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Woven Air Permeability Textile Fabric for Garment Automation

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Abstract: **This applied research study investigates the integration of air-permeability on the woven textile fabric into garment automation processes, focusing on enhancing efficiency and product quality in modern apparel manufacturing. Air-permeable fabrics, renowned for their breathability and comfort, are widely used in sectors such as sportswear and activewear. However, these materials pose challenges not to applying vacuum suction technology for grabbing fabric when applying vacuum suction grabbing technology for automated handling during loading and unloading of woven fabric in automated machines. Based on experimental calculations and analysis, it was determined that air-impermeable woven fabrics can be effectively grasped by vacuum suction grippers.**

The research explores how the textile structure of woven fabrics can be optimized for use within automated systems, addressing both the challenges and opportunities associated with their application. The methodology included a comprehensive literature review to understand current practices in garment automation, followed by experiments and simulations to evaluate the performance of air-permeable fabrics in automated machinery. Key factors such as yarn structure, permeability coefficient, pore length, pore width, and pore area were analyzed using specific formulas to assess how these properties influence grabbing technology for garment automation.

In conclusion, this research provides valuable insights for manufacturers seeking to integrate air-permeable fabrics into automated systems, offering recommendations for fabric selection and process adaptations. These findings contribute to the advancement of garment automation, supporting the production of innovative and efficient apparel products through robotic automation within the garment and textile industries.

Keywords: **Garment, Textile, Woven Fabric, Vacuum Suction Technology, Gripper.**

I. INTRODUCTION

In the rapidly advancing field of automated assembly production, the characteristics of materials used play a crucial role in determining the efficiency and quality of the manufacturing process. Among these characteristics, air permeability in textiles and woven fabrics has emerged as a significant factor. Air permeability, which refers to a fabric's ability to allow air to pass through it, can influence various aspects of automated production, from material handling to the final product's performance. As industries increasingly adopt automated assembly lines to enhance production efficiency and precision, understanding the material properties that affect these processes becomes essential. Air permeability in textiles and woven fabrics is a property that has garnered attention due to its significant impact on automated manufacturing systems.

This article delves into the applied research on how air permeability in textiles and woven fabrics impacts automated assembly production, highlighting its implications for manufacturing efficiency, product quality, and innovation in textile engineering.

A. Understanding Air Permeability

Air permeability is a measure of how easily air can flow through a fabric. It is influenced by factors such as fiber type, yarn structure, fabric weave, and finishing processes. In the context of automated assembly production, air permeability can affect several key areas:

- Material Handling and Processing:

Fabrics with high air permeability may be lighter and easier to handle in automated systems, reducing the risk of jams or misfeeds. Conversely, low air permeability fabrics might require adjustments in handling equipment to ensure smooth processing.

- Adhesion and Bonding:

In processes where adhesives or bonding agents are used, air permeability can influence the application and curing of these substances. Fabrics with appropriate air permeability levels can ensure even distribution and effective bonding, crucial for product integrity.

- Thermal Management:

Automated assembly often involves processes that generate heat. Fabrics with suitable air permeability can facilitate better heat dissipation, protecting both the material and the machinery from thermal stress.

- Quality Control and Inspection:

Air permeability can also impact the ease of quality control measures. For instance, fabrics that allow for better air flow might be more amenable to certain types of non-destructive testing, aiding in efficient quality assurance.

B. Implications for Product Performance

Beyond the production line, air permeability affects the end-use performance of textile products. In applications such as apparel, upholstery, and technical textiles, the breathability and comfort of the fabric are directly linked to its air permeability. Therefore, understanding and controlling this property during automated assembly can lead to superior product performance and customer satisfaction.

In the innovations in textile engineering, the focus on air permeability has spurred innovations in textile engineering. Researchers are exploring new fiber blends, weaving techniques, and finishing processes to tailor air permeability to specific production and product requirements. These advancements not only enhance automated assembly efficiency but also open up new possibilities for product design and functionality.

Air permeability in textiles and woven fabrics is a critical factor influencing automated assembly production. By understanding and optimizing this property, manufacturers can improve production efficiency, ensure product quality, and drive innovation in textile applications. As research in this area continues to evolve, it promises to unlock further advancements in both manufacturing processes and textile performance, reinforcing the importance of material science in the era of automation.

C. How does the demand for woven fabric affect the textile development

The world textiles and clothing trade patterns in 2022 have been released by the World Trade Organization Statistical Review 2023 and data from the United Nations (UNComtrade), as shown in Fig. 1. Affected by the slowing world economy and fashion companies' evolving sourcing strategies in response to the rising geopolitical tensions, mainly linked to China, the world's textiles and clothing trade in 2022 displayed several notable patterns different from the past.

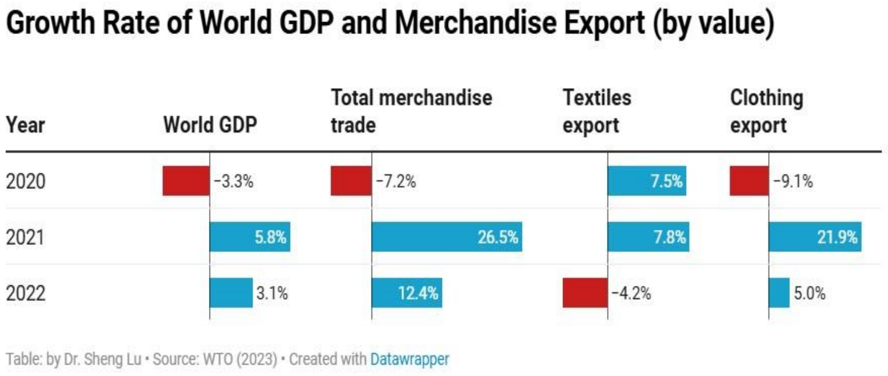


Figure 1: Growth Rate of World GDP and Merchandise Export

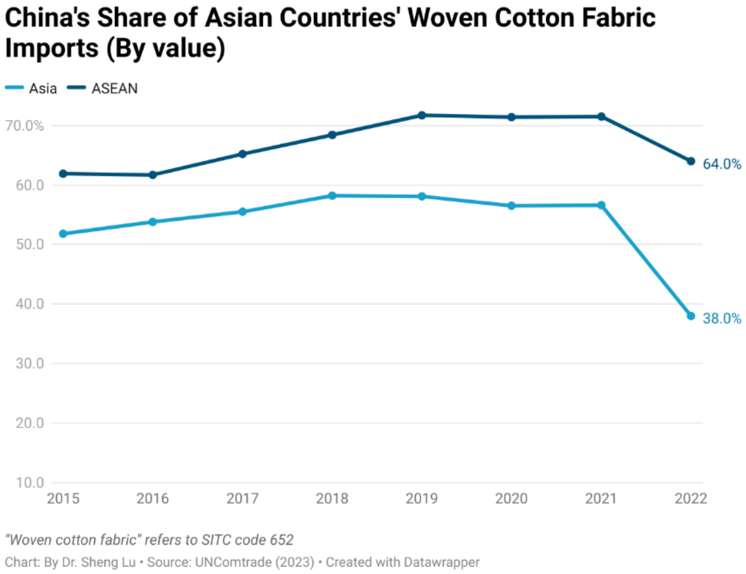


Figure 2: China's share of Asian countries' imports

The regional textile and apparel supply chains were in good shape in Asia and Europe, as shown in Fig. 2. The official implementation of anti-forced labour legislation in the US and other primary apparel import markets directly targeting cotton made in China's Xinjiang region, Asian countries significantly reduced their cotton fabric imports (SITC code 652) from China in 2022. Instead, Asian countries other than China accounted for 46.3 percent of the region's textile supply in 2022, up from around 42-43 percent between 2019 and 2021.

It is critical to watch how willing, to what extent, and how quickly Asian countries can effectively reduce their dependency on textile supplies from China. The result is also an important reminder that Western fashion companies' de-risking from China could exert significant and broad impacts across the entire supply chain beyond finished goods.

Referring to the AI and Robotic Exhibition in Guangzhou of China, in 2025, humanoid robotic and robotic fingers in Fig. 3 have been developed fast and are more reliable for automation. The knit fabric and textile structure can be grabbed by the mechanical gripper. The special character of woven textile fabric is tested to use the vacuum suction technique for applying to the grabbing gripper. The characteristic property of air impermeability of woven textile fabric can be suctioned by a vacuum suction gripper. It can work in the garment automation for the loading and unloading process of grabbing fabric pieces for the sewing machine.

This research paper shows the analysis of the air impermeability characteristic of woven fabric, a textile structure which to be grasped by the automatic grabbing technology.

Figure 3: AI and Robotic Exhibition in Guangzhou of China

II. LITERATURE REVIEW: AIR PERMEABILITY TEXTILE FOR WOVEN FABRIC

Referring to the Fotsing, J. A. M., & Ndadja, G. [3], the investigation on the moisture resistance of wood finishes shows an oil-based paint or glycerophthalic lacquers have good impermeability, good covering, high gloss, and adhesion. The good impermeability does not prevent the substrate from breathing. The coating for wood finishes with oil-based paint or glycerophthalic lacquers has good stain resistance and a fast rate of drying. The glycerophthalic lacquers products suffer from high toxicity, high flammability, weakening the pores, and average mechanical resistance. In the article by Fotsing et al., the analysis of oil-based paint, ECOLAC, an acrylic paint, and ACRYLUX was conducted in an environmental chamber. The environmental chamber has an air jet passed around the two thermometers. The dry thermometer indicated the temperature of the air, and the wet thermometer indicated a temperature normally lower than that of the dry thermometer. After the test, typical paints of this family include pliolite paints containing pliolites resins in the solvent phase, paints containing glycerophthalic resins, paints containing alkyd-urethane resins, and cellulosic lacquers for the metal body supports (bicycle, motorcycle, car).

Emulsion paintings owe their success to their convenience of application. Emulsion paints often have good flow properties, capable of achieving complete coverage with one application, and are odourless. Emulsion paint films are soluble in water before complete drying, therefore allowing easy cleaning with water of the spots and tools. Films formed by emulsion paints are relatively impermeable, have a degree of resistance to washings, and are colour-fast. Emulsion paints are non-flammable and of reduced toxicity. They have a good penetration in the substrate and dry very slowly in the event of high moisture or of low ambient temperature. Emulsion paints have good chemical resistance and are very sensitive to shocks. Some examples of this type of paint are acrylic resin-based paints, vinyl resin-based paints, epoxy resin-based paints, and unsaturated polyester resin-based paints.

The experiment reported here consisted of determining the efficiency of the two paints investigated to protect the wood surface from moisture in the surrounding atmosphere. It was found that oil-based paint gave better protection of wood in wet environments, areas with strong pluviometry (where the quantity of steam in the air is very high). It was advised to use emulsion paints for decorative purposes for interior surfaces in areas such as the dining room, corridor, etc. Glycerophthalic lacquer is more suitable for application in areas subjected to high emissions of water vapour or requiring frequent washing (bathroom, kitchen, WC, etc.).

Regarding the investigation of moisture resistance in wood finishes and the properties of different types of paints can be related to the concept of air permeability in woven fabrics through the broader theme of material permeability and its implications for performance in specific environments.

- Permeability and Breathability:

Just as the oil-based paints and glycerophthalic lacquers provide impermeability while allowing the substrate to "breathe," woven fabrics with certain structures can offer a balance between air permeability and breathability. This balance is crucial in applications where moisture management and air flow are important, such as in apparel or technical textiles.

- Material Properties and Application Suitability:

The choice of paint for wood finishes is based on the specific environmental conditions and desired properties, such as impermeability, gloss, and moisture resistance. Similarly, the structure of woven fabrics is selected based on the required air permeability and other performance characteristics for their intended use. For instance, fabrics with lower air permeability might be chosen for applications requiring wind resistance, while those with higher permeability might be preferred for breathability and comfort.

- Environmental Conditions:

The study highlights how different paints perform under varying moisture conditions, similar to how woven fabrics are evaluated for air permeability in different environmental settings. Understanding how materials interact with their environment is key to optimizing their performance, whether in preventing moisture ingress in wood finishes or managing air flow in textiles.

- Functional and Aesthetic Considerations:

Just as emulsion paints are recommended for decorative purposes due to their ease of application and aesthetic qualities, woven fabrics are often chosen for both their functional properties (like air permeability) and aesthetic appeal. The dual focus on functionality and appearance is common in both fields.

- Material Selection for Specific Conditions:

The recommendation to use glycerophthalic lacquer in areas with high water vapour levels parallels the selection of woven fabrics with specific air permeability levels for environments where moisture management is critical, such as in outdoor gear or sportswear.

In summary, the principles of material permeability, environmental adaptation, and application-specific performance discussed in the context of wood finishes and paints can be analogously applied to understanding and optimizing air permeability in woven fabrics. Both fields emphasize the importance of selecting materials based on their interaction with environmental factors and their suitability for specific functional and aesthetic requirements.

Referring to Umair, M. et al. [4], their study is related to the Effect of Woven Fabric Structure on the Air Permeability and Moisture Management Properties. The relationship between woven fabric structure and air permeability is explored in detail. Here is a summary of the key findings regarding this relationship:

- Fabric Weave Type:

The structure of the weave significantly influences air permeability. Fabrics with looser weaves, such as plain or basket weaves, tend to have higher air permeability because the spaces between the yarns allow more air to pass through. Conversely, tighter weaves, like twill or satin, have lower air permeability due to the denser arrangement of yarns.

- Yarn Density:

The density of yarns in the fabric, both in terms of warp and weft, affects air permeability. Higher yarn density typically results in lower air permeability as the fabric becomes more compact, reducing the spaces through which air can flow.

- Yarn Thickness and Twist:

Thicker yarns and those with less twist can increase air permeability by creating larger inter-yarn spaces. Conversely, finer yarns and those with higher twist may decrease air permeability due to the tighter packing of fibers.

- Fabric Thickness:

Thicker fabrics generally exhibit lower air permeability because the increased material volume restricts air flow. However, the impact of thickness can vary depending on the weave type and yarn characteristics.

- Finishing Processes:

Post-weaving finishing processes, such as calendaring or coating, can alter air permeability by changing the surface characteristics of the fabric. These processes can either increase or decrease air permeability depending on the desired fabric properties.

Umair, M. et al. highlight that the woven fabric structure is a critical determinant of air permeability, with various structural elements interacting to influence how air passes through the fabric. Understanding these relationships allows manufacturers to tailor fabric properties to specific applications, optimizing both performance and comfort.

Referring to Ogulata, Tugrul [5] highlights that woven fabrics with open structures, loose weaves, and thinner yarns tend to have higher air permeability. Conversely, tightly woven fabrics with thicker yarns and compact structures exhibit lower air permeability. The relationship between woven fabric structure and air permeability is critical for applications such as clothing, filtration, and industrial textiles where airflow control is essential. The key relationship between woven fabrics and air permeability is related to the fabric structure; the weave pattern (e.g., plain, twill, satin) affects the porosity and pore size distribution of the fabric, which directly influences air permeability. The tighter weaves (e.g., plain weave with high density) have smaller pores, resulting in lower air permeability. In contrast, looser weaves or open structures allow more airflow. The yarn properties in terms of type and thickness of the yarns used in weaving play a significant role. Thicker yarns reduce pore size, lowering air permeability. Yarn twist and crimp also affect the fabric's porosity; higher twist can compact the yarns, reducing airflow. The fabric thickness affects the air permeability. Thicker fabrics generally have lower air permeability because they create more resistance to airflow. The porosity of woven fabrics is determined by the ratio of open pores to the total fabric area. Higher porosity correlates with higher air permeability. The Post-Weaving Treatments that processes such as calendaring or resin finishing, can reduce pore size and lower air permeability. On the other hand, processes like singeing or sanding can increase pore size, improving air permeability.

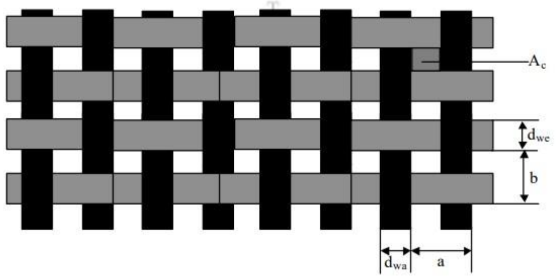


Figure 4: Plain woven fabric structure

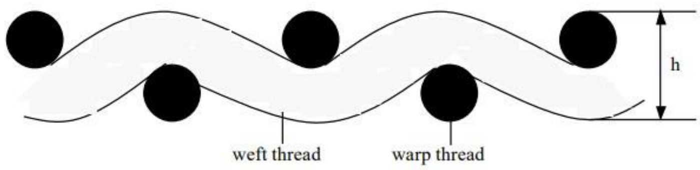


Figure 5: Cross-section of woven fabric structure

A woven fabric structure in plain woven and cross-section is shown in Fig. 4 and Fig. 5, respectively. During the transport of the air through the process of woven fabrics, part of the energy of the air is used to overcome the friction of the fluid on the fabric, and the rest to surmount the inertia forces. Ogulata, Tugrul has stated that the fluid friction of the fabric increases when the size of the pores decreases.

Referred to Zhu, G. [6], the diameter of cotton yarn was predicted by considering yarn count, twist, and packing density. Subsequently, the pore area and equivalent pore diameter of the fabric were predicted after finding the warp and weft densities of the fabric. The predicted values had very good agreement with the experimental results in yarn diameter and other structural parameters of the fabric. The air permeability of fabrics was measured, and several well-known analytical models for predicting air permeability were compared. The results revealed that the Hagen–Poiseuille equation had much better prediction than other models and also had good agreement with the experimental results, especially when it was applied for tight fabrics at low pressure drop (≦60 Pa). The Hagen–Poiseuille equation could be improved by considering the Reynolds number, interfiber interstices, and the deformation of pores under higher pressure drop.

The related considerations are that the pore in the woven fabric affects the air permeability. Figure 5 shows the Images of cotton woven fabrics with different weft densities (magnification 50*x*): (a) images from a microscope; (b) binary images from MATLAB in the article of Prediction of structural parameters and air permeability of cotton woven fabric in the Textile Research Journal.

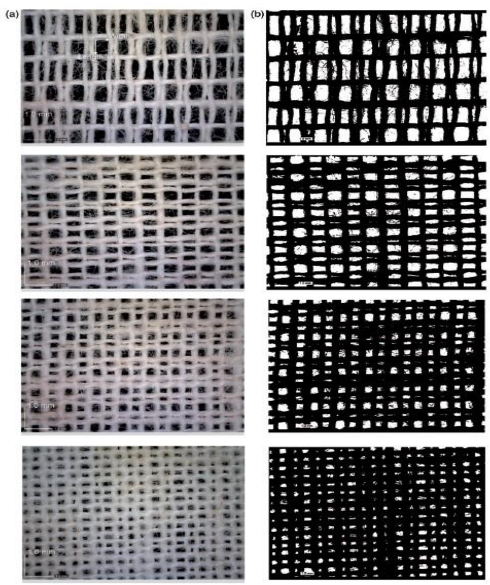


Figure 6: Images of cotton woven fabrics

The Pore length, pore width, pore area, equivalent pore diameter, and pore number. Assume the pore shape in woven fabric is rectangular (shown in Figure 1), then the pore length (shown in Fig. 6) can be calculated by below formulas.

$$a = c_1 \frac{10 - N_1 d_y}{(N_1 - 1)} \tag{1}$$

$$d_y = \sqrt{\frac{4T}{\pi \emptyset \rho_f}}\ 10^{-3} \tag{2}$$

$$\emptyset = 1/\sqrt{1 + (\pi d_y Z)^2} \tag{3}$$

where a is the pore length (mm), c_1 is the number of weft yarns attaching it (here $c_1 = 1$), and N_1 is the number of yarns per centimetre in the weft direction in formula (1).

where d_y is the yarn diameter (m), T is the yarn fineness (tex), $\emptyset$ is the packing density of the yarn, and ρ_f is the fibre density (kg/m³) in formula (2).

where Z is the yarn twist (numbers per unit length). It is worth noting that the packing density is also influenced by the materials and spinning technology in formula (3).

Similarly, the pore width (shown in Figure 1) can be obtained by below formulas.

$$b = c_2 \frac{10 - N_2 d_y}{(N_2 - 1)} \tag{4}$$

where b is the pore width (mm), c_2 is the number of warp yarns attaching it (here $c_2 = 2$), and N_2 is the number of yarns per centimetre in the warp direction.

Simply, the pore area, A_p (mm^2) is the product of pore length and pore width, which is given by formula (5).

$$A_p = c_1 c_2 \frac{10 - N_1 d_y}{(N_1 - 1)} \frac{10 - N_2 d_y}{(N_2 - 1)} \tag{5}$$

The equivalent pore diameter, d_p (mm), is defined as a quotient between the pore cross-sectional area A_p and the wetted perimeter of the cross-section C_p (mm), which can be expressed by the formula (6).

$$d_p = 4\frac{A_p}{C_p} = \frac{4ab}{2(a+b)} \tag{6}$$

The pore number, N_p, in the testing area is formula (7) is.

$$N_p = r\,\frac{A_T}{A_p} \tag{7}$$

where A_T is the testing area of the sample (mm^2) and r is the ratio of the pore area to the fabric area in the cross-section.

The pore length, a, and the pole width, b, can be calculated using the above formula. In the manufacturing process, we can measure the pore in the porosity of the woven structure, which is quite straightforward for air permeability.

Darcy's Law states that the rate of flow is directly proportional to the pressure drop causing flow.

$$q = k\,\frac{\Delta p}{\mu L} \tag{8}$$

where q is the rate of flow (m/s), k is the permeability coefficient, Δp is the pressure drop (Pa), μ is the dynamic viscosity of the flow (Pa.s), and L is the length of the tube or the thickness of the fabric (m) in the formula (9).

$$k = \frac{\varepsilon^3}{180(1-\varepsilon)}\,{d_y}^2 \tag{9}$$

$$\varepsilon = \frac{(1 - \rho_{fa})}{\rho_f} \tag{10}$$

where ε is porosity and ρ_{fa} and ρ_f are the densities of the fabric and fibre (kg/m³) respectively. Fabric density is the quotient between the fabric mass and the fabric area. The Kozeny–Carman equation is the permeability-porosity relation, which is widely used in the field of flow in porous media. The Kozeny–Carman equation relates the permeability k to porosity in formulas (9) and (10).

The lecture review statement connects the references they provided with the topic of air permeability in woven textiles. The user has given me several research papers authored by Kong and colleagues from 2024 and 2025. These papers cover topics like lean methodology for garment modernization, design of pulling gears for automated sewing machines, mixed-integer linear programming (MILP) for line balancing, innovative line balancing for aluminum melting processes, line balancing in the modern garment industry, innovative vacuum suction-grabbing technology for garment automation, an automated stretch elastic waistband sewing machine, AI intelligent learning for manufacturing automation, and AI magnetic levitation conveyors for automated assembly production.

Prof Dr Ray Wai Man Kong [7] [8] stated the lean methodology in garment modernization for garment automation machinery. Lean methodologies aim to eliminate waste and improve efficiency in production processes. This could relate to optimizing the manufacturing steps involved in producing woven fabrics with specific air permeability properties.

Design a New Pulling Gear for the Automated Pant Bottom Hem Sewing Machine from Prof Dr Ray Wai Man Kong [9] in 2024 discusses designing a new pulling gear for an automated pant bottom hem sewing machine. The garment woven fabric for pants is reliant on the development of the machinery used in garment production, which might be less directly related to air permeability, but could be relevant to the control of pulling gear, how automation can influence fabric quality or consistency during manufacturing.

Referring to Prof Dr Ray Wai Man Kong [10] [11] [12], there's one on MILP for garment line balancing and optimization technique for optimization. Line balancing is about evenly distributing tasks across workstations to maximize efficiency and minimize idle time. This could tie into optimizing the production of fabrics with desired air permeability by ensuring that each step in the weaving process is balanced and efficient. There is a key factor to make a consistent quality and standard time.

Furthermore, Prof Dr Ray Wai Man Kong [13] discusses line balancing in the modern garment industry, which again could relate to optimizing production processes that affect fabric properties like air permeability.

There's also a paper from Prof Dr Ray WM Kong [14] on innovative vacuum suction-grabbing technology for garment automation. This sounds like it involves machinery that uses a vacuum to handle fabrics during manufacturing. If this process affects how fabrics are handled or tensioned, it might influence the weave structure and thus air permeability.

Another article, Prof Dr Ray WM Kong [15], is about an automated stretch elastic waistband sewing machine. This seems specific to a type of garment, but could involve technologies that ensure consistent quality in stitching, which might relate to fabric integrity and indirectly to air permeability if stitching affects the openness of the weave.

The AI intelligent learning for manufacturing automation paper, Prof Dr Ray WM Kong [16] [17] in 2025, suggests using artificial intelligence to improve manufacturing processes. AI could be used to optimize weaving parameters to achieve the desired air permeability by adjusting variables like thread tension, density, or material composition dynamically during production.

AI magnetic levitation (maglev) conveyors are for automated assembly production. This technology uses magnetic fields to move objects without physical contact for garment automation, which could provide precise control over fabric handling in weaving machines, potentially allowing for more consistent and controlled weave patterns that affect air permeability from Prof Dr Ray WM Kong [18].

Now, connecting all these points back to the development of air-permeable textiles for woven fabrics, it seems like several of Kong's papers discuss automation, optimization, and innovative technologies in garment manufacturing. These advancements could be applied to enhance the control over weaving processes, enabling the creation of fabrics with specific air permeability characteristics.

Using lean methodologies (from the 2024 paper) could streamline production steps to eliminate waste and ensure that resources are used efficiently when crafting woven fabrics designed for high or low air permeability. The design of automated machinery with vacuum suction-grabbing technology (from another 2025 paper) might allow for more precise control over fabric layers, affecting how open or tight the weave is, which directly impacts air permeability.

The application of MILP in line balancing could help optimize the allocation of tasks in weaving production lines to ensure that each step contributes effectively to achieving the desired air permeability without unnecessary delays or inefficiencies. Similarly, AI technologies like intelligent learning systems (from a 2025 paper) could analyze data from weaving processes and adjust parameters in real-time to maintain consistent air permeability across batches of fabric.

Overall, these research areas seem to collectively contribute to advancements in manufacturing techniques that can precisely control the properties of woven fabrics, including their air permeability. By integrating lean methodologies, advanced automation technologies, AI-driven optimizations, and innovative machinery designs, it's possible to develop woven textiles with tailored air permeability suitable for various applications, from sportswear requiring breathability to industrial fabrics needing specific filtration capabilities.

It reflects these connections clearly, highlighting how each of Kong's research areas contributes to the broader goal of developing air-permeable textiles in woven fabrics. It should summarize the key points without getting too bogged down in technical details, making it accessible for an academic audience.

This lecture review explored the innovative advancements in textile manufacturing technologies and their implications on the development of air-permeable woven fabrics. Drawing from recent research by Kong et al., the discussion highlighted how lean methodologies can optimize production processes to enhance efficiency and reduce waste, thereby supporting the creation of textiles with controlled air permeability. The integration of advanced automation technologies, such as vacuum suction-grabbing systems and automated sewing machines, was emphasized for their potential to precisely control weave structures, directly influencing fabric openness and breathability.

Furthermore, the application of Mixed-Integer Linear Programming (MILP) in line balancing was presented as a strategic approach to optimize task distribution across production lines, ensuring consistent quality in achieving desired air permeability. The lecture also underscored the role of artificial intelligence (AI), particularly AI-driven intelligent learning systems and magnetic levitation conveyors, in dynamically adjusting weaving parameters for real-time optimization. These technologies enable precise control over fabric properties, facilitating the production of woven textiles with tailored air permeability suitable for diverse applications.

In summary, the lecture illustrated how a combination of lean manufacturing principles, automation innovations, and AI-driven optimizations is driving advancements in woven fabric technology. These developments are paving the way for the creation of high-performance textiles with controlled air permeability, addressing needs across various sectors from sportswear to industrial filtration.

III. WOVEN FABRIC FOR THE GRABBING TEST FROM VACUUM SUCTION TECHNOLOGY

The use of woven fabrics in vacuum suction-grabbing tests involves evaluating how these materials interact with and respond to vacuum-based handling technologies, as discussed in Kong et al.'s research. Woven fabrics are selected for their structural integrity, flexibility, and porosity, which are critical for applications involving vacuum systems.

- Weave Density:

A denser weave provides better resistance to tearing under suction pressure but may impede airflow efficiency.

- Yarn Type and Finish:

The type of yarn (natural vs. synthetic) and any finishes applied can affect the fabric's durability and how it interacts with vacuum systems.

- Mechanical Properties:

Tensile strength and flexibility are crucial for maintaining integrity during handling without damage.

Looking at the references, Kong et al. have written about innovative technologies like vacuum suction-grabbing for garment automation and automated waistband sewing machines. They've also discussed lean methodologies and line balancing in manufacturing processes. These topics suggest that their work focuses on improving efficiency and automation in textile production.

Woven fabrics' properties with how they perform in vacuum suction-grabbing tests. Woven fabrics have structures defined by warp and weft yarns, which influence their mechanical properties like tensile strength, flexibility, and porosity. These properties are crucial for applications involving vacuum suction, as the fabric needs to be handled without damage.

In a gripping test using vacuum suction technology, the fabric's ability to maintain integrity under suction pressure is essential. Factors like weave density, yarn type, and finish can affect how well the fabric holds up during handling. For instance, a densely woven fabric might offer better resistance to tearing but could also restrict airflow, impacting the efficiency of the vacuum system.

Kong et al.'s work highlights the importance of optimizing these properties through advanced manufacturing techniques like Mixed-Integer Linear Programming (MILP) for line balancing, ensuring consistent quality. Additionally, AI-driven systems can predict optimal weave patterns or identify potential weaknesses, enhancing performance in vacuum handling applications.

Woven fabrics' suitability for vacuum suction-grabbing tests is determined by their structural and mechanical properties, which can be optimized using advanced manufacturing techniques to ensure both testing performance and compatibility with automated garment production systems.

Grabbing Test on the air impermeability of woven fabric

Grabbing a test on the air impermeability of woven fabric is an important part of automation machinery development. Basic woven textiles are composed of two components: warp and weft tows/yarns that are interlaced with each other to produce a layer. To relate the textile structure for woven fabric, the pore length, pore width, and pore area of the fabric are the parameters of porosityε, ρ_{fa} and ρ_f are the densities of the fabric and fibre (kg/m³) respectively. Fabric density is the quotient between the fabric mass and the fabric area. The Kozeny–Carman equation is the permeability-porosity relation, which is widely used in the field of flow in porous media as referred above, permeability k to porosity in formulas (9) and (10).

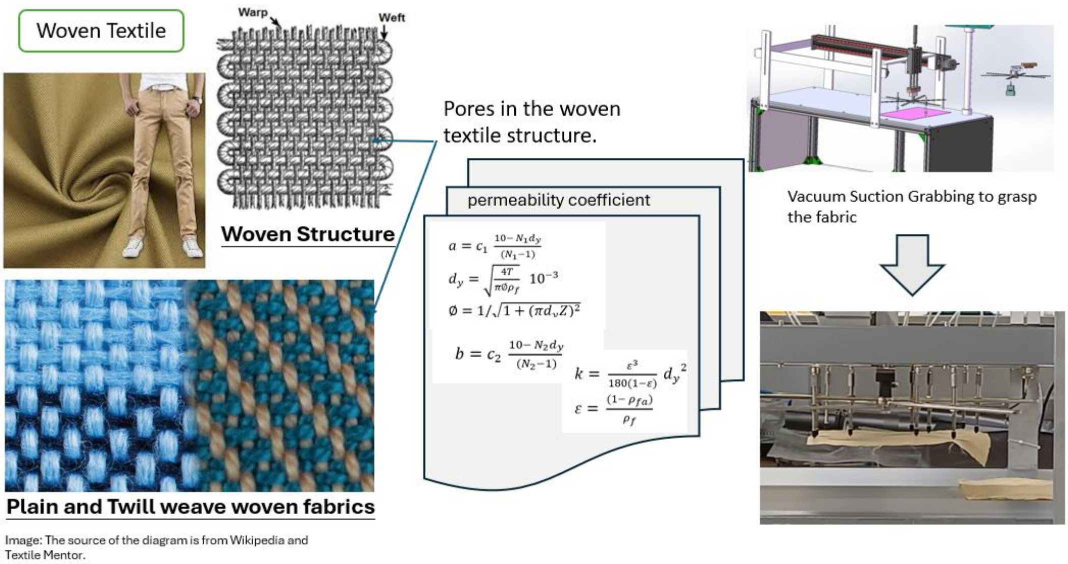


Figure 7: Woven Textile Fabric Grasped by Vacuum Suction Gripper Diagram

The woven textile fabric has been grasped by a vacuum suction gripper for garment automation machinery development. The Fig. 7 shows the relationship among the textile structure of woven fabric, pore, and air permeability study with the air permeability formula. The test experiment of the vacuum suction gripper can determine which woven textile structure fabric is grasped by the vacuum suction gripper, which is caused by the air impermeability structure of the textile structure.

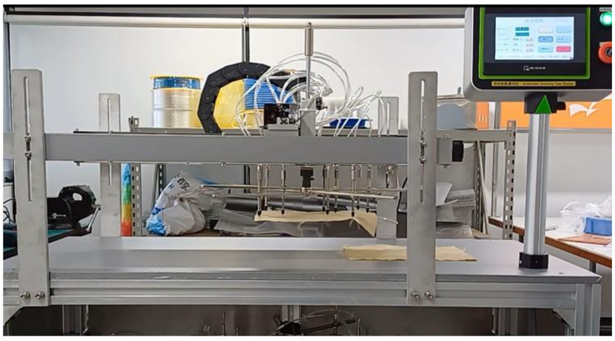
Grabbing Test on woven fabric

The experiment of the grabbing test is performed for the application of a woven textile structure. As a reference to the book chapter of Science and Technology: Developments and Applications (Vol. 6, pp. 148-170). BP International, Innovative Vacuum Suction-grabbing Technology for Garment Automation in K. M. Batoo (Ed.), the vacuum test-grabbing technology has been applied to test the woven fabric.

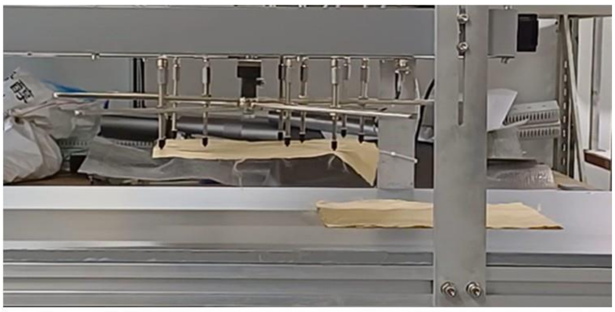
The experiment aimed to assess the performance of various woven fabrics when subjected to vacuum suction grabbing technology. This evaluation was conducted to determine their suitability for automated garment production processes, as outlined in Kong et al.'s work on innovative vacuum suction-grabbing technology.

- Materials Tested: A range of woven fabrics, including cotton, polyester blends, and other synthetic materials, were selected to represent different textures and densities commonly used in garment manufacturing.
- Vacuum Pressure Settings: The experiment utilized varying levels of vacuum pressure to simulate real-world handling scenarios in automated systems. These settings were calibrated based on industry standards for fabric gripping.
- Measurement Criteria: Key metrics included grip strength, fabric integrity post-testing, and resistance to tearing or deformation under the applied vacuum conditions.
- Grip Strength: Fabrics with higher density exhibited better grip strength under vacuum pressure, indicating their suitability for automated handling systems.
- Fabric Integrity: Synthetic materials showed greater resilience against damage compared to natural fibers like cotton, suggesting potential for longer operational life in automated processes.
- Resistance to Deformation: Blends of polyester and cotton demonstrated an optimal balance between grip retention and resistance to deformation.
- Implications for Garment Automation:
- The findings underscore the importance of selecting fabrics that not only meet aesthetic requirements but also perform well under automated handling technologies. This aligns with Kong et al.'s emphasis on integrating advanced manufacturing techniques, such as lean methodologies and AI-driven systems, to enhance efficiency and quality in garment production.

The experiment provides valuable insights into the application of vacuum suction grabbing technology for woven fabrics, offering practical guidance for manufacturers looking to optimize their automated processes, as shown in Fig. 8. By referencing Kong et al.'s research, the study highlights the potential for technological advancements to revolutionize textile handling in the garment industry.



Vacuum Suction Grabbing Test Station



Zoom of Vacuum Suction Grabbing Test Station to grasp the woven fabric

Figure 8: Grabbing test station to test a vacuum suction gripper to grasp a woven textile fabric

The test result for a few fabric samples has failed on the vacuum suction grabbing test, as shown below:

TABLE I: VACUUM SUCTION GRABBING TEST

Item Number	Fabric Composition	Vacuum Suction Grabbing Test Result (Pass or Fail)	Suction Pressure Value (MPa)
727368-06F	100% Polyester knitted fabric (fleece surface)	Fail	-0.52MPa
341553-4LD	100% single-sided knitted velvet fabric, velvet as the surface	Fail	-0.52MPa
586450-5CH	100% Polyester knitted mesh	Fail	-0.52MPa
423780-4NP	100% Poly TRICOT knitted mesh	Fail	-0.52MPa
473333-46W	100% TRICOT knitted mesh (horizontal weave on the back)	Fail	-0.52MPa

Table 1 shows the failure of the grab test because of pores of the woven fabric have great air permeability. The vacuum suction cannot form a suction force by the vacuum suction gripper. This woven fabric is a net shape of yarn texture, which has a great pore that allows air to pass through the woven fabric easily. The air permeability of fabric affects the grabbing test result. Figure 9 shows a photo of the samples.

Referring to Darcy's Law, the fluid flow is applied to the air flow for the experiment, and the negative pressure resistance is zero because air flows through the fabric.

$$\Delta p = q\frac{\mu L}{k} \tag{11}$$

For the test case, although the supply pressure is provided at 0.62MPa positive pressure, and then the vacuum generator provides the negative suction pressure to the gripper, the resistance of the negative pressure meter measures the zero value beside the head loss of the supply pressure meter and the resistance pressure meter. Increment Δp is 0.62MPa. It means that the suction air is passing through the pores of the fabric. A larger number of large and great pores in the air-permeable fabric allows the air through, as shown in Fig. 10.

Figure 9: Woven Fabric Sample for vacuum suction grabbing test

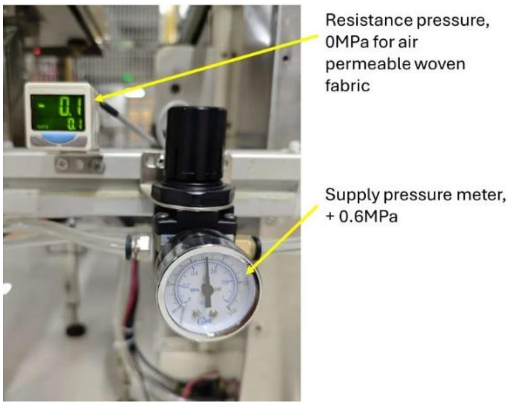


Figure 10: Supply pressure meter and resistance pressure meter

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The experiment of vacuum suction pressure grabbing test is a fast way to test the air permeability of woven textile. Based on the article from Zhu, G and Prof Dr Ray WM Kong, the experiment has proven that the air impermeable woven textile fabric can use the vacuum suction gripper to grasp the fabric cut piece.

Besides the above air-permeable woven fabric, the air-impermeable woven fabric structure is suitable for the vacuum suction grabbing test for automation.

TABLE II: VACUUM SUCTION GRABBING TEST FOR AIR IMPERMEABLE WOVEN FABRIC

Vacuum Grabbing Test for Automation

Experiment Summary

Test Lot /项目	Fabric Piece Application 裁片使用	Fabric 布种	No. of Gripper 需求数量	Outline rectangular Length & Width (cm)	Supply Negative Air Pressure 供抽吸气压	Result (pass/fail) 结果（通过/失败）
1	Pocket Bag	100%Polyester; Plain Weave; TEXTILE-WOVEN	6	26cm x 19cm	-55kPa	通过 Pass
2	Pocket Bag	68% Polyester, 32% Nylon; Taffeta; Plain Weave; TEXTILE-WOVEN; TEXTILE-WOVEN	12	30cm x 36cm	-55kPa	通过 Pass
3	Pocket Bag	96% Nylon (Mechanically Recycled), 4% Elastane; TEXTILE-WOVEN	6	26cm x 19cm	-55kPa	通过 Pass
4	Pocket Bag	100% Polyeste; TEXTILE-WOVEN; Satin/Sateen	6	26cm x 19cm	-55kPa	通过 Pass
5	Pocket Bag	100% Polyester (Recycled); Taffeta; TEXTILE-WOVEN	12	30cm x 36cm	-55kPa	通过 Pass
6	Pocket Bag	100% Nylon; Taffeta; TEXTILE-WOVEN	8	26cm x 19cm	-55kPa	通过 Pass
7	Pocket Facing	100%Polyester; Plain Weave; TEXTILE-WOVEN	6	26cm x 5cm	-55kPa	通过 Pass
8	Pocket Facing	68% Polyester, 32% Nylon; Taffeta; Plain Weave; TEXTILE-WOVEN; TEXTILE-WOVEN	6	30cm x 5cm	-55kPa	通过 Pass
9	Pocket Facing	96% Nylon (Mechanically Recycled), 4% Elastane; TEXTILE-WOVEN	6	26cm x 5cm	-55kPa	通过 Pass
10	Pocket Facing	100% Polyeste; TEXTILE-WOVEN; Satin/Sateen	6	26cm x 5cm	-55kPa	通过 Pass
11	Pocket Facing	100% Polyester (Recycled); Taffeta; TEXTILE-WOVEN	6	30cm x 5cm	-55kPa	通过 Pass
12	Pocket Facing	100% Nylon; Taffeta; TEXTILE-WOVEN	8	26cm x 5cm	-55kPa	通过 Pass

The pocket bag in woven textile fabric is shown in Figure 11 and Table II; the structure of woven fabric has been grasped by a vacuum suction gripper for garment automation machinery development, which passes the vacuum suction grabbing test. The test experiment of the vacuum suction gripper can determine which woven textile structure fabric is grasped by the vacuum suction gripper, which is caused by the air impermeability structure of the textile structure.

.**Figure 11: Air impermeable woven fabric sample passes the vacuum suction grabbing test**

IV. CONCLUSION

In conclusion, the effectiveness of vacuum suction grippers in handling woven fabrics depends significantly on the fabric's permeability. Air-permeable fabrics, characterized by their porous structure, fail to maintain a sufficient vacuum seal due to excessive airflow through their pores, leading to poor performance in automated systems. Conversely, air-impermeable woven fabrics, such as those with tight weaves or specific constructions like plain weave, taffeta, and satin/sateen, successfully hold the necessary vacuum pressure, enabling effective handling by vacuum grippers.

This distinction is crucial in garment manufacturing automation, where maintaining a secure grip on fabric pieces is essential for accuracy and efficiency. The choice of fabric type directly impacts the performance of automated systems, with air-impermeable fabrics being ideal for applications requiring precise manipulation, such as assembling pocket bags or facings. Understanding how weave structures influence permeability can guide manufacturers in selecting appropriate materials, enhancing both production processes and product quality.

In summary, the use of vacuum suction grippers is optimized when paired with air-impermeable woven fabrics, ensuring reliable performance in automated garment manufacturing.

Looking to the future, the textile and automation developer can refer to this study and experiment with how to use a suitable air impermeable woven fabric for the design of automated machinery on the garment jacket, down-fill jacket, and pants.

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