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DEVELOPMENT OF FEATHER NONWOVEN MATERIALS BY A DRY LAID NEEDLE PUNCHING PROCESS

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ABSTRACT

Annually the world produces about 4 billion tons of waste just from chicken feathers which in most cases are incinerated in landfills resulting in pollution of atmosphere and land. For these reasons, it is crucial to find new ideas of applications of the byproduct of feathers and downs as a fiber. The production of nonwovens is a process where the web is formed by fibers mechanical entanglement with the help of hundreds of needles with barbs that transform the fibers from horizontal and vertical positions. Therefore, this paper is focused on the manufacturing of nonwovens out of feathers with the help of the dry laid needle punched process and the physical, mechanical and thermal properties analysis of the produced materials. Thanks to these experiments, we noticed that feather nonwovens possess presents good thermal properties. This study proved that is possible to avoid unnecessary poultry industry waste discarded in the landfills or disposals using nonwoven manufacturing.

KEYWORDS: Nonwoven, Feather Fiber, Waste, Needle Punched Dry Laid & Commercial Use

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Original Article

INTRODUCTION

Recycling resource plays an essential and necessary role in the sustainability of the environment. Textile raw materials are almost 100% reclaimed. For this motive, organic natural fibers are ideal because they are abundant and renewable raw material ecological by its nature.

Feather fibers are a waste material and in general, poultry feather production is linked to the meat consumption. Worldwide poultry meat production increased by about 2.4% in 2012 (FAO, 2013). Currently, United States, China, Brazil, European Union (France as first European country) and India (ABRA, 2012) are the world biggest poultry meat producers. In 2013, approximately 82 million tons of poultry meat was produced by the poultry industry (UBABEF, 2014). Due to this vast poultry production, there emerged a serious problem of feather disposal. For instance, 20 thousand tons of waste feathers per year in France have to be processed (SÉVILLANO, 2014).

Manufacturing nonwoven fabrics is one of the fastest growing segments of the textile industry. In fact, their use is becoming more and more common thanks to a high demand for nonwovens. Today it is estimated a nonwoven world production of about 7.6 million tons in 2011 with growth by around 8% and a market estimated at 5.6 billion euros (PAYEN, 2013). According to EDANA (2013) the overall production of nonwoven just in Europe grew by around 5% in 2014 reaching more than 2 million tons.

The aim of this research was to develop a nonwoven in order to recycle feather waste transforming the fibers into technical fabrics. The complex structures of feathers do not allow the production of knit and conventional woven fabric. For this reason we opted for production of nonwovens.

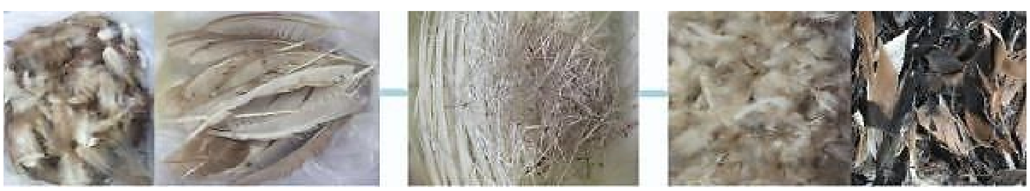
Very few studies have been found in literature on the recycling of feathers, with even less in feather nonwovens using dry laid needle process. This product is unique in comparison with bedclothes as the most wide-spread current application of feathers.

Different kinds of poultry feathers and downs were used: chicken, turkey, duck and goose. The obtained nonwovens were analyzed in terms of physical, mechanical and thermal properties. Thanks to their interesting properties, new applications of these fabrics will be proposed to develop the circular economy that can be fruitful for the above-mentioned countries.

MATERIALS AND METHODS

Feathers Sterilization and Preparation

We sterilized feathers with 5g/L of ECE detergent at 75ºC for 30 minutes according to ISO 6741/3 standard normalization. Then, we prepared samples according with ASTM D 4524/12 and NF EM 1883/98 standards. Carefully, we detached fibers from their rachis with tweezers or scissors. We can notice in figure 1 that the fibers were previously separated from the rachis.



(a) (b) (c)

Figure 1: Samples Preparation: Down Feather and Feathers Raw Respectively (a); Rachis (b) and Down Feather and Feather Fibers Respectively (c) (ASTM D 4524/12 and NF EM 1883/98)

Nonwoven Production

The chosen process for nonwoven manufacturing is the dry laid with needle punched consolidation. The needle punch loom produces porous web thanks to the entanglement of the fibers compression (NF EN ISO 11111-3/05). The needling action interlocks fibers and holds the structure together by friction forces (XIULING, 2008).

This way a new methodology was developed for manufacturing of the feather nonwoven fabric by needle punching. In order to structure feather nonwovens we used a needle loom (Model: Oskar Dilo Maschinenfabrik) and a very light polypropylene nonwoven of 15g/m² generated in spun bonded process (Producers: Fiberweb France and Wigofil) to provide support for the fibers.

To prepare the support, we cut two layers of 1.30m by 0.5m. With a felt pen we drew a rectangle of 10cm by 15cm. The feather fibers were arranged between the two polypropylene layers (forming a sandwich polypropylene - feather fibers- polypropylene). That way, the fibers do not fall in the needle punching mat maintaining the required structure. A design of experiments was established for the production of nonwovens (table 1). In this table we indicate 5 types of different samples manufactured from each animal: feather 2g, down feather 2g, feather 4g, down feather 4g and cut down feather 4g.

Table 1: Nonwoven Design Experiments of Chicken, Duck, Turkey and Goose Feather and Down Feather and Its Surface Mass

Mass/ Mass per Unit Area	2g (133 g/m^2)	4g (267 g/m^2)
Fibers	Chicken feather	Chicken feather
	Chicken down feather	Chicken down feather
	-	Cut chicken down feather
	Duck feather	Duck feather
	Duck down feather	Duck down feather
	-	Cut duck down feather
	Turkey feather	Turkey feather
	Turkey down feather	Turkey down feather
	-	Cut turkey down feather
	Goose feather	Goose feather
	Goose down feather	Goose down feather
	-	Cut goose down feather

In order to obtain a representative sampling from each nonwoven, we produced 5 fabrics where the down feather cutting operation was always performed in three equal parts.

Nonwoven Characterization

The samples were conditioned at the temperature of 20°C ± 2°C and the relative humidity of 65% ± 4% between 24 hours and 48 hours before the characterization tests (ISO 139/2005 and ASTM D 1776/08). We tested the 2 layers of polypropylene in 5 repetitions in order to analyses the influence of these layer on the tensile results.

Surface Analysis

A scanner (Epson Perfection 4990 Photo) coupled to a computer was used to scan the surface and analyze the structure of the nonwoven of each animal. The software was programmed to create color images with 48 bits (quantity of different shades of color). The resolution was set to 2400 dpi (number of pixels per inch). The chosen image size was 10 cm by 10 cm.

Tensile

The nonwoven fabric is submitted to a tensile test using an Instron dynamometer (model 33R4204, USA) up to its mechanical rupture, which indicates the exerted pulling force and the elongation of the fabric. We measure twice each animal nonwoven. The distance between claws was 15 cm and claws velocity was 100 mm/min. We divided our sample of 10 cm per 15 cm in 2 parts in order to obtain 2 samples of 5 cm per 15 cm (NF EM 29073-3 and NF EN ISO 13934-1/13).

Air Permeability

The machine used is TEXTEST (model FX 3300 Luftdurchlassigkeits - Prufgerat) with a basic sample of 20 cm^2 and a difference of pressure of 196 Pa. A total of 5 tests were performed in different zones of each nonwoven of 10cm per 15cm. We carried out tests on 5 nonwovens from each animal. A total of 25 measures from each kind of animal nonwoven were made. The obtained air permeability is expressed in L/m²/s (MILIN et al, 2011, ASTM D 737/46 and NF EN ISO 9237/95).

Thermal Conductivity

Thermal conductivity is the ability of a material to transmit or retain heat (TEXTEST, 2010). We performed thermal conductivity evaluation based on Kawabata Evaluation System. This range of device is able to measure thermal conductivity properties using the guarded hot plate principle (INCROPERA, 2008). A total of 5 tests were performed in different zones of each nonwoven of 10cm per 15cm. We carried out tests on 5 nonwovens from each animal. A total of 25 measures from each kind of animal nonwoven were made.

Thickness

The thickness of nonwovens under different pressures was determined according to ISO 5084/96 standard and using the Sodemat 10 apparatus. For nonwovens this device is more recommended because it has a higher testing surface (5 cm^2) that the KES-FB3- Kawabata (KES-F7, 1980) (2 cm^2). A total of 5 tests were performed in different zones of each nonwoven of 10cm per 15cm. We carried out tests on 5 nonwovens from each animal. A total of 25 measures from each kind of animal nonwoven were made. Reading the results is done after 30 seconds of operation until the fibrous samples reaches full stability.

Statistical Analyses

To evaluate the results, t study (ANOVA), pair comparing and correlation statistical analyses were performed using JMP® software. In table 2 a legend was prepared in order to organize the results displayed in Results and Discussion topic.

Table 2: Legend

CF	Chicken feather
CDF	Chicken down feather
CCDF	Chicken cut down feather
DF	Duck feather
DDF	Duck down feather
DCDF	Duck cut down feather
TF	Turkey feather
TDF	Turkey down feather
TCDF	Turkey cut down feather
GF	Goose feather
GDF	Goose down feather
GCDF	Goose cut down feather
S	Significant
NS	Not significant

RESULTS AND DISCUSSIONS

Fiber Properties

In table 3 we can see the average results of the feather fibers diameter (µm) and the diameter average significance.

Table 3: Fiber Diameter and Diameter Average Significance

Fiber	Diameter (µm)		CF	CDF	DF	DDF	TF	TDF	GF
CF	47.6	CF							
CDF	05.3	CDF	S						
DF	37.4	DF	S	S					
DDF	12.3	DDF	S	S	S				
TF	30.8	TF	S	S	S	S			

Table 3: Contd.,

TDF	11.8	TDF	S	S	S	**NS**	S		
GF	40.0	GF	S	S	**NS**	S	S	S	
GDF	12.4	GDF	S	S	S	**NS**	S	**NS**	S

We notice that chicken feather fiber (47.6 µm) has the highest diameter followed by goose feather (40 µm), duck feather (37.4 µm), turkey feather (30.8 µm), goose down feather (12.4 µm), duck down feather (12.3 µm), turkey down feather (11.8 µm) and chicken down feather fiber (5.3 µm) has the lowest one.

Considering the significance degree of the fibers average, we can conclude that duck down feather and turkey down feather; goose down feather and duck down feather; duck feather and goose feather and turkey down feather and goose down feather do not present a significant difference. In table 4 we observe the feather fiber length (cm) and the length average significance.

Table 4: Fiber Length and Average Significance

Fiber	Length (cm)		CF	CDF	DF	DDF	TF	TDF	GF
CF	3.3	CF							
CDF	1.8	**CDF**	**S**						
DF	3.4	DF	NS	**S**					
DDF	3.5	DDF	NS	**S**	NS				
TF	3.4	TF	NS	**S**	NS	NS			
TDF	4.3	**TDF**	**S**	**S**	**S**	**S**	**S**		
GF	5.4	**GF**	**S**	**S**	**S**	**S**	**S**	**S**	
GDF	3.4	GDF	NS	**S**	NS	NS	NS	**S**	**S**

We notice that goose feather (5.4 cm) presents the largest length subsequent to turkey down feather (4.3 cm), duck down feather (3.5 cm), turkey feather (3.4 cm), goose down feather (3.4 cm), duck feather (3.4 cm), chicken feather (3.3 cm). Chicken down feather (1.8 cm) has the smallest length.

Analyzing the significance degree of the average length of fibers, we come to the conclusion that chicken and turkey down feather and goose feather are significantly different from all the others fibers.

Surface Analysis

Thanks to the image analysis nonwovens surface of chicken, duck, turkey and goose can be observed. Figure 2 presents the obtained images for the test materials. The production direction of all the nonwovens from this figure is the vertical one.

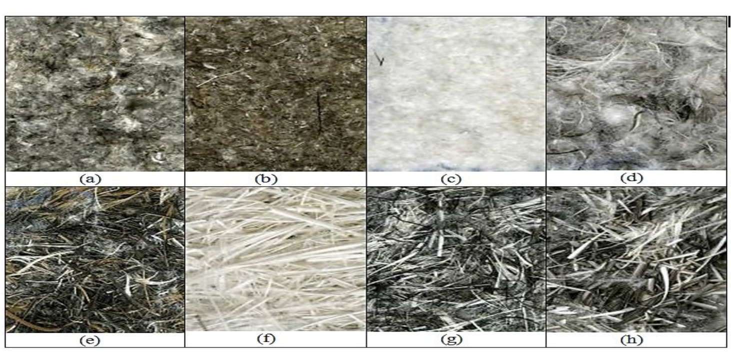


Figure 2: Nonwoven Surface From (a) Chicken (b) Turkey (c) Duck and (d) Goose down Feathers and (e) Chicken (f) Turkey (g) Duck and (h) Goose Feathers

Firstly, we can observe that fibers are entangled with each other forming a heterogeneous surface composed of shorter (from 1.8 cm) and longer (5.7 cm) irregular fibers. On down nonwovens more hairiness is noted because of the disorder of the small barbs. Therefore, nonwovens produced of feathers have the surface which is less homogeneous than expected.

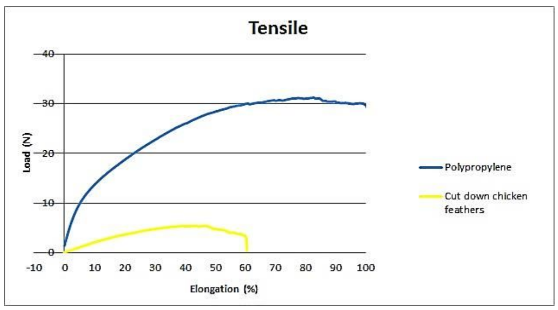
We can notice clearly that nonwovens from down feathers present more regular appearance than feathers due to shorter and thinner fibers.

Samples Mass

In this article we analyzed separately the different samples. The nonwovens samples were divided into groups; 2 grams and 4 grams in order to compare the characterization results with the same mass per unit area.

Tensile

Graph 1 shows the results obtained in the tensile tests of polypropylene and cut down chicken feathers nonwoven.



Graph 1: Load and Elongation from Polypropylene and Cut Down Chicken Feather Nonwoven Comparison

Analyzing the tensile behavior of both curves it is obtained that the feathers nonwoven present a structural deformation smaller than polypropylene.

The effect of the two layers of polypropylene nonwoven does not significantly affect the resistance results of feathers nonwovens; therefore we can say that there is no influence of the polypropylene nonwoven on the feathers nonwovens due to the needle perforation and the damage of the nonwoven during the production.

The average for elongation ranges from 46.7% to 104.5%, when the breaking force is in the range from 1.4N to 17.2N.

We notice that elongation average from down feather of 4g is higher than feather of 4g and cut down feather of 4g. And the average breaking force from down feather of 4g is higher than other samples of 4g, except for goose cut down feather 4g.

The standard deviation for elongation is anywhere from 10.2 to 37.9, while the breaking force ranges from 0.3 to 10.0.

We can observe that breaking force data are more concentrated around the mean than elongation data. In table 5 we outline the results of elongation average and significance of the nonwovens with feather of 2g.

Table 5: Elongation Average and Significance

Feather Nonwovens (2g)	Elongation (%)		CF	CDF	DF	DDF	TF	TDF	GF
CF	55.7	CF							
CDF	60.9	CDF	NS						
DF	53.1	DF	NS	NS					
DDF	91.7	DDF	**S**	**S**	**S**				
TF	54.2	TF	NS	NS	NS	**S**			
TDF	73.3	TDF	NS	NS	NS	NS	NS		
GF	63.7	GF	NS	NS	NS	**S**	NS	NS	
GDF	73.5	GDF	NS	NS	NS	NS	NS	NS	NS

According to this table, we can note that duck down feather (91.7%) presents the highest elongation values, followed by goose down feather (73.5%), turkey down feather (73.3%), goose feather (63.7%), chicken down feather (60.9%), chicken feather (55.7%) and turkey feather (54.2%). The smallest elongation is obtained from duck feather nonwoven (53.1%). Also, we see that down feathers have tendencies to be more extensible than feathers.

We compared elongation values with other nonwovens with $50g/m^2$ of mass per unit area. Globally, the results of elongation from feather nonwoven $133.3\ g/m^2$ (53.1% to 91.7%) are higher, thus this type is more extensible than others: Polyester (9.4%) and 70% Polyamide/ 30% Polyester (12.5%) (KAYAR, 2014).

Interpreting the table 5 we notice that duck down feather is significantly different from chicken down feather, duck feather, turkey feather, goose feather and chicken feather. The other nonwovens are not significantly different among themselves. In table 6 we list the average breaking force results and average significance from the nonwoven feather of 2g.

Table 6: Breaking Force Average and Significance

Feather Nonwovens (2g)	Breaking Force (N)		CF	CDF	DF	DDF	TF	TDF	GF
CF	4.1	CF							
GDF	8.4	CDF	NS						
DF	4.5	DF	NS	NS					
DDF	9.3	DDF	S	S	S				
TF	3.2	TF	NS	S	NS	S			
TDF	7.0	TDF	S	NS	NS	NS	S		
GF	5.0	GF	NS	NS	NS	S	NS	NS	
GDF	8.4	GDF	S	NS	S	NS	S	NS	S

We can observe that the duck down feather (9.3N) nonwoven is the most resistant fabric followed by goose down feather (8.4N), turkey down feather (7.0N), chicken down feather (6.6N), goose feather (5.0N), duck feather (4.5N), chicken feather (4.1N). Turkey feather nonwovens are the least resistant (3.2N).

We notice that duck down feather, chicken feather, chicken down feather, duck feather, turkey feather and goose feather are significantly different one from another. Also, goose down feather, chicken feather, duck feather, turkey feather, goose feather are significantly different. And turkey down feather, chicken feather, turkey feather are significantly different one from another.

Air Permeability

In table 7 we can see the air permeability (L/m²/s) average results and significance of the nonwoven feather with a mass of 2g.

Table 7: Air Permeability Average and Significance

Feather Non wovens (2g)	Air Permeability (L/m²/s)		CF	CDF	DF	DDF	TF	TDF	GF
CF	2326	CF							
CDF	1460	CDF	S						
DF	2008	DF	S	S					
DDF	596	DDF	S	S	S				
TF	2474	TF	**NS**	S	S	S			
TDF	1690	TDF	S	**NS**	S	S	S		
GF	2048	GF	**NS**	S	**NS**	S	S	S	
GDF	561	GDF	S	S	S	**NS**	S	S	S

By comparison turkey feather 2g (2474 L/m²/s), chicken feather 2g (2326 L/m²/s), goose feather 2g (2048 L/m²/s) and duck feather 2g (2008 L/m²/s) are more permeable than down feathers. It can be explained by the fiber diameter. Chicken, goose, turkey and duck feather fibers present a higher diameter than down feathers. In other words, less airflow can pass through the down feather than in the feather materials. Other properties can influence air permeability, for instance: fabric weight, porosity and thickness for example (OMER BERK BERKALP, 2006, KAWABATA). In the other hand, the less permeable nonwovens are: goose down feather 2g (561 L/m²/s) and duck down feather of 2g (596.2 L/m²/s).

Analyzing table 7, we can observe that turkey and chicken feather; chicken and goose feather; goose and duck feather; turkey down feather and chicken down feather; and duck down feather and goose down feather average are not significantly different one from another.

Thickness

In table 8 we can observe the thickness average results and significance of nonwovens feather of 4g.

Table 8: Thickness Average Results

Nonwoven (4g)	Thickness (mm)		CF	CDF	CCDF	DF	DDF	DCDF	TF	TDF	TCDF	GF	GDF
CF	227.2	CF											
CDF	157.0	CDF	S										
CCDF	198.8	CCDF	S	S									
DF	220.4	DF	NS	S	NS								
DDF	142.0	DDF	S	NS	S	S							
DCDF	206.8	DCDF	NS	S	NS	NS	**S**						
TF	249.2	TF	NS	S	S	NS	**S**	S					
TDF	241.8	TDF	NS	S	S	NS	**S**	S	NS				
TCDF	221.4	TCDF	NS	S	NS	NS	**S**	NS	NS	NS			
GF	350.2	**GF**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**		
GDF	237.8	GDF	NS	S	S	NS	**S**	NS	NS	NS	NS	S	
GCDF	218.8	GCDF	NS	NS	NS	NS	**S**	NS	NS	NS	NS	S	NS

As we can notice in this table, goose feather (350mm) is thicker than the others nonwovens samples followed by goose feather, turkey feather (249.2mm), turkey down feather (241.8mm), goose down feather (237.8mm), chicken feather (227.2mm) and turkey cut down feather (221.4mm) are the thickest. Duck down feather (142mm) is the thinnest, followed by chicken down feather (157.0mm), chicken cut down feather (198.8mm), duck cut down feather (206.8mm), goose cut down feather (218.8mm) and duck feather (220.4mm). It is important to notice that feather nonwovens were produced without homogeneity controls, thus it will not have a perfect material surface distribution.

In the statistical analysis, we notice that goose feather and duck down feather are significantly different from the others nonwovens. Also, chicken feather is significantly different from chicken down feather and chicken cut down feather. Chicken down feather is different from chicken cut down feather, duck feather, duck cut down feather, turkey feather, turkey down feather, turkey cut down feather, and goose down feather.

Thermal Conductivity

In the table 9 we can observe the thermal conductivity average results and significance from nonwovens feather 2g.

Table 9: Thermal Conductivity Results and the Significance of Nonwovens of 2g

Feather Nonwovens (2g)	Thermal Conductivity (W/cm °C)		CF	CDF	DF	DDF	TF	TDF	GF
GF	0.022	CF							
CF	0.029	CDF	S						
TF	0.031	DF	S	S					
GDF	0.035	DDF	S	S	NS				
DDF	0.037	TF	NS	S	S	S			
DF	0.039	TDF	S	S	NS	S	S		
TDF	0.041	GF	S	S	S	S	S	S	
CDF	0.050	GDF	S	S	S	NS	NS	S	S

In this study we observe that goose feather (0.022 W/cm °C), chicken feather (0.029 W/cm °C), turkey feather (0.031 W/cm °C), goose down feather (0.035 W/cm °C), duck down feather (0.037 W/cm °C), duck feather (0.039 W/cm °C), turkey down feather (0.041 W/cm °C) and chicken down feather (0.050 W/cm °C) have a good thermal conductivity performance.

We compared thermal conductivity feather nonwoven 2 grams values from others fibers: cotton 0.028 W/cm °C, silk 0.014 W/cm °C, wool 0.004 W/cm °C and flax 0.028 W/cm °C (MORTON, 2008).

The results of thermal conductivity of feathers nonwovens of 2 grams are in the range from 0.022 W/cm °C to 0.050 W/cm °C. Thus we conclude that depending on the kind of the used feather it can be more conductive than some above-mentioned types of fiber.

Also thermal conductivity of a textile fabric depends on the air entrapped within it much more than on the fibre conductivity. We could note that feather nonwovens have a good conductivity capacity.

In the statistical analysis, we notice that down feather and duck down feather; chicken feather and turkey feather; duck feather and turkey down feather; duck down feather and goose down feather and turkey feather and goose down feather do not have a significant difference one from another. The other nonwoven samples have a significant difference among themselves.

The P value (0.000) of this correlation is significant. The Pearson coefficient of correlation is -0,625. This value represents a good correlation between the two parameters.

The regression equation of this model is as follows: Thickness (mm) = 238.5 - 2546 Thermal Conductivity (W/ cm °C).

We notice that there is an inverse regression. It means that when the thickness increases, the thermal conductivity decreases.

We can certify the results according to Mahlia et al. (2007) that affirm the thicker insulation material is, the less thermal transmission will be, because thermal transmission depends upon the thermal conductivity and the thickness of that material.

We can infer that feather fibers have a higher diameter. Nonwovens feather have a higher thickness and a smaller thermal conductivity than down feather nonwovens.

CONCLUSIONS

In this study we chose to develop new products made of waste feathers by dry laid needle punching process due to the simplicity, low cost and low environment impact.

Feathers from different kind of animals the most consumed worldwide were studied. The purpose was to find a commercial utilization in order to recycle these waste materials. We compared the properties of each kind of animal feather to identify the best properties in each type of feather.

Looking at the summary of characteristics of nonwovens, we can observe that duck down feather of 2g has good elongation properties. We observed that down feather nonwoven has a tendency to be more extensible than feather nonwovens. As expected, this result is linked to the breaking force where we noticed a higher resistance from down feather nonwoven in comparison with feather nonwovens.

Goose feather 4g is the more thick than others nonwovens. We can affirm that the nonwoven feathers are thicker and are characterized by less thermal conductivity than nonwoven down feather.

Turkey feather 2g, chicken feather 2g, goose feather 2g and duck feather 2g are the most permeable nonwovens studied. As we saw in the fiber diameter analysis, feather fibers have a higher diameter than down feathers. We noticed that the more diameters they present, more permeable they are.

Chicken feather of 4g, turkey feather of 4g and goose down feather of 4g have high thermal conductivity properties.

Thanks to these experiments, we noticed that feather nonwovens possess good thermal properties. The possible applications could be in building or transport insulation.

Recycling of this waste will be a valuable economic and sustainable opportunity for both the poultry and nonwoven industry. Every year a huge amount of poultry feathers are wasted worldwide.

This study proved that is possible to avoid unnecessary poultry industry waste discarded in the landfills or disposals using nonwoven manufacturing needle punching dry laid system. Moreover feathers reclaimed reduce not only the costs but also create a positive environmental impact.

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Standards

ISO 6741/3 - Fibres and yarns - Determination of commercial mass of Consignments - Part 3: Specimen cleaning procedures

ISO 11111-3/05 - Textile machinery - Safety requirements - Part 3: Nonwoven machinery

ISO 139/2005 - Textiles: Standard atmospheres for conditioning and testing.

ASTM D 1776/08 - ASTM D 1776/08 – Conditioning Textiles and Textile Products for Testing.

ASTM D 4524/12 - ASTM D4524/12 – Standard Test Method for Composition of Plumage

NF EN 29073-3 - Textiles - Test methods for nonwovens - Part 3: Determination of tensile strength and elongation.

NF EN ISO 13934-1/13 - Textiles - Tensile properties of fabrics - Part 1: Determination of maximum force and elongation at maximum force using the strip method

NF EN ISO 9237/95 - Textiles - Determination of the permeability of fabrics to air

NF EN 1883/98 - Plumes et duvets - Échantillonnage en vue d'essais