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Research Article

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Studies on Degree of Isotropy and Physical Properties of Cross-Laid Needle Punched Sandwich Fabric

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Abstract

In this research study, the authors have been made an effort to investigate the tensile properties of needle punched cross-laid nonwoven polyester fabric along with woven fabric (Dhoti) in sandwich form i.e. woven fabric layer in between two nonwoven fabrics prepared by needle punching machine. Five types of fabric specimens have been studied, namely Nonwoven fabric, nonwoven-nonwoven double layer fabric, woven fabric, nonwoven-woven punched fabric and nonwoven-woven-nonwoven sandwich fabric for measuring the fabric areal density, air permeability, compression and resiliency, tensile properties and also analyzed nature of isotropy in terms of tenacity. Tensile properties of studied fabrics have been measured not only in machine direction (MD) and cross direction (CD) but also at various angles (22.5^0, 45^0 and 67.5^0) with respect to the width of fabric, in order to appraise degree of isotropy. Maximum strength observed to be more in CD then gradually reduces towards MD. Calculated data unveils that double layer nonwoven fabric exhibit maximum isotropy and woven fabric possess minimum degree of isotropy in respect of tenacity of fabrics.

Keywords

Nonwoven; Cross-laid fabric; Needle punching; Tenacity; Degree of isotropy

Introduction

Nonwoven technology is totally based on new innovative and cheapest technique of producing fabric directly from fibers, at the same time waste or recycled fibers can also be assembled into fabric by using this technology [1]. Nonwoven fabric structure has been formed by the sequence of web formation and web bonding process [2]. Web formation is the technique to form a web or batt from staple fibers or filament, as a precursor of final fabric [3]. The web formation is a technique of converting staple fibers or filaments into a two-dimensional web or a three-dimensional web assembly known as batt, which is the precursor for the final fabric. The structure and composition of the fibers strongly influence the dimensions, structure and properties of the final fabric. Carding normally used in case of staple fiber play an important purpose of web formation [4]. Similarly, fiber properties such as fiber crimp, cross-section, finish etc. are the deciding factors for the physical interaction of fibers within the web. Interconnection and alignment of fibers in the web is another criterion which affects the properties of fabric. When the fibers are laid in machine direction it is termed as machine laid or parallel laid fabric, when the fibers are laid perpendicular to machine direction, i.e, in width direction, they are termed as cross laid and while the fibers are laid in various directions of the web, that is called random laid [5]. Web bonding strengthen the interaction between them by some way of bonding of consolidated web. The degree of bonding is the primary factor to determine fabric mechanical properties like strength, porosity, flexibility, softness and density. Both natural as well as synthetic fibers can be used in nonwoven technology [6]. Ray and Ghosh observed that in cross laid fabric, the fibers are laid at an angle but not exactly in width direction [7]. Complicated nature of fiber orientation in cross laid nonwoven fabric is the influencing factor for isotropy of fabric structure. They also reported that the laying angle of fibers decides the tensile properties of nonwoven fabric [8]. Roy et al has reported the factors like punching that influenced the fiber orientation in fibrous assembly and thereafter the properties also varied [9]. The most important works related to the field of needle punched nonwoven fabrics have been carried out by various researchers [10]. Based on experiments we have done to establish an influence of nonwoven and woven fabrics in tensile properties and also, we gain knowledge of isotropy on behalf of tenacity of fabrics shown in Figures 1 and 2 [11].

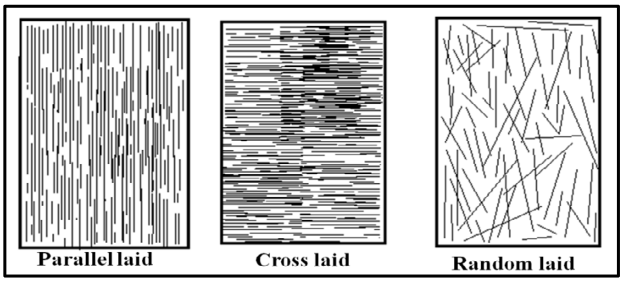

Figure 1: Types of fibre laid in nonwoven fibrous sheet.

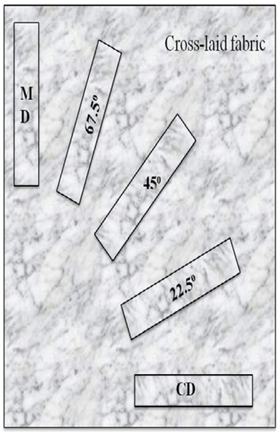

Figure 2: Fabric sample marking according to direction for the experiment.

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Materials and Methods

In this study, a plain woven 100% bleached cotton dhoti fabric (53 GSM) was used. Analyzed data of the fabric being used are shown in Table 1. The polyester fiber used in order to produce needle punched nonwoven fabric. The detail of the fiber is given in Table 2.

Table 1: Key characteristics of Dhoti used in this study.

Fabric parameters	Measured values
Warp count (Ne)	60
Weft count (Ne)	60
Ends/inch	126
Picks/inch	100
Areal density (g/m²)	53

Table 2: Details of polyester fiber used.

Fibre	Fineness (denier)	Cut length (mm)	Tenacity (cN/den)	Elongation (%)
Polyester	15	50	4.6	32

Nonwoven fabric production

The cross laid needle-punched nonwoven fabric produced in laboratory model needle punching machine (DILO Machine GmbH, Germany). This laboratory model needle punching machinery consists of fiber opener, chute feed card with camel back cross lapper, needle loom with two needle boards punching from one side only, cloth winding unit and electrical control panel for controlling the operations. Fibers were opened manually before feeding into the opener. Opener is followed by card feeder, worker and stripper type card, camel back lattice or lapper and cross lapping zone. Finally, the web passes through needle loom as well as cutting and winding device attached to this needle loom consisting of 1 lab winder with 2 edge cutters. Polyester fabric made up of 8 layers of web, was feed in the needle loom again for punching in the other side of the fabric. Needles of gauge 40, triangular cross-section, 3 apexes and 2 barbs per apex with regular barb were used in the study. Depth of needle penetration of needle was set to 10 mm and density of needles/inch² in the needle board was 17. The number of needles per meter in the needle beds is 4500 and width of the machine is 600 mm also in every sample stokes per minute maintained at 238 [12,13].

Sample preparation for study

Total five types of fabric samples were required for the study of physical properties of sandwich fabric and later on to compare with basic nonwoven and woven fabric. The punch densities were maintained by passing all the fabrics through the needle board 4 times respectively.

The five samples identified by following codes for overall analysis:

- N – Basic nonwoven fabric
- W – Basic woven cloth (dhoti)
- NN – two nonwoven fabric combined punched
- NW – one nonwoven and one woven fabric combined punched
- NWN – one woven fabric punched in between two nonwoven layer

Measurement of physical properties

The methods of measurement of following properties are described below

Areal density and thickness: ASTM standard D6242 was followed to measure the basis weight of fabrics. The specimen size of 10.2 cm× 10.2 cm was taken randomly from different places. The average of 5 readings weighed on electronic balance was taken into consideration. The thickness of the fabrics was measured according to ASTM D1777-96 standard with AIMIL made digital thickness gauge at a pressure of 1 kPa.

Air permeability of fabric samples: Air permeability of each sample calculated with the help of PROLIFIC air permeability tester.

Following relation used to evaluate air permeability of fabrics

Air permeability = K× rotameter reading from machine, where K is the conversion factor 0.01667 for 10 cm² for the said experiment.

Testing of tensile properties of fabric

The tensile properties of the fabrics were measured in ZWICK ROELL (Model - Z010) Tensile Tester as per ASTM D 5035-5(R2003), which works on constant rate of extension principle. The upper jaw is movable and lower jaw is fixed. Samples are clamped between the jaws. The maximum load capacity is 10 kN having testing speed of 1 mm/min to 2000 mm/min. Tensile properties such as tenacity, extension, breaking load have been measured in CD, MD, bias (45^0) direction, 22.5^0 and 67.5^0.

Results and Discussions

Air permeability

We can observe from Table 3. that air permeability reduces with increase in fabric areal density. The fabric becomes thicker and denser and resulting in consolidated structure which opposed air to pass through it. The number of pores increases with increase in number of fibers, pore size becomes smaller. The nature of variation of air permeability values of different fabrics are shown in Figure 3.

Table 3: Air Permeability of Fabric Samples.

Fabric Code	Air Permeability (m³/m²/min)
N	125.02
W	195.70
NN	97.52
NW	88.18
NWN	67.51

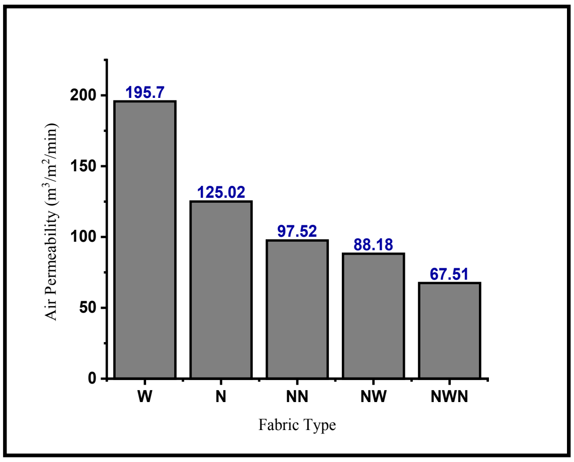

Figure 3: Air permeability of fabric samples.

Compression and recovery property of the fabric

The data related to compression and recovery during static loading and unloading are shown in Table 4 and nature of the variation of compression and recovery percentage values different fabrics are shown Figure 4 respectively. Compressibility as well as the recovery in general, increases with increase in load irrespective of type of fabric. But for same load, the compressibility differs from fabric to fabric, the recovery is almost same. The recovery values are in the range of 36.53-41.07% and 35.71 -47.46% for the removal of load of 5-1 and 10-1 kPa respectively.

Breaking load and tenacity of different fabric samples

The breaking loads of different fabrics at different directions of testing are given in Table 5 and the nature of trend in variation of such load is shown in Figure 5. As observed, the sandwich fabric made of two layers of nonwoven and one layer of woven at the middle has the maximum breaking load. The minimum breaking load has been observed for single nonwoven and woven fabric but the nature of variation in Tenacity are in opposite direction. As the GSM of the fabrics are different, the breaking load values have been converted in to tenacity (cN/tex) for comparison purpose. The tenacity (cN/tex) values of five types of sample fabrics at different direction namely CD, 22.5°, 45°, 67.5 and MD are shown in Table 6. In general, the tenacity of the fabrics varies with direction of testing. Excepting the woven fabric, the tenacity has gradually decreased from CD to MD direction. Tenacity is maximum in woven fabric in comparison to the other fabrics. Moreover, the woven fabric is stronger in MD than CD (CD:MD= 0.43), mainly due to higher thread density in warp in comparison to weft direction. In all other fabrics, the tenacity in CD 1s higher than MD and the CD:MD ratio 1s in the range of 1.16 to 1.50. The tenacity of two-fold nonwoven is greater than single nonwoven in all directions, which may be due to more Compacting and entangling of fibers during needling. But addition of woven fabric with nonwoven in both the cases have resulted decrease in tenacity. This decrease in tenacity is mainly due to the unequal 1oad sharing by the woven and nonwoven component in one hand and less weight sharing of woven fabric in the sandwich fabrics. The nature of variation of tenacity values of in all direction are shown In Figure 5.

Table 4: Compression % and Recovery % of different fabric sample.

Fabric type	Load range in KPa			
	1 – 5		1 – 10	
	Compression %	Recovery %	Compression %	Recovery %
N	17.28	39.02	25.62	44.44
W	11.30	36.36	14.50	35.71
NN	11.86	38.09	17.70	47.61
NW	18.90	41.07	28.47	44.04
NWN	12.65	36.53	22.87	44.68

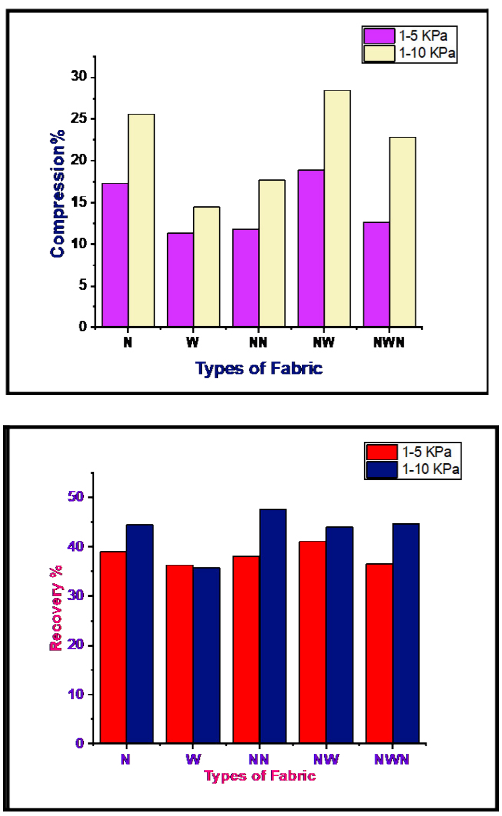

Figure 4: Compression % and Recovery % of different fabric sample.

Breaking elongation of different fabric sample

The breaking elongation value of all fabric samples are shown in

Table 5: Breaking load of different fabrics at various direction.

Type of fabric	Direction of testing				
	CD	22.5°	45°	67.5°	MD
	Breaking load (N)	Breaking load (N)	Breaking load (N)	Breaking load (N)	Breaking load (N)
N	111.42	90.08	103.40	81.37	84.32
W	50.56	59.39	85.39	54.50	119.23
NN	200.44	198.66	187.83	173.29	172.43
NW	100.47	67.84	85.87	45.32	67.58
NWN	224.25	233.03	271.81	194.38	172.12

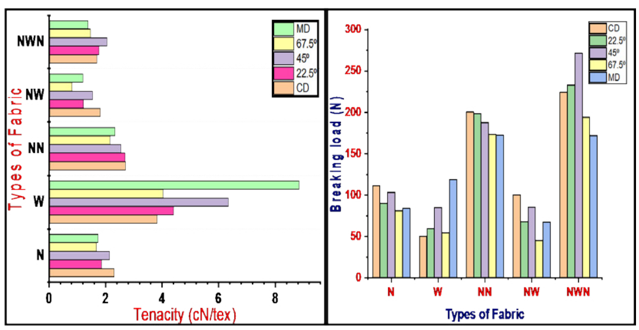

Figure 5: Breaking load and tenacity of different fabric samples.

Table 6: Tenacity of different fabrics at various direction.

Type of fabric	Direction of testing				
	CD	22.5°	45°	67.5°	MD
	Tenacity cN/tex	Tenacity cN/tex	Tenacity cN/tex	Tenacity cN/tex	Tenacity cN/tex
N	2.30	1.86	2.14	1.68	1.74
W	3.83	4.41	6.34	4.04	8.85
NN	2.71	2.69	2.54	2.16	2.33
NW	1.81	1.22	1.54	0.82	1.20
NWN	1.70	1.77	2.06	1.47	1.38

Table 7. It is observed that elongation of fabrics depends on type of fabric structure and direction of testing (alignments of fiber/yarn in the fabric). The breaking elongation values are maximum for NWN fabric in the range of 62.39 to 88.36. The value is so lower for woven fabric in the range of 9.66 to 20.06. Presence of woven fabric also influences the elongation of sandwich nonwoven fabrics. However, for any particular fabric there is so less amount of difference in breaking elongation on different direction of testing shown in Figure 6.

Degree of isotropy in terms of tenacity of different fabric sample

For the same, absolute (mod) value of deviation of tenacity in any direction from the average tenacity has been obtained and then converted to deviation percentage. Thenceforth degree of isotropy has been incurred by deducting deviation percentage from 100 percent.

Degree of isotropy = $100-\{(T_i-T_a)/T_a\times100\}$

Where, T_i = Tenacity at any direction and T_a = Average tenacity of all directions.

In order to quantify the extent of isotropy, degree of isotropy as proposed by literature has been used in the study. It is the degree of matching strength in MD, CD & other directions with respect to the average tenacity of all direction. Based on the data related to tenacity of five types of fabric samples at various directions, the degree of isotropy of tensile property has also been measured and shown in following Table 8. As observed from table, the deviation from the average tenacity varies in the range of 2 to 40%. Moreover, the average degree of isotropy for all type of fabrics varies within range of 69.4 to 92.1%. From these findings, it can be concluded that basic nonwoven, double nonwoven and sandwich (NWN) fabric produced in the study are highly isotropous, so far as tenacity concerned. Figure shown that,

Table 7: Breaking Elongation of different fabrics at various direction.

Type of fabric	Direction of testing				
	CD	22.5°	45°	67.5°	MD
	Extension %	Extension %	Extension %	Extension %	Extension %
N	46.77	42.98	46.71	42.50	47.22
W	13.33	17.88	20.06	15.15	9.66
NN	68.04	68.94	68.99	65.45	86.94
NW	10.97	28.47	17.75	27.46	5.91
NWN	72.81	62.39	67.70	72.59	88.36

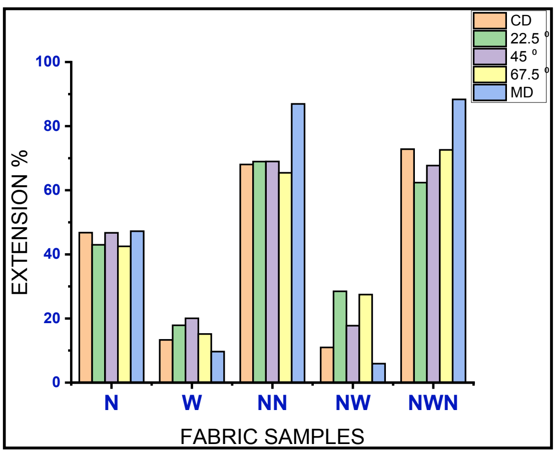

Figure 6: Breaking elongation of different fabric sample.

Table 8: Degree of isotropy in terms of tenacity of different fabric sample.

Fabric sample	Direction of testing	Tenacity (cN/tex)	Average Tenacity (cN/tex)	Deviation from the average %	Degree of Isotropy %
N	CD	2.30	1.94	18.6	88.6
	22.5°	1.86		4.2	
	45°	2.14		10.4	
	67.5°	1.68		13.5	
	MD	1.74		10.4	
W	CD	3.83	5.49	30.2	69.4
	22.5°	4.41		19.6	
	45°	6.34		15.5	
	67.5°	4.04		26.5	
	MD	8.85		61.2	
NN	CD	2.71	2.48	9.3	92.1
	22.5°	2.69		8.5	
	45°	2.54		2.5	
	67.5°	2.16		12.9	
	MD	2.33		6.1	
NW	CD	1.81	1.31	38.2	78.0
	22.5°	1.22		6.8	
	45°	1.54		17.5	
	67.5°	0.80		39.9	
	MD	1.20		8.4	
NWN	CD	1.70	1.67	1.8	87.9
	22.5°	1.77		5.9	
	45°	2.06		23.4	
	67.5°	1.47		11.9	
	MD	1.38		17.3	

in the same direction degree of isotropy of different sample varies from 61.8 to 98.2% (except in case of woven MD the value is 38.8). The average degree of isotropy of five samples can be observed in the range of 69.4 to 92.1%. When the basic nonwoven fabric has been transmuted into double nonwoven layer then its isotropy increases about 3.5%. Where incase of woven fabric and the needle punched woven & nonwoven combined fabric the isotropy has been increased about 8.6%. In case of sandwich fabric, the isotropy has been measured around 87.9% shown in Figure 7.

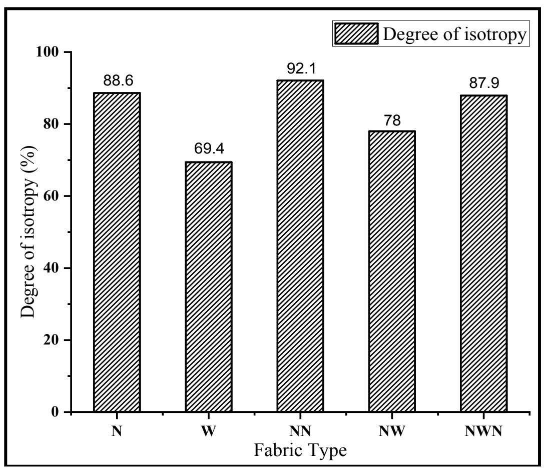

Figure 7: Degree of isotropy in terms of tenacity of different fabric sample.

Conclusions

Different combinations by woven and nonwoven fabric ensembles are evaluated for physical characteristics. The overall variation in properties of the fabrics under study is due to variation in fabric parameters as well as structure of the fabrics. Primarily the thickness and secondarily the porosity are the two important factors which determine the permeability properties of the fabric. Air permeability of woven fabric was higher than the single nonwoven fabric mainly due to selection of very open structured woven fabric. It decreased for sandwich fabrics, as combination of two or three layers of fabric results more compact fabric and hence the more resistance of air flow through the fabrics. Compressibility as well as the recovery in general, increases with increase in load irrespective of type of fabric. But for same load, the compressibility alters from fabric to fabric, without much variation in the recovery percentage. None of the fabrics was highly resilient. Basis GSM, thickness and tensile property depended on punching parameters of needle punching zone. Apart from these parameters, the type and structure of the fabric and orientation of fibres or yarns in the fabric played a substantial role in the tensile properties of the fabric. In general, the tenacity of the fabrics varied with direction of testing. Excepting the woven fabric having the maximum tenacity, the tenacity has gradually decreased from CD to MD direction. The CD: MD ratio is in the range of 1.l6 to 1.50. Addition of woven fabric with nonwoven in both the cases have resulted decrease in tenacity. The breaking load was high for sandwich fabric whereas the tenacity was high for woven Fabric. This is due to consideration of mass in calculating the tenacity. Elongation varies widely, minimum in woven fabric, whereas the maximum was in nonwoven, the same was in between for sandwich fabrics. The average Degree of isotropy values of the fabrics in terms of tenacity are in the range of 69.4 to 92.1%, the minimum is for the woven one (W) and the maximum for twofold nonwoven (NN). These values reflect the orientation of fibers in the nonwoven fabrics. Also, combination of woven fabric with nonwoven influences the physical properties of the resultant fabric.

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