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Denim Fabric: Construction, Thermophysiological Comfort and Future Trends

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Abstract: Denim fabric is widely used in fashion, known for its durability, versatility, and style. However, its effect on thermophysiological comfort, particularly in a variety of environmental situations, remains a source of curiosity and research. This review focuses at the intricate relationship between denim fabric structure and thermophysiological comfort, which include data from current studies in textile science, ergonomics, and apparel development. Fibre type, yarn structure, fabric weight, weave pattern, and finishing treatments are studied in terms of heat regulation, moisture management, breathability, and overall wear comfort. The effect of denim construction on physiological responses, such as skin temperature, moisture retention, and subjective comfort, is explored in a variety of climatic and activity settings. Furthermore, advances in textile technology and novel techniques to improving denim comfort qualities are studied. This paper aims to provide insights on optimizing denim fabric construction for increased thermophysiological comfort, to help to the development of more comfortable and functional denim apparel.
Keywords: thermophysiological comfort, twill weave, functional denim, sustainability, blended yarns

I. INTRODUCTION

The French fabric known as serge de Nimes, which is named after the French town of Nimes, is assumed to be the source of the term "denim." Denim has always been made of cotton, although it was once made of wool and silk. Another type of fabric was called jean, and it originated in Genoa, Italy. It was a combination of cotton, linen, and/or wool. Denim was becoming more and more popular; it was stronger and cost more than jean fabric by the eighteenth century. Men's clothing was made entirely of denim by then, which was prized for its ability to last through numerous washings [1]. The German Hohenstein Institute linked the field of clothing comfort research to the 500 BC Greek philosopher Empedocles, who believed that human skin breathed. Empedocles suggested that clothing shouldn't block respiration and prevent toxic chemicals from entering the body. It demonstrates that people have always preferred comfortable outfits. The invention of synthetic fibres and the need for more innovative garment designs in the early 1900s brought the subject of comfortable clothes into sharp relief. Due to a complex and interconnected fusion of physical, psychological, and sensory sensations, clothing comfort is difficult to describe and heavily depends on an individual's subjective assessment. The material, size, and style of clothing play a crucial part in maintaining the balance between human body and the exterior environment.

A stream of heat through the fabric can be modified by changing its thickness, structure, and filament arrangement. Furthermore, the application of various textile auxiliaries can modify the behaviour of cloth during high temperatures and mass exchange [2].

What is comfort in one sentence it will be very difficult because:

- Comfort is the wearer's physiological reaction.
- Comfort regulates body temperature.
- Comfort is the absence of discomfort.
- Comfort is the psychological, physiological, and physical harmony between a person and their environment.

Denim fabric, known for its durability and adaptability, has an important role in the world of textiles. Denim, which originated as strong cotton twill weave, has become a global fashion staple that transcends cultural and age borders. However, in addition to its aesthetic appeal, denim provides exceptional physiological comfort due to its unique properties [3]. Denim fabric has outstanding breathability and moisture absorption qualities, which are critical in guaranteeing comfort, especially in warm conditions or during strenuous activity. Denim's natural fibres promote air circulation, avoiding the accumulation of heat and moisture against the skin. This breathability not only adds to the sensation of coolness, but it also aids in the regulation of body temperature, giving a sense of ease even during extended usage [4]. Physiological comfort, an important consideration in garment design, refers to a textile's capacity to give a comfortable wearing experience by controlling body temperature, moisture, and ventilation. Denim fabric provides significant physiological comfort due to its natural fibre makeup, mostly cotton. Cotton is very breathable, letting air to circulate freely about the body, aiding in moisture absorption and perspiration evaporation, and keeping the wearer cool and comfortable, particularly in hotter conditions or during intense activity [5]. Cotton is very breathable, letting air to circulate easily about the body, aiding in moisture absorption and perspiration evaporation, keeping the wearer cool and comfortable, particularly in hotter climes or during intense activity. Furthermore, the weight and thickness of a denim fabric might affect its physiological comfort. Lighter weight denim, such as that used in summer pants or denim shirts, has greater breathability and flexibility, improving comfort during extended usage.

2. CLASSIFICATION OF DENIM FABRIC

Denim fabric can be classified based on a variety of properties, including weave, weight, finish, colour, and composition. Denim fabric can be divided into numerous sorts based on these elements, each with its own set of characteristics and applications in the fashion and textile industries. This is a detailed classification:

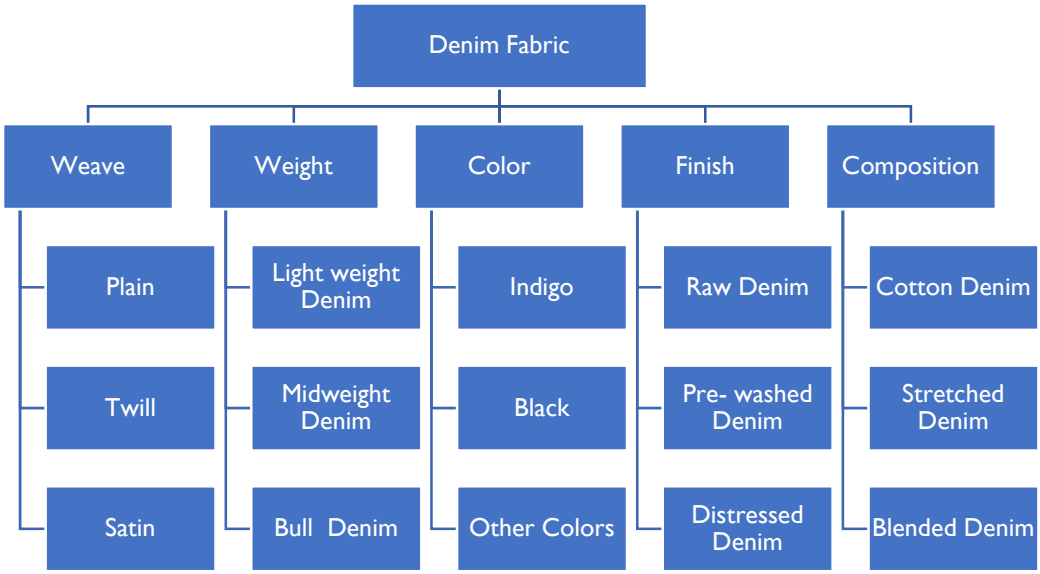


Fig.1: Classification of Denim Fabric

3. CHARACTERISTICS AND PROPERTIES OF DENIM

Denim is a strong cotton twill fabric that is woven with white weft and coloured warp threads to create the distinctive "twill lines" diagonal ribbing pattern. The following are some of the main attributes and qualities of denim [6].

a) Durability: Denim is a popular material for apparel that must survive repeated wear and tear because of its strength and durability [6].
b) Comfort: Denim may be soft and comfy even though it's durable, especially once it's been worn and washed a bit. It is therefore appropriate for daily wear.

c) Versatility: Denim is a versatile fabric that works well for a variety of outfits, including dresses, skirts, and jackets.
d) Indigo dyeing: Traditionally, denim is dyed using natural indigo dye, which gives fabric its distinctive blue colour. This dyeing method contributes to denim's distinctive appearance and ageing properties.
e) Fade: One of denim's distinguishing characteristics is its ability to fade over time with wear and washing. This feature is especially valued by denim fans who admire the unique appearance that the fabric develops as it matures.
f) Weight: Denim comes in a variety of weights, from lightweight to heavyweight. The weight of denim can influence its feel, drape, and adaptability for different seasons and uses.
g) Breathability: Despite being rather dense in comparison to other textiles, denim still provides adequate breathability, making it appropriate for year-round wear.
h) Texture: Denim's twill weave creates a rough surface that adds visual appeal and complexity to clothing produced from it.
i) Shrinkage: Denim may shrink slightly when washed and dried, especially if it is composed entirely of cotton. Pre-shrunk or sanforised denim is designed to reduce shrinking.
j) Fade Resistance: While denim is known to fade with time, modern denim can be treated to resist fading to some extent, allowing the colour to last longer.
k) Stretch: Some denim fabrics use elastane or spandex fibres to offer stretch, which improves comfort and flexibility.

These features and properties help to explain denim's lasting popularity and reputation as a staple fabric in fashion globally.

4. CONSTRUCTION OF CONVENTIONAL DENIM

Conventional denim, an excellent casual wear fabric, is created using a careful process that combines old craftsmanship and modern technology. It begins with raw cotton, which is spun into yarns of various thicknesses. These threads are then dyed indigo, which gives denim its distinctive blue hue. The dyed yarns are then woven on shuttle looms into a strong twill weave, usually with a diagonal ribbing pattern called the "right-hand twill." This weaving technique not only adds endurance but also gives denim its characteristic texture. Following weaving, the denim fabric goes through finishing operations like singeing to remove projecting fibres and sanforization to pre-shrink the cloth, resulting in little shrinkage after washing. Finally, the denim is examined for quality before to being cut and sewed. Into garments ranging from jeans to jackets, showcasing its timeless appeal and enduring popularity in fashion [7]. Conventional denim is normally made up of many crucial characteristics that add to its vintage appearance and durability. The fabric itself is commonly composed of cotton twill weave, which is distinguished by its diagonal ribbing pattern. Denim is suited for tough wear due to its strong and durable weave structure. Indigo dyeing is one of denim's most recognisable properties. Traditionally, denim is dyed with natural indigo dye, which gives fabric a rich blue colour that fades with wear and washing, resulting in unique wear patterns known as "fades."Denim clothes frequently have contrasting stitching in a golden or yellow colour to enhance visual interest and highlight seams and pockets. This stitching is frequently strengthened for extra durability, particularly in areas prone to stress, such as pockets, and belt loops [8]. Other common features noticed in traditional denim construction are robust buttons or riveted metal buttons for closures, belt loops to retain accessories such as belts, and patch pockets for storage. Overall, these nuances combine to create the timeless and classic look of denim, which has made it a staple in fashion for ages [9].

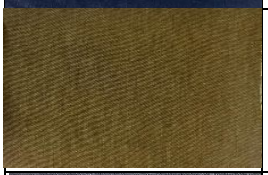
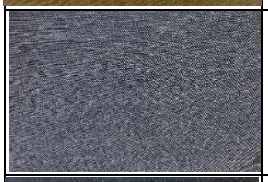
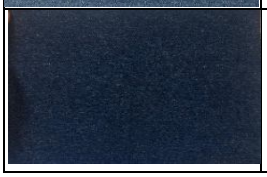
Denim production involves a variety of weaving techniques, the most prevalent of which are:

a) Plain Weave: This is the most basic weaving technique, with the warp and weft threads interlacing alternately to form a plain crisscross pattern. Most denim fabrics are woven using a simple weave.
b) Twill Weave: The weft thread runs over or under many warp threads, forming diagonal lines or ridges. Denim fabrics are frequently woven in a twill weave, usually 3x1 or 2x1 twill, which produces the characteristic diagonal ribbing pattern.
c) Satin Weave: Although less prevalent in denim manufacture, satin weave can be utilised to give denim fabrics a smooth, lustrous finish. Satin weave permits more warp or weft threads to float above the others, producing a shiny finish.

These weaving techniques can be combined or modified to create a wide range of denim fabrics with different weights, textures, and appearances, catering to various fashion preferences and functional requirements.

Table .I. Construction Parameters of Conventional Denim Fabrics

Denim Fabrics	Weave	Warp count (Ne)	Weft count (Ne)	EPI	PPI	GSM
	Twill	23.53	21.85	81	47	209

	Twill	37.30	37.75	111	59	152
	Twill	23.21	20.81	91	53	207
	Twill	8.43	10.63	78	48	280
	Twill	6.71	16.14	80	50	432
	Twill	10	9.79	77	44	446
	Twill	11.23	11.70	71	49	352

Denim is classified according to its weight, which is represented by the phrase "grammes per square metre" (GSM). The GSM of denim ranges from 150 to 400. Denim, such as t-shirts and children's apparel, is created with a weight of roughly 150 GSM. Jeans with 350-450 GSM. Heavy denim over 450 GSM, commonly known as bull denim [10].

5. THERMOPHYSIOLOGICAL COMFORT OF DENIM FABRIC

Thermophysiological comfort is the impression of comfort resulting from the exchange of heat and moisture between the human body and the environment. Thermophysiological comfort of denim fabric is influenced by multiple factors [11]:

a) Breathability: The breathability of denim fabric determines how well air and sweat may move through it. Breathable denim materials can assist regulate body temperature and avoid excessive sweating, resulting in increased comfort.
b) Moisture Management: Denim's capacity to absorb and wick moisture away from the skin affects comfort. Fabrics with moisture-wicking characteristics help keep the skin dry and alleviate the discomfort caused by perspiration accumulation [11].
c) Insulation: Insulation capabilities of denim dictate its capacity to keep body heat in. While denim is commonly considered a very thick fabric, differences in weight and manufacturing can influence its insulating properties, affecting comfort in different environments and climates [12].
d) Fabric Structure: The weave or knit structure of denim influences its breathability and moisture management properties. Open weaves or knits allow for more ventilation and moisture evaporation, which increases comfort.
e) Fit and Style: The fit and style of denim clothes affect thermophysiological comfort. Tight-fitting jeans may limit movement and airflow, whereas looser fits can improve ventilation and comfort.

5.1. ROLE OF POROSITY IN THERMOPHYSIOLOGICAL COMFORT OF DENIM

Porosity plays a very important function in thermo-physiological comfort. Porosity is another word for a fabric's openness. Porosity is said to be a function of the geometry of fabric. Fabric geometry depends upon the following factors:

- Type of fibre: filament or staple.
- Surface of fibre.
- Fibre fineness and the number of fibres in a cross section of yarn

- Yarn diameter.
- Yarn compactness.
- Warp and weft per unit length.
- Type of weave or knitting.

Plenty of literature available that investigate how porosity affects the thermal and sensory characteristics of clothes. Through convection and channel effect, porosity allows heat from the inside of the human body to escape. Radiation could, however, emit a little amount. The literature point out that convection-based heat dissipation has been the primary area of study. The kind of fabric also affects the air crossing. More air may pass through fabric made from staple fibers than filament fibres. According to reports, the type of weave has no discernible effect on airflow, but the application of various softeners has an impact as well because airflow is a function of porosity [14]. The effect of ventilation on thermo-physiological comfort was studied by Ruckman. Two outfits composed of fabrics coated with polyurethane (PU) and polytetrafluoroethylene (PTFE) were compared. Their results demonstrated that clothing with maximum holes restricts the rise in body temperature that occurs during physical activity. But when the body is at rest, the fabric plays a more important role [15,16,17]. The effects of covering fabric with hybrid aluminium nitride (AlN) particles of different sizes and epoxy resin modified with polydimethylsiloxane hydroxyl-terminated have been investigated by Wenying. They discovered that adding 50% filler increased heat conductivity, which was not achievable by just covering the material in its resting position the primary reason that it was filler, which creates a conduit for heat transmission by filling in the gaps in the fabric. The authors conclude that when hybrid fillers are used in place of a coating without fillers, the combined impact results in better heat conduction capability. The redesigned matrix and the interaction between the filler and matrices allowed the coating to display good high temperature resistance at the same time. Filling causes the fabric to thicken, which results in higher heat resistance [18,19].

6. INFLUENCE OF FINISHING TREATMENTS ON THERMOPHYSIOLOGICAL COMFORT OF DENIM.

Finishing processes have a significant impact on textile thermophysiological comfort. Thermophysiological comfort refers to a textile material's ability to regulate heat and moisture transmission between the body and its surroundings, hence impacting the wearer's experience of comfort. Finishing treatments can have an impact on several areas of thermophysiological comfort, including moisture management, breathability, thermal insulation, and overall tactile sensation. Some of the commonly used finishing treatments and their impact on thermophysiological comfort include [19]

a) Moisture Management: Finishing treatments like moisture-wicking or moisture-absorbing finishes can improve the textile's ability to transport moisture away from the body, resulting in faster evaporation and keeping the wearer dry and comfortable [19,20].
b) Softness and Comfort: Finishing treatments such as softeners or fabric softening substances can improve textiles tactile sensation, making them smoother and more pleasant on the skin, improving overall comfort [20].
c) Breathability: Finishes that promote textile breathability, such as the microencapsulation of phase change materials (PCM) or the use of breathable coatings, can improve air permeability and ventilation, allowing heat and moisture to exit more efficiently and increasing comfort.
d) Thermal Insulation: Textile finishing techniques can have an impact on their thermal insulation capabilities. Thermal insulating coatings or treatments, for example, can aid in the retention of body heat in cold weather, whereas phase change materials can give temperature-regulating qualities, keeping the wearer comfortable across a wide temperature range [20].
e) Antimicrobial Finishes: Textiles coated with antimicrobial finishes help prevent the growth of odour-causing bacteria, ensuring freshness and comfort, especially in garments worn during active activities [20].
f) UV Protection: Finishing treatments containing UV-blocking chemicals can protect against harmful ultraviolet radiation, lowering the risk of sunburn and heat accumulation and so helping to comfort, particularly in outdoor environments.

The choice of finishing treatments has a considerable impact on the thermophysiological comfort of textiles, and manufacturers frequently customise these treatments to the finished product's intended use and performance needs. Furthermore, advances in textile technology continue to drive innovation in finishing treatments, resulting in textiles that offer improved comfort and performance in a variety of conditions.

7. DEVELOPMENT OF FUNCTIONAL DENIM

Traditional denim is composed entirely of cotton, given a thorough washing, and then given textile additives to give it a supple texture. The most popular colours are blue and black. Researchers are referring to a fabric created by taking use of the following regions as "functional denim" [21].

- Blending of different fibres in spinning
- Application of different textile auxiliaries
- Applying different weaving techniques
- Using different fibres in the warp and weft.

Functional denim refers to denim fabric or garments that have been engineered or treated to possess specific functional properties beyond the traditional characteristics of denim, such as durability and aesthetics. The development of functional denim involves various processes, treatments, and innovations aimed at enhancing performance, comfort, and usability. The movement of mass and heat are necessary for thermo-physiological comfort, as was previously indicated. Thermophysiological comfort will be significantly affected if the behaviour of fabric towards heat and mass transfer changes. Therefore, regular denim will provide considerably different thermo-physiological comfort in wet and dry conditions. The goal is to clarify the properties of functional denim fabrics by establishing connections between modifications to the structure, fibre composition, textile auxiliary use, and thermal parameters [21].

7.1. FUNCTIONAL DENIM WITH BLENDED YARNS

When yarn is blended, it shows that multiple fibre types were used to create the yarn. Because different materials have varying thermal conductivity values, such blending of fibres results in variations in effective thermal conductivity. Additionally, the arrangement is impacted by their physical makeup, which ultimately results in a shift in porosity. The result of all these modifications is a change in thermo-physiological comfort. Numerous research evaluating the effect of blending on thermo-physiological comfort are available in the literature; however, all of these studies focus on fabric created with blended yarn in dry environments. Studies on the use of blended yarn denim in damp environments are limited. Several studies involving different fabric categories demonstrate that mixing significantly affects thermal features [22]. Research like this on creating various textiles from blended yarns can serve as a foundation for creating effective denim product. Through the use of polyester, cotton, and polypropylene, three standard weaving procedures, and twelve various washing techniques, researcher was able to create 180 different sorts of denim. Following a number of experiments, researchers came to the conclusion that functional denim has the best moisture management potential when polypropylene is used as the weft yarn. Such a material is able to retain its thermal resistance property for a longer time as compared to conventional denim, under wet conditions. A study investigated the relationship between fabric thickness and the behaviour of knitted fabrics made of a blend of cotton and jute. The researchers found that as the quantity of jute blend increased, the heat conductivity dropped. However, it was also found that thermal conductivity and fabric thickness were inversely related, suggesting that thermal resistance would be high. The knitted fabric's thermal conductivity in a jute/cotton blend was found to be influenced by the tightness factor and air permeability values. There is a negative correlation between air permeability and the fabric tightness factor. The idea that blending two distinct fibres will produce the required level of thermo-physiological comfort is supported by this study [23].

In another study, the air jet textured polyester and cotton yarn materials' thermophysiological comfort properties their method for creating air jet textured polyester yarns involved using two feed yarns with different filament counts and fineness. They observed that thermal conductivity and resistance of fabrics are not influenced by the texturing parameters or by the textured yarn structure [24]. The amount of coated material to study the effects of various polymer coatings. Knife-over-roll coating was employed consistently at a pilot plant and on small-scale laboratory apparatus. On polyester fabric, they applied a mixture of polyaniline, polythiophene, and polypyrrole with an acrylic binder polymer. They discovered that the coating caused a significant alteration in thermal conductivity. The majority of the time, the coating is applied to just one side of the cloth, giving the consumer dual-sided fabric [25]. A study was carried out to try and determine how fibre content affected moisture transport. The authors combined viscose and polyester to create eight distinct fabrics with varying amounts for this purpose. Additionally, they measured the amount of water vapour that passed through the fabric using Permetest. They measured the textiles liquid water transmission properties using a vertical wicking tester, and they concluded that the absorbency and water vapour permeability of material are positively correlated with the number of hydrophilic fibres. [26]. A study comparing fabrics made of functional and conventional denim. The SDL Atlas Moisture Management Tester was used to evaluate denim samples according to AATCC evaluate Method 195-2009. Due to its ability to provide several indices and aid in quantifying the movement of water in various directions within a textile material, the device is utilised. The OMMC capability of denim textiles composed of various fibres is displayed in the table. It has been noted that the denim manufactured from spun PP has the highest OMMC, which affects how well it keeps skin dry in damp weather. Additionally, it is found that traditional denim made entirely of cotton has very little capacity to regulate moisture [27].

8. THERMAL ABSORPTIVITY OF CONVENTIONAL AND FUNCTIONAL DENIM FABRICS.

Thermal absorptivity of denim fabric varies depending on their composition, structure, and functional treatments. Thermal absorptivity is the ability of a material to absorb thermal energy (heat) [28].

8.1. Conventional Denim Fabric: Cotton fibres are typically woven in a twill weave pattern to create conventional denim fabric. Cotton has strong thermal conductivity, which means it can easily absorb and release heat. Due to its breathability and air permeability, thermal absorptivity of denim may not be as great as that of other textiles [28].

8.2. Functional Denim Fabric: Functional denim textiles have been treated or contain additional components to improve specific attributes, such as thermal absorptivity.

For example:

a) Thermal Coating: Certain denim fabrics may be treated with thermal insulating materials or coatings to improve their ability to absorb and retain heat. The composition and efficiency of these coatings vary greatly.
b) Phase Change Materials (PCM): PCM-infused denim fabrics contain materials that may absorb and release heat as they change phase (for example, from solid to liquid and vice versa) at certain temperatures. This can assist in regulating body temperature by absorbing extra heat when warm and releasing it when cool [29, 30].
c) Metallic additions: Some denim fabrics may have metallic additions or fibres that improve thermal performance. Metallic nano particle containing fabrics, for example, may have higher heat conductivity and absorptivity.
d) Thermal Dyes or Pigments: Functional denim fabrics can be dyed or printed with thermal-absorptive dyes or pigments, which improve their ability to absorb heat from the environment or the body.
e) Microencapsulation: Denim fabrics can also be treated with microcapsules holding phase change materials or other chemicals that can collect and release heat as necessary.

8.3. Examples of Functional Denim Fabrics with Enhanced Thermal qualities are

a) Thermo-regulating denim: It uses phase change compounds or other thermally active chemicals to assist control body temperature [30].
b) Insulated denim: It refers to denim fabrics that have been treated with insulating ingredients or coatings to increase thermal retention.
c) Thermal-lined denim: Denim fabrics lined with thermal materials such as fleece or synthetic insulation to enhance warmth.
d) Smart denim: Some denim fabrics are embedded with smart textile technologies that can actively respond to changes in temperature, moisture, or other environmental factors to optimize thermal comfort [30].

9. FUTURE TRENDS AND CHALLENGES IN FUNCTIONAL DENIM FABRIC MANUFACTURING

9.1. Trends:

In the realm of denim fabric manufacturing, several notable trends are shaping the trajectory of industry, responding to evolving consumer preferences, sustainability concerns, and technological advancements [31].

9.1.1. Advances in sustainable Denim Production Methods: Concerns about environmental effect and social responsibility have prompted the fashion industry to focus on sustainable denim production processes. In recent years, several advancements have been made to overcome these challenges.

a) Waterless or Low-Water Techniques: Conventional denim manufacture takes a lot of water for the washing and dyeing operations. To tackle this, several waterless or low-water approaches have been developed. This includes procedures like laser finishing, ozone treatment, and foam washing, all of which use much less water [32].
b) Use of Organic and Recycled Materials: Many denim makers are switching to organic cotton, which is farmed without synthetic pesticides or fertilisers, hence minimising environmental effect. Furthermore, recycled denim and other materials are being used to make sustainable denim products, lowering the demand for virgin resources [33].
c) Biodegradable Dyes and Chemicals: Traditional dyeing techniques frequently use harsh chemicals that are damaging to the environment. Advances in biodegradable dyes and environmentally friendly chemicals are being used to reduce pollution and the carbon footprint of denim manufacturing.
d) Energy-Efficient Manufacturing: Denim manufacturers are expanding their investment in energy-efficient manufacturing procedures to reduce greenhouse gas emissions. This includes utilising renewable energy sources such as solar and wind power, as well as optimising production machines to reduce energy usage.
e) Recycling and upcycling: This can include typical recycling processes, such as breaking down denim fabric into fibres and reusing them to make new denim goods. Upcycling is the creative reworking of discarded denim clothes into new things, such as bags, accessories, or home furniture, extending their lives [33].
f) Closed-loop systems: These are designed to reduce waste by recycling and reusing resources throughout the production process. This involves recycling water, reusing chemicals, and repurposing waste materials into new goods or inputs.

9.1.2. Novel Denim Fabric Construction and Blends to Improve its Comfort and Performance

Improving comfort and performance in fabric structures requires a combination of new materials, weaving or knitting techniques, and fabric blends. Here are a few new approaches:

a) Moisture-Wicking Blends: Combining natural fibres like cotton or bamboo with synthetic fibres like polyester or nylon can result in fabrics that drain moisture away from the body, keeping the wearer dry and comfortable while exercising [34].
b) Breathable Mesh: Using mesh panels or open-knit constructions in specific parts of a garment can improve breathability by allowing air to circulate and heat to escape, which is especially useful for active wear and sportswear.
c) Temperature-Regulating Fibers: Fabrics constructed from temperature-regulating fibres, such asmerino wool or phase change materials (PCMs), may respond to fluctuations in body temperature, keeping the wearer warm in cold situations and cool in hot conditions [34].

9.2. Challenges

Functional denim fabric manufacturing faces various obstacles as the business grows and consumer demands change. Here are some possible future challenges:

a) Sustainability: As people become more conscious of environmental issues, the textile industry faces increased pressure to decrease its environmental footprint. Functional denim manufacturing procedures frequently require chemical treatments and finishes, which can be detrimental to the environment if not handled properly. It will be critical to find sustainable alternatives to standard chemicals, as well as to reduce water and energy usage during manufacturing operations [35].

b) Performance and Durability: Functional denim fabrics are designed to give specific performance attributes such as moisture-wicking, stretch, and abrasion resistance while retaining the aesthetic appeal and comfort of classic denim. Balancing these performance features with durability and longevity is difficult, since consumers expect their garments to resist regular wear and washing without sacrificing usefulness.

c) Cost-effectiveness: Because functional features require specialised materials and methods, incorporating them into denim fabrics can drastically increase manufacturing costs. Finding cost-effective ways to add functional components without compromising quality will be vital to ensuring that functional denim remains available to a wide variety of consumers [35].

10. CONCLUSION

The construction and thermophysiological comfort of denim fabric are crucial in influencing its performance and popularity in the fashion business. Durability, adaptability, and aesthetic appeal of denim have helped it become a wardrobe staple around the world. Denim makers continue to improve the quality of fabric, its comfort, and sustainability by developing new construction techniques such as varied weaving patterns, dyeing procedures, and finishing treatments. Stretch denim, moisture-wicking characteristics, and breathable textiles have met consumer comfort demands while maintaining traditional appeal of denim. Furthermore, research into thermophysiological comfort has highlighted the relevance of breathability, moisture management, and temperature regulation in denim clothes. Understanding these characteristics enables designers and producers to create denim products that provide optimal comfort in a variety of climates and activities. Future developments in denim fabrication are expected to emphasise sustainability, innovation, and customisation. With rising environmental concerns, the industry is under increasing pressure to adopt eco-friendly methods like as using recycled materials, conserving water, and limiting chemical treatments. In addition, technical breakthroughs such smart textiles have the potential to revolutionise denim production and design, providing consumers with personalised and technologically advanced clothes. In conclusion, the structure, thermophysiological comfort, and future trends of denim fabric demonstrate the industry's continued dedication to quality, innovation, and sustainability. By implementing these concepts, denim makers may continue to suit consumers changing wants and tastes while reducing their environmental impact.

REFERENCES

[1]. Downey, L., 2007. A Short History of Denim. Levi Strauss & Co., San Francisco, CA, USA. Paul, R., Pardeshi, P.D., 2003.
[2]. Hohenstein Institute. Clothing physiological research in the service of wear comfort, http://www.hohenstein.com/media/downloads/FC_EN_Bekleidungsphysiologie_ mail.pdf
[3]. Denim: The Forever Classic! Here's Why? By Fibre2Fashion, Nov 2019
[4]. Aravin Prince Periyasamy* and Saravanan Periyasami, Critical Review on Sustainability in Denim: A Step toward Sustainable Production and Consumption of Denim, ACS Omega 2023, 8, 4472−4490 https://doi.org/10.1021/acsomega.2c06374
[5]. Md Rashedul Islam , Kevin Golovin and Patricia I. Dolez, Clothing Thermophysiological Comfort: A Textile Science Perspective, MDPI,2023
[6]. Denim fabric: (Characteristics and different types) by Sarina Tariq, 2023
[7]. Denim Fabric Weaving – Manufacturing Process, Methods, and technologies by Ashok Hakoo ,2022
[8]. J N Chakraborty, R B Chavan , Dyeing of denim with indigo, Indian Journal of Fibre & Tex tile Research,2004
[9]. The Real Reason Why There Are Metal Buttons on Your Denim Pockets by Erika Owen, 2017
[10]. Bilisik, K., Yolacan, G., 2011. Tensile and tearing properties of newly developed structural denim fabrics after abrasion. Fibres Tex. East. Eur. 19 (88), 54–59 No. 5.
[11]. Dinesh Bhatia and Urvashi Malhotra, Thermophysiological Wear Comfort of Clothing: An Overview, Journal of Textile Science & Engineering,2016 https://doi.org/10.4172/2165-8064.1000250
[12]. Denim Insulation Review: Comparison Guide and Pros and Cons. By Lee Wallender, 2024
[13]. Esin Sarıoğlu and Osman Babaarslan, Porosity and air permeability relationship of denim fabrics produced using core-spun yarns with different filament finenesses for filling, Journal of Engineered Fibers and Fabrics Volume 14, January-December 2019 https://doi.org/10.1177/1558925019837810
[14]. Hes, L., 2008a. Heat, moisture and air transfer properties of selected woven fabrics in wet state. J. Fiber Bioeng. Inform. 968–976

[15]. Çay, A., Atav, R., Duran, K., 2007. Effects of warp-weft density variation and fabric porosity of the cotton fabrics on their colour in reactive dyeing. Fibres Tex. East. Eur. 15, 91–94
[16]. Wenying, Z., Demei, Y., Qunli, A., 2009. A novel polymeric coating with high thermal conductivity. Polymer-Plastics Technol. Eng. 48, 1230–1238 https://doi.org/10.1080/03602550903159051
[17]. Hardy, J.D., 1968. Heat transfer. In: Newburgh, L.H.E. (Ed.), Physiology of Heat Regulation and the Science of Clothing. Hafner, New York.
[18]. Vigneswaran, C., Chandrasekaran, K., Senthilkumar, P., 2010. Effect of thermal conductivity behaviour of jute/cotton blended knitted fabrics. J. Ind. Text. 49–64
[19]. Mangat, M.M., 2012. The Effect of Moisture and Finishing on Thermal Comfort and Selected Mechanical Properties of Denims with a Portion of Synthetic Fibres, Ph.D. Research, Technical University, Liberec, Czech Republic
[20]. Ekanić, Tihana & Pušić, Tanja & Soljacic, I. (2015). Influence of special finishes on denim properties. Indian Journal of Fibre and Textile Research. 40. 170-174
[21]. Mangat,M.M.,Hussain,T..,Bajzik,V.,2012. Impact of different weft materials and washing treatments on moisture management characteristics of denim. J. Eng. Fibres Fabrics 7,38-49
[22]. Nasrin Akter,Md.Reazuddin Repon,Daiva Mikučionienė, Mohammad Abdul Jalil, TarikulIslam, Md.Rezaul Karim, Fabrication and characterization of stretchable denim fabric using core spun yarn, Heliyon,2021https://doi.org/10.1016/j.heliyon.2021.e08532
[23]. Vigneswaran, C., Chandrasekaran, K., Senthilkumar, P., 2010. Effect of thermal conductivity behaviour of jute/cotton blended knitted fabrics. J. Ind. Text. 49–64
[24]. Rengasamy, R.S., Das, B.R., Patil, Y.B., 2009. Thermo-physiological comfort characteristics of polyester air-jet-textured and cotton-yarn fabrics. The J. Text. Inst. 100, 507–511. https://doi.org/10.1080/00405000801977183
[25]. Rehnby, W., Gustafsson, M., Skrifvars, M., 2012. Coating of Textile Fabrics with Conductive Polymers for Smart Textile Applications [Online]. School of Textiles, University College of Borås,
[26]. Das, B., Das, A., Kothari, V., Fanguiero, R., Araujo, M.D., 2009. Moisture flow through blended fabrics -effect of hydrophilicity. J. Eng. Fibers Fabrics 4, 20–26. https://doi.org/10.1177/155892500900400405
[27]. Maryan, A.S., Montazer, M., Rashid, A., 2013. Introducing old-look, soft handle, flame retardent and anti-bacterial properties to denim garments using clay. J. Eng. Fibers Fabr. 8 (4), 68–77 https://doi.org/10.1177/155892501300800416
[28]. Lubos Hes, Marie Manákova, Olga Paraska, The effect of long time wear on thermal comfort properties of various parts of denim trousers, Journal of Textile Engineering & Fashion Technology,2021
[29]. In, Shu. (2012). Phase Change Materials' Application in Clothing Design. Transactions of the Materials Research Society of Japan. 37. 103-106. https://doi.org/10.14723/tmrsj.37.103
[30]. Prasad S. Bhatkhande, Development of thermo-regulating fabric using phase change material (PCM),2011
[31]. Kertmen, Nuriye. (2021). New Trends in Fibers Used in Denim Fabric Production. Tekstil ve Mühendis. 28. 48-59. https://doi.org/10.7216/1300759920212812106
[32]. Revolutionizing Sustainability: Steps for the Indian Denim Industry to Conserve Water, ace turtle, 2023
[33]. Sedef Uncu Akı, Cevza Candan, Banu Nergis and Neslihan Sebla Önder, Understanding Denim Recycling: A Quantitative Study with Lifecycle Assessment Methodology, Waste in Textile and Leather Sectors,2020
[34]. Patra, A.K. & Pattanayak, A.K.. (2015). Novel varieties of denim fabrics. Denim: Manufacture, Finishing and Applications. 483-506. https://doi.org/10.1016/B978-0-85709-843-6.00016-0
[35]. Fabric Innovation: How Brands & Manufacturers Are Weaving the Future of Denim,2023