WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Advances in Nonwoven Fabric Technology: From Production to Performance

Minakshi Sharma[1], Shalini Rukhaya[2], Neelam M. Rose[3], Saroj Yadav[4], Divya[5]

Deptt. of Apparel and Textile Science, I.C. College of Community Science
CCS Haryana Agricultural University, Hisar- 125004, India
Corresponding author: *sharmaminakshi2425@gmail.com*

ABSTRACT :

Nonwoven fabrics are engineered textile materials produced by bonding or interlocking fibres through mechanical, thermal, or chemical means, eliminating the need for traditional weaving or knitting. This review paper explores the advancements in nonwoven fabric technology, focusing on production methods and performance characteristics. The techniques include mechanical bonding, thermal bonding and chemical bonding. Each method imparts distinct structural and functional properties to the fabrics, influencing their suitability for various applications. The paper delves into the mechanical properties of needle-punched nonwovens, highlighting aspects such as thermal insulation, fabric density, compression behaviour, air permeability, thermal resistance, sound absorption, water absorbency, and bulk properties. These characteristics are critical in determining the performance of nonwoven fabrics in applications ranging from hygiene products and medical textiles to automotive components and industrial filters. The review also discusses the role of fibre composition, fabric structure, and processing parameters in tailoring nonwoven fabrics for specific end-uses. The paper underscores the versatility and growing importance of nonwoven fabrics in various sectors, driven by continuous research and technological advancements that enhance their performance and expand their application scope.

Keywords: Nonwoven fabrics, functional properties, technical textiles, performance optimization.

Introduction

Nonwoven fabrics are engineered textiles produced by bonding or interlocking fibres through mechanical, chemical or thermal processes, without the need for weaving or knitting. Their manufacturing process is more straightforward and time-efficient compared to woven or knitted fabrics, resulting in lower production costs. This cost-effectiveness makes nonwoven fabrics ideal for disposable products such as wipes, feminine hygiene items, and diapers, where performance and affordability are paramount (Pourmohammadi,2013). These nonwovens can be suitable for a variety of applications such as aerospace applications, acoustic/thermal insulation, fire retardant materials, industrial filters, puncture, cut-resistant materials, synthetic and composite materials for industrial uses, welding protection, wall coverings, truck liners, and vehicle seats (Ajmeri and Ajmeri, 2016).

- Mechanical bonding: needle punching, stitch bonding, hydrogen tangling
- Thermal bonding: through air, calendar bonding, or ultrasonic bonding
- Chemical bonding: spray, foam, print, impregnation

Mechanical Bonding strengthens nonwoven fabrics through the physical entanglement of fibres without altering their inherent properties. Techniques such as needle punching, hydroentangling, and stitch bonding are commonly used (Barea and Navarro, 2015). These processes involve the repeated insertion of barbed needles or high-pressure water jets to interlock the fibres, enhancing the fabric's strength and structure without significantly affecting its absorbency (Russell,2006). Thermal bonding utilizes heat and pressure to soften and fuse thermoplastic fibres, creating bonds at fibre intersections. The process involves heating the web to the fibres glass transition temperature, allowing bonding fibres to liquefy and surround the main fibres (Singh and Tang, 2020). Upon cooling, these fibres solidify, forming a cohesive structure. Methods include calendering, where the web passes between heated rollers, and through-air bonding, where hot air is directed through the web (Chaudhari and Mandot, 2008). Chemical bonding involves applying a bonding agent, such as a latex or emulsion, to the fibre web. This agent is then activated using heat, causing it to form bonds between the fibres (Singh and Tang, 2020). The binder can be applied in various forms, including powders, films, or foams, and serves to enhance properties like strength, softness and water resistance (Zhang and Lu, 2014).

Needle punching is a mechanical bonding technique used to consolidate fibrous fleeces (Debnath and Madhusoothanan, 2010). In this process, barbed (felting) needles are repeatedly driven through a moving web of fibres using a needle loom, causing the fibres to entangle and form a cohesive fabric. Typically, a needle board containing multiple barbed needles reciprocates at high speeds as the fibrous batt moves beneath it. To achieve uniform bonding, it is often necessary to needle the fleece from both sides. This can be done either by passing the material through the machine twice flipping it between passes or by using a dual-needle board system, where one board punches downward and the other upward. Needle punching is particularly well-suited for producing medium to heavy-weight nonwoven fabrics (Kittlemann and Dilo, 2003).

2. Methods of Manufacturing Non-wovens:

2.1 Nonwoven fabric:

Nonwoven fabrics are broadly characterized as sheet or web-like structures formed by bonding fibres or filaments either by mechanical entanglement, thermal processes, chemical treatment, or through perforated films. These fabrics are typically flat or tufted, porous sheets produced directly from individual fibres, molten polymers, or plastic films, without the need for spinning yarn or traditional weaving and knitting methods. As engineered materials, nonwovens can be designed for single-use applications, short-term use, or long-lasting durability depending on the requirement.

They are known for delivering a range of functional properties such as absorbency, liquid repellency, resilience, elasticity, softness, tensile strength, flame resistance, washability, cushioning, thermal and acoustic insulation, filtration capabilities, bacterial barrier, and sterility. Often, these features are combined to tailor nonwovens for specific applications, providing an optimal balance between performance, cost and intended lifespan.

Nonwoven fabrics can replicate the look, feel, and strength of woven textiles while also being manufactured to the bulk and thickness of heavy padding materials. When combined with other materials, they can provide many useful and attractive features. Nonwovens find extensive applications across various industries, including apparel, home furnishings, healthcare, engineering, and numerous industrial and consumer products.

2.2 Different Methods:

Non-woven fabrics can be made in various methods like

- Thermal bonding
- Hydroentanglement
- Needle punching/needle felting
- Chemical bonding

2.2.1 Thermal bonding:

Thermally bonded nonwoven fabrics are produced by applying heat to melt thermoplastic fibres or powders, such as polyester or polypropylene. When heat is applied, the fibres soften at their points of intersection, allowing them to fuse. As the material cools, these bonded intersections solidify, creating a stable structure. This bonding process enhances the overall strength and integrity of the fabric, making it suitable for a wide range of applications.

2.2.2 Hydroentanglement:

A bonding technique used to produce nonwoven fabrics from fibrous webs formed through carding, air laying, or wet laying processes. This method involves directing fine, high-pressure jets of water onto the fibre web. As the water jets penetrate the web and strike the conveyor belt beneath, they rebound and cause the fibres to entangle with one another. This entanglement results in a cohesive and durable nonwoven fabric without the need for additional binders or adhesives.

2.2.3 Chemical bonding:

Chemical bonding in nonwoven fabrics involves the use of adhesive materials, known as chemical binders, to join fibres together. These binders are typically polymers produced through emulsion polymerization, with water-borne latexes being the most commonly used today. Due to their low viscosity similar to that of water these binders can easily penetrate the fibrous structure of nonwovens when applied as an emulsion. Application methods such as immersion allow the binder to evenly coat the web. Following application, the fabric is dried, causing the water to evaporate and leaving behind an adhesive film. This film forms at the points where fibres intersect, effectively bonding them together and providing structural integrity to the fabric.

2.2.4 Needle punching:

Needle-punched nonwoven fabrics are produced from fibrous webs most commonly carded webs where fibres are mechanically bonded through entanglement and friction. This is achieved by repeatedly driving fine barbed needles through the web, which entangles the fibres and holds them together. The interaction between the fibres and the needle barbs creates a distinctive structural pattern in the fabric. During the needling process, fibre segments are reoriented and drawn from the surface into the interior of the fabric, forming fibre columns that are generally aligned perpendicular to the fabric plane. Among the various bonding techniques, needle punching stands out as one of the most effective methods for producing strong and structurally sound nonwoven fabrics (Yilmaz and Powell, 2013).

3. Mechanical Properties of Needle Punched Nonwovens

3.1 Thermal insulation:

Polyester is widely used in textile applications due to its easy availability, low cost, and favourable mechanical properties. One of the key functional attributes of textile materials, especially in technical textiles, is their thermal insulation capability. Common methods for evaluating thermal insulation values (TIV) include the disk method, constant temperature method, and cooling method. Generally, as the fabric weight increases, the number of fibres per unit area also rises, leading to an increase in fabric thickness. This added thickness enhances thermal resistance, as it reduces thermal conductivity, thereby improving the fabric's insulation performance. For instance, in jute fabrics, a direct correlation is observed between fabric thickness and TIV thicker fabrics exhibit better insulation. However, in the case of hollow polyester fibres, the use of fine linear density fibres during the needle-punching process leads to higher fibre consolidation. This tight packing results in reduced air pockets within the structure, ultimately leading to lower thermal insulation performance in hollow polyester needle-punched nonwovens (Debnath, 2011).

3.2 Fabric density, percentage compression and thickness:

As the fabric weight increases, both the thickness and density of the fabric tend to rise this trend has been specifically observed in polypropylene needle-punched nonwoven fabrics. A higher fabric weight implies a greater number of fibres within a given area, which enhances the ease of forming a more consolidated structure during the needle-punching process. This is because the increased fibre content allows for more effective entanglement, resulting in a denser and more compact fabric. Additionally, in polyester samples with different cross-sectional shapes, a consistent trend is observed: the percentage of compression decreases as fabric weight increases. This reduction in compressibility is attributed to the higher number of fibres per unit area, which enables a larger distribution of the compressive load across the fabric. Consequently, the fabric structure becomes more resistant to compression with increasing fabric weight (Debnath and Madhusoothanam, 2010).

3.3 Air permeability:

Both air permeability and SAP (Super Absorbent Polymer retention) tend to decrease as fabric weight increases. This is primarily because heavier fabrics become thicker and denser, leading to a more compact and consolidated structure. Although the total number of pores may increase with the addition of more fibres, the individual pore size decreases, which results in lower air permeability and reduced SAP values. This trend is evident in both polyester and jute needle-punched nonwoven fabrics, where an increase in fabric weight consistently leads to a decline in air permeability (Debnath and Madhusoothanan, 2010).

Needling density has minimal influence on air permeability. However, airflow resistivity is found to rise as fibre diameter and porosity decrease (Çinçik and Koc, 2012).

Additionally, due to the lower density of polyester fibres compared to viscose fibres, polyester-rich fabrics exhibit greater thickness than viscose-rich fabrics of the same mass per unit area. Consequently, the air permeability of polyester-dominant fabrics is lower than that of their viscose counterparts. It is also observed that air permeability decreases with an increase in fabric mass per unit area. On the other hand, higher needling density can slightly improve air permeability. In multilayered fabric structures, both air permeability and airflow resistance follow similar patterns, being influenced by fibre composition, structure, and processing parameters (Broda and Baczek, 2020).

3.4 Thermal resistance:

Thermal resistance tends to increase with rising fabric weight. This effect is particularly visible at lower needling densities, where the increase in fabric weight leads to a more significant improvement in thermal resistance. However, at higher needling densities, the influence of fabric weight on thermal resistance becomes less pronounced. Overall, the impact of fabric weight on thermal resistance remains relatively consistent across various needling densities (Çinçik and Koc, 2013).

Conversely, both thermal resistance and specific thermal resistance decrease as the needling density increases. This is likely due to the increased compaction of fibres, which reduces the insulating air pockets within the fabric structure. Furthermore, as fabric weight increases, both thermal resistance and thickness show a clear upward trend. At the same time, air permeability and sectional air permeability decrease significantly, regardless of the jute content in the fabric. This indicates a trade-off between thermal insulation and breathability, driven by structural changes within the nonwoven material (Debnath, 2011).

3.5 Sound reduction:

In recent years, noise pollution has become a growing concern across the globe due to its negative impact on human health and well-being. Elevated noise levels are known to cause sleep disturbances, increased stress, hearing impairment, and a decline in productivity and learning capacity, making effective noise control essential. Among various solutions, needle-punched nonwoven fabrics have gained attention for their potential in acoustic insulation (Yilmaz and Banks, 2011).

Several factors influence the sound reduction capability of these fabrics, including areal density, fabric type, fibre composition, source intensity, number of fabric layers, and the distance of the fabric from both the sound source and the receiver. For instance, jute exhibits the lowest sound reduction performance among the tested samples due to its compact structure and lower void volume, which corresponds to higher fabric density. In contrast, synthetic fibres generally offer better sound reduction, and blends of different fibre types tend to perform even better than their individual counterparts (Shahani and Soltani, 2014).

Moreover, when the position of the sound source remains constant and the distance of the receiver is varied, the sound reduction remains relatively stable. However, increasing the areal density of the fabric consistently enhances its ability to reduce sound. Interestingly, a decrease in fabric density, when paired with increased areal density, also leads to improved sound reduction, indicating the importance of optimizing structural parameters for effective acoustic insulation.

3.6 Water absorbency:

Water absorbency is a critical property of textile materials, especially since fabrics often undergo processes like dyeing and finishing, where moisture interaction plays a key role. Jute-based fabrics, in particular, serve a variety of purposes such as floor coverings, absorbent materials, cleaning products

and agro-textiles, where effective water absorbency significantly impacts performance. Among long vegetable fibres, jute exhibits excellent wettability, making it well-suited for such applications (Yilmaz and Powell, 2013).
The porous structure of needle-punched nonwoven fabrics is expected to enhance their water-holding capacity. Additionally, fabric density is believed to influence water absorbency, with denser structures potentially offering reduced absorbency due to limited pore space. With deeper needle penetration, bulk density tends to decrease at lower punch densities, whereas it increases at higher punch densities. These structural changes, influenced by needling parameters, directly affect the fabric's ability to absorb and retain water (Sengupta, 2009).

3.7 Bulk and physical properties:

The bulk and physical properties of a fabric play a crucial role in determining its performance during use and overall serviceability. While the physical characteristics of a fabric are either directly or indirectly influenced by its bulk, the bulk properties themselves have a direct impact on thermal and compressional behaviour. For instance, studies have shown that air permeability is generally higher in random-laid nonwoven fabrics compared to cross-laid ones, primarily due to the greater number of pores in the random-laid structure (Tascan and Vaughn, 2008).
Fibre fineness significantly affects both the bulk and physical properties of nonwoven fabrics. These properties, particularly in needle-punched fabrics, are key indicators of the material's suitability for specific applications. Factors such as fibre characteristics, web formation, machine design, processing variables, and finishing treatments all contribute to the final fabric performance.
Typically, denser nonwoven fabrics made from the same raw materials and with equal web weight tend to exhibit lower air permeability but improved strength and elongation. Higher consolidation in such fabrics is often achieved through increased needling density and greater needle penetration. As needle penetration depth increases, fabric compressibility tends to decrease, while compressional recovery improves, enhancing the fabric's resilience and structural integrity (Midha and Mukhopadyay, 2005).

3.8 Acoustical characteristics and sound absorption coefficient:

The use of textile materials to control acoustic phenomena in workplaces and residential environments has attracted significant attention in recent years. Among these, nonwoven fabrics are recognized as excellent acoustic insulators, largely due to their high volume-to-mass ratio. The influence of various fabric parameters such as fibre fineness, surface texture, punch density, areal density, and chemical bonding highlighted their collective impact on sound absorption performance.
The fibre fineness plays a crucial role in enhancing the acoustic absorption of nonwoven fabrics. Additionally, surface structure was found to influence sound absorption behaviour, with plain-surfaced samples exhibiting the highest sound absorption coefficients, followed by velour and cord surfaces. This variation is attributed to the different mechanisms of fibre transfer associated with fork and felting needles during the needling process (Tascan and Vaughn, 2008).
Moreover, both areal density and punch density were found to have a positive effect on the sound absorption capacity of needle-punched fabrics. As these parameters increase, the structure becomes more compact and better suited to absorb sound energy, further validating the effectiveness of nonwoven textiles in acoustic insulation applications (Shahani and Zarrebini, 2014).

3.9 Oil sorbents:

Oil spills are a major environmental concern, commonly occurring in large bodies of ocean water and surrounding land areas. These spills often result from oil leaks during extraction and transportation, poorly constructed storage tanks, or explosions caused by natural disasters or wartime activities. To minimize environmental damage, it is crucial to remove or neutralize spilled oil as quickly as possible. Traditional oil spill cleanup methods, such as skimmers, chemical dispersants, and bioremediation using bacteria, are often slow, expensive, and can have adverse environmental effects.
In the search for more efficient and eco-friendly alternatives, fibrous materials have emerged as promising candidates for oil spill remediation. The nonwoven fabrics made from natural fibres like milkweed and kapok exhibit exceptional oil sorption capacity and fast absorption rates. Moreover, milkweed and cotton-based fabrics demonstrated excellent oil selectivity, with oil replacing approximately 90 and 85 percent of previously absorbed water in their structures, respectively (Chen and Dirican, 2019).
However, a key limitation of these natural fibre nonwovens is their low tensile strength, which compromises durability and may lead to failure during practical use. The need to develop reinforced or modified natural fibre nonwovens with enhanced mechanical strength, making them more reliable and effective as oil sorbents for environmental cleanup applications (Renuka and Rengasamy, 2016).

4. Conclusion:

In conclusion, among the various nonwoven manufacturing techniques, needle punching stands out as a highly effective and widely adopted method, particularly well-suited for technical applications. Ongoing research and development continue to expand the potential of nonwoven fabrics, with ample opportunities still available for further innovation and enhancement. Today, nonwovens play a significant role across multiple technical textile sectors, including geotextiles, medical textiles, agricultural textiles, and automotive applications, highlighting their versatility and growing importance in industrial and commercial domains.

REFERENCES:

1. 1)Debnath, S., & Madhusoothanan, M. (2010). Thermal insulation, compression and air permeability of polyester needle-punched nonwoven.
2. 2) Sengupta, S. (2010). Sound reduction by needle punched nonwoven fabrics.
3. 3) Midha, V. K., & Mukhopadyay, A. (2005). Bulk and physical properties of needle-punched nonwoven fabrics.
4. 4)Shahani, F., Soltani, P., & Zarrebini, M. (2014). The analysis of acoustic characteristics and sound absorption coefficient of needle punched nonwoven fabrics. *Journal of Engineered Fibres and Fabrics*, 9(2), 155892501400900210.
5. 5)Tascan, M., & Vaughn, E. A. (2008). Effects of total surface area and fabric density on the acoustical behaviour of needlepunched nonwoven fabrics. *Textile Research Journal*, 78(4), 289-296.
6. 6)Debnath, S. (2011). Thermal resistance and air permeability of jute-polypropylene blended needle punched nonwoven.
7. 7)Yilmaz, N. D., Banks-Lee, P., Powell, N. B., & Michielsen, S. (2011). Effects of porosity, fibre size, and layering sequence on sound absorption performance of needle punched nonwovens. *Journal of Applied Polymer Science*, 121(5), 3056-3069.
8. 8)Sengupta, S. (2009). Water absorbency of jute needle punched nonwoven fabric.
9. 9)Yilmaz, N. D., Powell, N. B., Banks-Lee, P., & Michielsen, S. (2013). Multi-fibre needle-punched nonwoven composites: effects of heat treatment on sound absorption performance. *Journal of Industrial Textiles*, 43(2), 231-246.
10. 10)Çinçik, E., & Koç, E. (2013). The effect of blend ratio and process parameters on tensile properties of polyester/viscose blended needle-punched nonwovens. Fibres and Polymers, 14(6), 1040-1049.
11. 11)Çinçik, E., & Koc, E. (2012). An analysis on air permeability of polyester/viscose blended needle punched nonwovens. *Textile Research Journal*, 82(5), 430-442.
12. 12)Yilmaz, N. D., Michielsen, S., Banks-Lee, P., & Powell, N. B. (2012). Effects of material and treatment parameters on noise-control performance of compressed three-layered multifibre needle-punched nonwovens. *Journal of Applied Polymer Science*, 123(4), 2095-2106.
13. 13)Renuka, S., Rengasamy, R. S., & Das, D. (2016). Studies on needle-punched natural and polypropylene fibre nonwovens as oil sorbents. *Journal of Industrial Textiles*, 46(4), 1121-1143.
14. 14)Broda, J., & Bączek, M. (2020). Acoustic properties of multi-layer wool nonwoven structures. *Journal of Natural Fibres*, 17(11), 1567-1581.
15. 15)Shahani, F., Soltani, P., & Zarrebini, M. (2014). The analysis of acoustic characteristics and sound absorption coefficient of needle punched nonwoven fabrics. *Journal of Engineered Fibres*, 9(2), 155892501400900210.
16. 16)Venu, L.B.S.; Shim, E.; Nagendra, A.; Behnam, P. (2012). Three-Dimensional Structural Characterization of Nonwoven Fabrics. *Microsc. Microanal.*, *18*, 1368–1379.
17. 17)Pourmohammadi, A. (2013). Nonwoven materials and joining techniques. *Join. Text.*, 565–581.
18. 18)Ajmeri, J.R.; Ajmeri, C.J. (2016). Developments in nonwoven materials for medical applications. *Adv. Tech. Nonwovens*, 227–256.
19. 19)Russell, S.J. (2006). *Handbook of Nonwovens*; Woodhead Publishing: Cambridge, UK, p. 544. ISBN 9781885736030.
20. 20)Ben Mlik, Y.; Jaouadi, M.; Jmali, M.; Slah, M. (2016) New Lab-Scale Device for Nonwoven Production: Optimization of Setting Parameters. *J. Text. Inst.*, *107*, 1636–1643.
21. 21)Chen, C.; Dirican, M.; Zhang, X. (2019) Centrifugal Spinning High-Rate Production of Nanofibres. *Electrospinn. Nanofabr. Appl.*, 321–338.
22. 22)Kittlemann, W.; Dilo, J.P.; Gupta, V.P.; Kunath, P. (2003). Needling Process. In *Nonwoven Fabrics: Raw Materials, Manufacture, Applications, Characteristics, Testing Processes*; Albrecht, W., Fuchs, H., Kittlemann, W., Eds.; Wiley-Vch: Weinheim, Germany.
23. 23)Zhang, X.; Lu, Y. (2014). Centrifugal Spinning: An Alternative Approach to Fabricate Nanofibres at High Speed and Low Cost. *Polym. Rev.*, *54*, 677–701.
24. 24)Singh, N.; Tang, Y.; Ogunseitan, O.A. (2020). Environmentally Sustainable Management of Used Personal Protective Equipment. *Environ. Sci. Technol.*, *54*, 8500–8502.
25. 25)Barea, E.; Navarro, J.A.R. (2015). Textile/Metal-Organic-Framework Composites as Self-Detoxifying Filters for Chemical-Warfare Agents. *Angew. Chem. Int. Ed*, *54*, 6790–6794.