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Nonwoven Garments: Critical Literature Review

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Abstract

This paper aims to analyse the published works on nonwoven garments and underline the area of improvements in the nonwoven hydro entangled fabrics and how the properties limitations such as shearing rigidity, drape and thermal properties of nonwoven can be addressed through adopting special techniques of pattern-making that enable nonwoven hydro entangled fabrics for garment manufacturing. A garment's mechanics largely depend on the fabric properties and other factors like design and pattern making. Historically, nonwoven garments started from paper clothing in 1960 but could not succeed because of ill fit, lack of adequate strength and flammability. Over time, advanced technology and innovative materials enhanced the functionality of nonwoven fabrics that support the nonwoven fabric entering the clothing industry as the main fabric. Research institutes and research companies developed nonwoven garments using advanced nonwoven fabrics such as Tyvek® and Evolon®. However, medical and processing industries could only commercialise nonwoven fabrics as the main body wear for single-use or multi-use protective garments. Lack of drape, high shearing rigidity and minimal conforming properties of nonwoven fabric are the highly challenging areas of hydroentangled nonwoven fabrics for clothing application. Adopting an appropriate pattern technique mechanism can enhance functionality and comfort, where nonwoven garments perform expectedly.

Keywords: Nonwoven garment • Pattern • Clothing • Nonwoven fashion • Garment engineering

Introduction

Nonwoven garments are used in the clinical, chemical and processing industries as protective garments because of their superior barrier properties, such as Tyvek nonwoven fabric by DuPont, which was developed using HDPE fibres through flash spun-bonded technology [1]. There needs to be more literature on nonwoven garments used next to the skin because of the lack of required properties such as softness, flexural rigidity, shearing rigidity and thermal comfort [2]. A garment's mechanics largely depend on the fabric properties and other factors like design and pattern making. The mechanics of nonwoven hydroentangled fabrics are different from those of traditional woven fabrics because of the unique manufacturing processes of nonwoven fabrics. Traditionally, nonwoven fabrics were used in apparel as supportive fabrics such as to maintain the shape of the garment's parts like collar, cuff or sometimes used as the inner shell of the garments; it was not considered to be used as body wear because of some limitations such as softness, durability, drapability and thermal comfort [3].

The apparel industry depends on the traditional ways of producing fabrics for garments. Conventional textile processes involve many production steps (ginning, carding, spinning, weaving and knitting). Each process also has a sub-process. For instance, there is a warper beam process, sizing and drawing processes before weaving. The traditional way of apparel manufacturing is lengthy and costly and because of the large chain of textile processes, it will adversely affect the environment.

Advancements in materials and technology enabled nonwoven technology to gain importance in the clothing industry because of its unique cost and production advantage in the manufacturing process [4]. Nonwovens are made directly from fibres without yarn and weave/knit processes, made from fibres to the fabric.

Nonwoven

According to INDA, nonwoven fabrics are "sheet or web structures bonded by entangling fibers or filaments mechanically, thermally, or chemically. They are porous sheets made directly from fibers."

Woven

Woven fabric is defined as "producing fabric through the interlacement or intersecting of two perpendicular sets of yarns" [5].

In woven fabrics, the constituting element is yarn and in nonwoven, the constituting element is fibres. Different nonwoven fabric types can be differentiated based on their manufacturing processes, such as thermal bonding, chemical bonding and mechanical bonding. The most relevant nonwoven process for apparel usage is the mechanical bonding process, such as hydro entangled fabric; the nonwoven fabrics produced by hydro entanglement technology (mechanical bonding) can be used in the apparel industry because of their acceptable aesthetical and mechanical properties for clothing.

Hydro entanglement is a nonwoven technology through which carded loose fibres, or filaments, are entangled and mechanically bonded by applying high pressure of multiple rows of water jets that convert the array of fibres into a coherent fabric structure. The nonwoven fabric's mechanical and aesthetical properties can be altered according to the desired application [6].

Literature Review

From the literature, it was observed that researchers primarily highlighted the mechanical properties of nonwoven fabrics and compared them to woven fabrics, such as tensile strength, wicking, air permeability and bending properties. For example, Sanad R, et al. [7] worked on the mechanical properties of nonwoven and woven fabrics and found that nonwoven fabric's drapability is acceptable in the clothing industry; they worked on performance-based analysis of woven and nonwoven fabrics and did not focus on garment engineering areas like pattern making, formability and sewability of nonwoven fabrics. In a study of analysis of hydroentangled nonwoven fabrics, Cheema SM, et al. [2] developed hydroentangled nonwoven fabrics. They performed some mechanical tests like air permeability, strength and absorbency to see

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the performance of the nonwoven fabric. They found that the properties of hydroentangled nonwoven fabrics can be altered according to the end usage and these fabrics can be used in the clothing industry.

Although these properties are essential for the garment, the most critical and primary area of research is low-stress mechanical properties and fabric formability of the nonwoven fabrics that help the fabric to adopt the shape of the human body in three-dimensional and the interrelationship between fabric mechanical properties and the garment manufacturing process like sewing process. For example, Behera BK [8] defined the clothing manufacturing process as a "method of conversion of a flat two-dimensional structure into a three-dimensional shell structure". For garment manufacturing, fabrics' more critical primary mechanical properties are shearing, bending and compression. These properties influence the sewability and the ability of fabrics to transfer from two-dimensional to three-dimensional shape. This process requires mechanical deformation of the fabric and formability, enabling the fabric to be converted from 2D to 3D shape to fit on the body and it all depends on the above-mentioned mechanical properties.

Hunter found a similar observation in his study: fabrics can be assessed by two approaches: one is from a consumer point of view and the second is from the clothing manufacturing point of view., the consumer prefers comfort, durability, aesthetics and appearance in the garment, but on the other hand, clothing manufacturing prefers easy laydown of fabric, cutting, sewing ability and formability. As per his findings, shearing, bending, extensibility and relaxation are the properties that are important from a manufacturing point of view.

There is minimal literature on nonwoven fabrics assessed from a clothing manufacturing point of view. Low-stress mechanical properties of nonwoven fabrics, such as shearing, bending, compression and elastic properties, need to be addressed from the manufacturing point of view and how the limitations in nonwoven fabrics can be overcome through garment designing and pattern-making techniques. This area needs attention to enhance the acceptability and functionality of nonwoven fabrics in the clothing industry.

Interrelationship between fabric and pattern

There is a very critical relationship between fabric properties and pattern development. Bragance worked on the interrelationship between fabric and pattern and found that clothing may cause discomfort when it resists body movements in a dynamic state, which leads to customer dissatisfaction. So, the mechanical properties of the fabric need to be considered during pattern making, like stretch. A similar finding was found by Malehi, who stated that in dynamic conditions, the garment would try to adapt to body dimension and, in this condition, fabric tensile behaviour will determine the fabric extensibility and sustain of strain energy in the fabric, causing the fabric pressure on the skin. They also found that a garment made from a higher tensile modulus fabric requires greater force to create specific elongation in the fabric that exerts more pressure on the body. So, it is evident that fabric properties play an essential role in pattern making. Nonwoven fabrics (Hydroentangled fabric) structures differ entirely from woven fabric and need special attention in developing the pattern for nonwoven fabrics.

Some challenges that prevent nonwoven fabrics from entering the clothing industry are lack of shearing rigidity, bending and formability properties. Nowadays, primarily nonwoven fabrics are being used in protective single-use garments. Tyvek fabric is used in the clothing industry for protective clothing because of its compact structure that resists water and air permeability. It cannot be used as a skin garment because of the lack of drape and high shearing rigidity [3].

Advances in nonwoven technology, materials and finishing processes improved the aesthetical and mechanical properties of nonwoven fabrics, encouraging researchers to develop nonwoven fabrics that suit the clothing industry and accept their functionality as the main fabrics for bodywear.

Narayanan V, et al. [9] developed a durable military uniform from nonwoven composite fabric based on one loose-knit structure sandwiched between two nonwoven carded webs made of Nylon, cotton and Kevlar fibres. 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 exhibits three times higher air permeability than the woven military uniform.

Another example is Evolon by Freudenberg (Germany). It is developed by split-able bi-component PET/PA6 Island-in-the-sea synthetic filaments through hybrid technology of splaying and hydroentanglement. Among the current nonwoven fabrics, Evolon's new generation of nonwoven fabrics can be used in the clothing industry as the main fabric.

Because of the ultrafine filament and thermally bonded nature of "Evolon 100", fabrics restrict air permeability and cause thermal discomfort for the wearers [2]. The appearance of Evolon is not systematic like woven or knitted structures. Scattered filaments can be observed because of uncontrollable parameters during spunlaying and hydroentanglement processes, as shown in Figure 1. On the other hand, woven fabric shows a systematic warp and weft structure. The physical appearance of the fabrics affects the psychological comfort of the wearer.

Garment utilisation and style depend on the physical properties of the fabric, such as strength, drape and thermal comfort; there is no or minimal literature on the scientific development of nonwoven garments by using specific pattern development techniques based on the nonwoven physical properties.

Fabric properties and pattern making

Pattern development is a very critical stage of transferring the two-dimensional phase of fabrics into a three-dimensional body shelter and the purpose of the pattern is not only to sketch the garment style parts and join them through the sewing process; wearer comfort and fit must be considered during pattern making; ease of quantification and garment construction. As the garment conforms to the body and assists in a high degree of mobility, gentle touch to the skin, fabric affordable pressure on the body during specific body movements and thermal comfort define the garment fit and comfort. These required attributes depend on the fabric properties and the pattern development mechanism that converts the two-dimensional fabric into three-dimensional garments according to fabric properties [10]. The ability of the fabric to shear deformation is a compulsory element for conformable fitting to three-dimensional garments. Shearing rigidity depends on the movements of the yarns/fibres in the fabric structures; from Figure 1, it is noted that the yarns/fibres can easily displaced in woven structures as compared to nonwoven fabric. The filaments in nonwoven structures are tightly compacted and cannot be displaced or moved, especially on the concave shape of the body and could exert more pressure on the body that makes it uncomfortable or unfit for the wearer.

Inogamdjanov D, et al. [11] worked on woven fabric shear. They analysed different weave structures and concluded that different types of woven fabric structures showed different shear rigidity, such as plain weave structure that has more cross points of warp and weft showed higher shear rigidity than satin weave structure that have lower cross points of warp and weft. They also pointed out that the higher number of yarns per centimetre exhibits higher shear rigidity than the looser structures. The reason for the high shear rigidity of the compact structures is the mobility of the yarns within the fabric structures

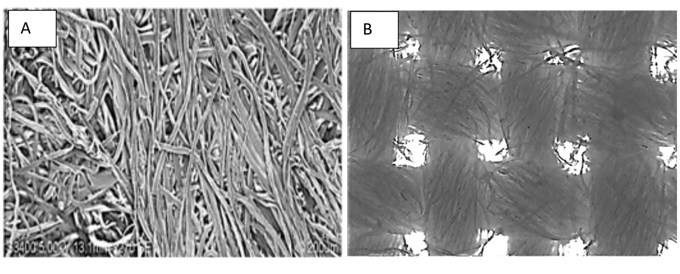

Figure 1. A) Fabrics structural view of evolon fabric and **B)** Woven fabric (SEM 200 μm).

during the rotational movement of the fabric structures. So, it is evident that shear rigidity depends on the constructional properties of the fabrics and in the case of making patterns, the fabric's physical and mechanical properties play an essential role in getting fit and comfortable garments.

Nonwoven fabric's structural properties are different from the woven fabric's structural properties, so the pattern for woven fabric cannot be used on the nonwoven fabric. There should be a separate technique of pattern development for nonwoven fabrics. Due to a lack of proper pattern techniques for nonwoven structures, nonwoven garments could not succeed in the apparel market. Furthermore, they also found that good shearing of fabric leads to good fitting over curved surfaces and large shearing strains resulting from the low shear stress required in fabric to fit a piece of fabric in a three-dimensional surface.

A similar finding of different fabric structures was found by Zhang X, et al. [12]. They found in their research that garments made with different fabric structures exert different pressures on the high-pressure zones in the areas of the waist, hips and upper chest. They made two garments using denim and knitted fabrics. They found that the garment made with denim exerted more pressure in high-pressure zones of the body in the range of 12 to 25 gf/cm^2 and on the other hand, the garment made with knitted fabric exerted low pressure in high-pressure zones of the body with 3 gf/cm^2. So, it is evident that fibres and fabric mechanical properties affect garment comfort and it can be controlled by adopting specific techniques of pattern-making based on the fabric structures.

In his research, Cheema MS [3] observed that Evolon fabric showed higher flexural rigidity than woven fabrics and fabric/garment drape depends on flexural rigidity. Garment drapes can be enhanced by modifying the pattern or quantifying the ease allowance. The flexural rigidity of Evolon fabrics can be improved by passing them through finishing processes.

Despite these challenges, some hydroentangled nonwoven structures are very close to the woven fabric in terms of aesthetical and mechanical properties and exhibit thermal comfort for the wearer. A hydroentangled nonwoven fabric was developed by Cheema MS [3] that was prepared by using fibrillated micro Tencel and bicomponent sheath/core PE/PET micro fibres through hydroentanglement process and compared mechanical and aesthetical properties with plain weave woven fabric that was composed of cotton/polyester 70/30 ratio as shown in Figure 2.

Developed nonwoven hydroentangled fabric showed similar properties to woven fabrics, such as the tensile strength was higher than the woven fabric, exhibited almost similar flexural rigidity properties and showed higher thermal comfort than woven fabrics because of porous structures, as shown in Figure 2. One limitation of such fabric is the disintegration of its structure during the washing procedure. Its washing strength is less than woven fabric and fibres can be disentangled after a few washes. However, it can be used as bodywear like woven fabric for specific garments or limited fashion life garments such as wedding dresses and fashion garments like jewel embroidered shirts that are supposed to be dry cleaned rather than washed.

Only a little work has been done on the specific pattern mechanism for nonwoven garments. In their research, Kristina and Ancutiene K and Sinkeviciute D [13] found that pattern development and garment fit depend on the fabric's structural properties and Wearer comfort depends on the garment pressure and ease allowance. These parameters depend on the fabric's mechanical and aesthetical properties. In their research, Liu K, et al. [14] found that garment pressure depends on the fabric's mechanical properties, changing behaviour, ease allowance distribution and garment pattern. They also found in their research that different factors, including waist-hip factors, greatly influence the wearer's comfort of pants; flexible fabric exerts lower pressure on the body than rigid-structure fabrics.

Some commercial nonwoven hydroentangled structures, such as Evolon®, possess low air permeability that may cause thermal discomfort for the wearer. However, this limitation can be overcome in garment design and pattern-making Atasagun HG, et al. [15] found in their research that wearer thermal comfort depends on not only the fabric's properties but also the garment's properties, such as garment fit, closures and vents, body movement and environment. So, it is evident that thermal comfort can be addressed through the garment's ventilation system. Fabric air permeability and garment ease allowance greatly influence the dry heat of the body. So, it is in great demand to work on particular techniques of pattern making and ease allowance quantification for nonwoven garments to optimise functionality and comfort. Ease allowance also assists in the thermal comfort of the wearer. Weder MS, et al. [16] found that the thermal insulation of loose garment structures is 30% higher than that of fitted garments.

Our literature review reveals that minimal papers on nonwoven garment fit and comfort, nonwoven fabric properties and their effects on garment fit and comfort and pattern techniques for nonwoven structures have been published. Much work is needed to find the best fit for nonwoven garments in the clothing industry. It can be done through research studies about the relationship between the fabric structures and garment fit, ease allowance mechanism through adopting special pattern development techniques for nonwoven fabric and area of applications (fit, loose fit, or loose garment) of nonwoven fabrics.

Nonwoven body wear

Customers' primary perception of nonwoven fabrics is as disposable or supporting materials in the clothing industry, either in fashion or casual garments. There have been few attempts since 1960-70 when Paper Scott tried to enter the nonwoven fabrics in the clothing industry as disposable dresses. However, because of ill fit, lack of suitable strength and discomfort, it could not attain its share in the market and swiftly disappeared [17]. Another manufacturer, Mars of Asheville, introduced cellulose-based paper-fashioned garments, as shown in Figure 3.

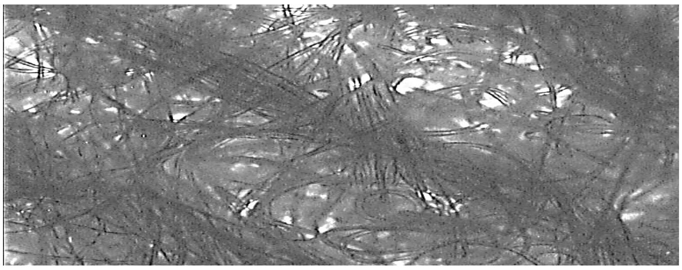

Figure 2. Hydroentangled nonwoven fabric [3].

Figure 3. Mars of asheville cellulose-based paper garments [17].

Paper-based garments attracted many customers because of their convenience, multi-coloured, eye-catching designs and cost. However, paper clothing disappeared from the market in the late 60s because of colour fading, flammability risk and thermal comfort [18].

Paper-based garments were made through conventional paper-making technology by using cellulose fibres; these fabrics showed poor strength because of short fibres that led to poor bonding between the fibres. 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, due to a lack of advanced technology and innovative materials, nonwoven fabrics were unsuitable for clothing applications because of their rigid structure and lack of tactile properties. Nonwoven garments disappeared from the market. There was no involvement of specific patterns and ease of quantification at that time led the nonwoven garments out of the market-a similar approach of introducing disposable bodywear by DuPont in the 1960s era. DuPont invented flash-spun nonwoven Tyvek by using synthetic fibres. However, because of its lack of thermal comfort, its use was limited in the apparel industry, such as a water-resistant lightweight jacket by American Apparel, as shown in Figure 4 [19].

Students and staff in the School of Design at the University of Leeds have been working on nonwoven body wear since 2004 and have developed some designed garments, as shown in Figure 5, using Colback® and Evolon® nonwoven fabrics. Colback fabric by Colband was initially used for industrial purposes, so because of its harsh and rigid structure for skin and lack of drape, it is not fit for the garment industry as an outer wearer [20].

Gohar EEDS and Mohamed OS [21] constructed some women's blouses using nonwoven fabrics. They 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 low-cost women's blouses, as shown in Figure 6.

Cheema MS [3] developed a nonwoven formal shirt by using hydroentangled nonwoven fabric. The fabric was produced by using blends of micro fibrillated Tencel and micro bi-component sheath/core PE/PET fibres at specific ratios through hybrid processes of needling and hydroentanglement nonwoven processes and the resultant fabric exhibited very comfortable in terms 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 7.

Figure 4. Tyvek day jacket by American apparel [19].

Figure 5. Nonwoven fashion garments **a)** Colback® **b)** Evolon® by University of Leeds [20].

Figure 6. Women's nonwoven blouse [21].

Pattern and ease allowance

Experiential research considering ease is necessary to support development in this area. It requires that ease can be controlled in sampling prototype garments to ensure that differences in fabric properties between woven and nonwoven can be accounted for.

Ease allowance is extra space between the body and garments that facilitate the body's movements and thermal comfort. It depends on the fabric's mechanical properties and the types of garments as the elasticity of the fabric is similar; a formal suit requires less ease than sportswear [22]. Sportswear garments require maximum body movement assistance and highly supportive garment attributes (ease allowance, fibres, structure) that enhance the thermal comfort of players. Gu B, et al. [23] found that ease allowance depends on the style, body shape and fabric's properties.

Figure 7. Hydroentangled nonwoven shirt [3].

Gill S [24] suggests that wearer comfort depends on the ease allowance and ease allowance depends on the fabric's structure and mechanical properties, such as the stretching behaviour of woven, knit and nonwoven fabrics. So, it is evident that pattern development and the end-use of the garments depend on the fabric structure. For different fabric structures, there needs to be addition or subtraction in dimensions of the pattern to gain wearer comfort in terms of functionality. Kim IH, et al. [22] proposed a relationship between ease allowance and the aesthetic satisfaction of the wearer. They found that incremental ease allowance decreases the aesthetic satisfaction of the wearer, as shown in Figure 8. Its mean addition of ease should be acceptable because excess addition of ease affects the wear aesthetic satisfaction.

Different researchers used different approaches to quantify the ease allowance for woven-based garments. Chen Y, et al. [25] worked on a sensory evaluation approach for ease quantification; Tomita A and Nakaho Y [26] used a topography approach based on distance ease between the body and fabric surface to quantify ease allowance for woven-based pant garments. Gu B, et al. [23] used the distance ease approach to quantify the ease allowance and pattern development for women's suits and developed a perfect fit suit for women.

Substantial research has been done to quantify the ease and pattern development for woven and knitted clothing and research has yet to be conducted that has attempted to determine the ease allowance or pattern development or how to get the proper fit garment using nonwoven fabrics. So, it is essential to work on the ease of mechanism and pattern development to get a better functional garment by using nonwoven fabrics because of their unique fabric structure and mechanical properties.

Finding and Research Challenges

Some leading research institutes, such as the School of Design and the University of Leeds, developed nonwoven fashion garments in 2007 (vi). However, these garments could not get the attention of the garments market because of fabric structure and properties. There also needed to be a mention in the literature about the ease of nonwoven garments and pattern development procedures; it 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 apparels.

Second, more literature should have 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 prominent outerwear and possess properties that are almost similar to woven fabrics.

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

No doubt, because of technological advancement and materials, nonwoven fabrics have entered the garments industry as outerwear but need to be improved in some areas like drape, physical appearance, thermal comfort properties and wash ability. 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 be accepted by the target market because of lower production cost, less waste in processing and easier recycling than woven fabrics.

It is known from the literature that the close entangling behaviour of fibres/filaments in nonwoven structure restrict the fibre's movement, affecting the fabric's stretch and recovery properties. Liu K, et al. [14] found that different body parts apply different pressure forces on the fabric during walking, sitting, running and squatting. 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.

Minimal studies exist to understand the relationship between nonwoven fabric structure and wear comfort. Raccuglia M, et al. [27] found that many factors influence wear comfort. One is the fabric-to-skin pressure that depends on the fabric weight and clothing fit, which relates to tactile comfort. Liu K, et al. [14] also found that clothing pressure is one of the most critical elements influencing wearing comfort. It relates to the ease of allowance and garment

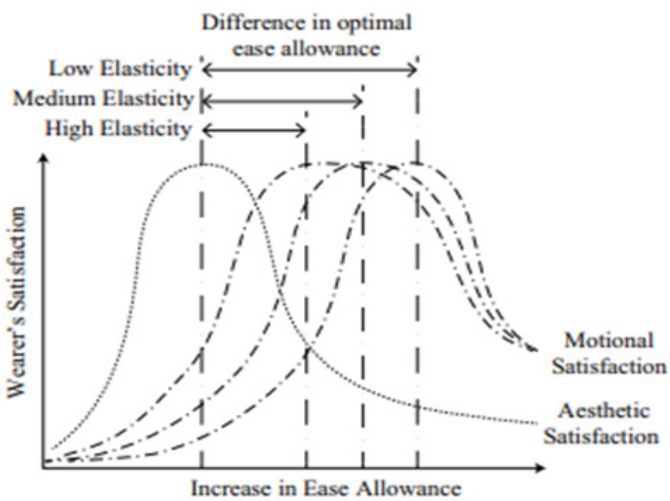

Figure 8. Relationship between ease allowance and wearer satisfaction with the fabrics [22].

pattern because nonwoven fabric comprises fibres 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 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.

Conclusion

Global apparel is seeking a new sustainable, environment-friendly and cost-effective approach to fabric manufacturing techniques for the garments industry. The nonwoven process is an unconventional way of fabric manufacturing and has environment-friendly processes because of less use of infrastructures and cost-effectiveness. Nonwovens used as bodywear started in 1960, going from paper to durable garments. Some institutes and researchers tried introducing nonwoven fabrics in the clothing industry by developing designer garments but could not attract impressive attention from the clothing market. The essential intended use of nonwoven fabrics in the nonwoven garment research was for industrial and hygienic purposes rather than clothing purposes.

Some Evolon fabric structures and mechanical and aesthetic properties help enter the clothing industry by working on finishing processes, alternative designs and pattern mechanisms. Limited literature was found on comparative studies on woven and nonwoven garments to determine the defined areas of improvement of nonwoven fabrics for the garments/clothing industry.

The success of nonwoven fabrics in the clothing industry as bodywear can be improved if the following areas are investigated.

- Alternative designs for nonwoven fabrics
- New pattern techniques for hydroentangled nonwoven structures
- Ease quantifications of pattern/garment

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None.

Conflict of Interest

The author declares that there is/are no conflict(s) of interest.

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