on their hairiness, evenness, and breaking strength. To maintain consistency in performance, the same spindle was used to produce all of the 29.2 tex yarns. Yarn hairiness was evaluated by taking ten measurements on each bobbin yarn sample using a YG172A hairiness tester running at a speed of 30 m/min. The hairiness for that specific bobbin yarn was calculated as the average of these ten measurements. By averaging the hairiness ratings of the five bobbin yarns, the equivalent hairiness of the spun yarn was determined; the empirical findings are presented in Figure 3. According to simulation results from our previous work [34], increasing negative pressure leads to a reduction in hairiness due to the ensuing increase in total airflow velocity, which eliminates the spinning triangle (Figure 3). In contrast, the use of a guiding device that generates a moderate level of negative pressure produces optimal hairiness outcomes. This is attributed to the guiding device’s single, angled side opening, which enables airflow from the side and increases the transverse condensing force. This, in turn, reduces fibre width. Consequently, the flow velocity component appears to be advantageous in reducing yarn hairiness.

The breaking force of the yarn was calculated by running ten tests at a speed of 500 mm/min and a pre-tension of 0.5 cN on a YG020 fully automatic single yarn strength tester in line with the ASTM D2256 international standard. The breaking force for that particular bobbin yarn was calculated by taking the average of these ten measurements. Averaging the breaking force values of the five bobbin yarns yielded the matching breaking force of the spun yarn, and the empirical findings are presented in Figure 4. Figure 4 and the analysis of variance (ANOVA) result indicate that using a guiding device improves the breaking force of yarn. This is because the increased total

Figure 2. (a) Guiding device, with all dimensions provided in millimetres. (b) The side perspective view of the condensing zone incorporating the guiding device.

Table 1. Details the spinning procedure parameters utilized in this study

<table>
<thead>
<tr>
<th>Linear density (tex)</th>
<th>Spindle speed (rpm)</th>
<th>Negative pressure (Pa)</th>
<th>Twist (turn per meter)</th>
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</thead>
<tbody>
<tr>
<td>29.2</td>
<td>10,000</td>
<td>3,000</td>
<td>630</td>
</tr>
</tbody>
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Figure 3. Hairiness characteristics of the spun yarns. (A) Yarns produced without a guiding device. (B) Yarns produced using the guiding device.
the yarn becomes more compact, with improved evenness. The use of the guiding device resulted in substantially greater measured strengths, hairiness, and evenness than those obtained without the guiding device. This is due to the fact that the guiding device helps to centralize airflow around the air vacuum flume above the surface, resulting in a more stable and constant flow field that encourages fibre condensation. Without a guiding device, airflow is diffused and less efficient for negative pressure applications. The experimental results are qualitatively consistent with previous simulation studies [34]. The incorporation of a lattice apron in conjunction with a 3D-printed guiding device represents a novel approach in this work. The lattice apron structure is designed to provide enhanced control and guidance of the yarn path, while the 3D-printed guiding device component helps to precisely direct the yarn flow through the spinning system. By integrating these two elements, this work achieves improved yarn quality and processing efficiency compared to without using guiding device methods.

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