

Mechanism of Trapping Air Cleaner Particles and High-performance Filter Element

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ABSTRACT

Attempting to extend the life of the air cleaner filter element, a consumable part, the project discussed in this paper layered wet- and dry-type non-woven filters to develop a high-performance long-life element.

Based on the results of an analysis of the mechanism of capturing dust particles, the lipophilic properties of the fibers of the non-woven used in the wet layers were enhanced to increase oil retention, enabling dust to be accumulated in specific areas and thus reducing clogging. Dry layers have also been used to produce a multi-layered structure, reconciling the achievement of extended life with a higher level of efficiency in capturing particles of all sizes and types.

1. Introduction

In an effort to protect the natural environment, in the process of automobile development attention is being focused on achieving increased fuel efficiency, greater recyclability, and reduced exhaust emissions. Active efforts are also being made to reduce waste and increase convenience for users by extending the interval for maintenance of oil (engine oils, etc.) and the life of consumable parts. The air cleaner filter element (“filter element” below) is a part that calls for periodic maintenance and replacement. Different filter element materials are used and different maintenance intervals are set depending on the characteristics of the substances to be filtered in different regions. Particularly in dusty regions, where fine particles need to be filtered, it is necessary to use short-life filter elements with fine mesh. Based on an understanding of the mechanism by which particles are captured by filter materials, a new concept has been used to enable the development of a high-performance filter element that has a long life and is able to capture fine dust particles. This development has enabled the interval for filter element maintenance to be extended.

2. Performance Requirements for Filter Elements

There are three basic performance parameters for filter elements.

- (1) Dust life
The amount of dust that can be captured up to the driving distance established in the market for replacement of the filter.
- (2) Cleaning efficiency
Ratio of amount of particles of differing diameters captured to amount of particles filtered.
- (3) Air flow resistance
Ability to enable passage of air
Dust life and cleaning efficiency are generally in an antagonistic relationship. For example, when a filter element with a fine mesh is used to increase filtering efficiency in order to reduce the infiltration of dust into the engine, clogging occurs more easily, reducing the dust life of the filter, and shortening the product replacement cycle.

3. Types of Substances Trapped by Filter Elements

Filter elements used in the market were collected and the substances trapped in them were analyzed. These substances can be broadly classified into three types on the basis of their composition and properties.

- (1) Carbon
Particles of 1 μm or less in diameter, e.g., particulate matter (PM) present in the air.
- (2) Inorganic dust
Particles from 1-50 μm in diameter, mainly silicates of

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mineral origin (sand, clay).

(3) Other substances

Substances other than (1) and (2). Often rubber dust generated by tire friction.

Figure 1 shows an example of the ratios of these substances.

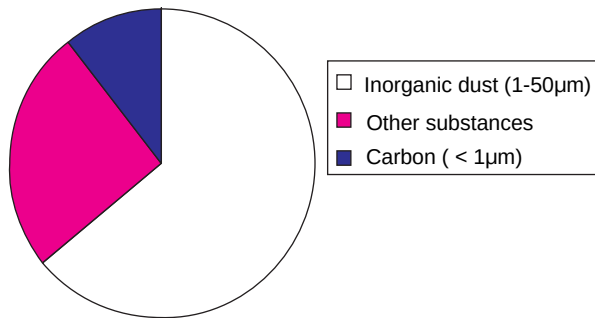


Fig. 1 Classification of trapped particles from used elements in Japan

4. Mechanism of Capture of Particles

(1) Mechanism of capture of carbon particles

Because carbon particles have a small diameter, they are normally captured using the static electricity generated by friction between the air and the fibers of the filter element⁽¹⁾, i.e., by the charge that builds up in the filter element. The higher the volume resistance, the higher the charge that builds up, and cleaning efficiency therefore increases with the volume resistance (Fig. 2).

(2) Mechanism of capture of inorganic dust and other particles

Figure 3 shows an image of dust trapped in the fibers of a filter element. Dust is trapped in the spaces in the fiber, but the mechanism by which the particles are trapped differs depending on their diameter. Figure 4 shows the relationship between the space ratio of the filter element and its cleaning efficiency in the case of large-diameter

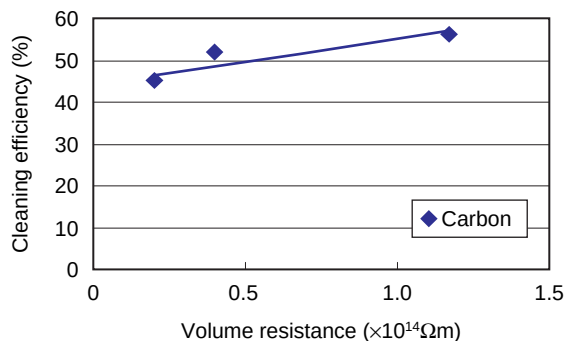


Fig. 2 Cleaning efficiency by Volume resistance

particles. The lower the space ratio, i.e., the finer the mesh, the higher the cleaning efficiency of the filter. For ultraparticles of 5 μm or less in diameter, capture by static electricity, as in the case of carbon particles, is highly effective (Fig. 5).

In wet-type filter elements (paper-type filter elements that have been impregnated with oil), the dust captured by the oil on the surface of the filter is infiltrated by the oil, and this dust in turn captures more dust, generating a chain reaction. This capture mechanism is known as cake filtration⁽²⁾ (Fig. 6).

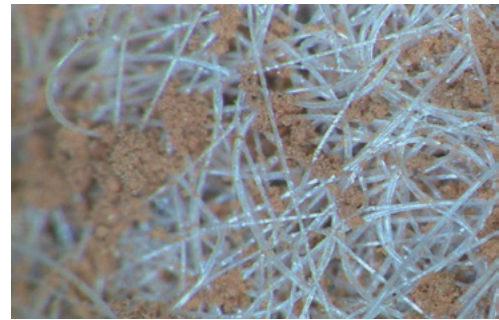


Fig. 3 Dust (1-50μm) and other substances trapped in filter-fiber

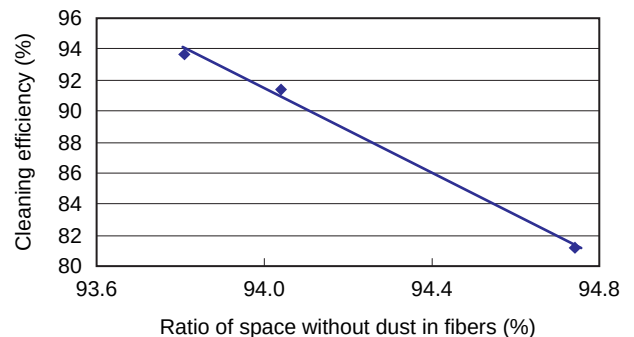


Fig. 4 Correlation of space ratio and cleaning efficiency

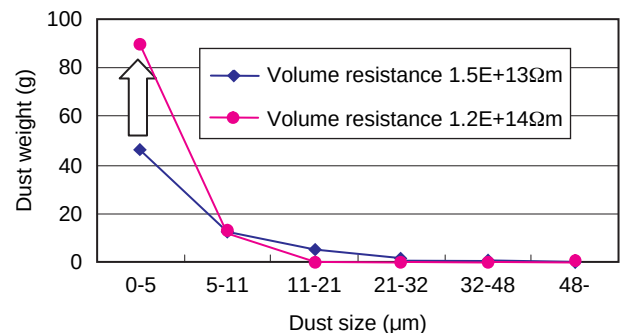


Fig. 5 Ultraparticle dust capture by static electricity

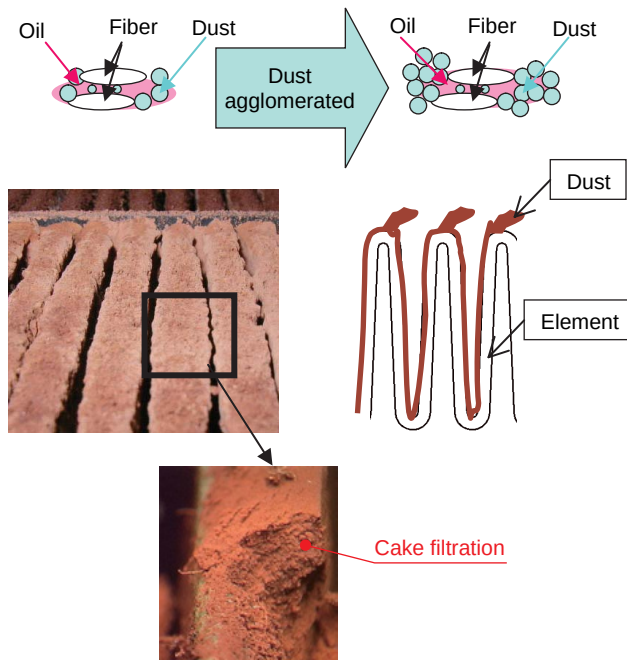


Fig. 6 Cake filtration

5. Types of Filter Elements and Characteristics

Paper, non-woven, and porous filter elements are standard types. Classified by material, the main types are paper and non-woven filters. These can be further divided into wet or dry types depending on whether or not additives are used (impregnated with oil).

A combination of three types is generally used, from considerations of dust cleaning efficiency and carbon

cleaning efficiency. The characteristics of these various filter types are shown in Fig. 7. Figure 7(a) shows dust cleaning efficiency, Fig. 7(b) shows dust life, Fig. 7(c) shows carbon cleaning efficiency, and Fig. 7(d) shows carbon life. Dry paper-type filters display a high cleaning efficiency, but their dust and carbon lives are short. Wet paper type filters have long dust lives, but low carbon cleaning efficiency. Dry non-woven filters have long dust lives and display high carbon cleaning efficiency, but their dust cleaning efficiency is low.

The high degree of freedom of design and manufacture of non-woven filters enables the density and thickness of each layer to be varied, and, as Fig. 8 shows, multi-layering enables dust cleaning efficiency to be increased at identical levels of decline in pressure.

However, non-woven filters are unable to achieve a balance between an extended dust life and cleaning performance on the level of a dry paper filter. For this

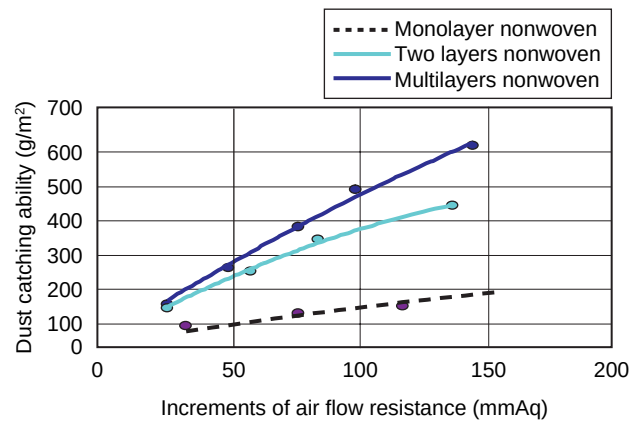


Fig. 8 Effect of multilayer structure

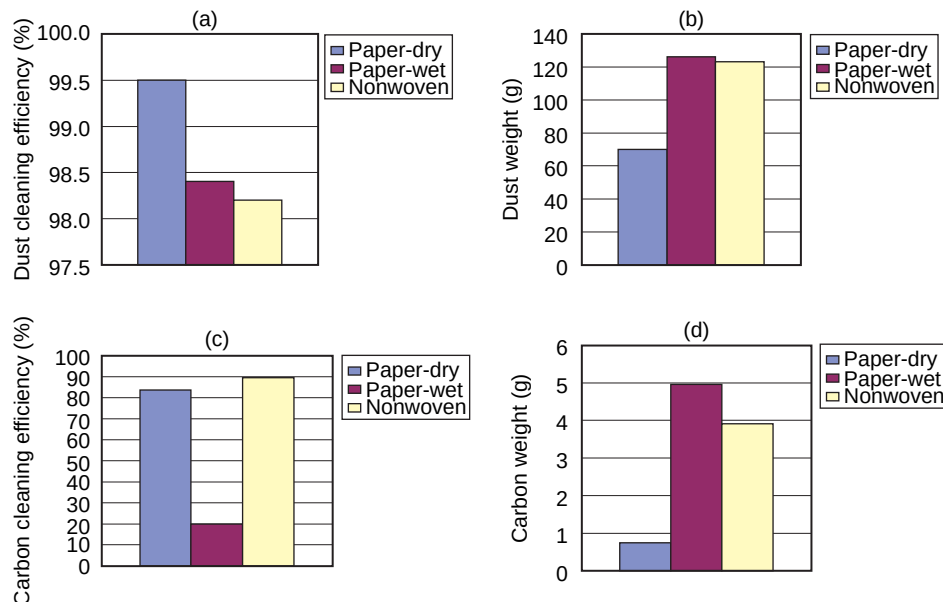


Fig. 7 Filter performance by structure

reason, dry paper filter elements with fine meshes are used in regions characterized by a high volume of fine particles, and maintenance using an air blower, etc., is called for, for example, every 10000 km.

6. Development of High-performance Filter Element

Due to the procedure used in their manufacture, paper filter elements have fine meshes, and this makes the achievement of longer life a challenging issue. A combination of a long-life wet-type paper filter and a non-woven filter was therefore examined as a method of achieving a longer filter life. This would enable filtration by the capture of particles in the spaces between the fibers of the non-woven filter, at the same time as cake filtration by the capture of particles on the surface of the wet-type filter.

6.1. Oil-impregnated Non-woven

The ability of the fibers to hold oil is an important issue in achieving cake filtration using a non-woven filter. Fibers with unusual forms that resulted in increased surface area were therefore compared in terms of oil adhesion and retention. Figure 9 shows cross-sections of the fibers. Figure 10 shows oil retention. Oil retention is highest in the high surface PET.

Comparison of the performance of a wet non-woven with a standard circular cross-section PET and a wet non-woven with a high surface PET showed that the latter

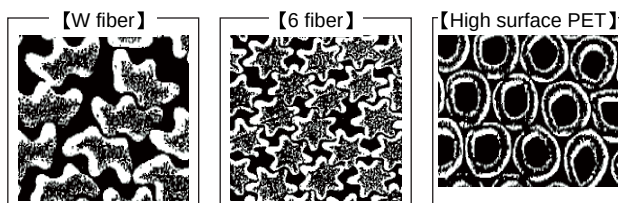


Fig. 9 Photo of fiber cross section

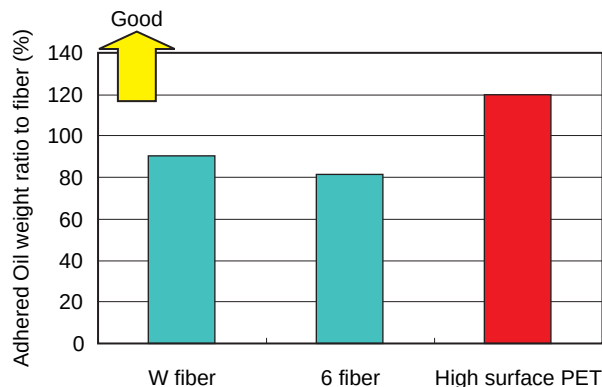


Fig. 10 Property of oil adhered to fibers

displayed lower air flow resistance at identical levels of cleaning efficiency (Fig. 11). This is believed to be because particles are captured on the fibers themselves rather than into the meshes. However, because making the filter a wet type reduced the amount of static electricity built up in the fibers and thus reduced carbon cleaning efficiency, a carbon capture layer was called for.

6.2. Optimization of Filter Performance and Dust Life by Multi-layering

Figure 12 shows an exemplar layer structure of the developed filter element with an added dry layer for carbon particle capture.

The use of a multi-layered configuration with rough wet layers of oil-impregnated fibers on the dust side and dry layers with a high density on the clean side has enabled the achievement of increased dust and carbon cleaning efficiency and increased dust life.

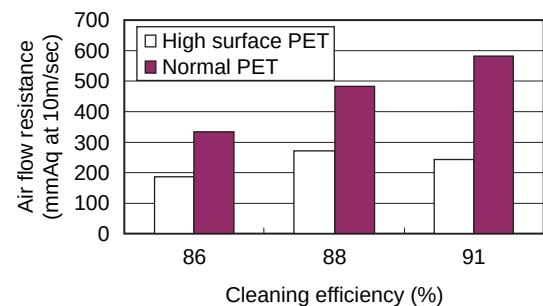


Fig. 11 Dust cleaning efficiency performance

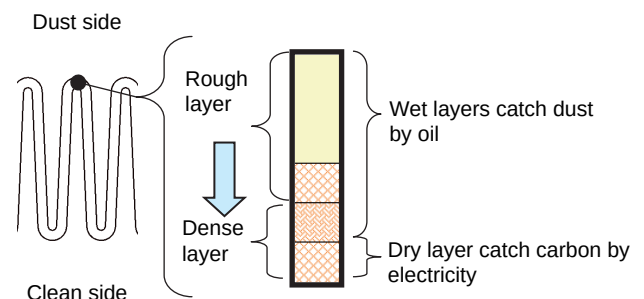


Fig. 12 Filter composition

7. Performance Level of Developed High-performance Filter Element

Figure 13 shows the dust life performance of the developed filter element.

Dust life has been increased against conventional filters without sacrificing cleaning efficiency or carbon life.

In addition, the optimization of the type of fibers employed and of the density of the fiber layers has

enhanced the ability of the filter to capture particles of all types and sizes, in particular JIS11 ultraparticles as shown in Fig. 14.

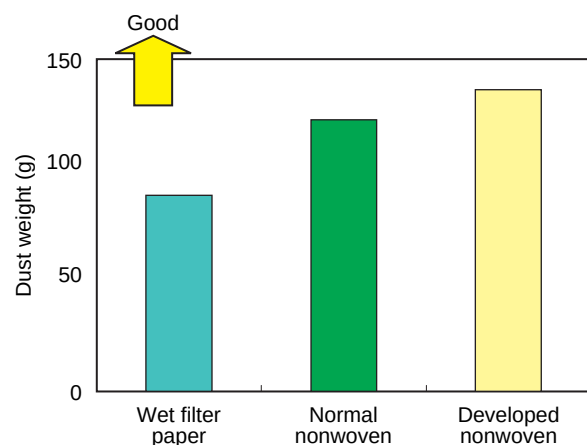


Fig. 13 Trapping dust weight by filter structure

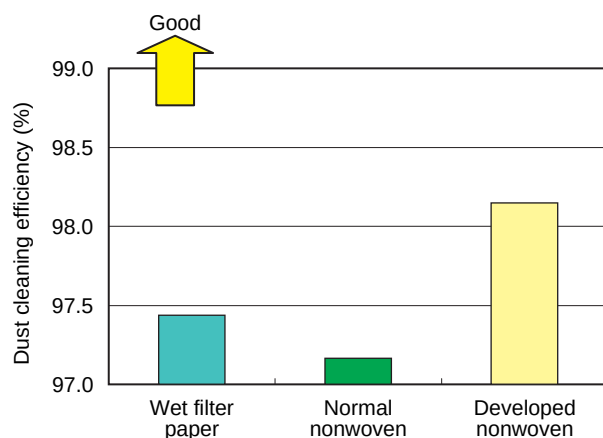


Fig. 14 Cleaning performance for ultra-fine particle (JIS Z 8901 TYPE11) dust

8. Conclusion

The achievement of long life and the enhancement of ultraparticle capture performance have represented issues in the development of filter elements. Based on an analysis of the mechanisms by which particles of various types are captured, the project discussed in this paper developed a filter with a multi-layered structure that reconciles the antagonistic needs of particle capture performance and long life.

The use of the new filter configuration has helped ensure dust capture performance in dusty environments at the same time as increasing dust and carbon life. The new filters have already gone into production, and have been employed in the new model ACCORD and FIT.

References

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