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Critical Review on Nonwoven Bodywear and Wearer Comfort Through Ease-mechanism

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ABSRACT

Advancements in technology and materials have positioned nonwoven technology as an emerging trend in the clothing industry due to its unique advantages, particularly its cost-effective, continuous manufacturing process that begins with web formation and ends with fabric production. Nonwoven body wear originated with paper clothing in the 1960s but failed to gain market success due to poor fit, insufficient strength, and high flammability. Research institutes and companies have since developed garments using advanced nonwoven fabrics like Tyvek, Colback, and Evolon. However, despite the innovations, nonwoven fabrics have not been widely commercialized as mainstream body wear, except for single-use or multi-use protective garments in the medical and processing industries. The research approach for this paper involves a comprehensive examination of existing literature on nonwoven clothing to identify gaps and explore opportunities for enhancing nonwoven fabrics through specialized pattern-making techniques. The approach consists of identifying the gaps, evaluating the limitations, and exploring the enhancement opportunities through the relationship between fabric properties and pattern-making techniques.

Keywords: nonwoven technology, nonwoven fabrics, specialized pattern-making techniques

Introduction

The apparel industry, traditionally reliant on elaborate textile production methods, undergoes multiple labor-intensive processes, including ginning, carding, spinning, weaving, and knitting, each encompassing further sub-processes. This conventional approach not only prolongs manufacturing timelines but also escalates costs, presenting environmental concerns owing to its extensive resource utilization.

However, advancements in materials and technology have catalyzed the emergence of nonwoven technology as a viable alternative within the clothing industry. Offering distinct advantages in cost and production efficiency, nonwoven fabrics are directly manufactured from fibers, bypassing the conventional yarn spinning and weaving/knitting processes (1). Advances in nonwoven technology, materials, and finishing processes improved the aesthetical and mechanical properties of the nonwoven fabrics which encouraged the researchers to develop such kinds of nonwoven fabrics that suit the clothing industry and accept their functionality as main fabrics for bodywear (2).

Despite these advances, nonwoven fabrics have primarily been adopted in medical and industrial sectors for single-use or protective garments. Challenges such as limited drapes, high shearing rigidity, and minimal conforming properties persist for nonwoven fabrics in clothing applications.

Nonwoven garments serve as disposable garments in various industries, including clinical, chemical, and processing sectors. Notably, materials like Tyvek nonwoven fabric, pioneered by DuPont, are manufactured through flash spun-bonded technology and are used for protective disposable clothing (3). Despite their value in protective applications, there remains a gap in the literature concerning nonwoven garments for direct skin contact. This gap arises due to deficiencies in essential properties such as softness, flexural rigidity, shearing rigidity, and thermal comfort (4).

Nonwoven fabrics are defined as “sheet or web structures bonded by entangling fibers or filaments mechanically, thermally or chemically. They are porous sheets made directly from fibers” (5). Various types of nonwoven fabrics exist, differentiated by their manufacturing processes, including thermal bonding, chemical bonding, and mechanical bonding. Among these processes, mechanical bonding, exemplified by hydroentanglement technology, is particularly relevant for apparel applications. Hydroentangled fabrics, produced through this method, exhibit aesthetically pleasing and mechanically suitable properties for clothing. Hydroentanglement involves entangling and mechanically bonding carded loose fibers or filaments by subjecting them to high-pressure water jets, transforming them into a cohesive fabric structure. The mechanical and aesthetic characteristics of the resulting nonwoven fabric can be tailored to meet specific application requirements (6).

The mechanics of a garment depend not only on fabric properties but also on garment design and pattern making. Behera et al aptly define clothing manufacturing as the "conversion of a flat two-dimensional structure into a three-dimensional shell structure." Shearing, bending, and compression emerge as critical mechanical properties influencing fabric sewability and its ability to transition from two-dimensional to three-dimensional forms (7). This process relies on mechanical deformation and formability of fabric, enabling fabrics to conform to the body's contours. Similar findings were found by (8) providing valuable insights into fabric assessment from both consumer and clothing manufacturing perspectives. Consumers prioritize comfort, durability, aesthetics, and appearance in garments, while clothing manufacturers prioritize factors like fabric laydown, cutting, sewing ability, and formability. From a manufacturing standpoint, properties such as shearing, bending, extensibility, and relaxation are deemed crucial, and high importance. Despite this, there is a dearth of literature examining nonwoven fabrics from a clothing manufacturing perspective. Low-stress mechanical properties of nonwoven fabrics, including shearing, bending, compression, and elasticity, necessitate investigation from a manufacturing standpoint. Understanding how these properties impact garment design and pattern-making techniques is crucial for overcoming the limitations of nonwoven fabrics and enhancing their acceptability and functionality in the clothing industry.

Nonwoven Garments

The history of nonwoven garments is very old and for the first time in the 1960s paper disposable dresses were attempted to market but were not successful because of ill fit, poor strength, fire hazards, and lack of thermal comfort. Initially, paper clothing was very famous because of wild designs and bright colors, and it was based on “throwaway fashion”. Two major U S companies Paper Scott and Mars sold 100s of thousands of paper dresses, but these dresses were quickly out of the market because in the 1970s, sustainable movement and environmental issues along with technical issues like ill fit and poor strengths (9). As shown in Figure 1.

Figure 1. Paper dresses in by Mars 1960s (Textile and Clothing Museum 2018).

Initially, paper-based garments attracted many customers because of their convenience, multi-colored eye-catching designs, and cost. But paper clothing disappeared in the late 60s from the market because of color fading, risk of flammability, and thermal comfort (10). Paper-based garments were made through conventional paper-making technology by using cellulose fibers, these fabrics showed poor strength because of short fibers that led toward poor bonding between the fibers. It also showed no permeability that affected the thermal comfort. Because of poor patterning, these garments were also misfit, and the wearer felt aesthetic discomfort. In 1960, lack of advanced technology and innovative materials, the nonwoven fabrics were not suitable for clothing applications because of rigid structure and lack of tactile properties nonwoven garment disappeared from the market. There was no involvement of specific pattern and ease quantification at that time lead the nonwoven garments out of market.

In the 1960s, DuPont introduced a similar approach to disposable bodywear with the invention of flash-spun nonwoven Tyvek. This material, made from synthetic fibers, offered unique properties such as water resistance and lightweight durability. Despite these advantages, Tyvek's lack of thermal comfort limited its widespread use in the apparel industry. One notable application was a water-resistant lightweight jacket by American Apparel, as illustrated in Figure 2 (11).

Figure 2. Tyvek Day Jacket by American Apparel

Tyvek's ability to repel water made it suitable for applications where moisture protection was essential. The fabric's lightweight nature and durability were ideal for protective clothing and certain specialized apparel items. Due to the discomfort and impracticality of regular wear, Tyvek was primarily used in niche markets, such as protective clothing, rather than mainstream fashion. At the end of the last century, Kimberly-Clark launched nonwoven protective clothing with the trade name KLEENGUARD®. This fabric was made by using thermoplastic fibers and thermoplastic filaments via the meltblown and spunbond processes. A meltblown web of the thermoplastic microfibers was sandwiched between the two spunbond layers of the thermoplastic filaments (SMS), which resulted in a durable nonwoven fabric (12). The protective garment is shown in Figure 3.

Figure 3. Kleenguard Protective Garment

The nonwoven fabric produced through this technology is only used in protective clothing. Because of structural constraint, it can be used as the main fabric next to skin clothing. Narayanan et al developed a durable military FR uniform from nonwoven composite fabric based on one loose-knit structure that was sandwiched between two nonwoven carded webs made of Nylon, cotton, and Kevlar fibers. It was passed through the hydroentanglement process. The resultant uniform fabric showed dimension stability and comfort. It is 25% lighter and stronger than the woven uniform and also exhibits higher such as three times higher air permeability than the woven military uniform (13). As shown in Figure 4.

Figure 4. Nonwoven composite military uniform (21)

Canesis Network Ltd was established in 1961 by The Wool Research Organization of New Zealand (WRONZ). They have developed a lightweight apparel nonwoven fabric made from 100% wool and after some finishing, it showed unique properties, and the fabric was found to be suitable for fashion apparel applications as shown in Figure 5 (14).

Figure 5. Nonwoven wool garments by Canesis Network Ltd. (Emad G., 2001)

The appearance and drape of garments are acceptable for the fashion industry, but the pattern-making techniques are still ambiguous.

The University of Leeds (15) also constructed some fashion-designed garments by using different nonwoven fabrics. These fabrics were supplied by different nonwoven suppliers like Freudenberg Nonwovens, Mogul, Fiberweb, Colbond, Tredegar Film Products, etc. These garments are shown in Figure 6.

Figure 6. Nonwoven garments designed by the University of Leeds (INDX 2008)

Satam, Lee, and Wilusz (16) worked on a nonwoven military uniform by using Cad technology and developed a customized lightweight military uniform by using hydroentangled nonwoven fabrics. These garments showed better quality, function, and economic feasibility. Their research proved that after applying the CAD technology the garment showed better fit, and comfort as shown in Figure 7.

Figure 7. Superhydrophobic Nonwoven Military Uniform (Satam and Lee 2010)

Gohar Emad et al (17) constructed some women's blouses by using nonwoven fabrics and found that nonwoven fabrics gave some extra edge over woven fabrics for garment construction such as reducing seams, stiffness of nonwoven fabric enabled shape and resistance to fraying. They conclude that nonwoven fabrics can be used for women's blouses at low cost as shown in Figure 8.

Figure 8. Women's nonwoven blouse (Gohar 2014)

Cheema MS et al (18) developed a nonwoven formal shirt by using hydroentangled nonwoven fabric the fabric was produced by using blends of micro fibrillated Tencil and micro bicomponent sheath/core PE/PET fibers at specific ratios through hybrid processes of needling and hydroentanglement nonwoven processes and the resultant fabric exhibited very comfortable in term of hand feel and drape and functional garment like assist in body movement as compared to a woven shirt. It showed thermal comfort because of the porous structure of the nonwoven fabric, improved drape, and appearance as shown in Figure 9.

The Nike Forward hoodie launched in 2022 is an interesting advancement in nonwoven technology, especially with its use of needle-punched fabrics. Its lightweight nature and significant reduction in carbon footprint highlight the growing trend towards sustainable textile.

Figure 9. Hydroentangled nonwoven shirt

While the technical details on the fabric's composition are available, the lack of detailed pattern-making techniques can be a limitation for designers looking to replicate or innovate upon this style. Pattern making for nonwoven garments can differ from traditional methods, often requiring adjustments in fit and construction techniques due to the unique properties of nonwoven materials (21).

Figure 10. Nike Forward Nonwoven Needle Punched Hoodie

Interrelationship between fabric and pattern

Nonwoven fabrics pose specific challenges in pattern development because of their structural differences from woven fabrics. Unlike woven textiles, nonwoven fabrics lack the inherent interlacing of yarns, which contributes to their higher shearing rigidity, high bending rigidity, and limited formability. These deficiencies make it difficult to shape nonwoven fabrics into complex or fitted designs commonly required in garment construction. Bragance (19) emphasizes the critical role that fabric properties play in patternmaking, particularly in ensuring comfort and garment performance during dynamic body movements. They found that fabric stretch, and tensile behavior directly affect how well a garment adapts to body dimensions and how it manages pressure on the skin. Fabrics with low stretch and high resistance to deformation can lead to discomfort when worn in dynamic conditions, as they do not accommodate natural body movements. Fabrics with a high tensile modulus require more force to stretch, which means they exert more pressure on the body. In clothing, this can create tension, particularly in tighter or form-fitting garments, leading to discomfort and potential pressure points on the skin.

Fabrics with high tensile modulus may require more ease in the pattern to prevent tightness and pressure on the body. As noted by Cheema (18), nonwoven hydroentangled fabrics have a high tensile modulus and lower stretchability, making them more rigid and less adaptable to body movement than traditional woven or knit fabrics as shown in Figure 11.

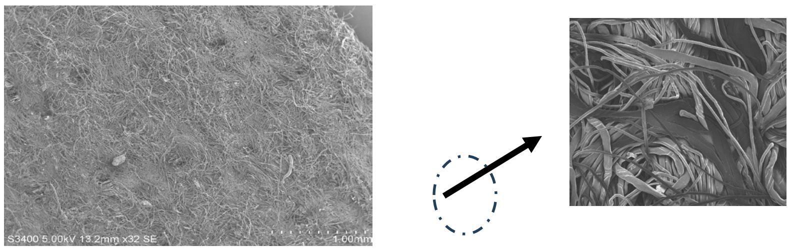

Figure 11. SEM of Hydroentangled Structure

The compact structure of nonwoven fabrics restricts the movements of filament fibers in the fabric, which causes higher flexural rigidity and reduces the fabric's stretchability.

However, these limitations can be addressed through strategic pattern-making techniques to create functional and comfortable nonwoven garments. The research conducted by Kristina and Dovile (20) underscores the intricate relationship between fabric structural properties, pattern development, garment fit, wearer comfort, and ultimately, the mechanical and aesthetic properties of the fabric and found that fabric structural properties, such as weave, knit, or nonwoven construction, directly influence how the fabric behaves when cut and sewn into garments.

Researchers such as Gill (22), Kim (23), and Gu (24) have found that ease allowance in garment patterns plays a crucial role in ensuring comfort, particularly when considering the fabric's mechanical properties. The concept of ease allowance refers to the extra space added to a pattern beyond the body's actual measurements to accommodate movement, fabric behavior, and overall comfort. The ease allowance required in a pattern is closely linked to the mechanical properties of the fabric, such as stretch, tensile strength, drape, shearing, and flexural rigidity. Different fabrics behave differently when subjected to body movement and external forces, meaning patterns must be adapted based on these characteristics.

The lack of stretchability in nonwoven fabrics presents a significant challenge in garment manufacturing, particularly when using traditional approaches to pattern making. Unlike woven or knit fabrics, nonwovens generally lack elasticity as shown in Figure 10, meaning they cannot easily conform to body movements, potentially causing discomfort if not accounted for in the design process. Relying on conventional pattern-making techniques without adapting them to these unique fabric properties can lead to issues such as restricted movement, increased pressure on certain body parts, and a poor overall fit.

Substantial research has been done to quantify the ease and pattern development for woven and knitted clothing; however, no research has attempted to determine the ease allowance, pattern development, or how to get the proper fit garment using nonwoven fabrics.

Finding and research challenges

Some leading research institutes such as the School of Design, University of Leeds developed some nonwoven fashion garments in 2007, but these garments could not get the attention of the garments market because of fabric structure and properties. There was also no mention in the literature about the ease of nonwoven garments and pattern development procedures, it seems most likely concentrated on the visual appearance of the garments. Mostly nonwoven fabrics were needle punched and thermal bonded which restricts the aesthetical and thermal properties of the fabrics and garments that affect the drape, soft handle, stretch, recovery, and thermal comfort. These properties are very considerable essential for apparel.

Second, very limited or no literature discussed the relationship between nonwoven fabrics and the ease mechanism of pattern/garments in terms of functionality and comfort.

It needs to research specific nonwoven fabrics that can be accepted by the industry as main outerwear and possess almost similar properties to woven fabrics.

It also needs to research the comparison between nonwoven and woven garments in terms of functional, comfort, aesthetic, and psychological properties and highlight the areas of nonwoven fabrics where improvement can be enhanced through materials, processes, and finishing and pattern construction mechanisms.

No doubt, because of the advancement in technology and materials, nonwoven fabrics have entered the garments industry in R&D as using outerwear but need to be improved in some areas like drape, physical appearance, thermal comfort properties, washability, etc. Based on current literature, nonwoven fabrics cannot be used in the design of every garment as woven fabrics. The challenge is to find out the designs of alternative garments for nonwoven fabrics where these fabrics can show their serviceability and can be accepted by the target market because of lower production cost, less waste in processing, and easier recycling as compared to woven fabrics.

It is known from the literature that because very close entangling behavior of fibers/filaments in nonwoven structures restricts the fibers movement which affects the fabrics stretch and recovery properties of the nonwoven fabrics. Kaxiuan et al, found that different body parts apply different pressure forces on the fabric during a walk, sit, run, and squat (19). So, the fabric should have the strength to withstand the external pressure and to retain its dimension stability after releasing the pressure. It can be controlled by adding an ease allowance in specific parts of the garments where body stress can be assumed during movements or working conditions of the wearer.

Currently, there are very limited studies to understand the relationship between nonwoven fabrics structure and wear comfort. Raccuglia, Havenith et al found in their research that many factors influence wear comfort one of them is the fabric-to-skin pressure that depends on the fabric weight and clothing fit which relate to tactile comfort (20). Kaixuan Liu, Jianping wang, et al also found that clothing pressure is one of the most important elements influencing wearing comfort and it relates to the ease allowance and garment pattern (19). Because nonwoven fabric comprises fibers or filaments that reduce the fabric weight per unit area which leads to a lightweight of nonwoven fabrics that improve the fabric-to-skin pressure mechanism for the wearer.

More in-depth research should be carried out to investigate the relationship between specific nonwoven structures and pattern development and also find alternative designs for nonwoven fabrics according to their properties and structures. Comparing the nonwoven garments with woven garments highlights the improvement areas of nonwoven fabrics and based on the comparison analysis develops such nonwoven fabrics that satisfy the garment manufacturing standards for accepting the nonwoven fabrics in the apparel industry as the main body wear fabric.

See the summary of the literature below,

Author(s)	Year	Source	Research Problem	Key Findings	Research Gap
Ogunleye, C., Anandjiwala, R.	2016	*Journal of Industrial Textiles*	Development of nonwoven protective garments	Identified improvements in processes and finishing techniques for disposable and protective clothing.	Lack of research on casual nonwoven garments worn next to the skin, and the relationship between nonwoven fabrics and pattern-making techniques.
Cheema, M.S., Anand, S.C., Shah, T.H.	2018	*Journal of Textile Science & Engineering*	Development of nonwoven fabrics for clothing	Evaluated the characteristics of nonwoven fabrics, such as tensile strength, air permeability, and flexural rigidity, comparing them to woven fabrics. Concluded that hydroentangled nonwoven fabrics have potential as the main material for clothing.	Insufficient studies on the relationship between nonwoven fabrics and pattern development techniques, as well as sewing challenges associated with nonwoven garments.
N/A (Online Source)	N/A	*Victoria and Albert Museum Website*	Exploration of single-use paper dresses	Highlighted the appeal of single-use paper garments due to their low cost, vibrant designs, and visual impact.	Limited research on pattern-making methods for paper garments and the relationship between fabric properties and garment performance.
N/A (Online Source)	N/A	*DuPont Website*	Protective garments	Developed lightweight, durable fabrics that resist water and offer moisture protection.	Focused only on protective garments; no discussion of pattern-making methods for nonwoven protective garments.
N/A (Online Source)	N/A	*Nonwovens Industry Website*	Development of nonwoven fabrics for military uniforms	Developed strong, lightweight, and permeable nonwoven military uniforms	Lacked detailed discussion of fabric characteristics and their relationship

Author(s)	Year	Source	Research Problem	Key Findings	Research Gap
				composed of three layers.	with pattern-making techniques.
Emad, G., Olfat, M.	2001	*International Design Journal*	Development of nonwoven wool garments	Developed nonwoven garments based on 100% wool after applying specific finishing techniques.	Limited evaluation of fabric's mechanical characteristics and their relationship with garment performance, especially regarding pattern-making techniques.
N/A (Online Source)	N/A	*Nonwovens Network*	Nonwoven fashion garments	Developed nonwoven garments using various fabrics such as Colbond and Evolon.	Lacked mention of fabric characteristics and their relation to garment performance, as well as pattern-making techniques.
Gohar, E.E.D.S., Mohamed, O.S.	2014	*International Design Journal*	Development of nonwoven women's blouse	Developed nonwoven women's blouses and highlighted reduced seams, resistance to fraying, and cost efficiency compared to woven fabrics.	Insufficient evaluation of nonwoven fabric characteristics and their relationship with pattern-making techniques.

Conclusion

Nonwoven fabrics present a promising, sustainable, and cost-effective alternative for the global apparel industry, which is increasingly seeking environmentally friendly manufacturing methods. While nonwoven fabrics have traditionally been used for industrial and hygienic applications, advances in fabric technology, such as Evolon structures, have improved their mechanical and aesthetic properties, making them more suitable for clothing.

However, the limited stretchability, drapability, and rigidity of nonwovens pose significant challenges when using traditional pattern-making techniques. To fully realize the potential of nonwovens in the clothing industry, further research is necessary to develop innovative pattern development techniques, finishing processes, and alternative garment designs tailored to the unique characteristics of these fabrics.

With continued exploration and development in these areas, nonwoven fabrics could emerge as a viable option for mainstream bodywear, contributing to a more sustainable and cost-effective future for the apparel industry.

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