High Efficiency Particulate Air (HEPA) Filters from Polyester and Polypropylene Fibre Nonwovens

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Abstract

Abstract

In this work, High Efficiency Particulate Air (HEPA) Filters are designed to keep small harmful particles from entering a control environment or to prevent them from escaping.

Nonwoven fabrics for filtration application were produced from polypropylene (PP) and polyester (PET) fibres. The nonwoven spunlaced filters made from these fibres are softer and more flexible compared to traditional glass fibre filters for this application.

They also have relatively smaller pores which render high air filtration efficiency. Glass fibres are more harmful to human, compared to polypropylene and polyester fibre which are chemically inert. Hydroentanglement and chemical bonding techniques were utilised in manufacturing nonwovens for dry filtration. Acrylic chemical binder as a foam was applied on wet spunlaced material and subsequently cured in an oven. The crosslinks between the fibres and binder were developed with resulted small pores in the material. Three different waterjet pressures and two different concentrations of chemical binder were applied during the processing. The physical, mechanical and performance properties were evaluated and analysed.

Hydroentagling process binds the fibres in a homogeneous way and stabilizes the structure of nonwoven. With the use of finer fibres, the surface area of the filter media shows an increasing number of finer pores. The improved surface of the media and homogeneous cross-section after chemical bonding results in better filtration efficiency.

INTRODUCTION

High efficiency particulate air (HEPA) filters can remove high percentage of biological and particulate material from the air with relatively low pressure drop and energy consumption. HEPA filters provide high level filtration efficiency for the smallest as well as the largest particulate contaminants. Theoretically at least 99.97% of dust, pollen, mold, bacteria and any airborne particles with a size of 0.3 micrometres (µm) can be removed by them. The primary issues for the improvement of particulate filters are: 1) lower energy consumption, 2) longer filter life, 3) greater dust retention and 4) easier maintenance without compromising filter efficiency [1].

An application, environment, efficiency, physical geometry and structural requirement, among other issues, have to be taken to consideration when designing the filters. Textile filters are the most important and widely acceptable groups of materials used for filters. The main advantage of textile filters is the wide range of pores and fibre configuration. Two or more types of fibres can be combined in a fabric to provide a combination of good strengths and filtration properties [2].

Nonwovens, predominately made by needle-punching technology, are the major media for air filtration and compose almost 70% of the total filter media. A random arrangement of fibres in nonwovens provides more favorable conditions for the trapping and retention of particles in comparison to the same quantity of tightly bundled fibres converted into weft and warp yarn. Nonwovens have higher filtration efficiency, no chance of yarn slippage and good cake discharge property [2].

Single fibre characteristics in nonwovens may affect and control filtration performance due to their properties such as diameter, shape, surface finish, electrical charge and hardness. The smaller the fibre and a fibre spacing, the greater is the surface area which results in the greater filter efficiency and capturing of small particles [3].

In this work, the nonwovens, suitable for high efficiency filtration application, from PP and PET fibres were prepared by using both hydroentanglement and foam chemical bonding in tandem.

The effect of amount of binder at 25 and 40 % on the pore size and its distribution and its effect on the filtration properties were investigated and analyzed.

Spunlace technology utilized high pressure water jets to interlock fibres of webs. The turbulence of the water causes rearrangement and entanglement of the fibres which results in fibre structure consolidation. The absence of fibre mechanical damage, compared to needle-punching technology, prevents the passing of dust particles through the filter media and leads to an increase filtration efficiency of the fabric [4]. The resulting nonwoven fabric is soft, drapable and has relatively high strength. Applied chemical bonding process will create additional bonding between the fibres.

As the result, the crosslinks between the fibres are developed during the thermal bonding process [5].

EXPERIMENTAL

Polypropylene (PP) fibres (2.2 dtex , 40 mm staple length) and polyester (PET) fibres (3.6 dtex, 60 mm staple length) were selected for this experiment, because they provide the necessary strength and durability to the nonwoven fabric to withstand the forces acting during filtration.

Fibres were opened first by carding and the fibrous web was formed through carding process. After cross-lapper, the batt was transported to the hydroentanglement unit for the bonding. Three different pressures of AuaJets namely 60, 120 and 200 bars were applied at second and third jets for this trial.

Then the chemical coating was applied on spunlaced wet fabric by traversed foam delivery unit. It is important to apply the resin on the wet material for the creating the better bond between fibres and binder. Received fabric went through the oven for drying and curing. Process parameters such as speed of conveyors were kept constant, but the water jet pressure was increasing according to the plan of experiment.

The chemical binder application by weight of material was 25% and 40% respectively with 30% binder concentration in solution. Heat curable aqueous acrylic resin Acronal 32 D was used as a chemical binder for this experiment.

According to the plan of experiment, twelve samples were selected for the properties evaluation and comparison

TESTING OF PROPERTIES

Samples were tested for physical, mechanical and performance properties. All nonwoven samples were conditioned at 22 ± 1°C and 65 ± 2% relative humidity for at least 24 hours before testing.

The area weight of fabric was measured according to ASTM D 3776 test method by Electronic balance. The measurement of fabric thickness was performed according to ASTM D5729-95 on a digital thickness gauge for textiles (EV- 06) under the pressure weight of 1 kPa using a metal disk of 170g and 50 mm in diameter. Tensile strength and elongation were measured on Titan tensile testing machine according to ASTM 5034 test method.

Pore size and its distribution were measured on a PMI Capillary Flow Porometer according to Test method 6212005-134 which corresponding to ASTM E 1294. The liquid extrusion technique was used for evaluation of pore size in nonwovens. In this technique a wetting liquid Galwik with known surface tension of 15.9 dynes/cm, fills the pores of the sample and pressurized gas removes the liquid from pores. Differential gas pressure and flow rates through wet and dry sample are measured from which the most constricted through pore diameters, the largest pore diameter and the mean flow pore diameter were calculated.

Filtration properties were measured on a Dust Filtration Device (DF-1) manufactured in house. The tests were conducted according to ASHRAE 52.1– 92 Standard Method.

Table 1 illustrates the measured physical properties such as area weight, thickness, calculated fabric density of the samples and applied variable processing parameters namely water jet pressure and binder's application concentration.

Table.1 Physical properties of spunlaced and chemically bonded samples

Sample ID	Fibres compos.	AquaJet pressure (bars)	Binder application (%)	Aver area weight (g/m²)	Actual area weight (g/m²)	Thickness (mm)	CV (%)	Fabric density (kg/m³)
N1-T2	PP	60	25	125	120-130	1.48	2.67	84.46
N2-T2	PP	120	25	140	130-150	1.36	2.90	102.94
N3-T2	PP	200	25	165	160-170	1.13	2.68	146.02
N4-T2	PET	60	25	160	150-170	1.7	5.86	94.11
N5-T2	PET	120	25	140	130-150	1.35	1.44	103.7
N6-T2	PET	200	25	130	120-140	1.01	4.12	128.71

N7-T2	PP	60	40	210	200-220	2.28	6.22	92.11
N8-T2	PP	120	40	160	145-180	1.31	6.55	122.14
N9-T2	PP	200	40	145	140-150	1.05	1.56	138.1
N10-T2	PET	60	40	170	145-200	1.6	1.87	106.25
N11-T2	PET	120	40	180	150-210	1.36	2.44	132.35
N12-T2	PET	200	40	240	200-275	1.35	5.52	177.78

RESULTS AND DISCUSSIONS

Fabric Density

Fabric weight, thickness and density are interrelated physical parameters for the nonwovens using carding and cross-lapping web formation. In general, with an increase in fabric weight, the thickness of the fabric also increased [6]. The turbulence of high pressure water jets causes rearrangement, shifting and entanglement of the fibres. The fabric structure consolidates with resulted increase of fabric density caused by increasing pressure of water jets. This trend was observed for all samples with 25% binder and 40% binder of PP and PET fibres. The highest value was demonstrated by the sample N3 – PP fibres with the of water jet pressure of 200 bars. The coarser fibres of PET samples (3.6 dtex) tend to have a higher bending stiffness, resulting in the lower fabric density. However, the samples of PET fibres (samples N10, 11 and 12) demonstrated the higher values of fabric density compare to PP samples for all water jets pressures with 40% binder.

Tensile Properties

The tensile properties such as breaking strength and elongation were measured for all samples in machine (MD) and cross machine direction (CD). The summary of results is shown in the Table 2

Table 2. Breaking strength and elongation of spunlaced and chemically bonded materials with **25%** binder application

Sample ID	Fibre	AquaJet pressure, bars	Max force, N (CV%) MD	Max force, N, (CV%) CD	Elongation, %, (CV%) MD	Elongation, %, (CV%) CD
N1-T2	PP	60	95.94 (18.86)	232.22 (10.85)	163.33 (13.09)	124.64 (7.25)
N2-T2	PP	120	166.61 (8.33)	404.17 (6.87)	170.24 (8.45)	123.71 (6.83)
N3-T2	PP	200	202.48 (3.27)	371.22 (7.77)	140.96 (13.93)	121.03 (9.46)
N4-T2	PET	60	282.49 (9.18)	363.43 (23.77)	89.23 (8.01)	88.93 (4.16)
N5-T2	PET	120	194.35 (17.48)	220.41 (9.51)	85.0 (7.05)	94.48 (4.51)
N6-T2	PET	200	152.95 (4.22)	313.15 (3.22)	135.03 (5.87)	123.49 (7.60)

The tensile properties of nonwoven fabrics are different in the different directions of the fabric due to structural anisotropy. That is a result of the fibre alignment in the web during fibre carding and cross lapping. The strength of the samples in cross machine direction (CD) is higher than that in the machine direction (MD) for all samples.

For samples in MD, the breaking strength increased with the increase in applied water jet pressure for all PP samples (samples N1, N2 and N3). For samples containing PET fibres, the strength is higher for the 60 bar water jet pressure in MD. It was the same trend for the PET samples in CD. It can be explained by the structural characteristic of the fabric by being the thicker and heavier for all PET samples. The higher value was detected in CD for sample N2 – PP sample and with 120 bar pressure of water jet. One can imagine that increasing the water jet pressure would cause inevitable increase in breaking strength of nonwovens. But that was only applicable for the PP samples in MD. The opposite effect was observed for the PET samples in MD and

CD, except N6 (PET) in CD. The strength of the sample in CD is higher than in MD for all samples which can be attributed to the carding and cross-lapping processes and alignment of fibres.

Decrease in strength for the PET samples could be explained by the weaker nonwoven structure due to poorer interlocking of more coarser and rigid PET fibres compared to PP fibres. In MD higher value showed by PET sample (N4) at 60 bar water jet pressure. But that can be attributed to the thicker structure of the sample (with thickness of 1.7 mm) compared to the rest of the samples. The thickness of the material can directly affect the tensile strength as recorded in our previous work [6]. As a result, the samples with the lower tensile strength showed higher fabric extension. The samples cut in CD are significantly stronger and less extensible due to predominance of fibre orientation resulting in web formation techniques used in this experiment.

The Tensile properties of the samples N7 to N12 are summarised in the Table 3.

Table 3. Breaking strength and elongation on spunlaced and chemically bonded materials for HEPA application with 40**%** binder application

Sample ID	Fibre	AquaJet pressure, bars	MaxForce, N, (CV%) MD	Max Force, N,(CV%) CD	Elongation, %, (CV%) MD	Elongation, %, (CV%) CD
N7-T2	PP	60	68.89 (2.24)	177.33 (23.69)	97.06 (11.15)	65.1 (4.37)
N8-T2	PP	120	189.54 (5.64)	414.37 (4.69)	169.27 (8.57)	131.93 (6.44)
N9-T2	PP	200	179.28 (8.23)	385.85 (7.89)	158.21 (2.74)	123.04 (7.24)
N10-T2	PET	60	188.39 (7.23)	203.17 (8.15)	72.08 (13.82)	108.87 (7.58)

N11-T2	PET	120	294.78 (5.34)	307.8 (5.57)	71.5 (7.56)	88.11 (5.43)
N12-T2	PET	200	270.89 (7.17)	290.61 (11.25)	65.72 (10.34)	80.11 (9.63)

As it was established before, the orientation of fibres in the web contributed to the higher strength of the fabric in the cross machine direction (CD) compare to machine direction (MD).

The breaking strength increased with increasing water jet pressure but was higher for the samples prepared at 120 bars, than that for samples at 200 bars. This trend was observed for PP and PET samples in both MD and CD. The higher water jet pressure caused the higher entanglement and interlocking of the fibres, but also attributed to the development of more stiff fabric (compared to fabric spunlaced at 60 and 120 bars water jets) which tends to break more easily.

Pore Size and its Distribution

The pore size and its distribution are very important parameters in filtration application. The smallest pores contribute to higher filtration efficiency and increased dust holding capacity. The mean flow pore (MFP) diameter is such that fifty percent of flow is through pores larger than MFP diameter and the rest of the flow is through smaller pores. The mean flow pore diameter is a measure of permeability [7].

The pore size and its distribution for the samples with the 25% binder application are illustrated by Figure 1.

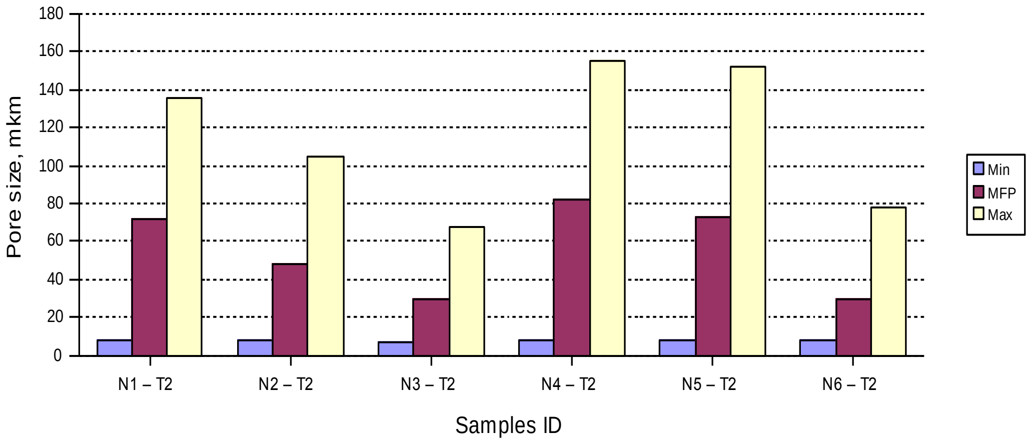

Fig. 1 Pore size and its distribution for nonwovens with 25% binder

The maximum reduction in pore showed by sample N3-T2 (PP) at 200 bars pressure of water jet. In the case of PET samples, the pores of PET sample N5-T2 at 120 bars pressure of water jet, didn’t show much different, compared to pores of sample N4-T2 with applied 60 bars pressure of water jet. However, the mean flow pores (MFP) and maximum pores significantly decreased in sample N6 – T2 with applied water jet pressure of 200 bars. Porosity of nonwoven fabric depends on the fibres specific surface area when finer fibres will create the smaller pores. That is why pores in all PP samples with 2.2 dtex fibre are smaller compared to pores in PET samples with 3.6 dtex fibre while applying the same pressure of water jet. It was observed that the smaller pores were created during more intense interlocking of fibres with the higher pressure of water jets such as 200 bars for PP and PET samples with 25 % binder application.

The pore size and its distribution for the samples with the 40% binder are illustrated by Figure 2.

The smallest pores were achieved for sample N9 - T2 made of PP fibres at 200 bars of water jet. The same trend on decreasing of MFP and Max pores was observed for both PP samples (N7, N8 and N9) and PET samples (N10, N11 and N12) with the increase in water jet pressure. However, the sample N12-T2 did not show a difference in terms of Max pore size, compared to N11-T2.

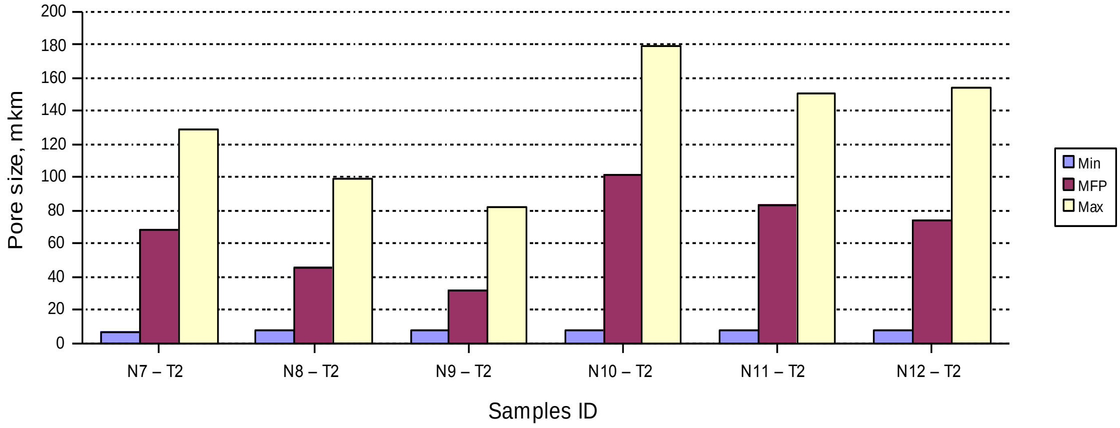

Fig. 2 Pore size and its distribution for nonwovens with 40% binder

Filtration Properties

All samples were tested for Filtration properties such as dust arrestance, dust holding capacity and resistance (pressure drop). The method and applied technique was described elsewhere [8]. The results on filtration properties for samples with 25 % binder application are illustrated in Table 4.

Table 4. Filtration properties (25% binder)

Filtration Properties	N1-T2 PP	N2-T2 PP	**N3-T2** **PP**	N4-T2 PET	N5-T2 PET	N6-T2 PET
Water jet pressure, bars	60	120	**200**	60	120	200
Dust arrestance, %	90.9	93.7	**99.4**	95.8	94.5	96.9

Dust holding capacity, g/m^2	62.7	45.6	**74.4**	48.7	59.4	68.1
Pressure drop, Pa	25	37.5	**25**	37.5	12.5	25

Within the samples with 25 % binder application, PP sample as N3-T2 showed the best performance properties within six samples in terms of all filtration parameters. Dust holding capacity improved for the PET samples with the increase in water jet pressure. A pressure drop also improved (decreased) for PET samples, but the dust arrestance for all PET samples remained almost the same.

The filtration properties such as dust arrestance, dust holding capacity and resistance (pressure drop) were evaluated on samples with 40% binder application. The results are summarised in Table 5.

Table 5. Filtration properties (40 % binder application)

Filtration Properties	**N7-T2 PP**	N8-T2 PP	N9 -T2 PP	N10 -T2 PET	N11-T2 PET	N12-T2 PET
Water jet pressure, bars	**60**	120	200	60	120	200
Dust arrestance, %	**97.3**	97.7	98.6	88.62	90.4	93.9
Dust holding capacity, g/m^2	**75.35**	52.48	72.84	49.65	64.21	37.16
Pressure drop, Pa	**37.5**	37.5	62.5	37.5	25	50

Dust arrestance was high for all manufactured PP samples and didn't increase with the increase in water jet pressure. Dust holding capacity decreased for the sample produced at 120 bars pressure of water jet, but increased for the sample at 200 bars pressure. Despite of that, the pressure drop increased for the sample of 200 bar pressure which is not desirable in such application.

For the PET sample N 11-T2 dust arrestance as well as dust holding capacity increased whereas the pressure drop decreased. However, similar trend was not observed for the sample N12-T2 at the higher water jet pressure of 200 bars. The increase in binder from 25% to 40% does not improve all performance properties of the filters. Too much binder clog empty spaces between the fibres with resultant increase in pressure drop at the same rate of air flow as observed in this study.

Glass and polymer fibres are the most common materials used in HEPA filters. In order to put a large amount of media into a small space, media filters can be pleated. Glass fibres are very brittle and have a tendency to break when it folded too severely. That is why polymer fibres are the good substitution to the HEPA filters. They add a significant amount of structural strength that allows pleating to be effective without significant impact on filter performance.

CONCLUSIONS

Hydroentagling process binds the fibres in a homogeneous way. With the use of finer fibres, the surface area of the filter media shows an increasing number of finer pores.

The results in this study showed an improvement in filtration properties such as arrestance and dust holding capacity for the spunlaced and chemically bonded material with the increase in pressure of water jet as a result of consolidation of material's structure. The fibres become more tightly packed, making it more difficult for particles to pass through the body of the fabric. Spunlacing technology provides high fibre entanglement which results in high filtration efficiency.

Sample N3-T2 (PP) with 25 % binder's application showed the best performance properties in terms of all filtration parameters. The results of good filtration properties were nicely correlated with the best results on their pore size and its distribution.

Among samples with 40 % binder application the best filtration properties were demonstrated by sample N7-T2 (PP) in terms of all filtration parameters and by sample N11-T2 (PET) in terms of dust holding capacity and pressure drop parameter. However, the results on their pore size did not support the theory on the decreasing of pore size with the increase in water jet pressure and binder application. .

It could be concluded that optimum parameters for the manufacture of filters from PP fibres, were 200 bar pressure of water jets and 25 % binder application.

The improved surface characteristics from the finer pores of finer fibres will result in the reduction of raw material for manufacturing of light filtration fabric with high filtration efficiency. Hydroentangled and chemically bonded nonwovens can be an alternative to the traditional filter media.

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