Advancements in Air-Laid Nonwoven Technology: From Production to Sustainable Innovations

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Abstract: ***Air-laid nonwovens are versatile materials produced by dispersing fibres in an air stream and depositing them onto a moving surface, followed by bonding using thermal, chemical, or mechanical methods. This manufacturing process allows for the incorporation of various fibre types, including natural, synthetic and recycled fibres, resulting in nonwovens with tailored properties such as high absorbency, softness and strength. The properties of air-laid nonwovens can be further enhanced by adjusting fibre blends, applying chemical additives and selecting appropriate bonding techniques. These materials find extensive applications across industries, including personal hygiene products, automotive textiles, filtration and medical textiles. In the hygiene sector, air-laid nonwovens are used in the production of biodegradable and flushable wipes, while in the automotive industry, they are increasingly employed for lightweight and sound-absorbing interior components. Recent innovations in air-laid technology focus on sustainability, with the development of biodegradable materials and the integration of smart functionalities. The COVID-19 pandemic has accelerated the demand for nonwoven fabrics in personal protective equipment, prompting research into eco-friendly alternatives. Despite the challenges of raw material costs and environmental concerns, the air-laid nonwoven industry is poised for growth, driven by the increasing adoption of bio-based materials and the expanding applications in healthcare, construction and advanced materials.***

Keywords: Air-laid nonwovens, Fibre, Web formation, Bonding, Sustainability

1. Introduction

In the rapidly evolving field of textile engineering, innovative manufacturing techniques have emerged to meet the growing demand for versatile and sustainable materials. Among these advancements, air-laid nonwovens have gained significant attention due to their unique properties and wide-ranging applications. As industries increasingly prioritize efficiency, sustainability and performance, air-laid nonwovens have become a focal point for researchers and manufacturers alike. Air-laid nonwovens are a type of nonwoven fabric formed by dispersing fibres in an air stream and depositing them onto a moving belt or forming surface. These materials are important in various industries due to their unique characteristics including high absorbency, softness and strength. Air-laid nonwovens find applications in personal hygiene products, filtration, automotive textiles and medical textiles (Maity *et al*., 2014). The air-laid manufacturing process involves three main steps: fibre preparation, web formation and bonding. In the fibre preparation stage, natural or synthetic fibres are selected and processed to achieve the desired properties. The web formation stage utilizes air-laying technology to disperse and deposit fibres onto a forming surface, creating a uniform web structure. Finally, the bonding stage consolidates the web using various techniques such as thermal bonding, chemical bonding or mechanical bonding like hydroentanglement (Deng *et al*., 2018; Maity *et al*., 2014). One interesting aspect of air-laid nonwovens is their potential for incorporating recycled fibres, contributing to sustainability efforts in the textile industry. For instance, recycled cotton and polyester fibres can be used to create eco-friendly nonwovens with acceptable mechanical and physical properties (Santhanam *et al*., 2018). Additionally, air-laid materials have shown superior properties compared to melt-extruded nonwovens in some applications when combined with specific chemical agents or coupling agents (Sakthivel *et al*., 2021). Air-laid nonwovens offer a versatile and efficient method for producing high-performance materials with tailored properties. Their manufacturing process allows for the incorporation of various fibre types, including recycled materials, making them suitable for a wide range of applications across different industries. As research in this field continues to advance, air-laid nonwovens are likely to play an increasingly important role in developing sustainable and functional textile products.

Nonwoven fabrics can be produced using various methods, including air-laid forming, which involves suspending fibres in an air stream and depositing them onto a moving belt or drum (Hubbe & Koukoulas, 2016). This method offers advantages in producing lightweight, high-loft fabrics with excellent absorbency and softness. Air-laid nonwovens are commonly used in hygiene products, wipes and absorbent materials. Different types of fibres are used in air-laid nonwoven production, including natural and synthetic fibres. Natural fibres such as cotton, wood pulp and flax are popular choices due to their absorbency and biodegradability (Jasbi *et al*., 2017; Ramamoorthy *et al*., 2015). Synthetic fibres like polyester, polypropylene and bicomponent fibres are also utilized for their strength and thermal bonding properties (Hargitai *et al*., 2008; Santhanam *et al*., 2018). Fibre selection significantly impacts the final product properties. For instance, the inclusion of longer fibres can enhance the strength and durability of air-laid nonwovens, while shorter fibres contribute to softness and uniformity. The blend of fibres can be tailored to achieve specific performance characteristics such as absorbency, strength and thermal insulation (Periyasamy, 2023). Air-laid nonwovens offer unique advantages in terms of bulk, softness and absorbency compared to other nonwoven production methods. The process allows for precise control of fabric weight, thickness and density, making it suitable for a wide range of applications. Air-laid technology enables the incorporation of superabsorbent polymers and other functional additives, further expanding the potential uses of these materials in various industries.

Manufacturing Process of Air-laid Nonwovens

Air-laid nonwovens can be bonded using various methods, including thermal, chemical and mechanical bonding techniques. Each method affects the material's properties and performance differently. Thermal bonding is one of the most widely used techniques for air-laid nonwovens. In this process, the web is heated to partially melt the crystalline regions of the fibres, allowing chain segments to diffuse across fibre-fibre interfaces, followed by cooling to re-solidify and trap the diffused chain segments (Michielsen *et al*., 2005). This method can produce structures with applications ranging from baby diapers to high-performance geotextiles (Rawal *et al*., 2007). Thermal bonding significantly influences mechanical properties such as tensile modulus, maximum stress, elongation, shear modulus and bending rigidity (Kim *et al*., 2001). The bond strength increases with bond area and bond size, while the effects on fibre morphology are generally negligible (Bhat *et al*., 2004). Chemical bonding involves the use of binders or adhesives to join fibres together. While not explicitly mentioned in the provided context, this method is commonly used in air-laid nonwovens to enhance strength and durability. Mechanical bonding techniques include needle punching and hydroentangling. Hydroentangling, in particular, has been shown to significantly improve wet tensile strength, ductile stretching properties, softness, air permeability and water absorbency of wet-laid fibre webs (Deng *et al*., 2018). This method also effectively reduces the dusting off rate and allows for easy dispersion compared to conventional carded hydroentangled nonwovens, making it suitable for personal hygiene applications.

Properties and Characteristics of Air-laid Nonwovens

Air-laid nonwovens are versatile materials with properties that can be tailored for various applications. Nonwoven fabrics, including air-laid ones, can be engineered to achieve desired properties such as absorbency, softness, strength andbulk. These properties are influenced by factors like fibre type, chemical additives and manufacturing techniques (Assis *et al*., 2018). For instance, softwoods are used for reinforcement, while hardwoods provide softness and a velvet-like surface feel. Mechanical pulps with stiffer fibres result in bulkier papers, while chemical pulps with flexible fibres offer better bonding ability and softness (Assis *et al*., 2018). Interestingly, there can be trade-offs between different properties. For example, as bulk increases, softness tends to improve, but tensile strength decreases (Morais *et al*., 2019). This relationship highlights the importance of carefully balancing properties for specific applications. Additionally, the use of different bonding techniques can significantly impact the final properties of nonwovens. Hydroentanglement, for instance, has been shown to improve wet tensile strength, ductile stretching, softness, air permeability and water absorbency in wet-laid fibre webs (Deng *et al*., 2018).

Applications of Air-laid Nonwovens

Air-laid nonwovens find extensive applications across various industries due to their unique properties and versatility. In the hygiene products sector, air-laid nonwovens are widely used in the production of flushable wipes. These wipes are designed to be biodegradable, dispersible and compatible with water treatment systems, making them environmentally friendly (Atasağun & Bhat, 2018). The growing market for flushable wipes is driven by their ease of use, hygiene, efficiency and consumers' environmental awareness. In the automotive industry, air-laid nonwovens made from agricultural lignocellulosic fibres like kenaf, jute, hemp and flax are being increasingly used for interior components. These biodegradable nonwovens offer advantages such as enhanced biodegradability, lighter weight compared to glass fibre-based materials and efficient sound absorption properties. They meet or exceed industry specifications for flammability, odor resistance, mildew resistance, bond strength, drapeability, tensile strength, elongation and compression properties (Parikh *et al*., 2002). Interestingly, air-laid nonwovens are also finding applications in electromagnetic shielding. Composites made from recycled fibres processed into needle-punched nonwovens and combined with conductive particles have shown promising results in electromagnetic shielding effectiveness. These light-weight, sustainable composites can be used in various general and professional applications, including household electronics, building materials andother areas requiring light-weight shielding materials (Atay *et al*., 2023).

Recent Innovations and Trends in Air-Laid Nonwoven Technology

Recent innovations in air-laid nonwoven technology have focused on sustainability efforts, biodegradable materials and smart functionalities. The healthcare industry has seen significant advancements in nonwoven materials, with a focus on barrier efficiency, breathability and comfort for applications such as surgical gowns, face masks and wound dressings (Dhabliya *et al*., 2024). The integration of nanotechnology and the development of smart nonwovens have further enhanced the capabilities of these materials. Interestingly, the COVID-19 pandemic has led to a rapid surge in demand for nonwoven fabrics in personal protective equipment (PPE) (Venkataraman *et al*., 2023). This has accelerated research into sustainable alternatives, including biodegradable options and customized healthcare solutions. The growing concern over the environmental impact of single-use nonwoven PPEs has prompted exploration of material and processing innovations to address sustainability issues. In terms of market trends and growth prospects, the global bioplastics and biopolymers market is expected to grow from USD 10.5 billion in 2020 to USD 27.9 billion by 2025, driven primarily by the packaging industry (Esposti *et al*., 2021). This growth is supported by intensive scientific and technological research focused on developing new materials with selected technical features that can substitute fossil-based plastic materials. The air-laid nonwoven sector is likely to benefit from this trend, as biodegradable polymers such as poly(lactic acid) (PLA) and poly(hydroxyalkanoates) (PHAs) gain traction in various applications (Elvers *et al*., 2016). Regional differences may emerge with startups and innovation events playing significant roles in consolidating efforts and investments by academia and industry to foster bio-based and biodegradable plastic-related developments, particularly in countries like Ukraine (Shevchenko *et al*., 2022).

Challenges and Future Outlook in Air-laid Nonwovens Technology

The air-laid nonwoven industry faces several challenges, including raw material costs, environmental concerns and competition from other nonwoven technologies. While the provided context does not directly address all these specific challenges, it offers insights into related aspects of nonwoven materials and their production. Raw material costs are a significant concern for the nonwoven industry. The use of recycled materials, such as recycled cotton (RC) and recycled polyester (RP), in air-laid nonwoven composites can help mitigate these costs (Sakthivel *et al*., 2021). However, the industry still heavily relies on synthetic materials, with about 66% of nonwovens using petrochemical-based materials (Santos *et al*., 2021). This dependence on synthetic materials not only affects costs but also raises environmental concerns. Environmental sustainability is a growing challenge for the nonwoven industry. The use of petrochemical-based materials in many nonwoven products leads to severe environmental issues, such as the generation of microplastics (Santos *et al*., 2021). To address this, there is a push towards using bio-based materials in nonwoven products. Lignocellulosic materials, including traditional pulp fibres, regenerated cellulose fibres and lignin binders, are of particular interest for developing more sustainable nonwovens (Santos *et al*., 2021). Regarding competition from other nonwoven technologies, the context provides limited information. However, it mentions that air-laid materials have more properties than melt extrusion, suggesting that air-laid technology may have some advantages over other methods (Sakthivel *et al*., 2021). Additionally, emerging nonwoven processes such as electrospinning and centrifugal spinning are being developed to produce unique ultrafine nanofibres, which may compete with traditional air-laid technology (Venkataraman *et al*., 2023). In terms of testing methods and quality control, the physical and mechanical properties of nonwoven composites can be tested in accordance with ASTM standards (Sakthivel *et al*., 2021). Specific tests mentioned include 24-hour soak and 2-hour boil conditions for determining physical properties. For sound absorption applications, the sound absorption coefficients can be measured according to ASTM E 1050 using an impedance tube method (Santhanam *et al*., 2018). These testing methods help ensure the quality and performance of air-laid nonwovens for various applications.

2. Conclusion

Air-laid nonwoven technology has emerged as a versatile and efficient method for producing nonwoven fabrics with diverse applications. The process involves forming a web of fibres using air and then bonding them through various techniques such as needle punching, hydroentangling, or thermal bonding (Maity *et al*., 2014). This technology offers several advantages, including the ability to use a wide range of fibres, including natural and synthetic materials and the production of fabrics with tailored properties. One of the key applications of air-laid nonwovens is in the healthcare industry, where they are used for surgical gowns, face masks and wound dressings due to their barrier efficiency, breathability and comfort (Dhabliya *et al*., 2024). In the field of personal protective equipment (PPE), air-laid nonwovens have seen a surge in demand, particularly during the COVID-19 pandemic (Venkataraman *et al*., 2023). Additionally, air-laid nonwovens have shown promise in building insulation, with studies demonstrating excellent thermal insulation properties comparable to conventional materials (Wazna *et al*., 2018). Interestingly, air-laid nonwovens have also been explored for use in composite materials. Research has shown that air-laid materials often exhibit superior properties compared to those produced through melt extrusion, particularly when incorporating recycled fibres and polymers (Sakthivel *et al*., 2021). This suggests potential applications in sustainable construction and manufacturing. Looking ahead, the future of air-laid nonwoven technology is likely to focus on sustainability and advanced functionalities. The development of biodegradable alternatives and the integration of smart technologies, such as nanotechnology, are expected to drive innovation in this field (Dhabliya *et al*., 2024). Furthermore, the growing emphasis on circular economy principles may lead to increased use of recycled fibres and eco-friendly bonding agents in air-laid nonwoven production. As research continues to optimize manufacturing techniques and explore new applications, air-laid nonwovens are poised to play an increasingly important role in various industries, from healthcare and construction to environmental remediation and advanced materials.

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