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Study on Properties of Intercalated Melt-blown Nonwovens

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Abstract

Based on the intercalating melt-blown non-woven material performance control principle, through the single factor analysis of variance, two-factor variance analysis and typical correlation analysis, partial least-squares regression model is established, a multi-objective optimization model, structure parameters and performance parameters of the respectively as sample, using the typical correlation analysis between the two sample data, the paper analyses the inner link, The results show that product thickness has a strong positive correlation with filtration resistance.Then the Pearson correlation coefficients between structural variables and product performance were calculated respectively, and the correlation size was judged by the value of the correlation coefficient. It was concluded that the product thickness and porosity had a strong positive correlation.Finally to filter products of the highest efficiency as objective function and combined with multiple constraints, single objective optimization model is set up, using simulated annealing algorithm to optimization, then the product of the highest filter efficiency and minimum drag as the objective function, combination of conditions such as receiving distance and speed of hot air to multi-objective optimization model is established.Then, according to the priority order of constraints, the multi-objective optimization problem is transformed into two single-objective optimization problems, and the rationality of the results is tested according to the factors such as the initial gas flow rate and the number of superimposed layers. It is concluded that the filtration efficiency and filtration resistance solved in this paper are the optimal solutions.

Keywords

Intercalated Melt-blown Nonwoven Material; Canonical Correlation Analysis; Partial Least Squares Regression Model; Objective Optimization.

1. The Introduction

With the acceleration of the world's industrialization process, automobile exhaust, industrial emissions caused by the worsening of the global air environment, has seriously endangered people's health, therefore, the air purification is particularly important.Melt-blown nonwoollen material is a kind of good air filtration material with small fiber diameter, large specific surface area and high porosity. Its characteristics such as good filtration effect, small permeability resistance, light weight, large capacity, environmental protection and moderate price represent the main development direction of filtration materials in the future.But the intercalating melt-blown non-woven material preparation process parameters is more, there are interactions between parameters, combined with layer after air flow is more complex, therefore, to establish the process parameters (receiving distance and speed of hot air), structure variables (thickness, porosity, compression resilience), the final product performance (filtration resistance and filtration efficiency and permeability) model, the relationship between It is of great significance for the research of the regulation mechanism of product performance.In this paper, a multi-

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objective model is established based on known product data. The reference of the model can provide a better solution for the research of product performance regulation mechanism[1].

2. Establishment of Correlation Analysis Model

2.1. Internal Correlation Analysis of Parameters

Structural variables and product performance contain three kinds of parameters. In order to reveal the internal relationship between these two groups of variables, this paper uses canonical correlation analysis to analyze them. SPSS is used to calculate the canonical correlation coefficient of each group of parameters, and the specific values are shown in Table 1[2].

Table 1. Analysis of the Typical Correlation between Process Conditions and Structural Variables

alternating quantity	Thickness (mm)	Porosity (%)	Compression back elasticity rate (%)
filtration resistance (pa)	0.919	0.391	0.006
filtration efficiency (%)	0.616	0.564	0.043
Breathability (MMS)	0.420	0.058	0.049

As can be seen from Table 1, different parameters are negatively correlated between the two groups of variables: compression resilience and filtration resistance, porosity and filtration efficiency, air permeability and product thickness.The different parameters of the other variables between the two groups were positively correlated, and the product thickness had a strong positive correlation with the filtration resistance[3].

2.2. Research on the Relationship between Structural Variables and Product Performance based on Correlation Coefficients

In order to accurately describe the relationship between structural variables and product performance, this paper uses SPSS to calculate the correlation coefficients of the included parameters respectively. The specific principles are as follows[4]:

$$\rho_{x_1,x_2} = \frac{cov(x_1,x_2)}{\sigma_{x_1}\sigma_{x_2}} = \frac{E[(x_1-x_2)]}{\sigma_{x_1}\sigma_{x_2}} \tag{1}$$

ρ_{x_1,x_2} x_1, x_2 In the formula, For the correlation coefficient of the different parameters, Represent two different parameters between structural variables or between product performance, respectively.This paper first calculates the correlation coefficient of different parameters between the structural variables, and the specific results are shown in Table 2.

Table 2. Correlation coefficients of the different parameters between the structural variables

Structural variable parameters	thickness (mm)	porosity (%)	Compression is back to the elasticity rate of (%)
thickness (mm)	1.000	0.921	0.473
porosity (%)	0.921	1.000	0.355
Compression is back to the elasticity rate of (%)	0.473	0.355	1.000

It can be seen from Table 2 that the compression resilience of products is negatively correlated with thickness and porosity, while the thickness of products is positively correlated with porosity, and the correlation is strong.

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Similarly, the correlation coefficients of different parameters of product performance are shown in Table 3[5].

Table 3. Correlation coefficients for different parameters of product performance

Product performance parameters	Filtration (Pa)	filter efficiency (%)	air permeability (mm/s)
resistance to filtration (Pa)	1.000	0.789	0.648
filtration efficiency (%)	0.789	1.000	0.778
Breathability. (mm/s)	0.648	0.778	1.000

It can be seen from Table 3 that the filtration resistance of the product has a strong positive correlation with the filtration efficiency, and a negative correlation with its air permeability.The filtration efficiency of the product is negatively correlated with the air permeability, and the correlation is strong[6].

3. Study on the Highest Filtration Efficiency of the Product

3.1. Establishment of Multiple Linear Regression Model

Process parameters include two aspects: product reception distance and hot air speed.According to the above analysis, both of these factors can affect the filtration efficiency of the product. In this paper, the receiving distance of the product and the hot air speed are taken as independent variables, and the filtration efficiency is taken as dependent variable to establish a multivariate nonlinear regression model.Firstly, SPSS was used to analyze the reception distance, hot air speed and filtration efficiency. It can be seen that there were a few points with a high degree of deviation from the sample during the experiment, so these points were eliminated in this paper.It can be seen from the data in the table that the filtration efficiency of the product decreases with the increase of receiving distance.The overall relationship between the efficiency and the hot air speed is relatively stable.Finally, the regression coefficients calculated by SPSS are shown in Table 4. [7]

Table 4. Linear multiple regression coefficients and values R^2

	quotiety	R^2	After adjustment R^2
constant (quantity)	75.969		
Receive distance (cm)	1.025	0.467	0.452
Hot wind speed (r/min)	0.007		

From Table 4: after adjustment, so the effect of the linear fit is not ideal. $R^2 = 0.452 < 0.9$

3.2. Solving Multiple Linear Regression Model

In order to accurately solve the process conditions when the product filtration efficiency is the highest, this paper proposes the points with a high degree of deviation from the sample, and carries out nonlinear regression according to the same steps. The new regression coefficients are shown in Table 5 [8].

Table 5. Linear multiple regression coefficients and values R^2

	quotiety	R^2	After adjustment R^2
constant (quantity)	75.969		
Receive distance (cm)	1.025	0.467	0.452
Hot wind speed (r/min)	0.007		

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From Table 5: after adjustment, so the linear fit is not ideal. $R^2 = 0.452 < 0.9$

3.3. Multiple Linear Regression Model based on the New Regression Coefficient

In order to accurately solve the process conditions at the highest product filtering efficiency, the nonlinear regression was performed according to the same steps. The new regression coefficients are shown in Table 6.

Table 6. Multiple linear regression coefficients after optimization

	receive distance	hot-blast air velocity	product thickness	interval rate	Compression back elasticity rate	filter obstruction	ventilate nature
quotiety	1.4364	0.0472	5.4419	5.012	3.5601	0.2497	0.0851

Table 6 shows the regression coefficients of product filtration efficiency and their respective variables under the multiple regression model, and the adjusted value is 0.972, indicating that the optimized model has a good fitting effect.

3.4. Establishment of the Single Objective Optimization Model

objective function[9]:

$$\max(g) \tag{2}$$

g In the formula, for the maximum filtration efficiency under different process conditions.

Constraints:

a) Hot air speed shall meet the experimental conditions, namely:

$$50 \leqslant R_f \leqslant 2000 \tag{3}$$

b) For the receiving distance, there are: J_s

$$0 \leqslant 100 \leqslant J_s \tag{4}$$

c) The product thickness shall meet: H_d

$$0 \leqslant H_d \leqslant 20 \tag{5}$$

d) Similarly, the porosity is: K_x

$$0 \leqslant K_x \leqslant 100\% \tag{6}$$

e) On the filtration resistance, including:

$$1 \leqslant F_z \leqslant 1000 \tag{7}$$

f) the resilience efficiency shall also meet:

$$0 \leqslant H_t \leqslant 100 \tag{8}$$

In conclusion, the single-objective optimization model established in this paper is:

$$\max(g)$$

$$s.t.\begin{cases} 50 \leqslant R_f \leqslant 2000 \\ 0 \leqslant 100 \leqslant J_s \\ 0 \leqslant H_d \leqslant 20 \\ 0 \leqslant K_x \leqslant 100\% \\ 1 \leqslant F_z \leqslant 1000 \\ 0 \leqslant H_t \leqslant 100 \end{cases} \tag{9}$$

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3.5. Simulated Annealing Algorithm is Used to Optimize the Highest Filtering Efficiency

The simulated annealing algorithm was used for optimization, and it was found that when the receiving distance was 22cm and the hot air speed was 1175r/min, the filtration efficiency of the product reached the highest, which was 83.525%[10].

4. Establishment of a Multi-Objective Optimization Model based on the Highest Over-Efficiency and the Lowest Filtration Resistance

4.1. Establishment of Objective Function and Constraint Conditions

Step1 Establish the objective function:

roblem four is to seek the maximum filtration efficiency and the minimum filtration resistance of the product, namely:

$$\max(g_1), \min(F_{z1}) \tag{10}$$

Step2 Analyze the constraints:

a) Receiving distance is less than or equal to 100cm, then:

$$0 < J_s \leqslant 100 \tag{11}$$

b)Hot air speed is not greater than 2000 r/min, namely:

$$0 < R_f \leqslant 2000 \tag{12}$$

c)The thickness does not exceed 3cm, then:

$$0 < H_d \leqslant 3 \tag{13}$$

d)The compression return elasticity rate shall not be less than 85% if possible, with:

$$H_t \geqslant 85\% \tag{14}$$

e)According to the analysis of data2 data, when the receiving distance is the same, for every 1 increase of the experimental group number, the hot air distance increases correspondingly by 100 r/min, then:

$$R_{fj} = R_{fi} + 100, if\ J_{si} = J_{sj}, j = i + 1 \tag{15}$$

R_{fj}, R_{ij} In the equation, the hot air velocity when the experimental group number is indicated. j, i

Step3 Establish the multi-objective optimization model

In conclusion, the multi-objective optimization model for product filtering efficiency and filtration resistance is as follows:

$$\max(g_1), \min(F_{z1})$$
$$s.t. \begin{cases} 0 < J_s \leqslant 100 \\ 0 < R_f \leqslant 2000 \\ 0 < H_d \leqslant 3 \\ H_t \geqslant 85\% \\ R_{fj} = R_{fi} + 100, if\ J_{si} = J_{sj}, j = i + 1 \end{cases} \tag{16}$$

4.2. The Sequential Algorithm is Used to Optimize the Highest Passing Efficiency and the Lowest Filtering Resistance

In this paper, according to the priority order of each constraint, the objective programming is decomposed into a series of single-objective programming problems, and then solved successively.The specific algorithm solving steps are as follows:

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Step1: Find the first-level objective $\min = d_1^-$, so that the optimal value of the objective function, that is $d_i^- = 0$, the first-level deviation is 0.

Step2: Find the first-level objective $\min = d_2^+ + d_2^-$, so that the optimal value of the objective function $d_2^+ + d_2^- = 0$, the second-level deviation is 0.

Step3: Check whether the optimal solution of the objective function meets the constraints and the actual situation.If yes, end the algorithm.If not, repeat loop step 1,2.

Finally, Matlab was used to solve when the receiving distance was 30cm and the hot air velocity was 1750r/min, the filtration efficiency and filtration resistance of the product reached the optimum, which were 97.75% and 37.2Pa, respectively.

4.3. Analysis of Results

By referring to relevant literature, it is concluded that the relationship between the number of superposed layers of PP melt-blown nonwovens and filtration efficiency and filtration resistance is shown in Figure 1 and Figure 2:

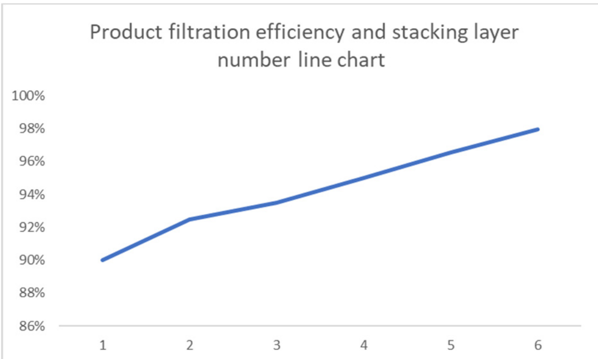

Fig 1. Relationship between filtration performance and stacking layer number at different gas flow rates

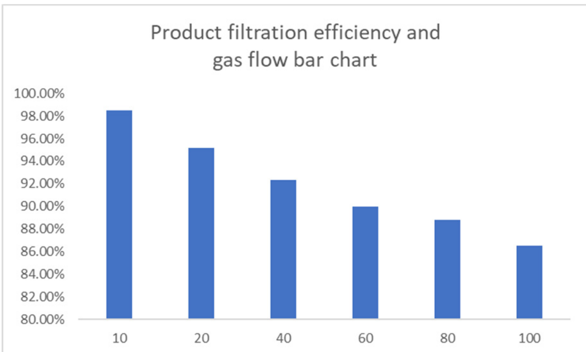

Fig 2. Relationship between gas flow rate and filtration performance of products

FIG. 1 shows the stacking layers of the product on the abscissa, and the filtration efficiency on the ordinate. It can be seen from FIG. 1 that the filtration efficiency is about 90.5% in the case of one layer of melt-blown nonwovens.In the case of two layers of melt-blown nonwovens, the filtration efficiency is about 92.75%. The filtration efficiency of the product is positively correlated with the product. In the case of 5 layers stacking, the difference of filtration efficiency is very small.

FIG. 2 shows the gas flow rate of the product (unit: L/min) on the abscissa, and the filtration efficiency of the product on the ordinate. When the experimental gas flow rate rises from

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10L/min to 100L/min, the filtration efficiency decreases continuously.This is because with the increase of the gas flow rate, the faster the outside particles move, the greater their kinetic energy, and the easier it is to penetrate the melt-blown nonwovens, which eventually leads to the reduction of filtration efficiency.

Therefore, it can be considered that under the relevant constraints, the filtration efficiency and filtration resistance obtained in this paper are the optimal solutions, indicating that the model has good stability.

5. Conclusion

5.1. Advantages of the Model

(1) Two-way analysis of variance with interaction effects is helpful to explore the interaction between independent variables, so as to explore the deeper relationship between independent variables, so as to save each group of variables with interaction relationship as a new variable, and in turn, as a member of the multivariate function, to provide better fitting effect.

(2) In this paper, a large number of charts are made to statistically analyze the data characteristics, so that the variation trend of each parameter is more intuitive.

(3) The combination of partial least squares and multiple linear regression for comparative analysis can explore whether there is a deeper relationship between multiple dependent variables, which is more conducive to the fitting of experimental data, so that it can get a more accurate fitting equation and predict the experimental results.

5.2. Shortcomings of the Model

(1) This paper should mine the data except the known information, and make further analysis by integrating the manufacturing process and materials of the mask.

(2) When the sequential algorithm is used to optimize the filtration efficiency and filtration resistance of the product, the linear weighting method and ideal point method can be used to compare and correct the results.

5.3. Generalization of the Model

(1) The two-factor analysis of variance model established in this paper is applicable in a wide range, which has certain reference value for studying the influence of one factor on another, and should be extended to related research work such as commodity sales and fruit growing environment.

(2) Partial least squares regression model is conducive to the study of the relationship between multiple dependent variables, and further attention to the potential correlation between multiple dependent variables is suitable for medical diagnosis, chemical experimental prediction and other aspects.

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