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Modelling of Polypropylene Multi-layer Nonwoven Fabrics Techniques and Mechanical Geometrical Properties of Technical Textiles

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Abstract

The modelling of nonwoven fabric manufacturing uses fibres or filaments laid down, without interlacing, in a web and bonded together mechanically (spun-bonding), (melt-blowing), or both. The resulting fabric, after bonding, typically produces a flexible and porous structure. These find use mostly in industrial and disposable applications. The present research aims to study the mechanical and geometrical properties of polypropylene nonwoven fabric modelling and illustrate the effect of the parameters of the fabric construction technique and fabric orientation (MD-CD) in tensile and elongation behaviour. Through production, six samples with different weights as 13, 30, and 60 g/m2.
The samples under investigation are two types of nonwoven fabrics consisting of two and three-layered polypropylene webs produced by the carding process (spun-bonding) and (melt-blowing). The outer layer's web consists of (spunbond/spunbond), and the inner layer is melt-blow. The results of statistical analysis for correlation coefficients show that the parameters of the fabric construction technique of polypropylene nonwoven fabric have a strong correlation that affects the functional performance of multi-layer nonwovens in addition to various combinations of the two approaches for different technical textile applications.

Keywords: Nonwoven fabrics; Mechanical behaviour; Polypropylene; Filament density, Spunbond, Meltblown

1. Introduction

The Textile industry has recently been considered a new driving force for the world's economic growth point [1]. Besides that, textiles have proved to be significant materials to human beings since immemorial [2]. Fibre materials meet people's needs for home textiles in daily life and are widely used in high-tech fields [1]. Consequently, the field of functional fibers and fabrics is increasing, partly driven by advancements in fabrication methods using different techniques [3], [4], [5], [6]. Also, with developments in the technical textiles sector, the use of textiles in high-end technical applications has increased [7].

Recently, nonwoven fabrics have become a significant part of the textile industry [8]. Nonwoven fabric is classified as technical textiles and ranks third in manufacturing textile surface materials after woven and knitted fabrics. It has several advantages over woven and knitted fabric: it can be designed with specifically targeted properties, produced with substantial variations in thickness, weight, elasticity, stiffness, and luminosity, and is comparatively cheap and quick to manufacture [9]. The mechanical performance of nonwoven fabrics presents a deformation and energy absorption capability during deformation that is more significant than woven fabrics [10], [11]. Its most prominent properties include elasticity, stretch, strength, absorption, liquid repellency, softness, flame retardancy, cushioning, washability, filtration, bacterial barrier, and sterilization [12]. For thesis unique properties, nonwoven fabrics are replacing traditional fabrics in some areas [13] and have innumerable applications used in almost all technical textile sectors, such as geotextiles, agricultural textiles, military, healthcare, personal care, filter media, home furnishing, clothing, automobiles, industrial materials, household, travel and leisure, etc [14], [15], [16].

Nonwoven fabric is a manufactured sheet or web that could be made from fibrous webs directly from polymer fibers or granules and then consolidated [17], [18], [19]. It may be composed of natural or synthetic fibers, and blending fibers of different lengths and fibers of other generic groups is possible [20], [21]. The nonwoven fibers may be orientated [17], [18], [19].

1. In the longitudinal direction.
2. In the transverse direction.
3. Or both of them.
4. Randomly bonded by friction, cohesion, and adhesion.

Manufacturing nonwoven fabrics involves two important sequential processes: web formation and consolidation. The main web formation methods are carding, air laying, wet laying, spun-bonding, melt-blowing, and electro-spinning. The main web consolidating

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methods are needle punching, spun lacing, chemical bonding, and thermal bonding, combined into a single step [22], [23], [24], [25], [26].

The fiber/bonding type and the manufacturing parameters determine the fabric's characteristic features and distinctive complex mechanical behaviour [27], [28]. Where the nonwoven strength is imparted to the loose microstructure during the bonding process. Thermal bonding, particularly the calendering one, is one of the most widely used technologies in the nonwoven industry [28].

Rawal et al., & Farukh et al. explained that to solidify the fibers, locally heat the fibers to their softening temperature and then cool them; the continuous filament web passes between the calendar rollers having embossed patterns that bind the filaments with bond points into a robust and integrated fabric— eventually, slitting and winding. Moreover, the bond point geometry design in thermo-bonded nonwovens is significant to the desired mechanical behaviour [29], [30], [31].

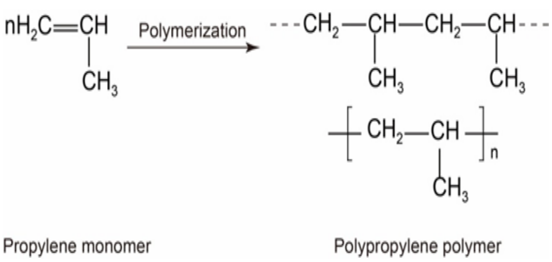
Mechanical anisotropy is one of the nonwoven materials' most crucial deformation characteristics that leads to their direction-dependent mechanical response. This phenomenon is related to the random orientation of fibers constituting complex microstructures of nonwovens, which is inherited from the web formation process in manufacturing. Randomness in the microstructure defines the related direction-dependent response observed in the tensile test results of nonwovens. Since it characterises their mechanical properties, this behaviour should be considered in the nonwoven design and numerical modelling. Several numerical models have been developed to simulate thermally bonded, nonwoven mechanical behavior [32], [33].

Jubera et al. displayed that different properties could be incorporated using a unique manufacturing process known as the Spun Bond Process (SBP), which converts PP granules into continuous filaments with excellent strength, durability, and abrasion resistance. [34], [35]. Moreover, the melt-blown technique is an approach in which nonwovens are obtained using high-speed air jets to attenuate the polymeric melt stream. Melt-blown nonwovens are a potential candidate for removing petroleum hydrocarbons [36] and have essential applications in filtration fields [37], [38], [39]. Melt-blown material has outstanding thermal insulation performance among various fibrous materials since it has a more specific surface area, tiny pores, and high porosity [40], [41]. Many new materials were successfully applied to the melt-blown process, and the corresponding nonwoven products have potential functions [37].

The so-called multi-layer or layered textiles, a combination of spun bond and melt-blown processes, should be mentioned here. There can be several such combinations, e.g., SSS-three-layer composite, where the spun-bond process makes each layer. SSMMS is a five-layer composite, with three layers made by the spun-bond process and two by the melt-blown process [42], [43], [44], [45]. For example, commercial filtration nonwovens (SMS nonwovens) are made by combining the melt-blown nonwovens with the spun-bond nonwovens [37]. SMS nonwoven fabrics combine the tensile resistance of spun-bond nonwovens with the filtration performance of melt-blown nonwovens. It has good filtration and tensile properties [46], [47], [48], [49]. In practical application, commercial filtration nonwovens [37] and functional nonwoven surgical gowns are usually made by combining spun-bonded and melt-blown nonwovens [46], [47], [48], [49].

Polypropylene Chemical Structure

Polypropylene fiber (PP) is a homopolymer obtained by the polymerization of propylene and is divided into man-made, organic, and polyaddition products [42], [43], [44], [45],[50]. Polypropylene has a stereo-regular isotactic molecular structure due to its high degree of crystallinity, handleability, strength, and melting point at regular use [48]. PP has various advantages, such as good processability [51], [52] non-polar and hydrophobic nature properties [48], lowest density, resistance to alkalis, and high resistance to solvents, as well as wide availability and low cost. The equation shown below represents the monomer, polymer, and chemical structure of polypropylene.



Polypropylene is used in many industrial applications, such as food packaging, medical devices, cables, etc. [42], [43], [44], [45] [48]. On the other hand, in healthcare, protective clothing. It is widely used in thermoplastic composites because it possesses several outstanding properties, such as low density, high softening point, good flux life, good surface hardness, scratch resistance, high abrasion resistance, and high tensile strength [46] [53], [54], [55] and low cost [51], [52].

PP fiber is the most commonly used polymer for SBP and is widely used for nonwoven fabric production [34]. Spun bond/Melt-blown/ Spun bond (SMS) nonwoven fabrics are the hygiene medical protective clothing materials [56], [57]. Polypropylene (PP) membrane has been widely used in water purification and other fields owing to its particular pore structure, excellent mechanical properties, and resistance to acids, alkalis, and organic solvents [58].

The geometrical characteristics of textile fabrics are significant for evaluating and simulating many functional properties [59]; calculating fabric geometrically could help predict textiles' functioning and performance properties before the commencement of fabric production. In addition, Testing can serve as an effective tool in characterisation and design of fabrics for any desired application [60]. The Functionality of technical textiles in a broad spectrum of end uses is intensely dominated by their air permeability, which depends on fabric structure and porosity [61]. A balance between the porous and cohesive characteristics is necessary for optimum performance. An estimation of the openness of the structure may help in designing a product for specific requirements [41]. The porosity of fibrous porous materials is an essential factor in the thermal insulating performance of the material [62].

Although the nonwoven fiber webs had different porous structures due to varying construction parameters, it was possible to develop predictive models of the porous parameters (volume porosity, pore surface area, and pore diameter). Fabric porosity results from the combination of fabric constructional parameters and the use of the technology of nonwoven production [63]. Porosity provides information on the overall pore volume of a porous material. It is defined as the ratio of the nonsolid volume (voids) to the total volume of the nonwoven fabric. Fabric porosity, therefore, relates directly to fabric thickness and density [64], [65]. Also, nonwoven deformation and damage behaviour are complicated because of discontinuity, randomness, and void spaces and porosity in their microstructure [66], [67]. In determining textiles' effectiveness, porosity is crucial in some end-use applications, such as surgical products, protective garments, and gas and fluid filtration products [14] [68], [69]. A textile material's performance depends on its constituent fibers' arrangement [41]. Recently, many papers have studied the influence of fiber arrangement on the tensile strength of the nonwoven fabric [14].

Accordingly, the objective of this research was to develop a model that could effectively evaluate the impact of web formation and consolidation on multi-layer nonwoven fabrics, produced by Spunbond and a combination of spun bond and melt-blown processes. The study aimed to investigate the intricate details of these processes and analyze how they influenced the characteristics of nonwoven fabrics. The model, which was derived from the study, is intended to predict the quality of the fabrics produced using these techniques.The research undertaken aimed to create a model to determine the impact of web formation and consolidation on multi-layer nonwoven fabrics. The fabrics were produced by utilizing Spunbond and a combination of spun bond and melt-blown processes. The study delved into the intricacies of these processes to understand how they affected the characteristics of the nonwoven fabrics. The model developed from the research aimed to predict the quality of the fabrics produced by these processes.

2. Materials and Methods

The samples studied were multi-layer nonwovens produced by spunbond and combinations of spunbond and melt-blown processes. Measurements of tensile strength and elongation were performed to determine the influence of the technological process of manufacturing a base layer of multi-layer nonwovens on some functionality. As part of the work, the geometric and engineering parameters of the selected samples, such as porosity, fabric-specific volume, fabric density, and packing factor, were determined using mathematical equations. The structural characteristics, such as thickness and mass, were analyzed.

2.1 Materials

The present fabric materials consist of layers of polypropylene nonwoven fabric, which are produced through a carding process utilizing both spun-bonding (S) and melt-blowing (M) techniques. There are six available samples, out of which three are composed of S/S layers, while the other three are made up of S/M/S layers. In both cases, the outer layer is spun bond, and the inner layer is melt-blown, as illustrated in the schematic diagrams displayed figures 1 and 2. [70].

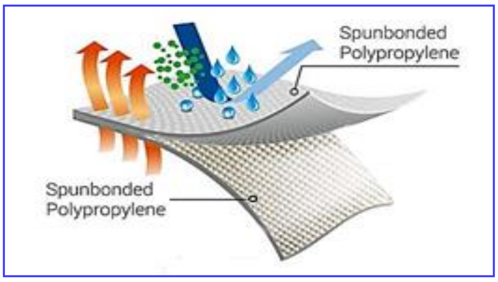


Fig. 1. (SS) Spun bond Two Layers

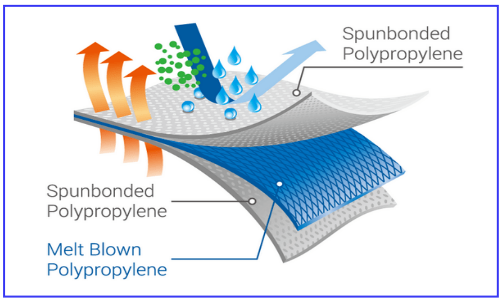


Fig. 2. (SMS) Spun bond Melt-blow Three Layers

2.2 Methods

2.2.1. Manufacturing

Schematic diagrams 3, 4, 5, and 6 showcase how spun bond and spun melt blow techniques are used to manufacture nonwoven fabrics. A widely used method in creating polymer-laid nonwovens is spun bonding, which is based on the melt-spinning technique. This method involves pushing the melt through a spinneret with multiple holes using spin pumps, and continuously cooling the filaments with additional room-temperature air, and conditioned air from quench air ducts below the spinneret block. Afterward, a ventilator under pressure sucks the filaments and mixed air down from the spinnerets and cooling chambers across the entire working width of the line [71].

Manufacturing of Spunbond/Spunbond (SS)Polypropylene Nonwoven Fabrics (Sample 1&2&3):

Polypropylene granules are introduced into a spun-bond machine through feeding tubes. Once inside, they are mixed with coloring agents, stabilizers, and other additives in the extrusion tube. The resulting mixture is then melted and separated from the additives via a filter in the extrusion tube. The melted mass is then pushed into the spinning box, where it is transformed into fibres that are between 10 to 30 micrometers in diameter. These fibres can either cool on their own or be dried in the forming system to improve their mechanical qualities. Once dry, the fibers are conveyed to a net-forming zone on a conveyor belt, where they are formed by heat. This method is the most commonly used for fiber-forming by heat. The fibres are then passed through a section of the spunbond machine called the calendar, where heated rolls make them adhere to one another and form a cohesive layer of fibres. Finally, the spun-bond nonwoven fabric is rolled and stacked for use. [72].

S/M/S Polypropylene Nonwoven Fabrics Manufacturing [73]

- **Mixing and preparation:** The main materials and ingredients are combined in specific ratios before being prepared. The PP chips and additives are melted using an extruder machine with eight heating zones.
- Spun Bond Process: The collected polymer is subjected to heat and pressure in the spun bond process. The molten polymer is pushed through fine die nosepiece extrusion units, creating continuous filaments. These filaments are exposed to a current of cold air with a temperature of 10-15°C, which turns them from a dough-like state to a flexible and hardened form.
- Melt-Blown Process: The melt-blown process delivers the molten polymer to the die nosepiece extrusion units through the polymer feed distribution system. Hot air at high speeds (250–300°C) from the air manifold is supplied and distributed through openings at the top and bottom of the "die nosepiece," called the "first air" stage. The hot air is forced through pressure units, and when the polymer is extruded from the spinneret plate, it rushes into the weak molten polymer, forming a tiny shape.
- Fibres Collection : The hot air stream containing the fibres moves towards the "collector screen," surrounded by cool air, solidifying the fibres into solid form. These solid fibres are then randomly collected over the collecting screen, forming a coherent, self-bonded, nonwoven web.

- **Thermal Bonding**:

To finish the process, spun bonds and melt-blown fibers are formed into a web when laid on a net and then thermally bonded. Finally, special in-line

Schematic diagrams 3, 4, 5, and 6 [72] [74] [75] showcase how spun bond and spun melt blow techniques are used to manufacture nonwoven fabrics.

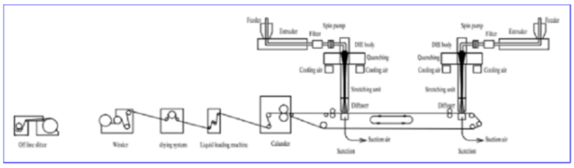


Fig. 3. Line of Manufacturing SS Polypropylene Nonwoven Fabrics

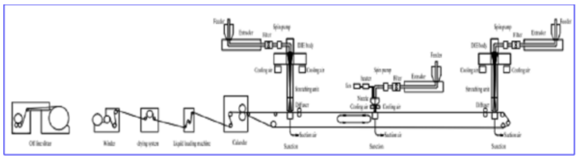


Fig. 4. Line of Manufacturing SMS Polypropylene Nonwoven Fabrics

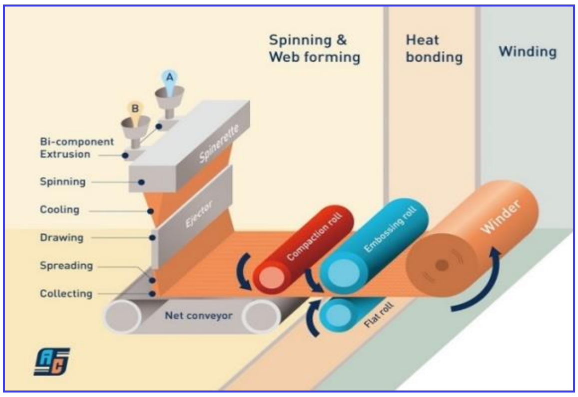


Fig.5. Polypropylene Spun Bond Nonwoven Fabric

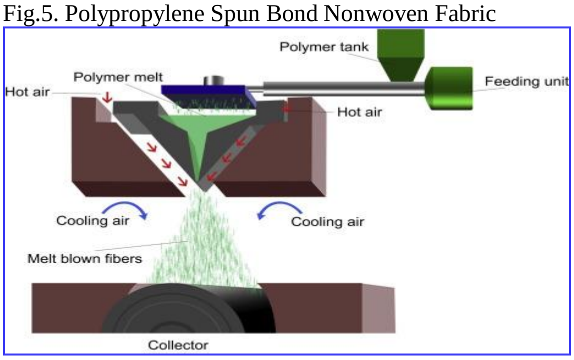


Fig. 6. B Spun-bonding melt-blowing

2.2.2. Samples Structure

Table 1 describe the structural properties of the selected multilayered nonwoven samples

2.3 Measurements

2.3.1. Physical and Mechanical Properties

Thickness.

Thickness is one of the fundamental physical properties of nonwoven fabrics. The thickness may require rigid control within specified limits in specific industrial applications. Nonwoven fabrics' physical properties and performance characteristics are often estimated from their thickness values [9]. The thickness of the specimens was measured between two parallel plates with a digital thickness measuring device According to the standard ASTM D5729-97(2004). Five thickness measurements in [mm] were made on each specimen [76], [77], as shown in graph (5).

Weight

The mass per unit area of a flat textile is referred to as its weight, measured in g/m2. The samples' weight was determined using the standard ASTM D3776 [78].

Tensile Strength.

Tensile strength is an imperative property of fabric that determines how much extension or elongation a fabric can bear under maximum force [79]. Grab Tensile properties were determined according to ASTM D 5034-21 [80].

The tensile force and strain of each sample were measured in two directions: Machine Direction MD (Machine directions or longitudinal direction) and Cross Direction CD (Cross machine direction or width direction), as shown in graphs (6&7).

Elongation.

Grab Elongation was determined according to ASTM D 5034-21. The Elongation of each sample was measured in two directions: Machine Direction MD (longitudinal direction) and Cross Direction CD (width direction) [80].

2.3.2 *Different Fabric Geometrical Parameters Calculation*

The design of the bond point geometry is of significant importance to the desired mechanical behaviour, which depends on machine direction (MD-CD) based on the randomness of their fibrous microstructure [28] [31], [32]

Fabric Density (g/cm³).

Fabric density, a critical property in textile engineering, is computed as the ratio of M, the mass per unit area of the fabric, to its thickness, and is expressed as g/cm3 [81].

Fabric Density (FD) was calculated according to equation (1)

$$FD = \frac{fabric\ weight}{fabric\ thickness}$$)

Fabric bulk density

The fabric bulk density can be determined by computing the ratio between the fabric weight per unit area in grams per square meter (g/m2) and its thickness in meters, as demonstrated in the following equation [82] :

$$Bulk\ density\ (kg/m3) = \frac{weight/area}{thickness}$$

Fabric Packing Factor.

The "packing factor" is a metric that measures the amount of air present in a textile structure relative to its total porosity. The calculation involves dividing the fabric density by the relative density of the fibers or polymers. Theoretically, this value can range from 0 (when there is only air and no material) to 1 (when there is no air, such as in plastic films). Lower values indicate higher porosity, with values closer to zero indicating greater porosity. This value is useful in determining the breathability and permeability of textiles, which is particularly crucial in certain applications such as medical textiles, protective clothing, and outdoor sportswear. [81]

Fabric Packing Factor was calculated according to equation (2)

Packing Factor = Fabric density ÷ Fiber density (2)

Polypropylene fiber density = 0.91 gm [83].

Fabric Specific Volume (g/cm³) [84].

Fabric Specific Volume was calculated according to equation (3):

$$vf = \frac{fabric\ thickness\ (cm)}{fabric\ mass\ (g/cm2)} \qquad \textbf{(3)}$$

2.3.7. Porosity.

The pore structure in a nonwoven may be characterised by the total pore volume (or porosity), the pore size, pore size distribution, and pore connectivity [35]. Fabric porosity refers to the void fraction or the total void space [81]. It provides information on the overall pore volume of a porous material [35]. Fabric porosity is the portion of voids or empty spaces in the fabric values between 0 and 100% in percentage.

Porosity is a critical property of nonwoven fabrics that refers to the proportion of voids or non-solid volume within the total volume of the material. The overall porosity of a fabric is influenced by the manufacturing process and its design. Both of these factors play a crucial role in determining the porosity of the material. [35]. The combination of these parameters must be considered during fabric development to ensure that the desired porosity is achieved. Therefore, understanding the influence of these factors on the porosity of nonwoven fabrics is essential for their optimal use in various applications. [85]

The volume fraction of solid material is defined as the ratio of solid fibre material to the total volume of the fabric. While the fibre density is the weight of a given volume of the solid component only (i.e., not containing other materials), The porosity P (%) can be calculated as follows: using the fabric bulk density and the fibre density [35], or using the mass per unit area (g/m2) of the fabric, the thickness (mm) of the fabric, and the relative density of the fibre/polymer (g/cm3) [81].

Fabric porosity is a critical parameter that refers to the fraction of voids present in a fabric and can range from 0 to 100%. The percentage of voids can be expressed as a fraction or percentage in theoretical models. The production technology of nonwoven fabrics and their constructional parameters significantly impact the fabric porosity. To calculate fabric porosity, several factors need to be considered, such as fabric bulk density, fibre density, mass per unit area, thickness of the fabric, and relative density of the fibre or polymer. [35],[63],[81],[86], [87], [88]. Porosity is an essential characteristic of nonwoven fabric, especially in items such as air filters, masks, and geotextiles. For instance, air filters allow air to pass through while trapping particles, and their efficiency depends on the size and distribution of the pores. Similarly, masks filter out harmful particles, and their effectiveness is determined by the pore size. Geotextiles provide separation, filtration, drainage, and reinforcement in civil engineering; their pore structure affects their performance in these applications.

To determine the fabric porosity, the standard equations are employed. These equations provide a reliable means of calculating the porosity of a fabric using theoretical models. **,** and the standard equations for fabric porosity are:

$$\boldsymbol{\phi = \frac{\rho fabric}{\rho fibre} \times 100\%} \quad \textbf{[35]}$$

$$\mathbf{P(\%) = (1 - \phi) \times 100\%} \quad . [35]$$

Where P is the fabric porosity (%), ϕ is the volume fraction of solid material (%), ρfabric (kg/m^3) is the fabric bulk density, and ρfibre (kg/m^3) is the fiber density . [35].

2.3.3. Scanning Electron Microscopy (SEM)

This study aims to compare the surface morphology of polypropylene web nonwoven fabrics. To create the fabrics, two methods were employed: spun bonding in two layers (SS1-SS2-SS3) and spun bonding in three layers, with two outer layers of spun bond and an inner layer of melt-blow (SMS1-SMS2-SMS3). The samples were studied using a USB digital microscope to obtain scanning (SEM) data The findings of the scanning microscope are presented in Table 2.

3. Results and Discussion

Various statistical methods, including the standard deviation, were used to analyze the laboratory test results. It's a well-known scientific fact that non-woven fabrics are anisotropic, meaning that their properties vary due to differences in the arrangement and number of fibers, as well as their distribution in different angles and directions. This leads to variations in physical and mechanical

$$\textit{\textbf{Fabric}}\ \mathbf{Porosity(\%) = 1 - \frac{\rho b}{\rho s} \times 100\%} \ [86].$$

$$\mathbf{Porosity(\%) = \frac{(\rho_0 - \rho)}{\rho_0} \times 100\%} \ [82].$$

whereρ_0, is the fibre density (kg/m^3) and ρ, the fabric density (kg/m^3).

Porosity (%) = [1 − Fabric density (g/m^3) / Filament density (g/m^3)] × 100 [87], [88].

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properties. To evaluate the impact of fabric techniques on the geometrical and mechanical properties of polypropylene nonwoven fabric, the ANOVA test, correlation coefficient, and regression were used to determine the type, strength, and effect of one variable on the other.

3.1 Physical Properties

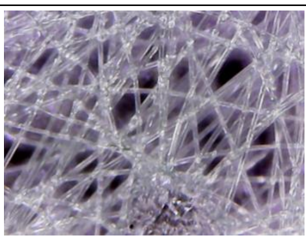
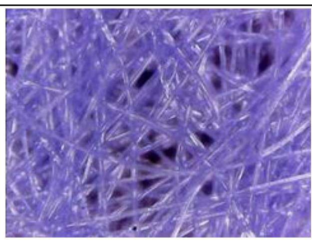
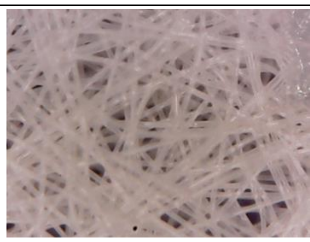
3.1.1 *Thickness Test Results*

Based on Table 3 and Figure 7, it was observed` that the three-layer nonwoven fabric samples SMS had a slightly greater thickness than the double-layer ones SS with the same weight per square meter. This finding is significant because it suggests that the melt-blow layer in the SMS samples contributed to their overall thickness. Therefore, the weight of the fabric played a crucial role in determining the thickness of the samples. Overall, these findings provide valuable insights into the properties of nonwoven fabrics and can be used to inform future research and development in this field.

Table 1 The Structural Properties of the Selected Multilayered Nonwoven Samples

Sample No.	Sample Code	Weight g/m2	Material Composition	Multilayered Sample Structure				
				1st Layer	*2nd Layer*	*3nd layer*	Layers	
1	SS1	13.05	PP	S	S	---	Bi-Layered	Spunbond : Spunbond
2	SS2	30.07	PP	S	S	---	Bi-Layered	Spunbond : Spunbond
3	SS3	60.18	PP	S	S	---	Bi-Layered	Spunbond: Spunbond
4	SMS1	13.15	PP	S	M	S	Triple-layered	Spunbond : Melt below : Spunbond
5	SMS2	30.08	PP	S	M	S	Triple-layered	Spunbond : Melt below : Spunbond
6	SMS3	60.17	PP	S	M	S	Triple-layered	Spunbond : Melt below : Spunbond

Table 2. Scanning Electron Microscopy (SEM) of the samples.

Sample Code	SS1	SS2	SS3
			
Sample Weight	13.05 gm	30.07 gm	60.18 gm

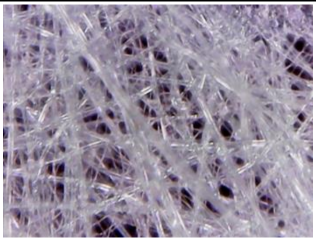
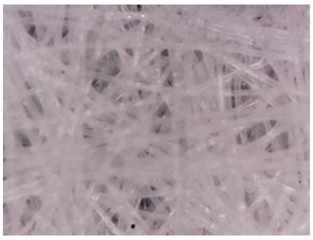
Sample Code	SMS1	SMS2	SMS3
			
Sample Weight	13.15 gm	30.08 gm	60.18 m

Table 3. Thickness and Weigth Test Results

samples	Weight g/m2		Thicknessmm	
	Mean	*Standard Deviation*	Mean	*Standard Deviation*
SS1	13.05	0.831	0.08	0.987
SS2	30.07	1.372	0.19	1.005
SS3	60.18	1.541	0.39	1.235
SMS1	13.15	0.734	0.09	0.870
SMS2	30.08	1.125	0.21	0.975
SMS3	60.17	1.391	0.43	1.125

Table 4. Tensile Strength and Elongation Test Results

samples	Weight		MD Grab Tensile /N		CD Grab Tensile /N		MD Grab Elongation %		CD Grab Elongation%	
	Mean g/m^2	*Standard Deviation*	Mean N	*Standard Deviation*	Mean N		Mean g/m^2	*Standard Deviation*	Mean N	*Standard Deviation*
SS1	13.05	0.831	57.53	1.204	19.8	1.221	46.53	1.244	65.22	1.087
SS2	30.07	1.372	119.22	1.329	61.7	1.259	58.83	1.261	67.50	1.251
SS3	60.18	1.541	191.77	1.767	101.2	1.780	69.12	1.367	99.18	1.330
SMS1	13.15	0.734	62.03	1.015	36.05	1.067	114.03	1.011	136.18	1.170
SMS2	30.08	1.125	150.16	1.076	51.62	1.019	57.12	1.179	71.53	1.082
SMS3	60.17	1.391	182.23	1.347	107.1	1.554	76.08	1.182	92.05	1.214

3.2 Mechanical Propertiess

3.2.1 *Tensile Strength Test Results*

The data presented in Table 4 and Figure 8 indicate that the properties of SMS and SS fabric differences have a significant impact on their tensile strength. The results suggest that fabrics with greater weight exhibit higher tensile strength in both the machine direction (MD) and cross-machine direction (CD) for both SS and SMS samples with the same weight. Furthermore, the tensile strength in MD is higher than in the CD direction for both SS and SMS samples. Additionally, the tensile strength of SMS samples is higher in both MD and CD directions compared to SS samples. These findings suggest that the weight and direction of the fabric play a crucial role in determining its tensile strength. Therefore, it is essential to consider these factors while selecting fabrics for specific applications. The arrangement of fibers is a crucial determinant of the tensile strength of non-woven fabrics. Non-woven fabrics that are made of filaments that are arranged in the longitudinal direction (Machine Direction) are significantly stronger than those with fibers arranged in the cross direction (CD). This is because parallel fibers next to each other are better at resisting tension when they are together. In addition, it is worth noting that the percentage of parallelism of fibers in the longitudinal direction is high for all SS and SMS samples. This means that non-woven fabrics with filaments arranged in the longitudinal direction have a higher degree of parallelism than those with fibers arranged in the cross direction. This results in better tensile strength. Furthermore, the melt-blown layer in non-woven fabrics helps consolidate the arrangement of fibers. This consolidation further increases the strength of SMS samples over SS. It is important to note that SMS samples have three layers that include a melt-blown layer sandwiched between two spunbond layers, while SS samples only have two spunbond layers. The presence of the melt-blown layer in SMS samples helps to consolidate the arrangement of fibers, which results in a higher tensile strength.

3.2.2 *Elongationtion Test Results.*

Table 4 , Figures 8 demonstrate that the elongation rate in both MD and CD for SS samples increases with an increase in fabric weight. Conversely, the opposite is observed for SMS samples. Which means that melt-blow layer effect on the fabric elongation ,Additionally, the elongation percentage in the MD is lower than in the CD direction for both SS and SMS samples. In contrast, the elongation in the CD direction of the fabric is higher in SMS samples than in SS samples. Moreover, the elongation in both directions (MD and CD) of SMS samples is higher than that of SS samples. These findings suggest that the weight difference between SS and SMS fabrics significantly affects their elongation properties, which should be taken into account when selecting fabrics for specific applications.

3.3 Geometric Properties

3.3.1 Fabric Specific Volume

Table 6 and Figure 9 indicate that the fabric-specific volume of the samples is directly proportional to the weight of the fabric. In practical terms, the thickness of the fabric or material consequently increases as its weight increases. This relationship implies that an increase in the weight of the non-woven fabric results in a proportional increase in its thickness or fabric density.

3.3.2 Fabric Density

The results were reviewed in Table 5 and Figure 10, where it turns out that the higher the weight, the greater the fabric specific volume of both SS and SMS samples. The SMS samples with a three-layer structure, including a Meltblown layer, appear to have a higher density than the SS samples.

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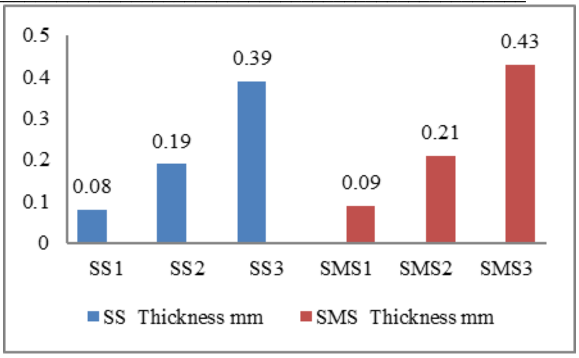

Fig. 7. Shows Thickness Test Results

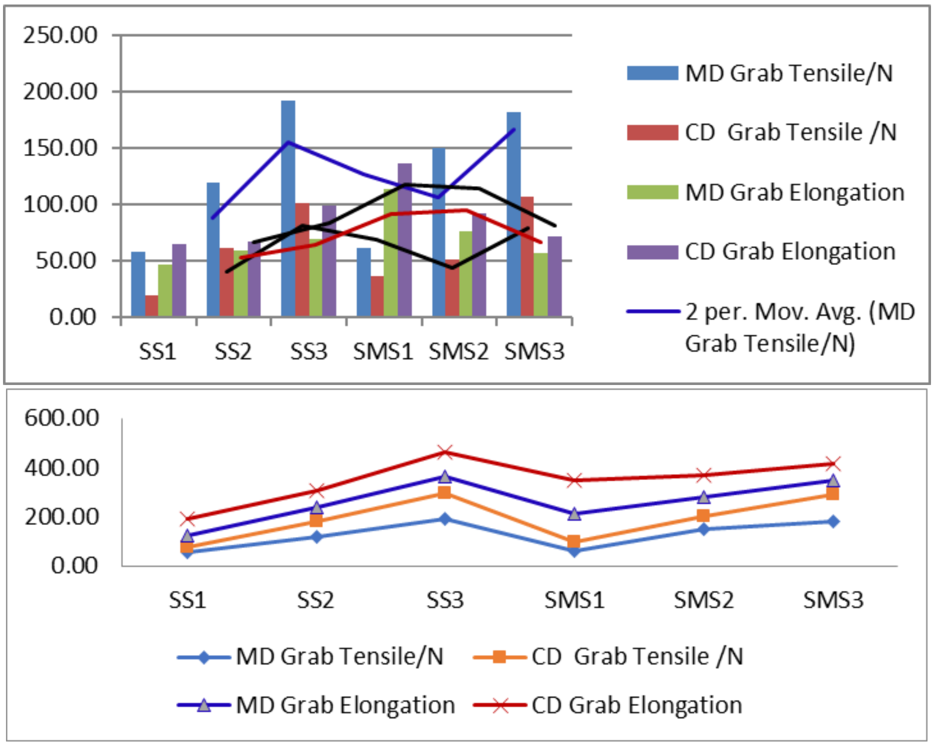

Fig. 8. Graphs Tensile & Elongation Test Results and Variable Relationships

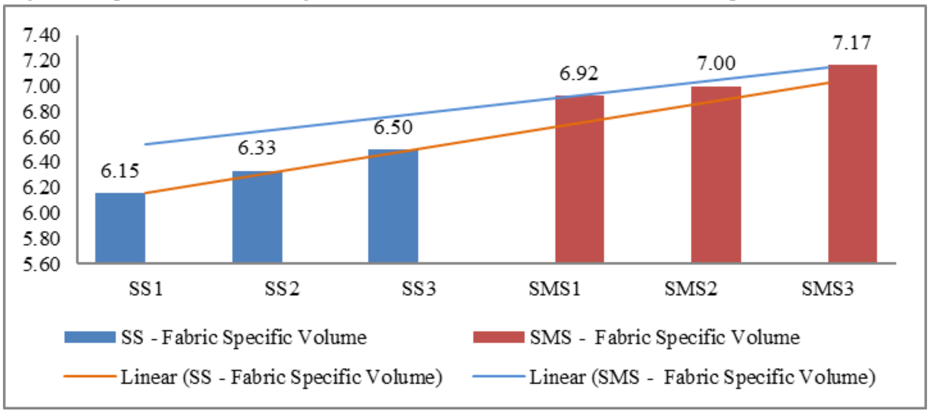

Fig. 9. Shows SS and SMS Fabric Specific Volume

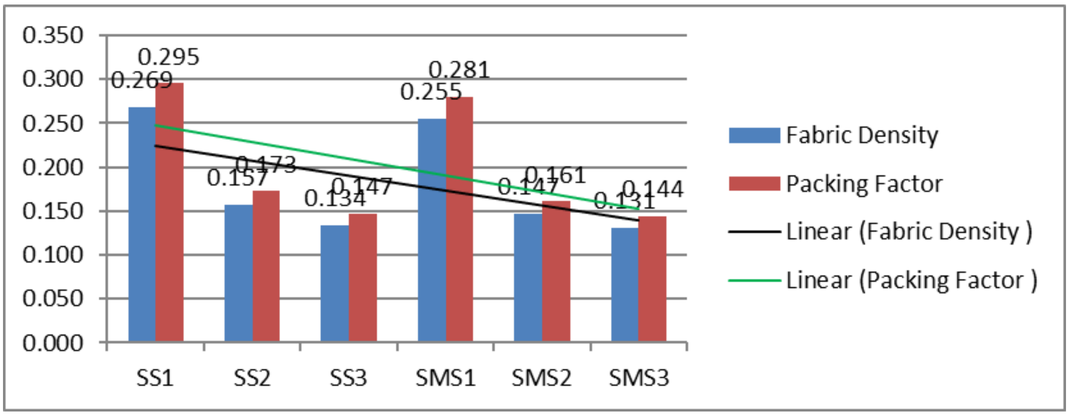

Fig. 10. Shows SS and SMS Fabric Packing Factor & Fabric Density

Table 5. Geometrical Parameter Values

Samples	Weight g/m2		Specific Volume	Fabric Density g/cm^3	Fabric Packing Factor	Porosity %
	Mean g/m2	*Standard Deviation*				
SS1	13.05	0.831	6.15	0.269	0.295	70.46
SS2	30.07	1.372	6.33	0.157	0.173	82.74
SS3	60.18	1.541	6.50	0.134	0.147	85.28
SMS1	13.15	0.734	6.92	0.255	0.281	71.93
SMS2	30.08	1.125	7.00	0.147	0.161	83.89
SMS3	60.17	1.391	7.17	0.131	0.144	85.58

3.3.3 Porosity and Packing Factor

Non-woven fabrics with a parallel arrangement of fibers have a lower porosity compared to those with a cross-distribution or random distribution of fibers. This is because parallel fibers are closely adjoined, leaving fewer spaces and pores between them. On the other hand, intersecting fibers create larger pores, leading to a random distribution of spaces and pore sizes between the fibers. This results in the formation of inter-spaces with varying numbers and sizes.

The samples with a melt-blown layer, known as three-layer SMS samples, exhibit higher density than those listed in Table 5 and Figure 11. This difference is statistically significant among the six samples at a 0.01 significance level. Sample SMS3 has the highest porosity of all nonwoven fabrics, followed by SMS2, SMS1, SS3, SS2, and SS1. The weight of both SS and SMS types affects the Porosity and Fabric-specific volume differently. Nonwoven fabrics' porosity ratio depends on parameters such as fiber properties, processing conditions, fabric weight and thickness, and fiber density. Non-woven fabrics with a parallel arrangement of fibers have a lower porosity compared to those with a cross-distribution or random distribution of fibers. This is because parallel fibers are closely adjoined, leaving fewer spaces and pores between them. On the other hand, intersecting fibers create larger pores, leading to a random distribution of spaces and pore sizes between the fibers. This results in the formation of inter-spaces with varying numbers and sizes.

Since all the samples (SS1, SS2, SS3, SMS1,SMS2,SMS3)have the same fiber composition, the fabric weight and production process conditions have influenced the porosity property of the samples. As the fabric weight increases, the samples' porosity property also increases. SMS samples have higher porosity compared to SS samples. Furthermore, as the fabric weight increases, the specific volume increases, too. SS samples have lower porosity than SMS samples.

The packing factor refers to the relationship between fabric density and fiber density. When it comes to polypropylene fiber with a density of 0.91, the packing factor is directly linked to the weight per square meter and the thickness sof the fabric. So, if we compare the packing factor of SMS and SS samples at an equal weight per square meter, SMS will have a higher packing factor because SMS has a denser fabric.

3.4 The Correlation Coefficients

Table 6 shows the correlation coefficient between the geometrical properties and the mechanical properties test results for SS and SMS types of nonwoven fabrics. This gives you a full picture of how the two types of properties relate to each other and how they affect the nonwoven fabrics. The table serves as an important analytical tool for researchers and industry professionals alike, enabling them to draw meaningful conclusions about the mechanical behavior of nonwoven fabrics based on their geometrical properties. Therefore, this table holds significant importance in the field of material science and engineering, and its findings are highly relevant for further research and practical applications.

The results of the grab tensile (N) test for both SS and SMS nonwoven fabrics in two directions, namely MD and CD, show a significant correlation with the specific volume of fabric. This correlation is observed across six samples of SS and SMS fabrics with a significance level of 0.05, as presented in 12 figures.

3.4.1 The Correlation Coefficient and Regression Between Fabric Specific Volume and Mechnical Test Results for SS and SMS non woven Fabric

The results of the grab tensile (N) test for both SS and SMS nonwoven fabrics in two directions, namely MD and CD, show a significant correlation with the specific volume of fabric. This correlation is observed across six samples of SS and SMS fabrics with a significance level of 0.05, as presented in figures. 12, 13 , 14 , 15

3.4.2 The Correlation Coefficient and Regression Between Fabric Porosity and Mechanical Test Results for SS and SMS Nonwoven Fabric

The presented figures 16, 17 , 18, 19 demonstrate a robust positive correlation between the porosity of fabric and the results of the grab tensile (N) test, in two different directions (MD+CD), for six samples of nonwoven fabrics (SS, SMS). The obtained correlation holds true at a statistical significance level of 0.05.

The Statistical Analysis

Analysis of variance method is a known statistical method employed to recognise the influential process parameter in the multi-response optimisation model. The significance of model terms is judged by terms of F-value or p-value [59]. The impact of filament density mechanism on the mechanical behaviour of fabrics (Thickness, Tensile Strength and Elongation, Porosity) was tested using analysis of variance (ANOVA) to determine the significance of fibres density mechanism and different numbers of layers on the mechanical behaviour of polypropylene nonwoven fabrics, as shown in table (7).

Table 6. the Correlation Coefficient Test Results.

Pearson Correlation Coefficients, N = 6

	Weight	*Thickness*	*MD Grab Tensile /N*	*CD Grab Tensile /N*	*MD Grab elongation*	*CD Grab elongation*	***Fabric specific volume***	***Porosity***	***Fabric Density***
Weight	1	-	-	-	-	-	-	-	-
Thickness	**0.99524**	1	-	-	-	-	-	-	-
MD Grab Tensile /N	**0.95057**	**0.94729**	1	-	-	-	-	-	-
CD Grab Tensile /N	**0.98346**	**0.98226**	**0.92486**	1	-	-	-	-	-
MD Grab elongation					1	-	-	-	-
CD Grab elongation					**0.96732**	1	-	-	-
Fabric specific volume	0.9978						1	-	-
Porosity							0.9993	1	1
Fabric Density	1	-	-	-	-	-	-	-	-

Bold marks significance at the 0.05 level

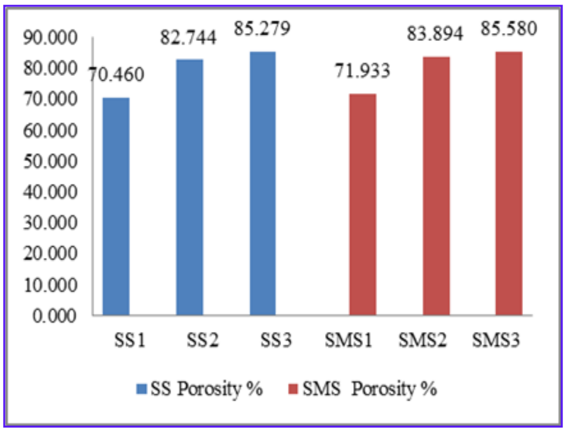

Fig. 11. Shows SS and SMS Fabric Porosity %

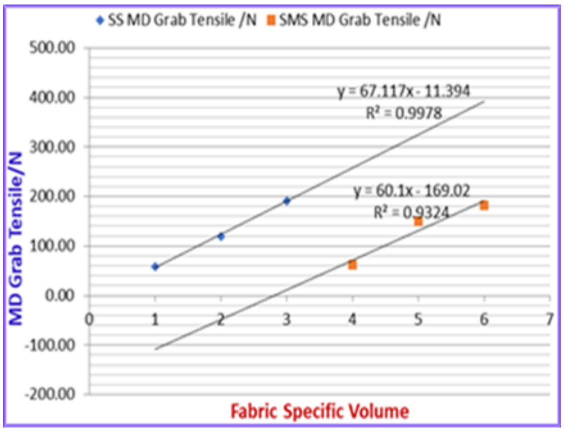

Fig. 12. Shows Correlation Coefficient and Regression between Fabric Specific Volume and MD Grab Tensile

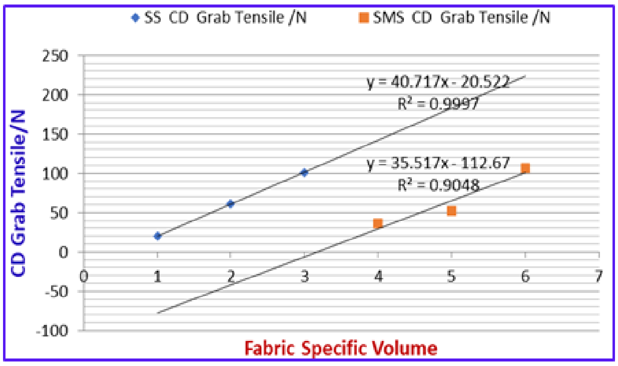

Fig. 13. Shows Correlation Coefficient and Regression between Fabric Specific Volume and CD Grab Tensile

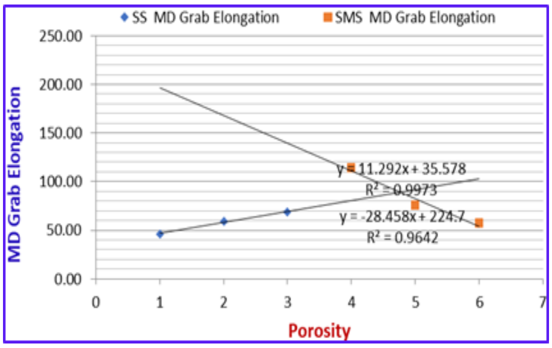

Fig. 17. Shows Correlation Coefficient and Regression between Fabric Porosity % and CD Grab Tensile

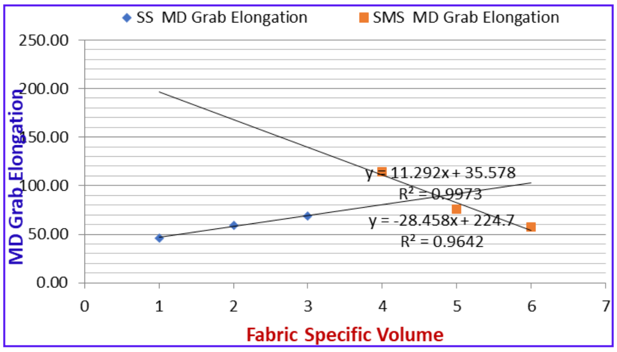

Fig. 14. Shows Correlation Coefficient and Regression between Fabric Specific Volume and MD Elongation Test Results.

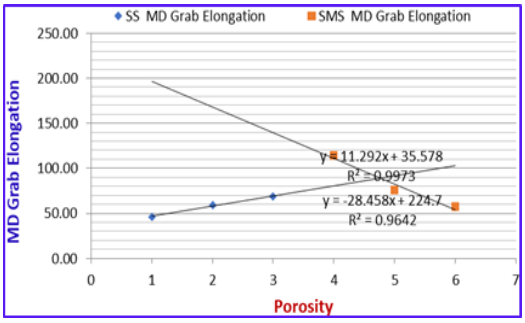

Fig. 18. Shows Correlation Coefficient and Regression between Fabric Porosity % and MD Grab Tensile

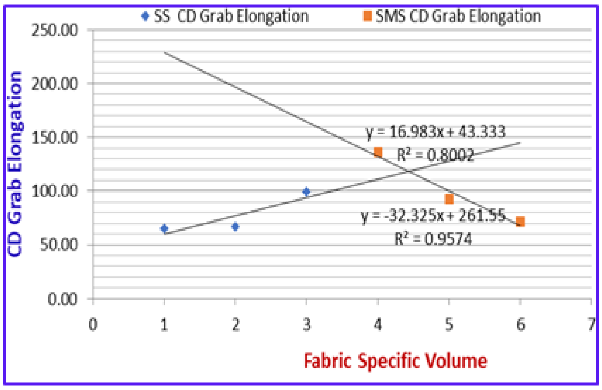

Fig. 15. Shows Correlation Coefficient and Regression between Fabric Specific Volume and MD Elongation Test Results.

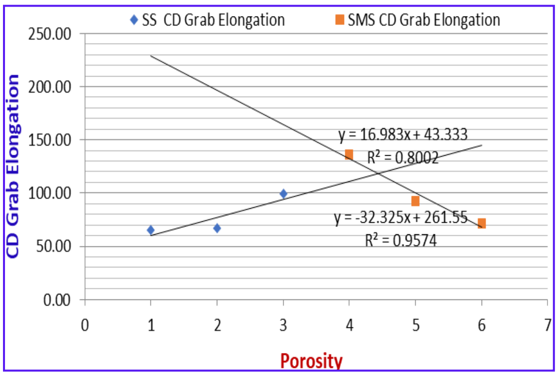

Fig. 19. Shows Correlation Coefficient and Regression between Fabric Porosity % and CD Grab Tensile

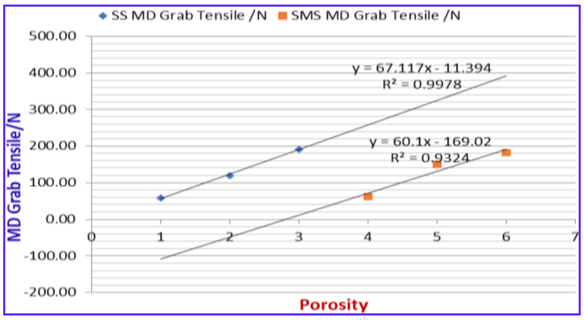

Fig. 16. Shows Correlation Coefficient and Regression between Fabric Porosity % and MD Grab Tensile

Table 7. Results of one-way ANOVA.

Source of Variation	SS.	df	MS.	F	P-value	F crit
ANOVA for Weight Results						
Between Groups	3254.911	1	3254.911	14.30371	0.00359	4.964603
Between Groups (without or with)	0.00463	1	0.00463	2.325582	0.266764	4.964603
ANOVA for Thickness Results						
Source of Variation	SS.	df	MS.	F	P-value	F crit
Between Groups	4.826008	1	4.826008	29.9811	0.000271	4.964603
Between Groups (without or with)	0.000817	1	0.000817	7	0.118083	4.964603
ANOVA for ASTM D 5034-21 (MD Grab Tensile /N) Results						
Source of Variation	SS.	df	MS.	F	P-value	F crit
Between Groups	47368.79	1	47368.79	28.04388	0.00035	4.964603
Between Groups (without or with)	111.8017	1	111.8017	0.529275	0.542551	4.964603
ANOVA for ASTM D 5034-21 (CD Grab Tensile /N) Results						
Source of Variation	SS.	df	MS.	F	P-value	F crit
Between Groups	11315	1	11315	18.4572	0.001571	4.964602744
Between Groups (without or with)	24.06671	1	24.06671	0.273621	0.653091	4.964602744
ANOVA for ASTM D 5034-22 (MD Grab elongation) Results						
Source of Variation	SS.	df	MS.	F	P-value	F crit
Between Groups	14194.13	1	14194.13	50.35346	3.31E-05	4.964602744
Between Groups (without or with)	882.0938	1	882.0938	1.240888	0.381223	4.964602744
ANOVA for ASTM D 5034-22 (CD Grab elongation) Results						
Source of Variation	SS.	df	MS.	F	P-value	F crit
Between Groups	22764.46	1	22764.46	61.98772	1.35E-05	4.964602744
Between Groups (without or with)	767.4966	1	767.4966	0.860565	0.451513	4.964602744
ANOVA for Fabric specific volume Results						
Source of Variation	SS.	df	MS.	F	P-value	F crit
Between Groups	80.44541	1	80.44541	344.3897	4.46E-09	4.964603
Between Groups (without or with)	0.742017	1	0.742017	445.21	0.002239	4.964603
ANOVA for Porosity Results						
Source of Variation	SS.	df	MS.	F	P-value	F crit
Between Groups	1.32734	1	1.32734	8.845768	0.013946	4.964603
Between Groups (without or with)	0.000468	1	0.000468	216.0769	0.004596	4.964603

(The differences are statistically significant at ($p \leq 0.05$))

Sum-of-squares (SS) column with no repeated measures, degrees of freedom (df), mean squares (MS), F-ratio (F), p-value, F-critical (F-crit).

Conclusion

As a result of modelling the nonwoven polypropylene fabric, the research found two distinct types of nonwoven fabrics: two- and three-layered polypropylene webs. These modelling nonwoven fabrics have been produced using the carding process: spun-bonding and melt-blowing. The outer layer of the web is made up of spun-bond/spun-bond, while the inner layer is melt-blown. The recent study has utilized statistical analysis to establish a robust association between various parameters of the fabric construction technique of polypropylene nonwoven fabric. In addition, the study has discovered that this correlation has a significant impact on the functional performance of multi-layer nonwovens.

It can be concluded that different methods of fabric manufacturing have an impact on the functional performance of nonwoven materials.The investigation uncovered important variables that greatly influence the fabric's performance. These findings are anticipated to have a significant impact on the development of enhanced nonwoven fabrics tailored to meet the precise requirements of technical textile applications. Implementing enhanced functional qualities in these fabrics is expected to provide key insights and fulfill a broader range of requirements, thereby contributing to the growth of the technical textile industry.

key insights and the fulfillment of a broader range of requir ements, hence contributing to the growth of the technical te xtile industry.

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7. Author Declarations

The authors declare that the data supporting the findings of this study are available in the article. The authors declare that there is no conflict of interest.

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