

# The Property of Automobile Engine Oil Filtration Material and the Development of New Filter

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## ABSTRACT

The main purposes of this paper are to research the structure and property of commonly used oil filtration materials on the basis of the hierarchical cluster method and to develop new filter material. For this objective we selected ten different oil filtration materials and made a comparison of their filtration properties. In addition, the hierarchical cluster method was used to classify these ten oil filtration materials into three different categories. Objective classification results in the case of data matrix of different properties had a rather accurate result, which was almost consistent with the result of subjective classification. It was found that three different kinds of filtration material had different structures and properties in practical application. In addition, the results indicate that the filtration property of the new filter developed on the basis of hierarchical cluster analysis was very close to the first material.

**Keywords:** Automobile engine oil filter, Filtration material, Structure, Property, New filter.

## INTRODUCTION

Automobile engine oil filter materials separate different particles from oil with the help of their porous structure [1], which can various types of filter papers and nonwovens [2, 3], such as cotton pulp filter papers, glass fiber nonwovens, polyester nonwovens, and polypropylene nonwovens. Furthermore, these commonly used filter materials are composed of different fibers and layers [4] and are sold on the basis of nominal filtration accuracy. For example, glass fiber filter material has different filtration accuracies of 5  $\mu\text{m}$ , 8  $\mu\text{m}$ , 10  $\mu\text{m}$  and 20  $\mu\text{m}$  in practical application. Based on the relevant information about filtration materials of some Chinese filtration companies and market

investigation, we found that the filtration effect of materials depended on their structures including fiber diameter, pore diameter, porosity, filtration area, thickness, and weight. However, it is difficult to know which kind of material has good filtration properties.

In general, the same materials which have different properties can be easily classified into a category, while it is difficult to distinguish the different materials which have different properties from other materials by subjective classification. The hierarchical cluster analysis is an objective classification and a comparatively simple method, which can easily classify two samples that have the same or similar properties into a category.

In this paper, ten different commonly used automobile engine oil filtration materials were selected from the market for research. Among them, some materials have good filtration properties while others have poor properties in application. So it was necessary to make an in-depth analysis of these automobile engine oil filtration materials. A new filtration material was developed on the basis of the results of the hierarchical cluster analysis and, a comparison of properties among them was made.

## HIERARCHICAL CLUSTER ANALYSIS

The hierarchical cluster analysis is a method of classifying samples which have the closest distance into a category and other samples which have the further distance into another category, until all the samples are classified into an entirety. The sample number is  $m$  and the parameter of each sample is  $p$ , so the data matrix  $A$  based on the samples and parameters can be theoretically defined [5].

$$A = \begin{pmatrix} x_{11}, x_{12}, \dots, x_{1p} \\ x_{21}, x_{22}, \dots, x_{2p} \\ \vdots \\ x_{m1}, x_{m2}, \dots, x_{mp} \end{pmatrix} \quad (1)$$

From Eq. (1) we know that the parameter of every sample can be thought as a point in p dimensional space, and all the samples can be thought as a data matrix [6]. Therefore, we can use the distance between two samples to evaluate the close extent of

similar samples. Any sample  $x_{ij}$  and the distance  $d_{ij}$  can be expressed as follows

$$D = \begin{bmatrix} d_{11}, d_{12}, \dots, d_{1p} \\ d_{21}, d_{22}, \dots, d_{2p} \\ \vdots \\ d_{m1}, d_{m2}, \dots, d_{mp} \end{bmatrix} \quad (2)$$

Where  $d_{11} = d_{22} = \dots = d_{mm} = 0, (m \leq p)$

The distance between two samples which have similar properties and short distances can be calculated from this equation and classified into a category.

## EXPERIMENTAL

### Materials

Through investigation of filtration materials in the Chinese market we found that the commonly used oil filtration materials are cotton pulp filter papers, glass fiber filters, polyester, and polypropylene nonwovens. Ten different filtration materials were purchased from HeNan Xinxiang Changcheng Filter Material Co.LTD for research. Among them, 1#, 2#, 6# and 7# are different polyester nonwovens, 3#, 8#, 9# and 10# are different cotton pulp filter papers, 4# and 5# are glass fiber nonwovens.

### Measurement of Properties

The weight (mass/unit area) was measured with an AR 2140 Electron Balance. The thickness was measured with an YG 141N device on the basis of

GB/T 3820-1997 Measurement Thickness of Textile and Fabric Products. Air permeability was measured with an YG 461E device in accordance with GB 5453-85 Measurement Air Permeability of Fabrics. The mechanical property was measured with an YG 065 device according to GB/T 3923-1997 Tensile Performance of Textiles [7, 8]. In addition, the pore diameter and filtration accuracy were measured

with an MP-15K  $\beta_x$  instrument in accordance with GB 5249-85, Permeable Sintered Metal Materials, Determination of Bubble Test Pore Size.

Moreover, porosity of these ten filter materials was calculated from the following expression

$$\varepsilon = \left( 1 - \frac{m}{\rho \cdot L} \right) \times 100\% \quad (3)$$

where  $\varepsilon$  is porosity of material (%),  $\rho$  is fiber density ( $\text{g}/\text{m}^3$ ),  $m$  is weight ( $\text{g}/\text{m}^2$ ) and  $L$  is thickness (mm) of material.

The breaking elongation of automobile engine oil filtration materials was calculated from

$$a = \frac{\Delta L}{L_0} \times 100\% = \frac{L_a - L_0}{L_0} \times 100\% \quad (4)$$

where  $a$  is ratio of breaking elongation of filtration material (%),  $\Delta L$  is breaking elongation (mm),  $L_a$  is length of material at the breaking point (mm),  $L_0$  is the original length of material (mm).

## RESULTS AND DISCUSSION

### The SEM Figures and Performances of Materials

The performances of these commonly used oil filter materials are shown in Table I and the SEM images are shown in Figure 1, and (a) to (j) is 1# to 10#, respectively. The SEM figures were observed with the JSM-6360LV instrument at the Beijing Institute of Clothing Technology.

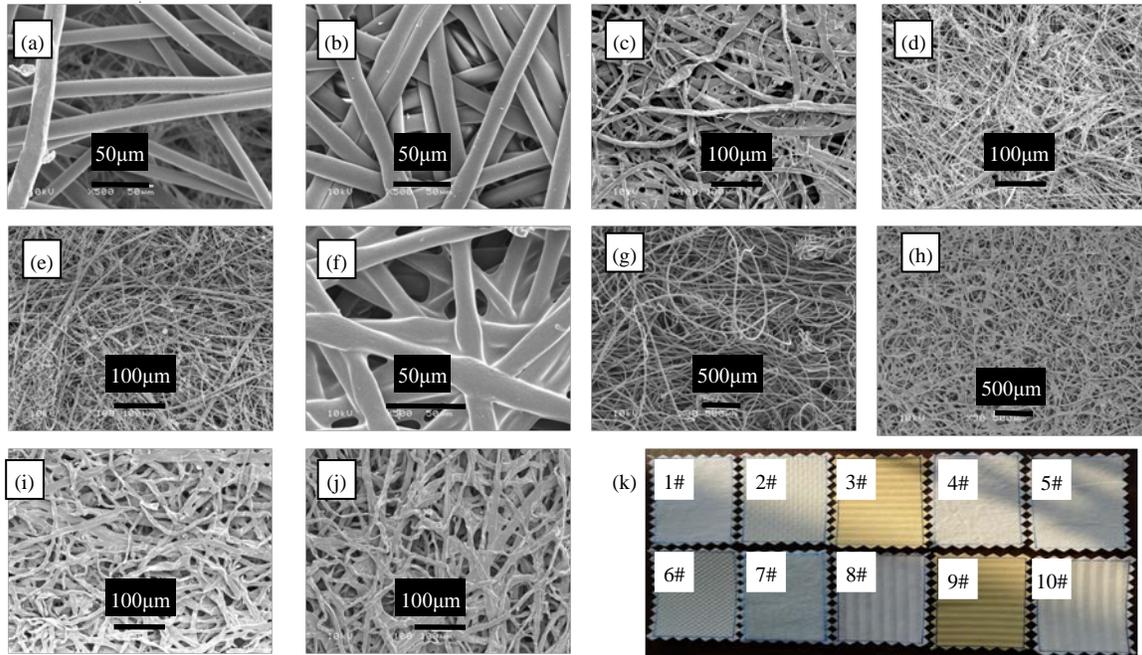


FIGURE 1. SEM images of filter material. (a)1#, (b)2#, (c)3#, (d)4#, (e)5#, (f)6#, (g)7#, (h)8#, (i)9#, (j)10#, (k) samples.

TABLE I. Experimental result of ten different filter materials.

	1#	2#	3#	4#	5#	6#	7#	8#	9#	10#
nominal filtration accuracy/ $\mu\text{m}$	5	8	10	10	10	10	10	20	20	20
thickness/mm	0.972	0.709	0.718	0.617	0.61	3.895	2.972	0.852	0.729	0.647
weight/ $\text{g}\cdot\text{m}^{-2}$	127.87	283.75	194.31	86.89	76.14	257.12	667.85	139.9	125.51	140.76
Mean pore diameter/ $\mu\text{m}$	39.5	53.9	39.2	96.8	23.6	44.7	76	57.6	59.6	51.4
Maximum of pore diameter/ $\mu\text{m}$	39.7	44.6	39.3	112.8	26.8	44.9	77.3	58	61.6	53.2
actual filtration accuracy / $\mu\text{m}$	8.8	8.9	15	21.6	5.2	9.1	15.5	22	22.8	19.6
maximum fiber diameter/ $\mu\text{m}$	18.8	20.7	31.1	8.6	5.6	19.2	31	34	36	39
minimum fiber diameter/ $\mu\text{m}$	10.8	16.2	9.1	2.6	1.5	0.2	14	6	11	12
mean fiber diameter/ $\mu\text{m}$	13.94	17.89	23.85	5.33	3.42	10.67	20.6	14.5	18.1	24.4
porosity/%	90.47	71	77.45	94.44	95.07	95.22	83.72	86.32	85.65	81.87
air permeability/ $\text{mm}\cdot\text{s}^{-1}$	59.408	53.817	59.397	139.444	333.146	432.498	198.958	216.65	195.308	203.878
breaking strength/N	14.699	1046.519	357.78	47.899	22.419	571.1	716.399	149.28	205.04	277.219
breaking elongation/mm	11.969	62.325	4.955	1.933	2.565	27.701	139.497	13.519	6.45	7.943
ratio of elongation/%	5.984	31.162	2.477	0.966	1.282	13.85	69.748	6.759	3.232	3.971
breaking work/J	104.027	103.876	55.17	54.316	54.26	54.314	42.136	2.977	1.891	1.295
breaking time/S	7.181	37.394	2.973	1.159	1.539	16.621	83.698	8.111	3.879	4.766
bursting strength/N	53.709	1031.92	82.539	15.839	12.6	1001.1	494.6	57.14	42	70.539
bursting elongation/mm	26.063	32.179	21.633	20.331	19.367	34.785	33.835	19.567	22.673	22.231

### Hierarchical Cluster Process

The hierarchical cluster method is used to classify the filter material data (m=10) presented in *Table I* into different categories. In fact, the samples which have higher relevance coefficient and similar property can be firstly classified into a category. The particular step of cluster process is shown in *Table II*. Among them, 8# and 9# are merged for a category, and then 8# and 10# are merged for a category. 1# and 4# are merged for another category, and then 3# and 8# are merged for a category. 1# and 5# are merged for a category, and then 1# and 3# are merged for a category. 2# and 6# are merged for a category. Subsequently, 2# and 7# are merged for a category and then all the samples are merged for a whole entirety.

TABLE II. Agglomeration Schedule.

Stage	Cluster Combined		Stage Cluster First Appears		Next Stage
	Cluster	Cluster	Cluster	Cluster	
	1	2	1	2	
1	8	9	0	0	2
2	8	10	1	0	4
3	1	4	0	0	5
4	3	8	0	2	6
5	1	5	3	0	6
6	1	3	5	4	9
7	2	6	0	0	8
8	2	7	7	0	9
9	1	2	6	8	0

### Hierarchical Cluster Results

Hierarchical cluster results of these oil filter materials are shown in *Figure 2* and *Table III*.

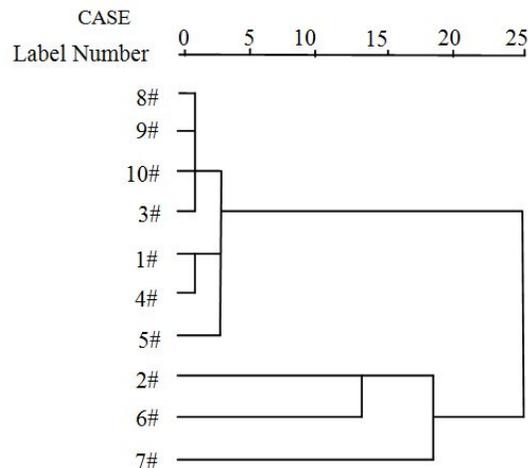


FIGURE 2. Hierarchical cluster tree of these oil filter materials.

8#, 9#, 10# and 3# are cotton pulp filter papers which have the similar filtration properties were merged for the first kind. 1# polyester nonwoven, 4# and 5# glass fiber nonwovens which have the best filtration properties among these ten materials were merged for the second kind. 2#, 6# and 7# polyester nonwovens which have the similar filtration properties can be classified into the third kind.

After a series of hierarchical cluster analysis, the ten different filtration materials were classified into three categories as a function of *Table I* and *Figure 2*. The experimental results indicate that the second kind of filter material has smaller thickness, weight, mean fiber diameter, breaking strength, breaking elongation and higher porosity. The third kind of filter materials has higher thickness, weight, mean fiber diameter, breaking strength and elongation. Additionally, the properties of first kind of material are in the range of these ten different filtration materials. *Table IV* is the property summary of three kinds of filtration materials.

The results demonstrate that 5# glass fiber nonwoven has the best filtration property among them due to its finer fiber diameter and smaller pore diameter. Through a comparison of filtration properties we know that the smaller fiber diameter can form a smaller pore diameter, smaller filtration accuracy and higher porosity, while the filter material possesses the smaller breaking strength in practical application.

The results of objective classification and subjective classification are shown in *Table V* and *Table VI*, respectively. It can be seen that the objective classification based on the data matrix of different properties has a rather accurate result, which is almost consistent with the result of subjective classification.

However, 1#, is classified into the third kind based on the subjective classification, which is also classified into the second kind in the case of hierarchical cluster analysis. Actually, the filtration properties of 1# are the same as 4# and 5# through hierarchical cluster analysis.

TABLE III. Vertical icicle.

Number of Clusters	Case																		
	7	6	2	10	9	8	3	5	4	1									
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
3	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
4	X		X		X		X	X	X	X	X	X	X	X	X	X	X	X	X
5	X		X		X		X	X	X	X	X	X		X	X	X	X	X	X
6	X		X		X		X	X	X	X	X	X		X		X	X	X	X
7	X		X		X		X	X	X	X		X		X		X	X	X	X
8	X		X		X		X	X	X	X		X		X		X		X	X
9	X		X		X		X		X	X		X		X		X		X	X

TABLE IV. Results of hierarchical cluster and performance summary.

	first kind	second kind	third kind	comprehensive
thickness/mm	0.647-0.852	0.61-0.972	0.709-3.895	0.61-3.895
weight/g·m <sup>-2</sup>	125.51-194.31	76.14-127.87	257.12-667.85	76.14-667.85
mean pore diameter/μm	39.2-59.6	23.6-96.8	44.7-76	23.6-96.8
maximum of pore diameter/μm	39.3-61.6	26.8-112.8	44.6-77.3	26.8-112.8
actual filtration accuracy /μm	15-22.8	5.2-21.6	8.9-15.5	5.2-22.8
maximum fiber diameter/μm	31.1-22.8	5.6-18.8	8.9-15.5	5.6-31.1
minimum fiber diameter/μm	6-12	1.5-10.8	0.2-16.2	0.2-16.2
mean fiber diameter/μm	14.5-24.4	3.42-13.94	10.67-20.6	3.42-24.4
porosity/%	77.45-86.32	90.47-95.07	71-95.22	71-95.22
air permeability/mm·s <sup>-1</sup>	59.397-216.65	59.408-331.146	53.817-432.498	59.408-432.498
breaking strength/N	149.28-357.78	16.699-47.899	571.1-1046.519	16.699-1046.519
breaking elongation/mm	4.955-13.519	1.933-11.969	27.701-139.497	1.933-139.497

TABLE V. The results of objective classification of hierarchical cluster.

	First Kind	Second Kind	Third Kind
Samples	8#,9#,10#,3#	1#,4#,5#	2#,6#,7#
Materials	cotton paper	polyester, glass nonwoven	polyester nonwoven

TABLE VI. The results of subjective classification (results of artificial classification).

	First Kind	Second Kind	Third Kind
Samples	8#,9#,10#,3#	4#,5#	1#,2#,6#,7#
Materials	cotton paper	glass nonwoven	polyester nonwoven

## DEVELOPMENT OF NEW FILTER

### Theoretical Basis of Developing New Filter

As mentioned above, we analyzed the structure and properties of ten different filtration materials on the basis of hierarchical cluster analysis. The results indicate that fiber diameter and pore diameter are the two important parameters for filtration and, the filtration accuracy increases as the increasing of fiber diameter (see *Figure 3*).

Since some of these commonly used oil filtration materials are cotton pulp filtration papers (3#, 8#, 9# and 10#), we used hemp fiber and cotton fiber to develop the new filtration material. The mean fineness of hemp fiber and cotton fiber are 14.306  $\mu\text{m}$  and 14.750  $\mu\text{m}$ , respectively, which is relatively close to 8# (the mean fineness is 14.5 $\mu\text{m}$ ). The hemp/cotton (60/40) spunlaced nonwoven was manufactured by us at DongHua University. The SEM figures, actual sample, and pore diameter distribution of this new filter are shown in *Figure 4*, respectively.

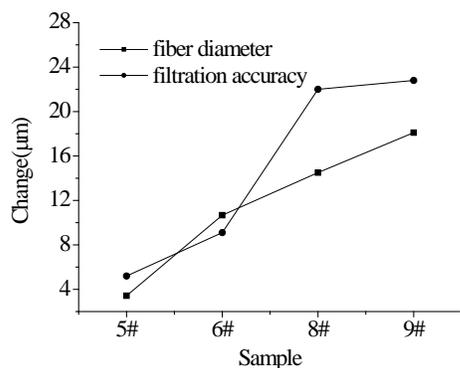


FIGURE 3. Relation between fiber diameter and filtration accuracy.

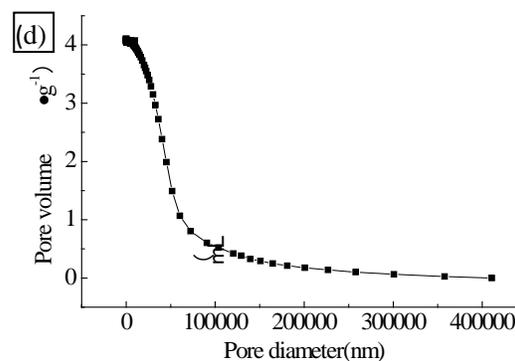
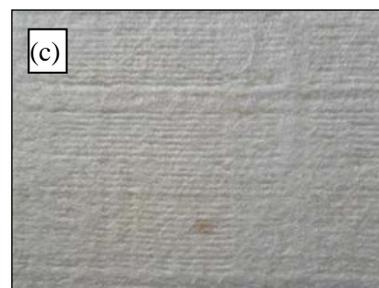
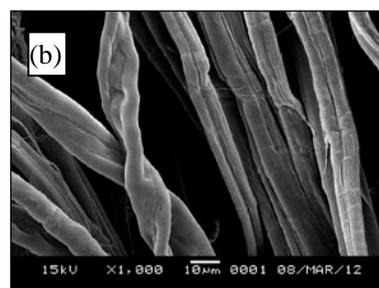
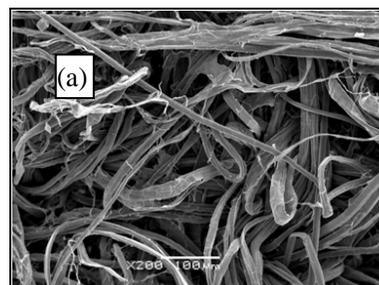


FIGURE 4. New filter material and its pore size distribution. (a) and (b) SEM figures, (c) actual sample and (d) pore diameter distribution. Porosity is 84.99% and mean pore size is 66.5  $\mu\text{m}$ .

### **Comparison of Properties Between New Filter and Commonly Used Filters**

Comparison of properties between new filter and the studied oil filtration materials are shown in *Table VII*.

TABLE VII. Comparison of property between new filter and ten kinds of commonly used filtration materials.

	New Filter	First Kind	Second Kind	Third Kind	Comprehensive
thickness/mm	1.173			△	△
weight/g m <sup>-2</sup>	152.73	△			△
mean pore diameter/μm	66.5	△	△		△
maximum pore diameter/μm	69.4	△			△
filtration accuracy/μm	25.4	○			▲
mean fiber diameter/μm	14.306 (hemp)	△			△
	14.75 (cotton)				
porosity/%	84.99	△		△	△
air permeability /mm s <sup>-1</sup>	88.5864	△	△	△	△

△-in the range, ▲-is not in the range, ○-close

The experimental results suggest that some properties of new filter are in the range of first kind of material (weight, mean pore diameter, mean fiber diameter, porosity and air permeability); however, some properties of the new filter are in the range of the second kind of material (mean pore diameter and air permeability) and other properties are in the range of the third kind of material (thickness, porosity and air permeability). Compared with the ten different filtration materials, we concluded that the new filter has the higher fiber fineness and pore diameter, and the moderate porosity. Furthermore, the filtration properties of new filter are very close to the first kind of materials.

### **CONCLUSION**

The ten different oil filtration materials were divided into three categories by the hierarchical cluster method of objective classification and then the new filter was prepared on the basis of these results.

It was found that the internal structures and filtration properties among the first kind, the second kind and the third kind of materials were obviously different. Furthermore, the second kind of filter materials had good filtration property in application and 5# glass fiber filter material had the best filtration property among them. Through a comparison among the three different kinds of filtration materials, we found that the fiber diameter and pore diameter were two important parameters for filtration property, and the filtration effect

increased with decreasing fiber diameter. Additionally, the objective classification based on the data matrix of different properties had a rather accurate result which is almost consistent with the result of subjective classification of the materials.

The new filter of hemp/cotton spunlaced nonwoven was developed on the basis of hierarchical cluster analysis results and a comparison of properties between the new filter and the three categories of materials. The experimental results indicate that the weight, mean pore diameter, mean fiber diameter, porosity, and air permeability of new filter are in the range of first kind of material and the filtration properties of the new filter are very close to the first kind of material.

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### **REFERENCES**

- [1] Patel R., Shah D., Prajapti B. G. and Patel M., Overview of industrial filtration technology and its applications, *Indian J. Sci. Technol*, 3 (2010) 1121.
- [2] Yeo S.Y., Lim D.Y., Byun S.W., Kim J.H. and Jeong S.H., Design of filter bag media with high collection efficiency, *J Mater Sci*, 42 (2007) 8040.
- [3] Aleksandrov V.P., Baranova R.B. and Valderg A.Y., Filter materials for bag filters with pulsed regeneration, *Chem. Petroleum Eng*, 46 (2010) 34.
- [4] Park Y.O., Park H.S., Park S.J., Kim S.D., Choi H.K. and Lim J.H., Development and evaluation of multilayer air filter media, *Korean J.Chem.Eng*, 18(2001) 1022.
- [5] Lin J.B., Lin C.X. and Liu M.D., in "Modeling and Application of SPSS 12 Book" (China Railway Press, Beijing, 2006).
- [6] Zhuang C.Q. and He C.X., in "Application of Statistical Basis Book" (The south China science and technology university press, Guangzhou, 2006).
- [7] Yao M., in "Textile Materials" (China Textile Press, Beijing, 2009).
- [8] Yu W.D., in "Textile Materials" (China Textile Press, Beijing, 2006).

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