Transactions on Materials, Biotechnology and Life Sciences
ISSN: 2960-1932, eISSN: 2960-2319 | Volume 4
NSCBM 2024

Research on the Model of Interlayer Melt Blown Non-woven Materials Based on Regression Prediction

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Abstract. Melt blown nonwoven materials are currently widely used air filtration materials, with fine fibers, large specific surface area, good fluffiness, multiple pores, and excellent filtration performance. After polar treatment, filtration efficiency can be greatly improved without increasing filtration resistance. Melt blown nonwoven materials are important raw materials for mask production, and their various excellent characteristics have attracted widespread attention from domestic and foreign enterprises. The modeling purpose of this article is to establish a relationship model between process parameters and structural variables, as well as between structural variables and product performance. By combining the given 8 process parameters, the structural variable data can be predicted. Study the relationship between structural variables and product performance, as well as the relationship between structural variables and product performance. And combined with the results, it can be concluded that the filtration efficiency of the product will reach the highest process parameter value.

Keywords: Grey Correlation Analysis, Correlation Analysis, Regression Prediction Model, Typical Correlation Analysis.

1. Introduction

Melt blown nonwoven materials are currently widely used air filtration materials, with fine fibers, large specific surface area, good fluffiness, multiple pores, and excellent filtration performance [1]. After polar treatment, filtration efficiency can be greatly improved without increasing filtration resistance. Melt blown nonwoven materials are important raw materials for mask production, and their various excellent characteristics have attracted widespread attention from domestic and foreign enterprises [2] [3]. The traditional melt blown nonwoven method is a non-woven material preparation method that uses high-temperature and high-speed hot air to blow the solution, which is quickly stretched into ultrafine fibers [4]. The traditional melt blown nonwoven material process flow is as follows: solution preparation→ filtration→ metering→ solution melt extrusion→ solution fine flow stretching and cooling→ mesh formation [5].

As is well known, the fibers of melt blown nonwoven materials are very fine, and their performance is often not guaranteed due to poor compression resilience during use [6]. So scientists have created the intercalation meltblown method. By inserting short fibers such as polyester (PET) into the melt blown fiber flow during the polypropylene (PP) melt blown preparation process, a Z-shaped interlayer melt blown nonwoven material is manufactured. Due to the complexity of the intercalation melt spraying process, many process parameters interact and affect each other. Therefore, the study of determining structural variables through process parameters and determining the final product performance through structural variables has become more complex.

2. Comparison of changes in structural variables and product performance data before and after intercalation

The changes in structural variables and product performance data before and after intercalation can be clearly seen from the data that all indicators before and after intercalation show an upward trend, indicating that the data after intercalation is more ideal than before.

The correlation analysis of internal indicators, through literature review, can yield limited conclusions, but it can be concluded that the relationship between thickness and porosity function is directly proportional. The compression rebound rate has a functional relationship with thickness, and the acceptance distance in the process parameters is directly proportional to the thickness. The acceptance distance is also related to the filtration performance of the material, that is, the acceptance distance is directly proportional to the air permeability. Through literature, it can be concluded that the acceptance distance is inversely proportional to the filtration efficiency and filtration resistance, while the filtration resistance is directly proportional to the filtration efficiency in the filtration performance. Therefore, the partial functional relationship between structural variables and product performance has been derived [7].

In order to verify the authenticity of the above conclusion, this article conducts a correlation analysis between structural variables and product performance. As shown in Figure 1 of the thermodynamic diagram, it can be clearly concluded that the correlation between thickness and porosity is very high and directly proportional, and the correlation between filtration efficiency and filtration resistance is also very high and directly proportional. However, the correlation between permeability and filtration efficiency and filtration resistance is negative and inversely proportional. In other aspects, it can be seen that compression rebound rate has little effect on product performance, while thickness and porosity are inversely proportional to filtration performance but directly proportional to permeability.

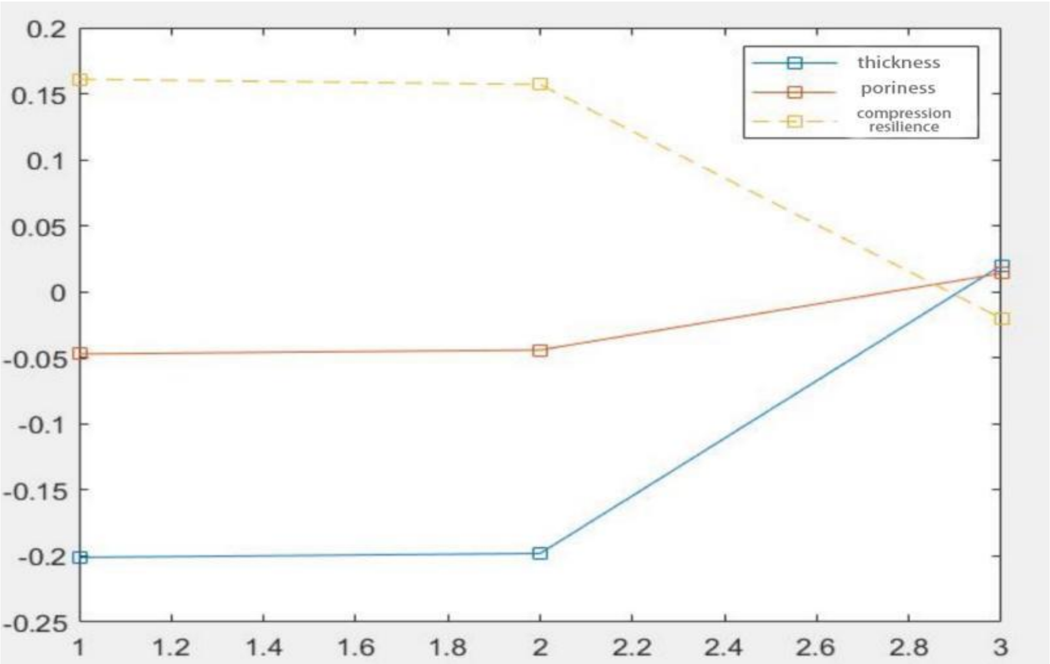

Figure 1. Correlation coefficient graph of structural variables.

2.1. Solving the correlation between mother sequence and feature sequence

As shown in Table 1, the correlation degree between thickness and porosity in the structural variables is 0.702, 0.692, and 0.687, respectively. This indicates that the interlayer ratio has the greatest impact on thickness. Using the same method to solve the correlation degree for product performance, the results show that the correlation degree for filtration efficiency is 0.719, the correlation degree for filtration resistance is 0.65, and the correlation degree for permeability is 0.638, indicating that the interlayer ratio has the greatest impact on filtration efficiency.

Table 1. Results of Mother Sequence and Feature Sequence.

Correlation result		
evaluating indicator	Relevance	ranking
thickness	0.702	1
Filtering efficiency	0.719	2
porosity	0.692	3
Compression rebound rate	0.687	4
Filter resistance	0.65	5
Breathability	0.638	6

2.2. Correlation analysis model

Correlation analysis is a statistical method used to study the correlation between two or more random variables. In data analysis, it is commonly used to analyze the relationship between continuous independent variables and continuous dependent variables [8]. When there are few features to be analyzed, graph analysis can be used. When there are many features, Pearson tools can be used for analysis, which can only determine linear relationships. If non-linear relationships need to be determined, continuous arrays can be grouped and variance analysis can be used to compare the differences between the groups.

For two-dimensional random variables, according to the mathematical expectation property, if X and Y are independent of each other. If EX and EY exist, then there is

$$E[(X-EX)(Y-EY)] = E(XY) - EX \cdot EY = 0 \tag{1}$$

So when $E[(X-EX)(Y-EY)] \neq 0$, there must be X and Y that are not independent of each other.

Let (X, Y) be a two-dimensional random variable, called $E[(X-EX)(Y-EY)]$.

The covariance of the random variables X, Y, denoted as $Cov(X,Y)$, i.e

$$Cov(X,Y) = E[(X-EX)(Y-EY)] \tag{2}$$

$$Cov(X,X) = E[(X-EX)(X-EX)] = DX \tag{3}$$

$$Cov(Y,Y) = E[(Y-EY)(Y-EY)] = DY \tag{4}$$

Therefore, variances DX and DY are special cases of covariance. From the definition, it can be seen that covariance is a special case of covariance. From the definition, it can be seen that covariance is related to the dimensionality of the variable's quantity. In this paper, we annotate random variables and obtain the dimensionality of the variable's quantity. In this paper, we annotate random variables and obtain the dimensionality of the variable's quantity.

$$X^* = \frac{X-EX}{\sqrt{DX}}, Y^* = \frac{Y-EY}{\sqrt{DY}} \tag{5}$$

The covariance of (X^*, Y^*) is $\frac{Cov(X,Y)}{\sqrt{D(X)}\sqrt{D(Y)}}$

Let (X, Y) be a two-dimensional random variable, and $\frac{Cov(X,Y)}{\sqrt{D(X)}\sqrt{D(Y)}}$ be called the Pearson correlation coefficient of the random variable X, Y, denoted as ρ_{xy} , i.e

$$\rho_{xy} = \frac{Cov(X,Y)}{\sqrt{D(X)}\sqrt{D(Y)}} \tag{6}$$

If $D(X)>0,\ D(Y)>0,\ \rho_{xy}$ is the correlation coefficient of (X, Y), then

If X and Y are independent of each other, then the necessary and sufficient condition for $\rho_{xy}=0$, $|\rho_{xy}| \leq 1$, $|\rho_{xy}|=1$ is the existence of Changshu to make $P\{Y = aX + b\} = 1(a \neq 0)$,The correlation coefficient ρ_{xy} describes the degree of linear correlation between random variables X and Y. The closer $|\rho_{xy}|$ is to 1, the closer the linear relationship between X and Y.

2.3. Model solving

A correlation analysis was conducted after adding intercalation rate, and the results showed that the thickness and porosity of the structural variables before adding intercalation rate were consistently negatively correlated with filtration performance and positively correlated with permeability [9]. The compression rebound rate was positively correlated with filtration performance and negatively correlated with permeability; after adding intercalation rate, for these changes, thickness and porosity remain negatively correlated with filtration performance, but positively correlated with permeability, with only a slight increase in correlation. However, the change in compression rebound rate and filtration performance becomes negatively correlated, while the correlation with permeability remains unchanged and increases. Comparing the two methods, the correlation analysis may be closer to the graph provided by the data, as shown in Figure 2.

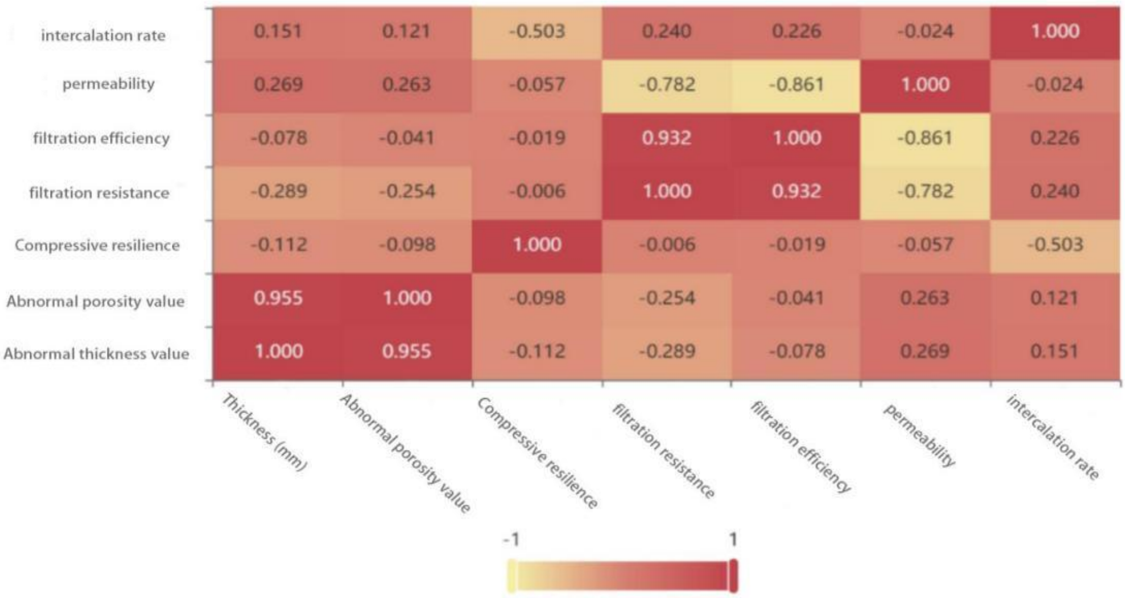

Figure 2. Thermodynamic comparison of correlation coefficients between intercalation rate, structural variables, and product performance.

In summary, from the analysis data of these correlation groups, it can be seen that the overall structural variables after intercalation are higher than before, with higher filtration efficiency and permeability, while the filtration resistance decreases. However, from the correlation between intercalation rate, structural variables, and product performance, the correlation degree of filtration resistance ranks second to last. From the comparison of two sets of analysis, it can be seen that the intercalation rate has little effect on the changes in product performance and the changes in compression rebound rate and permeability in the structural variables of thickness and porosity. It only increases its correlation, but has a significant impact on the changes in compression rebound rate and filtration performance in the structural variables, changing its trend of change. However, the above situation is only a macroscopic presentation in an ideal state, and there is actually a critical value for the changes in structural variables and product performance after intercalation, that is, there is an optimal state. When this critical value (optimal state) is exceeded, it will lead to the change becoming non-linear and unstable.

3. The relationship between process parameters and structural variables

By consulting literature, it can be known that the process parameters can be divided into acceptance distance and hot air velocity. According to the parameters in the table, the acceptance distance is set to X_1, the hot air velocity is set to X_2, and the hot air temperature is set to a constant value of 270℃. According to the literature, as the hot air temperature increases, the filtration efficiency and resistance of the material gradually increase. When the hot air temperature reaches 270℃, the filtration effect can reach more than 85%. However, after that, the temperature continues to increase, the change is not significant, and the filtration performance does not change significantly [10]. Therefore, we can know that when the hot air temperature increases, it can delay the cooling and solidification time of the fiber, thereby elongating the fiber and reducing its unevenness. Therefore, when the fiber is stretched, the unevenness of its fineness decreases. When laid on the mesh curtain, there is still a strong residual temperature, which is conducive to the adhesion between fibers to form a tight fiber network. Next, set the thickness in the structural parameters to Y_1, porosity to Y_2, and compression rebound rate to Y_3. According to known experimental conclusions, as the acceptance distance increases, the thickness of the sample also gradually increases. This is because when the acceptance distance is small, the residual temperature of the sprayed fibers when they reach the mesh curtain is still high, so they have strong adhesion and thinner thickness; but as the acceptance distance increases, the fiber reaches a lower temperature and the structure becomes fluffy, resulting in an increase in thickness. The effect of acceptance distance on porosity is that when the hot air pressure remains constant at 0.01 MPa, the overall porosity increases with the increase of acceptance distance. As for the compression rebound rate, no relevant conclusion has been found.

3.1. Correlation linear analysis

Perform correlation analysis on process parameters and structural variables using a correlation analysis model. After solving the model, the correlation coefficient table between process parameters and structural variables can be obtained as shown in Table 2. From the table, it can be seen that the correlation coefficients between acceptance distance, thickness, and porosity are 0.764 and 0.715, indicating a high correlation between the two and a significant impact. However, the correlation coefficient between compression rebound rate is only 0.239, indicating a weak correlation and a small impact; The correlation coefficients between hot air temperature, thickness, and porosity are 0.477 and 0.424, indicating that the two correlations are average and have a moderate impact. However, the correlation coefficient between compression rebound rate, receiving distance, and compression rebound rate is almost the same, with a correlation coefficient of 0.234, indicating that their correlation is low and their impact is low.

Table 2. Correlation coefficient graph between process parameters and structural variables.

Correlation coefficient table					
	Acceptance distance	Compressive resilience (%)	Hot air velocity	Thickness (mm)	Poriness (%)
Acceptance distance	1.000 (0.000***)	0.239 (0.251)	0.000 (1.000)	0.746 (0.000***)	0.715 (0.000***)
Compressive resilience (%)	0.239 (0.251)	1.000 (0.000***)	0.234 (0.260)	0.399 (0.048**)	0.391 (0.053*)
Hot air velocity	0.000 (1.000)	0.234 (0.260)	1.000 (0.000***)	0.477 (0.016**)	0.423 (0.035**)
Thickness (mm)	0.746 (0.000***)	0.399 (0.048**)	0.477 (0.016**)	1.000 (0.000***)	0.895 (0.000***)
Poriness (%)	0.715 (0.000***)	0.391 (0.053*)	0.423 (0.035**)	0.895 (0.000***)	1.000 (0.000***)
note:***, **, * representing respectively1%, 5%, 10%significance level					

As shown in Table 2, the receiving distance is a key indicator that plays an important role, while the hot air temperature plays an auxiliary role. Among them, thickness and porosity are most easily affected, while the correlation between compression rebound rate and process parameters is low. If there is no effect, the compression rebound rate can be set as an independent variable. Thus proving the feasibility of the above conclusion and determining the relationship between process parameters and structural variables.

3.2. Neural network regression prediction model based on genetic algorithm

Neural networks are a common mathematical model in machine learning that establishes structures similar to synaptic connections in the brain for information processing. In the process of neural networks, there are generally three types: input units, output units, hidden units, and also multiple layers,as shown in Figure 3.

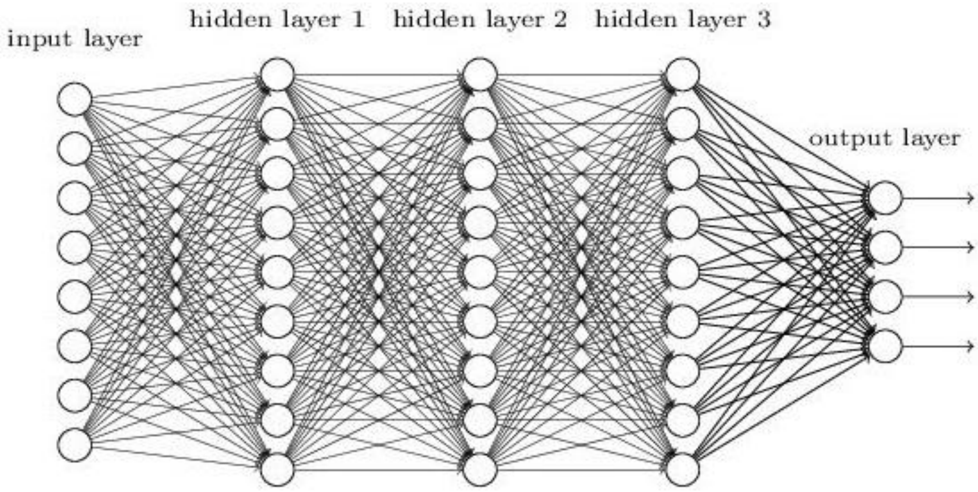

Figure 3. Internal structure of neural network.

3.3. Model solving process

After selecting the main hidden nodes and initializing the parameters, the initial population size of the process parameters is set to 50 and the maximum number of iterations is set to 150 based on the network structure. The fitness function of the neural network is determined to be the mean square error (and the excitation functions of the hidden nodes and output nodes are AAAi type functions). After calculating the fitness value, the training and testing samples are recorded, and the final output results are recorded.

From the results, the RR of the evaluation of the combination of process parameters and thickness is 0.958, which is very close to 1, indicating a high accuracy of the model. Similarly, continue to predict other structural variables separately to obtain the following table, which is Table 3:

Table 3. Model output result table.

	thickness	porosity	Compression rebound rate	Thickness (insert)	Porosity (insert)	Compression rebound rate (insert)
R^2value	0.855	0.758	0.052	0.747	0.868	0.077

Note: The closer the value is to 1, the higher the accuracy of the model.

In summary, the specific indicators for predicting structural variables based on the final combination of process parameters are shown in Table 4:

Table 4. Final Output Results Table.

Acceptance distance(cm)	Hot air speed(r/min)	Thickness/mm	porosity(%)	Compression rebound rate(%)
38	850	2.759	96.076	86.534
33	950	2.677	95.937	86.542
28	1150	2.781	96.094	86.261
23	1250	2.699	96.955	86.269
38	1250	3.501	97.261	85.378
33	1150	3.050	96.530	85.964
28	950	2.410	95.502	86.839
23	850	1.957	94.771	87.425

4. Conclusions

This article uses the grey relational model and correlation analysis model to analyze the impact of intercalation. Set the insertion rate as the independent variable, the structural variable as the dependent variable, then set the structural variable as the independent variable, and finally set the product performance as the dependent variable. By setting the structural variable as the feature sequence and the insertion rate as the parent sequence, solve the correlation degree of product performance using the same method. Compare two sets of data. Then, study the relationship between process parameters and structural variables. Combine the given 8 process parameters to predict structural variable data. Use correlation analysis method to analyze the data, and use genetic algorithm based neural network algorithm to predict the final results in order to improve the accuracy of the model. Research the relationship between structural variables and product performance, as well as the relationship between the elements they contain, and based on this, provide the optimal process parameters. Due to the existence of multiple sets of variables, this article considers using canonical correlation analysis to analyze these two relationships in detail, and obtains canonical correlation coefficients, load matrix heat maps, etc. Finally, the first constraint condition is obtained through grey correlation, and the optimal parameters are solved using simulated annealing model and genetic algorithm model.

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