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Building a product design support system for nonwoven geosynthetics

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ABSTRACT: This paper presents a new way of supporting the product design of nonwovens, and particularly nonwoven geosynthetics. In a more generalized research project, some predictive tools are developed, that are able to predict the functional properties of nonwovens according to the main structure parameters. Using these tools, the geosynthetic manufacturers could better check the relevance of the structure parameters of nonwovens and control their influence on the functional properties. It also allows the manufacturers to reduce cost and time for designing new products and thus to become more reactive and competitive. Such a procedure has the advantage not to be influenced by the features of the production process, often related to the manufacturer. In this paper, after introducing the general procedure of supporting the product design of nonwovens, the structure/properties relationships of a geosynthetics dedicated to filtration is presented as an application example. Some suitable techniques to characterize the structural parameters are then suggested. Also proposed are some techniques to identify the relevant structural parameters.

1 INTRODUCTION

1.1 *Background*

A key to success in worldwide competition, for any geosynthetic manufacturers, is the lean production. It requires production of the suitable product according to the customer requirements.

These specifications are related to the functions of the product. The objective of product designers is first to translate the functions into specific properties. Then, the second objective is to find the best way to obtain the product, which possesses these properties, at a low cost. It requires choosing the global structure of the product and then the corresponding technology to provide it.

The product design procedure is often made through successive trials on the production line. Such a procedure is very expensive (losses of production, consumption of material and energy) and is time consuming.

A great number of research works has been done for modeling the relationship between production parameters and product properties (Teodesiu et al. 2000). One of the aims is to better control the influence of each production parameter. However, it requires numerous experimentations and the results are strongly related to the production line. Moreover, it can not guarantee that the best structure of the nonwoven is obtained, to achieve the required functional properties.

1.2 *Nonwoven research project*

In the nonwoven research project, being carried out in our research unit, the correlations between functional properties and structural parameters of nonwovens are studied. The objective is to design predicting tools which are able to predict some functional properties according to the structural parameters (Fig. 1). This project allows the product designers to better understand and control the behavior of nonwoven. It also permits to reduce the cost and the duration of the product development and then provides a benefit for industrials in term of reactivity and competitiveness.

Some structural approaches have already been carried out (Akai et al. 2000, Kumsugar & Talukdar 2000) for the product design of geosynthetics, but few of them are based on a prediction model.

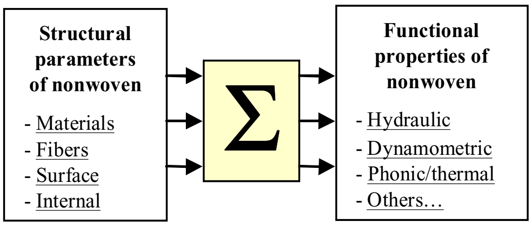

Figure 1. Correlation model between the structural parameters of nonwoven and the functional properties.

1.3 *Introduction to the procedure of design*

In this paper, a new procedure to support the product design of nonwovens is presented. This procedure is based on the prediction tools developed and defined as part of this research, and can be applied to nonwoven geosynthetics.

This paper is organized as follows. In section 2, the general procedure, proposed for designing new products, is introduced. Also suggested are some adapted methods to characterize the nonwoven structural parameters. Section 3 presents the definition of the structural parameters and the functional properties available for an application example. This case study corresponds to a geosynthetics nonwoven product dedicated to filtration. Section 4 gives then an analysis for checking the relationships between structure parameters and functional properties and for identifying the relevance of the structural parameters, with the use of the Principal Component Analysis (PCA) method (Fukunaga 1990). At last, further works in this line is introduced.

2 NEW PROCEDURE OF DESIGN

2.1 *Introduction*

A main part of this nonwoven research project is dedicated to the building of some correlation models. Two models are distinguished: a correlation model between production parameters and structure parameters of a nonwoven (specific to the manufacturer) and a correlation model between structure parameters and functional properties of a nonwoven product (independent to the manufacturer).

These two correlation models, shown in Figure 2, can be employed as prediction tools for the building of a new procedure of design applied to nonwoven products.

2.2 *Definition of the general procedure*

Using these previous prediction models, it becomes possible for product designers, in accordance with the geosynthetic specifications, to define the main structure parameters of the nonwoven and to deduce the corresponding production parameters to fit. Moreover, it would be easier for designers to readjust the production after controlling the conformity of the structure parameters and the properties. Thus, a summarized form of this procedure of product design is presented in Figure 3.

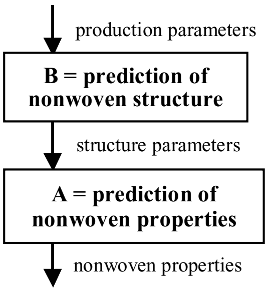

Figure 2. Two prediction tools for designing nonwoven products.

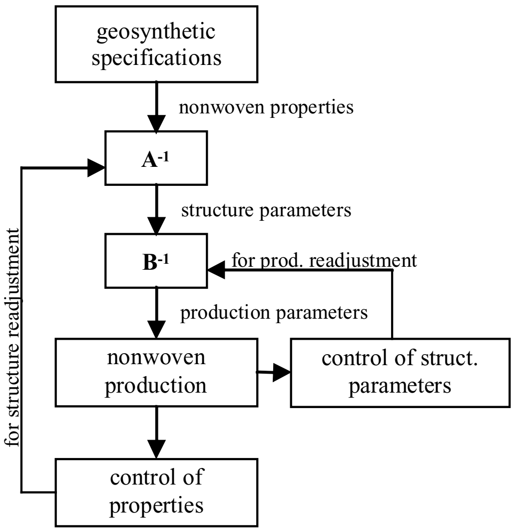

Figure 3. General procedure for designing nonwoven geosynthetics.

2.3 *Choice of the structural parameters and properties*

In the following part of the paper, a correlation model between structure parameters (inputs) and functional properties (output) is envisaged. In general, any correlation model can quickly become complex, because of the great number of structural parameters and functional properties that characterize the nonwoven. The complexity is introduced by the nonlinear relationships and the interdependencies between inputs and outputs of the models. Thus, the less are the number of relevant variables selected, the better. The first choice of the properties depends on the product specifications. Then, a further selection of input and output variables can be made by analyzing their relevance.

2.4 *Measure of the structural parameters*

The structural parameters define the characteristics of the nonwoven. They can be split into several categories corresponding to the materials (moisture regain, binders, surface energy), the fibers (nature, blend, length, count, crimp, wetability, etc.), the surface (roughness, evenness, covering of fibers, etc.), and the internal features of the nonwoven (fiber orientation, porosity, density, thickness, capillarity, etc.).

Some of these structural parameters are quite complex (like porosity or fiber orientation) or can be obtained by different ways (Lin & Cohen 1982). Thus, the relevance of these variables also depends on the measure method used. For instance, the fiber orientation can be easily estimated by the MD/CD resistance ratio. However, such information might not be well adapted.

In further works, we will concentrate effort to define and measure surface and internal characteristics of nonwovens by non conventional methods. Such methods may use optical profilers, X-ray, ultrasonic or vision systems (Wagner 1993).

3 APPLICATION

3.1 *Introduction*

In this study, it is proposed to observe structure parameters and functional properties obtained from a geosynthetic nonwoven dedicated to the process of filtration. In this section the parameters and properties available for our application are defined. In further works we will look for completing the study with other structure parameters, obtained by conventional or new methods.

3.2 *Structural parameters*

The following available structure parameters are obtained by measuring or estimating the main feature of the nonwoven:

- Thickness: the value (in mm) is obtained by measuring according to EDANA* normalization.
- Basis weight: the value (in gsm) is obtained by measuring according to EDANA normalization (recommended test).
- Percentage of binder: weight ratio of binder estimated during the nonwoven production
- Total pore volume: determines the capacity of the nonwoven to retain particles or liquid. The value (in percentage) is deducted by calculating the total volume of fibers contained in a referenced volume of nonwoven.
- Fiber orientation: corresponds to the main direction how the fibers are disposed in the nonwoven. The value can be estimated in a first approach by the MD/CD ratio of the breaking resistances.
- Fiber density per volume unit (per surface unit) : corresponds to the number of fibers contained in one cubic (square) meter of nonwoven.

3.3 *Functional properties*

The following available properties are obtained by measuring according to EDANA or specific normalizations:

- Dry breaking resistance MD or CD: determines the tensile strength of the nonwoven in the main direction (MD) or cross direction (CD). The value is expressed in N for a sample 5cm wide in dry conditions.
- Dry elongation at peak MD or CD: determines the elongation ability of the nonwoven in the main or cross direction. The value is expressed in percentage of the initial length of the tested sample.

* European Disposable And Nonwoven Association

- Water (Air) permeability: determines the rate of liquid (gaseous) transfer across nonwoven. The value is expressed in l/m^2/s.
- Filtration level: determines the largest particle which can strike through the nonwoven. The value (in µm) is homogenous to the diameter of a spherical particle.

3.4 *Implementation*

In this application example, the building of a correlation model between the available structure parameters and the functional properties of the nonwoven is expected, which is shown in Figure 5. Thus, one need to analyze the relevance of the different variables and their relationships in order to decrease the complexity of the model.

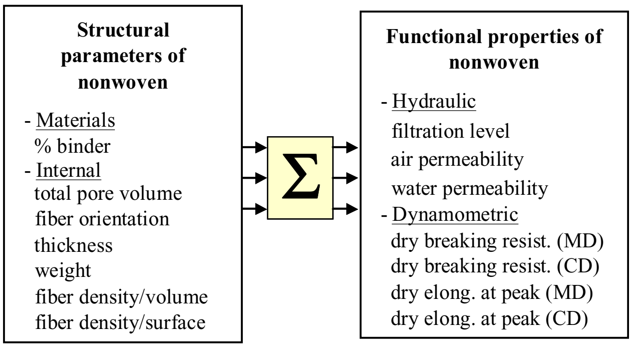

Figure 5. Example of correlation model between structure parameters and properties of a nonwoven.

4 DATA ANALYSIS

4.1 *Introduction*

In this section, at first, the relationships between two of the functional properties of the nonwoven (water permeability and the breaking resistance in the two main directions) and the available structural parameters are graphically presented. Secondly, the relevance of each variable by applying PCA technique is analyzed (Fukunaga 1990).

4.2 *First analysis of the relationships*

Before designing more elaborate techniques for analyzing the relationships between structural parameters and functional properties, some prior results can be graphically observed (Fig. 6, 7). This study was conducted on six nonwoven samples, belonging to the class of nonwovens defined in section 3, with different structure parameters.

Table 1. Apparent relationships between structure parameters and functional properties.

Funct. properties			Struct. parameters		
water permeability	I*	when	total pore volume	I	(NL**)
water permeability	D	when	thickness	I	(L)
water permeability	D	when	weight	I	(L)
breaking resistance	I	when	% binder	I	(?)
breaking resistance	I	when	thickness	I	(NL)
breaking resistance	I	when	weight	I	(L)
breaking resistance	D	when	total pore volume	I	(NL)
breaking resistance	I	when	fiber density (/m3)	I	(NL)
breaking resistance	I	when	fiber density (/m2)	I	(L)

* I=increases / D=decreases ** L=linear / NL=non linear

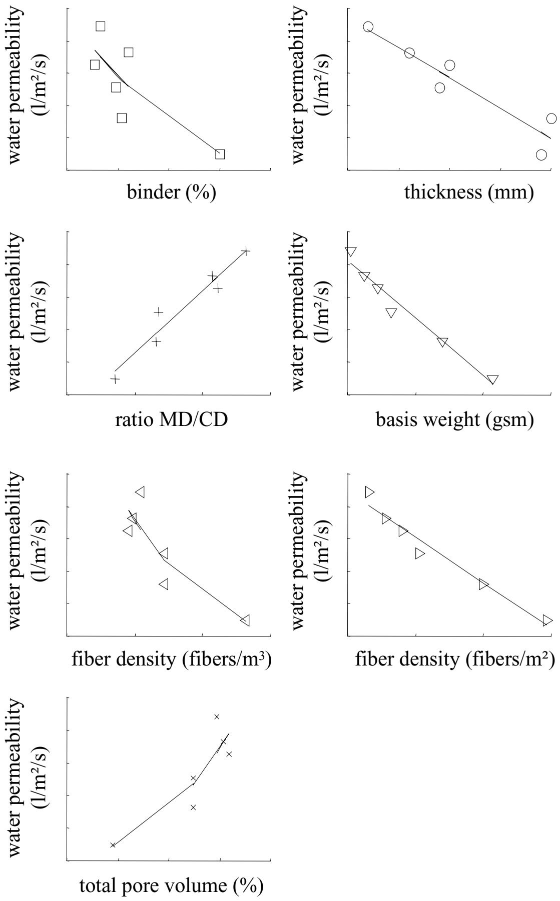

Figure 6. Relationships between water permeability and structure parameters.

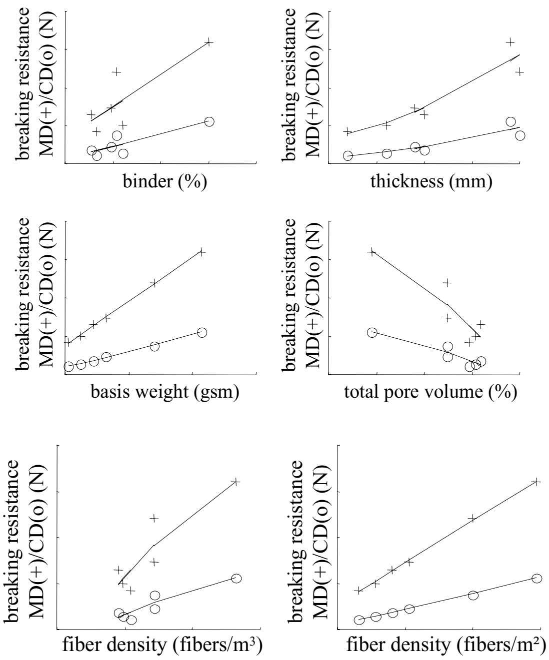

Figure 7. Relationships between dry breaking resistance and structure parameters.

Some of the correlations seem to be quite linear and correspond to well-known simple rules. Main relationships amongst functional properties and structural parameters are presented Table 1. They are expressed by using linguistic terms.

Interdependencies: Filtration level, water and air permeability are influenced in the same way by the available structure parameters. They seem to be proportional. Basis weight and fiber density per surface unit identically influence the properties.

4.3 *Relevance of the variables*

In the previous part, the relationships between two variables are observed. However it would be more complex to analyze the relationship between all input and output variables together.

PCA is a common way to visualize a multi-dimensional space of data, to analyze the relevance of variables and then to reduce the complexity of model (Fukunaga, 1990).

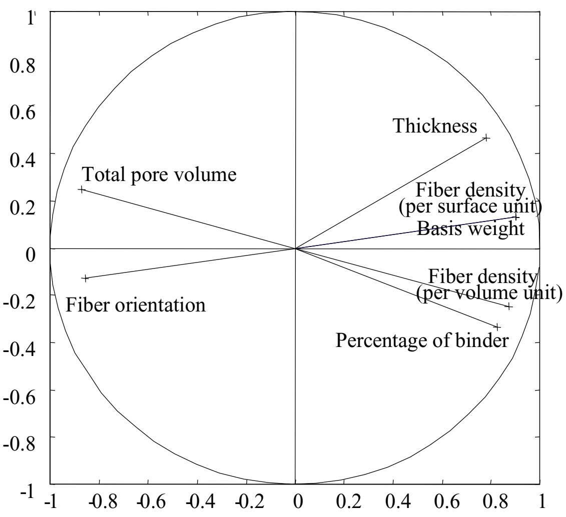

Figure 8. Principal component analysis of inputs only (structure parameters).

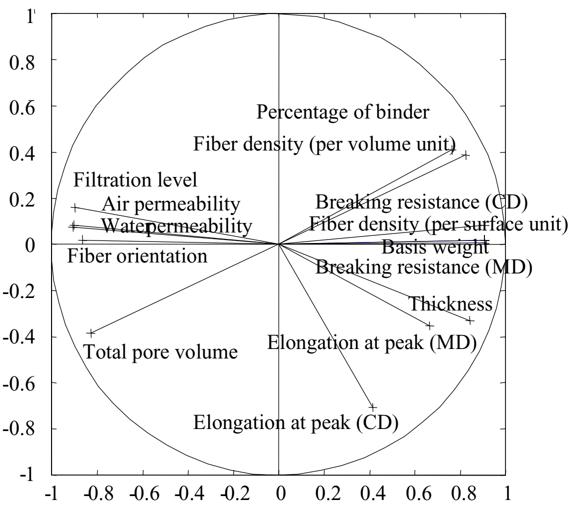

Figure 9. Principal component analysis of inputs and outputs together (structure parameters and functional properties).

PCA performs a linear transformation of the input and output variable vector for representing all original data in a two-dimensional space with minimal information lost. The projection of each vector represents the correlation with the two first order axis. PCA is first applied to the input variables (Fig. 8), secondly to the input and output data at the same time (Fig. 9)

The analysis of such figures gives information about the relationships between variables. Thus, the linear correlation and the interdependency between two variables are estimated when their corresponding vector are very close together, in the same direction. A correlation between two inputs or outputs variables also means they are redundant. In other way, two perpendicular vectors justify the relevancy of the variables.

This analysis leads to prediction of results in advance. For instance, Figure 8 shows that the basis weight and the fiber density (per surface unit) are well correlated. It also has correlation between the two variables: total pore volume and fiber density (per volume unit). Figure 9 confirms the relationship (and the redundancy) between filtration level, water and air permeability. This figure also shows a strong relationship between these properties and the basis weight and fiber density (per surface unit). A PCA can then provide a first selection of the more relevant variables.

5 CONCLUSION

In the first part, a new support procedure is introduced for designing nonwoven products according to the desired specifications. This procedure is based on two correlation models dedicated to the estimation of the nonwoven structure parameters and production parameters. Such a procedure is well adapted to nonwoven geosynthetics with dynamometric and hydraulic properties.

An example of correlation model between structural parameters and properties of a geosynthetic nonwoven dedicated to filtration is studied. In the first analysis of the data, some redundancies, proportionalities or interdependencies between variables were clearly observed. Apparent linear and non linear relationships between input and output variables were also observed. In a second part, PCA is used to validate previous information and to reduce the complexity of these two correlation models, related to the number of variables (structure parameters, functional properties, production parameters).

In further work, specific correlation models will be proposed, which will consider the non linear character and interdependencies of relationship between variables, by using advanced computing methods like fuzzy techniques or artificial neural networks. Another objective is also the design of new identification procedures for identifying new relevant structural parameters of nonwoven, by the use of advanced instruments like optic profilers.

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