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An Overview of Nonwoven Product Development and Modelling of Their Properties

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Abstract

Nonwoven fabric formation is highly emerging technology for production of cheapest material of textile for different purposes. Nonwovens used in garments, home textiles, decorative purposes and technical textiles with their own performance requirements which will be discussed in this paper. The articles, thus produced in the final stage of textile called making up process i.e. nonwoven product development will be delivered to customer or they can be utilized as semi-finished goods for non-textile production and assembly processes such as textile filters. The important modelling parameters essential for nonwovens products are pore size distribution rather than porosity, tensile strength for reinforcement applications in civil engineering, bending rigidity, permeability to fluids according to the purpose and filtration properties with minimum clogging.

Introduction

Nonwoven fabric formation is highly emerging technology for production of cheapest material of textile for different purposes. Nonwovens used in garments, home textiles, decorative purposes and technical textiles with their own performance requirements which will be discussed in this paper. The articles, thus produced in the final stage of textile called making up process i.e., nonwoven product development will be delivered to customer or they can be utilized as semi-finished goods for non-textile production and assembly processes such as textile filters. These products are available in market in different sizes and shapes according to the purpose of usage and requirements. Based on requirements the properties of nonwoven fabrics has been decided and pore size distribution, bending and tensile characteristics, filtration and permeability properties are discussed here. According to latest statistics, only 1% of nonwoven product is used for fashion/apparel purposes out of total consumption.

Concepts and Definitions

Transforming the textile fabrics into ready-made products called making-up process. This is underlined by the Latin origin of the word to confect: conficere – to make, to complete. The products can be make-up by adding woven, nonwoven fabrics, nontextile fabrics such as foils, membranes and trims (buttons, zippers, tapes and Velcro fasteners). The technology of product development comprises all machines and procedures that are exploited for the industrial production of finished textile goods (Figure 1).

Product Development

Nonwovens in apparel textiles

Patterning, feel, drape and fibre composition are the factors that decides the fabrics to be selected and product. Pattern design determines the product shape and it depends on the factors such as product-relevant physical dimensions and proportions of an average human being. Feel depends on mechanical characteristics of fabric and environmental conditions or wearing situation. Drape depends on factors such as fibre bending rigidity, yarn structure and fabric construction (weave parameters) (Figure 2).

Two dimensional patterns are developed as pattern design and converted into 3D product surface when those combined. The size pattern can be adjusted using proportion calculation called pattern (to enlarge or to reduce) either manually or systematically using software. Seam allowances are included during pattern design for joining the parts. Garment style or construction, body measurements and proportion are changes according to culture and traditions between individual countries [1-5].

In garments nonwoven fabrics used as linings for fixation and mainly to stiffen the daily usage clothing and sportswear parts. Nonwoven fabrics are surface treated to improve frictional characteristics for better adherence to the upper or outer clothing fabric. Voluminous nonwovens can be placed between the upper material and the lining of garments for the purpose of improving heat insulation as air gap has been increased (air is a good insulator of temperature). But to fix insulation fleece firmly, thermal weld method is often chosen which will decrease the insulation effect.(1, 3) Fan et al. reported experimental investigation of primary hand attributes of fusible interlining nonwovens using FAST system of measurement(Figure 3).

### Nonwovens in home and decorative textiles

Home and decor textiles includes linen, towels, beddings, curtains quilts, kitchen aprons, mittens, coasters, bathmats, bathrobes and rugs, and other textile materials used for their aesthetic appearance. Nonwovens are mainly used as filling material for thermal insulation and sound insulation in the home textile and decorative textile products and now-a-days nonwoven used as cheapest use and throw especially in kitchen textiles and dish cloth, tissue papers, wipes etc. because of their absorbency characteristics. Porosity and fibre composition determines the product as based on its functional requirement. Rarely nonwoven materials used as elastics voluminous fillers and local stiffeners [6-10].

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Figure 1: Technology for product development.

Figure 2: Particle size distribution sieve analysis**.**
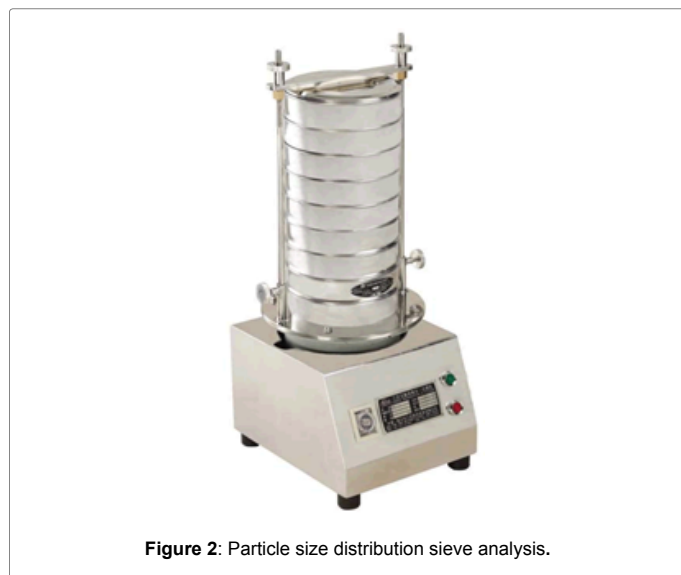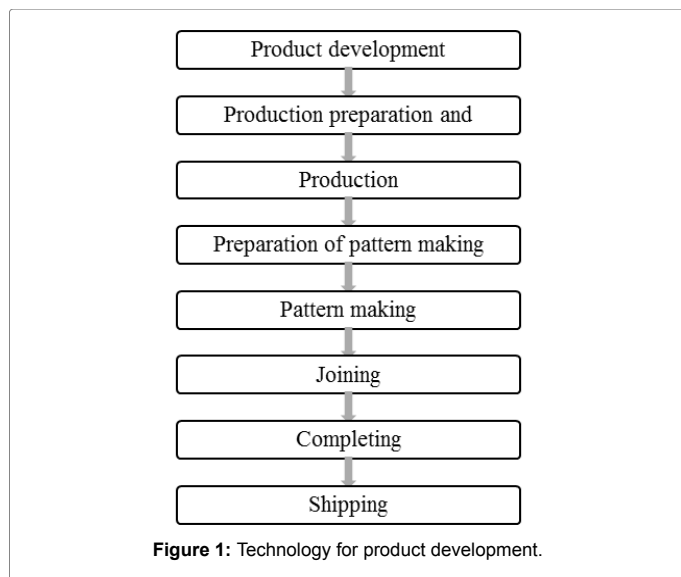
Nonwovens in technical textiles

Nonwovens used in technical textiles because of their performance and cost effective nature. Performance requirements are: strength, air permeability, water-vapor permeability, translucence, resistance against chemicals, biological effects, light, UV irradiation and/or climate, maintenance, care and cleaning properties and finally the recyclability based on their end use application. Numerous factors decides the properties of nonwoven fabric for particular performance requirement such as porosity, tensile strength along longitudinal and transverse direction, thickness, pore size distribution and bending property. Porosity and pore size distribution are important characteristics of nonwoven when they used in filtration function as the particles to be filled decides the minimum and maximum pore size and based on thermal and chemical conditions of filtrate fibres selected for fabric [10-15].

Tensile strength is an essential factor when it is used in civil constructions as reinforcement material. Drapability and particle filtrate efficiency against microbes, bacteria and fluids are main requirements

of fabric used in medical textiles. Nonwovens for this products have 2D or 3D geometry and more sophisticated pattern design is required. Materials can be effectively used when the material width is defined already in the product development stage. Seam properties must be assessed as their performance at seam area should not deviate from body part of the product.

Techno-economics

Nonwoven fabric manufacturing process skips roving frame to cone winding, sizing and fabric weaving processes. Thus simply fibres oriented through carding machine and laid on a conveyor and passed through bonding process (needling). Melt blown and spun bond nonwovens simplifies even more as fabric formed as the filaments extruded through spinneret and thus reduces the manufacturing cost through reduction in machine cost, processing cost, labor cost and maintenance cost (Figure 4).

For particular application such as disposables, nonwovens reduce the cost of usage by reducing maintenance expenses at the required performance. For example, medical gowns, masks can't be stitched which reduces the performance through lint formation and pore size variation and for sterilizing the materials after usage is the expensive maintenance cost. This can be reduced by using disposable nonwoven surgical gowns and masks, caps and gloves [16-18].

Modeling Parameters

Pore size distribution

Porosity is defined as fraction of void volume to the total volume of fabric. Porosity can be obtained from the ratio of the fabric density and the fibre density. It indicates the void space available in the total material for particular thickness and GSM. Porosity is one of basic parameters that determines most of fabric properties such as air and water permeability, liquid absorption. Porosity value ranges from 0 to 1, 0 indicates there is no fibre available in the nonwoven fabric and 1 indicates no void space is available. These two extreme cases in reality are not possible in nonwoven fabric.

Figure 3: Grab test.

Figure 4: Strip test.
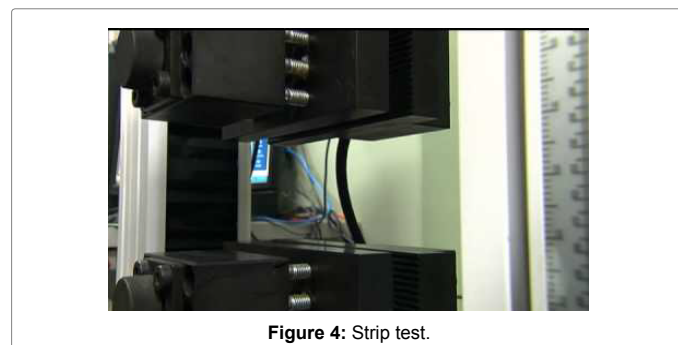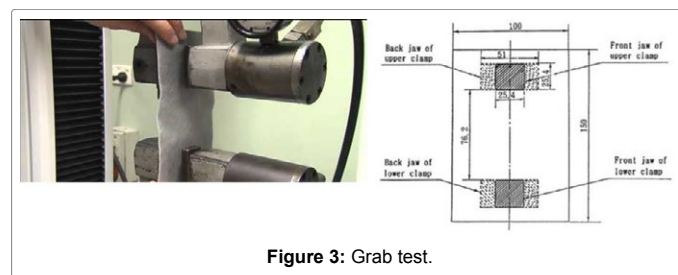
Porosity=1-FVF

FVF is Fibre Volume Fraction=Volume of fibre/Volume of fabric.

Pore size is another parameter which determines the filtration efficiency of fabric. There are different methods available to measure pore size and pore size distribution of nonwoven fabrics and these are optical methods, density methods, gas expansion and adsorption, electrical resistance, image analysis, porosimetry and porometry. Apparent pore opening size is measured by passing spherical glass beads of different sizes (50 mm to 500 mm). From bigger size to smaller size, for each size glass beads passed through fabric having largest pore of size equal and larger than glass beads. Three different conditions of measurement for AOS are dry sieving in which simply glass beads passed at dry stage, wet sieving in which continuously water must be sprayed and hydrodynamic sieving in which beads sieved as water flow with repeated immersion of the fabric in water (Figure 5).

There are three groups of pore size, which are:

Opening pore sizes (Apparent Opening Size – AOS) which are important for determining the filtration and clogging performance of nonwoven used in geotextiles application and it grades the filter fabrics as absolute value.

Constriction pore size (pore throat size), is different from AOS as it is the dimension of the smallest pore involves in flow and it is important for fluid flow transport through nonwoven fabrics.

Pore volume size.

Tensile strength

Nonwoven fabrics are extensively used in wide range of fields such as geotextiles, carpets backing, garment liners and used as reinforcing component in textile structural composites(10). Mechanical properties of nonwoven fabrics must be assessed in both machine direction (MD-along the output direction) and cross-direction (CD-perpendicular to output direction), and tested in bias directions if required.

There are two testing methods to determine the tensile strength of nonwoven fabrics as in the case of woven fabrics, are as follows:

a) **Grab test**: The width of the nonwoven fabric strip is 100 mm. The central section across the fabric width is clamped by jaws a fixed distance apart called gauge length. Clamping width in the central section of the fabric is 25 mm. The edges of the sample therefore extend beyond the width of the jaws and. The fabric is stretched at a rate of 100 mm/min (according to the ISO standards) or 300 mm/min (according to the ASTM standards) and the separation distance of the two clamps is 200 mm (ISO standards) or 75 mm (ASTM standards). Nonwoven fabrics usually give a maximum force before rupture.

b) **Strip test**: The full width of the fabric specimen is gripped between the two clamps. The width of the fabric strip is 50 mm (ISO standard) or either 25 mm or 50 mm (ASTM standards). Both the stretch rate and the separation distance of the two clamps in a strip test are the same as they are in the grab test. The observed force for a 50 mm specimen is not necessarily double the observed force for a 25 mm specimen.

c) **Bending rigidity:** Stiffness is an important hand parameter that is determined in terms of bending length measurement using cantilever principle. For nonwoven fabrics which are used as interlinings for garment stiffness should be little higher, gloves, aprons, medical gowns and caps, etc. requires bending rigidity should be lower.

To find bending rigidity (or flexural rigidity) of a nonwoven fabric, it is assumed to be composed of unit cells. The bending rigidity of the fabric is the sum of the bending rigidities of all the unit cells in the fabric, defined as the bending moment times the radius of curvature of a unit cell.

The general unit cell bending rigidity, $(EI)_{cell}$, is therefore as follows:

$$(EI)_{cell} = N_f \int_{-\pi/2}^{\pi/2} [E_f I_f \cos^4\theta + GI_p \sin^2\theta \cos^2\theta] \Omega(\theta) d\theta$$

where N_f=Number of fibres in the unit cell,

$E_f I_f$=Fibre bending rigidity around the fibre axis,

G=Shear modulus of the fibre,

I_p=Polar moment of the inertia of the fibre cross section, which is a torsion term,

$\Omega(\theta)$=The fibre orientation distribution in the direction, θ.

Two cases were considered for analytical establishment based on relative motion of the fibres inside a fabric.

Complete freedom: The fibres are free to twist during fabric bending (e.g. needle punched fabric), the torsion term ($GI_p \sin^2\theta \cos^2\theta$) will be zero

$$(EI)_{cell} = \frac{\pi}{64} d_f^4 N_f E_f \int_{-\pi/2}^{\pi/2} [\cos^4\theta] \Omega(\theta) d\theta$$

No freedom: Freedom of relative fibre motion is severely restricted

$$(EI)_{cell} = \frac{\pi}{48} d_f^2 N_f E_f \int_{-\pi/2}^{\pi/2} [\cos^4\theta] \Omega(\theta) d\theta$$

where, d_f=Fibre diameter

E_f=Young's modulus of the fibre

h=Fabric thickness.

Permeability

Intrinsic permeability of a porous material depends only on the properties of the material, not on the properties of fluid to be permitted. It is also called specific permeability or absolute permeability. This property of a nonwoven fabric is a characteristic feature of the fabric structure which represents void capacity through which a fluid (liquid, air) can flow.

The specific permeability k is defined by D'Arcy as: v=(k dp)/(η dx),

where v=Volumetric flow rate of the fluid in a unit flow area (m/s)

η=Liquid viscosity (Pa.s)
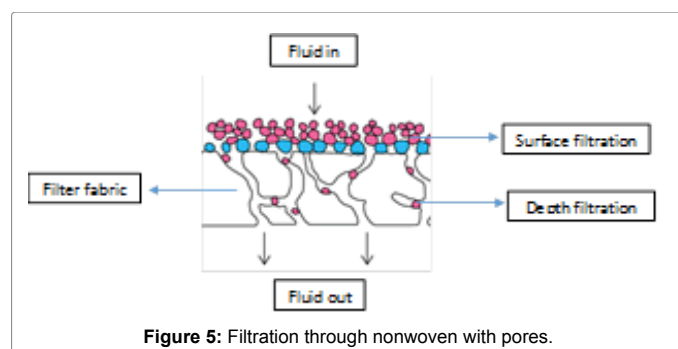
dp=Difference in hydraulic pressure (Pa)

Figure 5: Filtration through nonwoven with pores.

dx=Conduit distance (m) and

k=Specific permeability (m²).

The permeability as defined by Darcy's law (also called hydraulic conductivity) is in fact a property of both the material and the fluid. According to D'Arcy's law, permeability coefficient K is defined as: (2,12,17,19).

v=K×i

where, i=hydraulic gradient, (i.e., the differential hydraulic head per conduit distance (m/m)) and

K is the permeability coefficient (m/s).

The relationship between k and K is given as:

k=Kh/rg (m²)

where r=Liquid density (kg/m³) and

g=Gravity accelerator constant (m/s²)

At 20°C temperature of liquid water, the constant becomes, k (m²)=1.042 ×10⁻⁷ K(m/s).

Filtration properties

Filtration process simply defined as the separation of one material from another. Filtration processes are usually categorized as dry filtration (air filtration, aerosol filtration), wet filtration (liquid filtration). Objectives of filtration are (i) to obtain the maximum separation of targeted solid/liquid particulates from the fluid flow while (ii) minimizing the pressure drop of the fluid flow across the filter thickness.

Nonwoven filters are operated as depth filters, in which the targeted particles gradually penetrate through the filter in the direction of the filter thickness to be captured by individual fibres. Some singed, coated and/or composite nonwoven filters are used for surface filtration in which the targeted particles are blocked on the surface.

The mechanism of filtration varies with the properties of the targeted particles (such as size, shape and physical attraction) and the fluid carriers (viscosity, flow type, flow rate and chemical nature) and physiochemical interactions of the particle-fluid-filter material system, thus the filtration processes and the performance of a nonwoven filter cannot be treated in a universal model. If the dimensions of the particle are larger than the pore size in the textile nonwoven material, the particles are stopped easily. For the particles that are smaller than the pore sizes, there are five separate mechanisms of arrest as shown in Figure 6.

a) Interception: When a particle tries to pass the fiber surface at a distance smaller than the particle's radius, it merely collides with the fiber and may be stopped or arrested.

b) Inertial deposition: The velocity of a flow increases when passing the spaces of a filter because of the continuity equation. When a heavy particle is carried by the flow, it is thrown out of the flow streamlines due to its inertia (mass x speed). This may cause the particle to be caught by other fibers.

c) Random diffusion (Brownian motion): Due to Brownian-type motion (random vibration and movement of particles in a flow), instead of trying to pass straight through the openings of the filter, particles follow a zig-zag route which increases the chances of being caught by the fiber material.
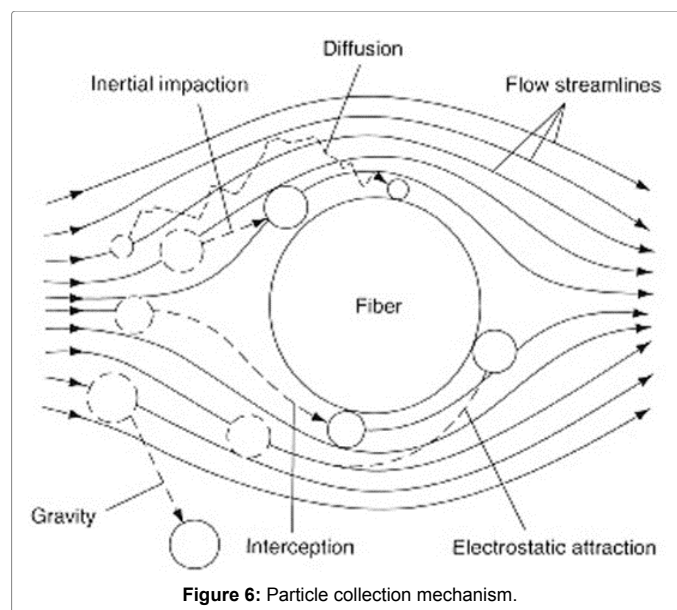

Figure 6: Particle collection mechanism.

d) Electrostatic deposition: Submicron particles are difficult to capture even with combination of mechanical methods. It is well known that strong electrostatic forces of fibres attract the particles. Therefore, fibers may be given permanent electrical charges to attract small or medium sized particles.

e) Gravitational forces: Under the influence of gravity, a particle that is sinking, may collide with the fiber and caught.

The major criteria characterizing the performance of a filter include the filter efficiency, pressure drop, filter loading, filter clogging and filter cleaning and filtration cycling time.

Filter efficiency: The filter efficiency, E, is the ability of the filter to retain particles and is defined as the percentage of particles of a given size retained by the filter. It can be calculated from the ratio of the particle concentrations in the upstream (Pin) and downstream (Pout) fluid flows respectively.

$$E = 1 - \frac{P_{out}}{P_{in}}$$

Pressure drop: The pressure drop refers to the difference in pressures across the filter thickness.

For dry filtration, $D_p = p_{in} - p_{out}$, where upstream (p_{in}) and downstream pressure (p_{out})

For wet filtration, $D_p = DP_{H-P} + DP_{B-P}$ where DP_{H-P} is the pressure drop for a Hagen - Poiseuille fluid, and DP_{B-P} is the pressure drop due to the particle flow resistance.

Conclusion

Nonwoven fabrics find application in wide market products, and the major areas divide into three categories as discussed in this paper. To define the property requirements for particular application, it is essential to establish a fundamental link and relationship between structural as well as physical parameters. Pore size and its distribution property highly effects filtration property and its efficiency.

Since nonwoven fabrics are manufactured by various methods using mechanical elements, hydraulic, thermal and chemical, properties of each variety exhibits their own property relationship. Thus further

detailed review can be done on property relationship for each type of nonwovens such as needle punched, spun bond, thermal bonded, chemical bonded, spun laced and their combinations.

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