

Organic Solvent Absorption Characteristics of Split-type Microfiber Fabrics

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Abstract: Split-type nylon/polyester microfiber and polyester microfiber fabrics possess drapeability, softness, bulkiness, and smoothness, so that they can be applied in various industrial fields. In particular, these fabrics are able to absorb various organic solvents, and can be used as clean room materials. To investigate the chemical affinity between solvents and the compositional materials of these fabrics, the contact angle of thermally pressed film fabrics was measured with different solvents. The thermally pressed nylon/polyester fabric films showed a chemical attraction to formamide. The sorption properties of the microfiber fabrics were investigated using a real time testing device, and these tests showed that the sorption behavior was more influenced by the structure of the fibrous assembly than by any chemical attraction. The effect of the fabric density, specific weight, and sample structure on the sorption capacity and rate was examined for various organic solvents. The sorption capacity was influenced by the density and the specific weight of the fibrous assembly, and knitted fabric showed a higher sorption capacity than woven fabric. However, the sorption rate was less affected in lower viscosity solvents. On applying Poiseuille's Law, the lower viscosity solvents showed higher initial sorption rates, and more easily penetrated into the fibrous assembly.

Keywords: Microfiber, Organic solvents, Absorption, Contact angles, Surface energy

Introduction

Split-type microfiber fabrics are prepared by split-type nylon/polyester bi-component filaments. As these fabrics are exposed to alkaline solution in combination with a thermal and a mechanical treatment, the bi-component conjugate filaments can become separated from each other [1-4], and hence, split-type microfiber fabrics can possess numerous capillaries due to splitting of the conjugated filaments.

Even though these fabrics are composed of synthetic filaments that usually have a degree of hydrophobicity, they rapidly absorb moisture and transport it via capillary action [5]. Split-type microfiber fabrics have excellent drapeability, softness, bulkiness, and smoothness, so that they are useful in various applications, such as general wiping cloths, cleaning for food service area, in clean rooms, and in medicine [6,7].

Such fabrics need to be able to absorb various solvents for their use as clean room materials, because various organic solvents, such as benzene, toluene, xylene, and isopropyl alcohol, are commonly used in the semiconductor and electronic industries [8].

Various test methods have been used to evaluate the sorption characteristics of fibrous assemblies. The longitudinal wicking test is one of the most commonly used test methods for observing the sorption characteristics of fibrous assemblies, and this method uses the risen height of water from a reservoir [9-11]. However, regardless of the weight of absorbed water, the longitudinal wicking test is not a measurement method appropriate for the thickness direction of a sample.

Another test method is the transverse wicking test, where a fluid is absorbed radially outwards along the plane of a sample from a single point at the bottom of a circular porous test plate that has numerous fine pores [9,12-14]. It is possible to calculate the sorption rate of a fibrous assembly by measuring the flow rate of the water.

Additionally, there are other test methods in addition to those mentioned above for determining the sorption properties of fibrous assemblies: the siphon test [12,15], the dynamic sorption rate test [16], the measurement of water uptake [17], and measurement of the contact angle [18].

In this work, the sessile drop method was used to determine any chemical affinity between the components of the fibrous materials and various organic solvents. Recently, using a real time testing device incorporating a transverse wicking test built by our research group [6,19], the absorption properties of split-type N/P microfiber and polyester microfiber fabrics in various solvents were investigated to determine the sorption characteristics according to the fibrous assembly structures. The objective of this research was to determine the dominant factors of the sorption mechanism of organic solvents: either chemical affinity or physical properties of the microfiber fabrics.

Experimental

Materials

The fabrics used for measuring the sorption characteristics were commercial wiping cloths composed of split-type nylon/polyester conjugated multifilaments and polyester microfibrils. Six samples were carefully selected with different weights, course-wale densities, thickness, fineness, and raw

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Table 1. Characteristics of the fibrous assembly samples

Sample no.	Material	Fineness (denier/filament)	Construction	Weight (g/m ²)	Thickness (mm)	Wale/course density (no./inch)
A	Polyester	DTY 75/72	Knit	170	0.56	56/52
B	Polyester	DTY 75/72	Knit	163	0.56	43/48
C	Nylon/Polyester	50/28	Knit	150	0.39	60/55
D	Nylon/Polyester	50/28	Knit	131	0.38	58/53
E	Nylon/Polyester	75/28	Knit	213	0.55	64/62
F	Nylon/Polyester	Warp: DTY 75/48 Weft: DTY 75/36	Woven	134	0.37	86/54*

DTY: draw-textured yarn, *density = (warp/weft)

construction materials. The physical properties of the samples are listed in Table 1.

The weight of the woven samples was measured using the ASTM D 3776-85 standard, "Standard Test Methods for Mass Per Unit Area (Weight) of Woven Fabric", and the weight and density of the knitted samples were measured using the ASTM D 3887-80 standard, "Standard Specification for Knitted Fabrics". In addition, the ASTM D 3775-85 standard, "Standard Test Method for Fabric Count of Woven Fabric" was used to calculate the woven density, and the ASTM D 1777-64 standard, "Standard Method for Measuring Thickness of Textile Materials" was employed to measure the thickness.

The solvents used in the experiments were benzene, toluene, xylene, isopropyl alcohol, ethylene glycol, and formamide. These were purchased from the Duksan Pure Chemical Co. Ltd., Korea. The average viscosity of each solvent was measured using a dial reading viscometer (LVF, Brookfield Engineering Labs Inc., USA). The viscosity, boiling point, and surface tension of the solvents are shown in Table 2.

A plain view optical microscopic image of the textile

Table 2. Physical properties of the organic solvents used

Solvent	Viscosity (cP)	b.p. (°C)	Surface tension (dyne/cm)
Benzene	4	80.1	28.8
Toluene	4.2	110.7	28.4
Xylene	5.4	137.2-140.5	30.1
Isopropyl alcohol	5.6	82.4	23.0
Formamide	5.8	200-212	58.2
Ethylene glycol	6.1	197.2	47.7

samples is shown in Figure 1. The images were taken at a magnification of 100X.

Sample Preparation for Contact Angle Measurements

To measure the contact angle of the film thermally pressed from the fabrics using different organic solvents, thin films of the fabrics were prepared using a compression molding machine (Carver Inc., USA). The split-type microfiber fabrics were composed of nylon/polyester, and were pressed at

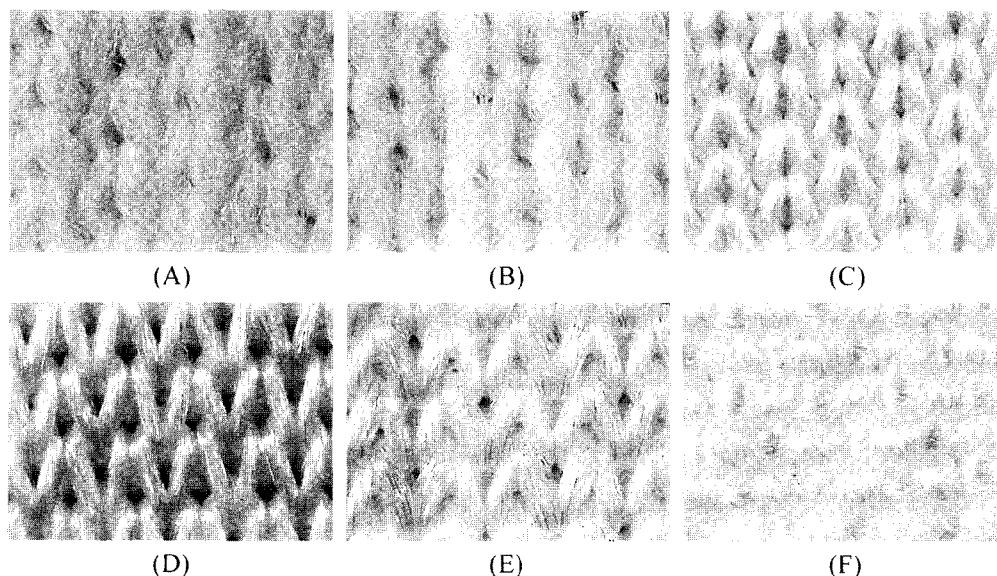


Figure 1. Microscopic planar views of the ultrafine fibrous assemblies. Magnification: 100X.

270 °C for 2 min. The polyester fabrics were also pressed under the same conditions. Polyester and nylon film reference samples were prepared by compression molding of virgin pellets to measure their contact angles. Polyester (I.V. = 1.07) and nylon 6 (melt index = 2.6) were provided by the Hyosung Corp. and Kolon Co., Korea. All the pellets were dried for 24 h at 100 °C in a vacuum to secure a completely moisture-free state. In addition, for film preparation, the polyester pellets and the nylon 6 pellets were thermally pressed at 275 °C and 235 °C for 5 min, respectively.

Measurement of the Surface Energy of the Films

The surface energy of each film was calculated using the Owens-Wendt-geometric mean of the prepared films [20]. We used the sessile drop method to measure surface energy of the films, using distilled water and methylene iodide on the film surfaces to observe the contact angle. The surface energy is composed of a dispersion force (γ_d) and a hydrogen force (γ_h), which can be obtained from the formula below

$$1 + \cos \theta = 2\sqrt{\gamma_{sd}}\left(\frac{\sqrt{\gamma_{ld}}}{\gamma_{lv}}\right) + 2\sqrt{\gamma_{sh}}\left(\frac{\sqrt{\gamma_{lh}}}{\gamma_{lv}}\right) \quad (1)$$

where θ is the contact angle; γ_{lv} is the surface energy of water and methylene iodide; γ_{ld} is the dispersion force of water and methylene iodide; γ_{lh} is the hydrogen force of water and methylene iodide; γ_{sd} is the dispersion force; and γ_{sh} is the hydrogen force of the film under test. The surface energy of water and methylene iodide has already been published many times [20,21], and examples are listed in Table 3.

Sorption Measurements

The intrinsic sorption capacity (ISC) and the extrinsic sorption capacity (ESC) were determined using equations (2) and (3), after measuring the dry sample weight (W_{dry}) and the wetted sample weight (W_{wet}) using a real time testing device.

$$ISC = (W_{wet} - W_{dry})/W_{dry} \times 100 \quad (2)$$

$$ESC = (W_{wet} - W_{dry})/D_{dry} \quad (3)$$

D_{dry} is the surface area of a dry sample. A schematic drawing of the real time testing device is shown in Figure 2.

Results and Discussion

Determination of the Contact Angle and Surface Energy

Before the sorption measurements commenced, the contact angles of the polyester and nylon films, as well as those of

Table 3. Surface energies of water and methylene iodide

Liquid	γ^d	γ^h	γ (dyne/cm)
Water	21.8	51.0	72.8
Methylene iodide	49.5	1.3	50.8

γ^d : component of dispersion force, γ^h : component of hydrogen force.

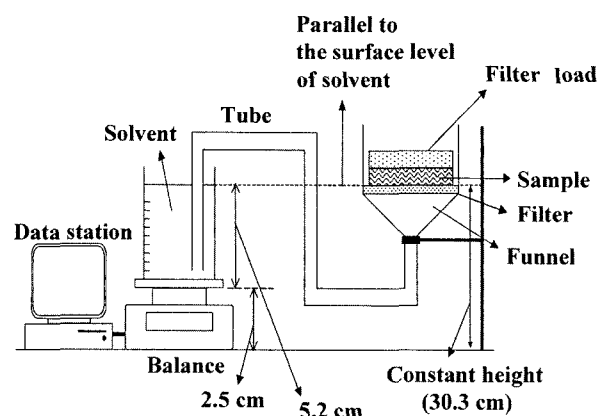


Figure 2. Schematic drawing of the real time testing device.

the thermally pressed films from the polyester fabric and nylon/polyester fabric, were measured using various organic solvents employing the sessile drop method, as shown in Table 4, in order to confirm attraction between the sample (polyester or nylon/polyester) and the solvents. The contact angles of the film's surfaces were very low, and in all the samples, the benzene, toluene, xylene, and isopropyl alcohol almost spread over all the film. However, much higher contact angles were shown by ethylene glycol, formamide, and water. In case of ethylene glycol and water, the contact angles of the films were similar regardless of the composition of the film material (polyester or nylon), but formamide showed an attraction to nylon alone. Thermally pressed films from nylon/polyester fabrics had higher contact angles than those of homogeneous nylon films with formamide. However, the thermally pressed nylon/polyester fabric films had lower contact angles of approximately 9° when compared to the thermally pressed films made from polyester fabrics. A chemical affinity between the thermally pressed nylon/polyester fabric films and the polar formamide may have induced hydrogen bonds to occur between them.

To investigate the surface properties of the films more specifically, the surface energy was measured, and the results

Table 4. Contact angles of the organic solvents used for films and thermally pressed films made from the fabrics under study

	Polyester film	Nylon film	Pressed film from polyester fabric	Pressed film from nylon/polyester fabric
Benzene				
Toluene	< 5°	< 5°	< 5°	< 5°
Xylene				
Isopropyl alcohol				
Ethylene glycol	51.8°	49.2°	48.8°	47.6°
Formamide	58.0°	39.0°	55.0°	45.8°
Water	68.4°	65.6°	67.4°	65.2°

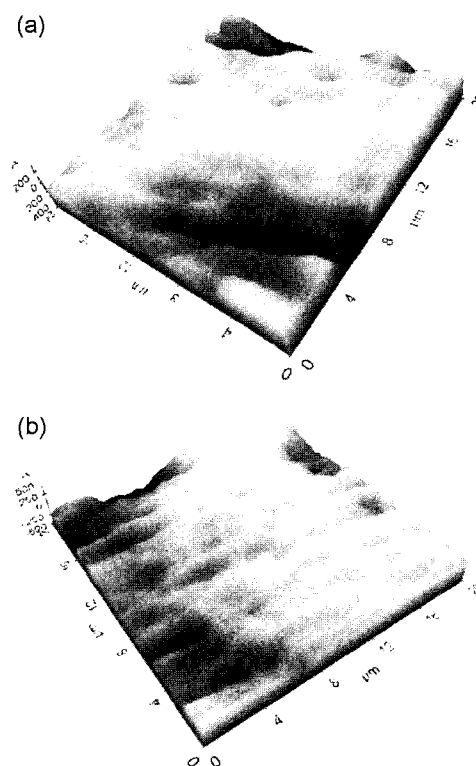
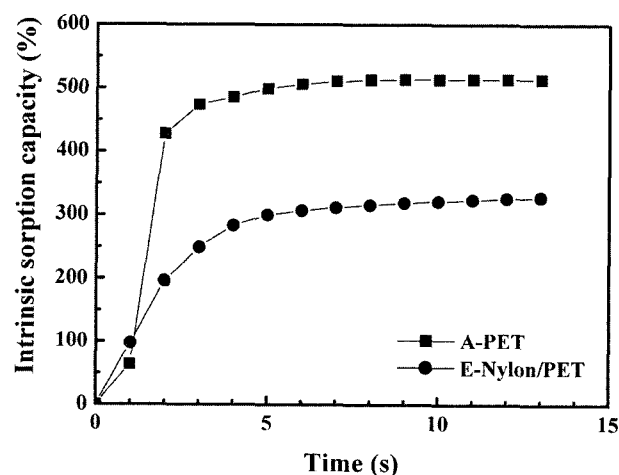
Table 5. Surface energy of the films used

	γ_s^d	γ_s^h	γ_s (dyne/cm)
Polyester film	35	9.6	44.6
Nylon film	41.1	9.1	50.2
Pressed polyester fabric	35.6	9.9	45.5
Pressed nylon/polyester fabric	40.8	9.4	50.2

are listed in Table 5. All the film samples had similar surface energies, which were composed of a dispersion force and a hydrogen force, although the nylon films and the thermally pressed nylon/polyester fabric films had a slightly higher surface energy than the polyester films. All the film samples had almost the same surface energy on their surfaces. In addition, the surface uniformity of the thermally pressed films made from nylon/polyester and polyester fabrics had to be established to determine these affinities, because the contact angles could have been influenced by the surface roughness of the samples. Therefore, atomic force microscopy (AFM) was employed to observe the surface roughness of the films. The scanning dimensions used were 20-micron m along the x- and y-directions, respectively. The AFM results are shown in Figure 3. The AFM micrographs of the thermally pressed polyester and nylon/polyester fabric films had very similar root mean square roughness values at the film's surface. The average surface roughness was 168.16 and 153.96 Å, respectively, for the polyester and nylon/polyester fabric film samples. These values suggest that there was a chemical affinity between the thermally pressed nylon/polyester fabric film and formamide, which did not depend on the surface characteristics of the nylon/polyester fabric.

Sorption Characteristics with Formamide

The sorption properties of polyester (Sample A) and nylon/polyester fabrics (Sample E) were evaluated with formamide by using the real time sorption test apparatus shown in Figure 4. From the textile sample's characteristics listed in Table 1, they had the same knit structure, similar fineness, and similar thickness. However, they differed in weight and density. Therefore, the intrinsic sorption method was employed for evaluating the sorption capacities per specific weight. The intrinsic sorption capacity is derived from the weight change before and after the measurement, divided by the weight in the dry condition. Although the nylon/polyester fabric was found to have an attraction to formamide, the polyester fabric was observed to have the highest sorption capacity and initial sorption rate. This is because Sample A had more vacancies to absorb any solvent because of its lower fabric density. These observations are mentioned in relation to the sorption behavior of microfiber fabrics to show that it was more dominantly influenced by the physical properties of the fibrous assembly than by any chemical affinity with the solvent.

**Figure 3.** AFM micrographs of the surface of thermally pressed films made from polyester (a) and nylon/polyester (b) fabrics.**Figure 4.** Intrinsic sorption curves of the polyester and nylon/polyester fabrics with formamide.

Effect of Sample Density on the Sorption Curves

The effect of the density of the samples on the absorption was investigated using Samples A and B. These samples were made of the same raw material and had the same fineness, thickness, and knit structure. However, they differed in wale/course density and weight. Therefore, the sorption characteristics of Samples A and B were examined using the intrinsic sorption method. The results of the observed intrinsic sorption capacity

of these samples in various organic solvents are depicted in Figures 5-10. Samples A and B showed similar tendencies in their absorption characteristics, but Sample B exhibited a higher sorption capacity than Sample A. This result was attributed to the higher number of vacancies that could hold solvent that existed between the fibers in Sample B, due to its lower fabric density. Benzene, toluene, and xylene had the lower viscosities relative to the other solvents used, and these solvents reached the maximum sorption capacity within 2-3 s, and therefore easily penetrated into the fibrous assembly. The sorption rates of Samples A and B were very similar overall, and did not depend on the sample density. In the case of ethylene glycol, which has a relatively high viscosity, the longest equilibrium sorption time to reach the maximum value was 20-25 s. The absorption tendencies were similar, because ethylene glycol gradually penetrated into the vacancies along the thickness direction, and a longer time was needed

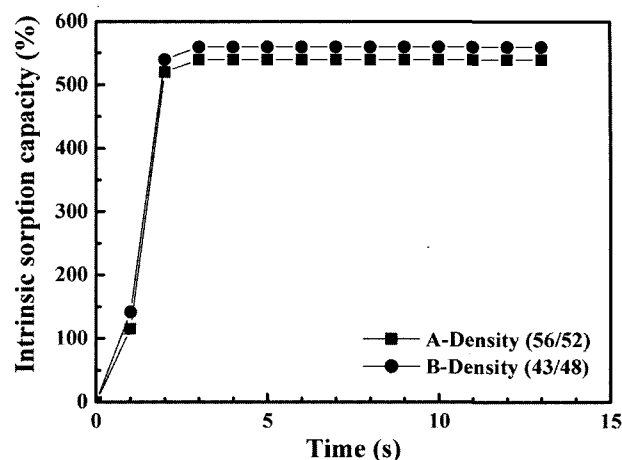


Figure 7. Effect of fabric density on the intrinsic sorption behavior of xylene.

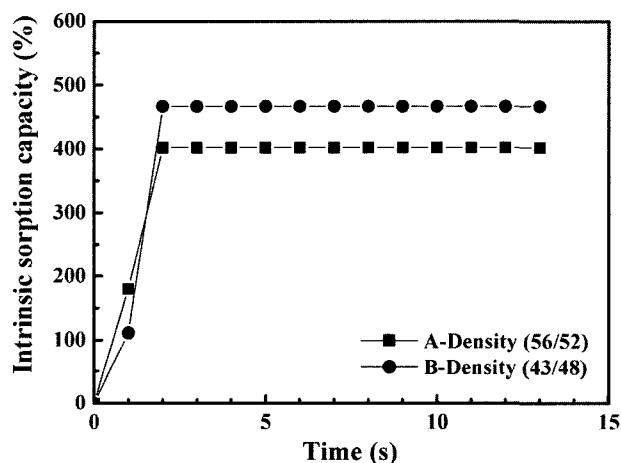


Figure 5. Effect of fabric density on the intrinsic sorption behavior of benzene.

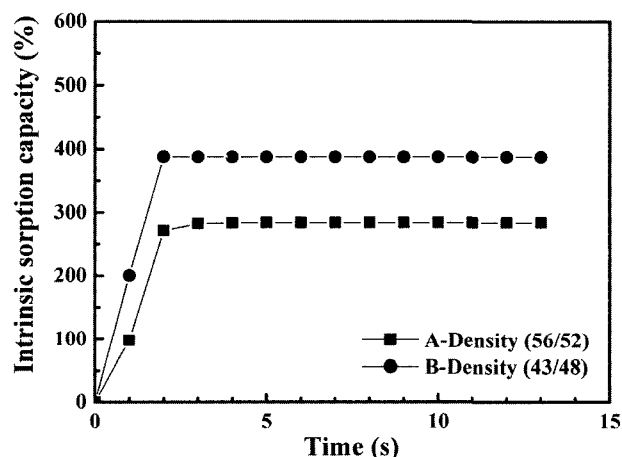


Figure 8. Effect of fabric density on the intrinsic sorption behavior of isopropyl alcohol.

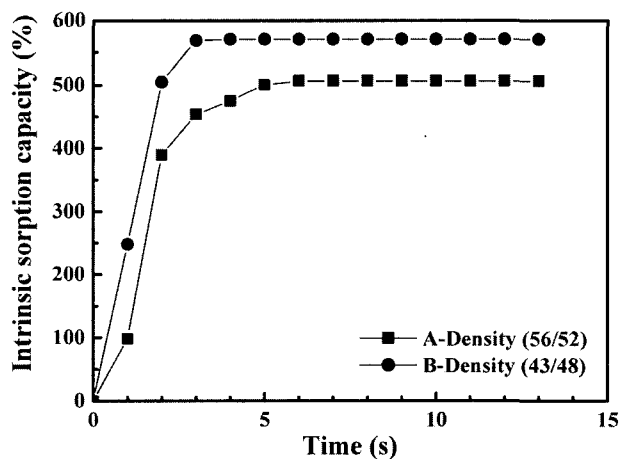


Figure 6. Effect of fabric density on the intrinsic sorption behavior of toluene.

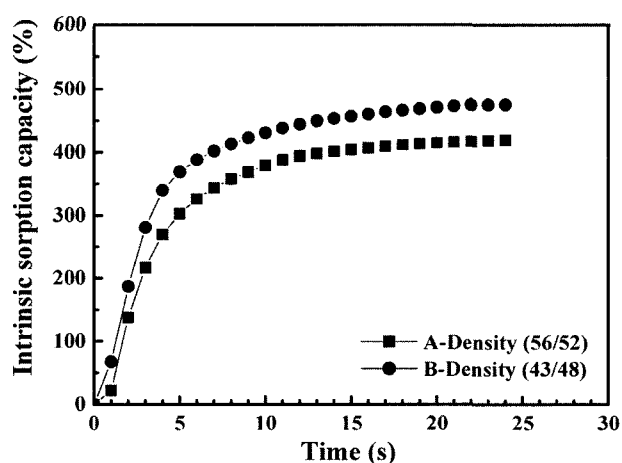


Figure 9. Effect of fabric density on the intrinsic sorption behavior of ethylene glycol.

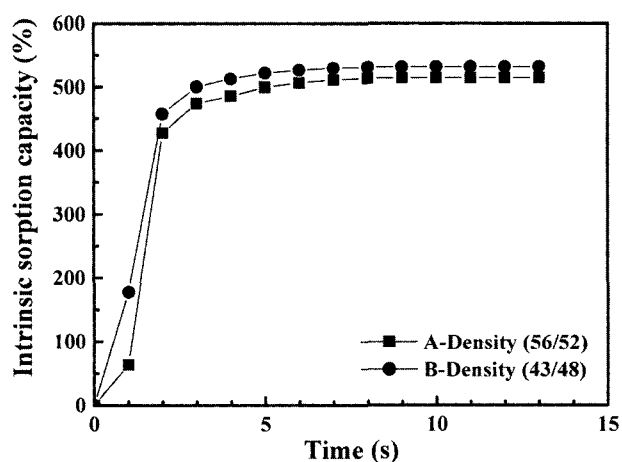


Figure 10. Effect of fabric density on the intrinsic sorption behavior of formamide.

for every vacancy to be filled in the knitted sample. Therefore, there was a difference in the maximum sorption capacity between samples A and B due to the different densities and to the different sorption rates between the samples. This was exhibited in the different slopes observed throughout the entire measurement time range.

Effect of Specific Sample Weight on the Sorption Curves

To determine the effect of the sample weight on its sorption properties, the extrinsic sorption capacity of samples C and D were examined using various organic solvents. Samples C and D consisted of the same material, fineness, knit structure, and they had other similar compositional characteristics, but differed in their weight. The results of the sorption measurements for these samples are shown in Figures 11-16. The sorption behavior and initial sorption rate of samples C and D showed similar tendencies. However, sample C exhibited a higher sorption capacity than sample D. These results suggest that sample C had a higher capability to absorb more solvent due to the higher number of capillaries between its fibers per unit dimension. In the case of lower viscosity solvents, their sorption rates were very similar, and independent of the specific weight. These tendencies mean that the lower viscosity solvents were less influenced by the number of capillaries, because the lower viscosity solvents more easily flowed into the capillaries, and rapidly transported the solvent along the thickness direction of the samples. However, ethylene glycol, which has a relatively high viscosity, was more slowly transported along the capillaries than the lower viscosity solvents. Therefore, its sorption rate was more dependent on the number of capillaries in the sample. The tendencies in the sorption rate were different depending on the sample density and the specific weight of the sample, as shown in Figures 9 and 15, respectively, because the spaces related to the density were usually larger than the capillaries. Therefore,

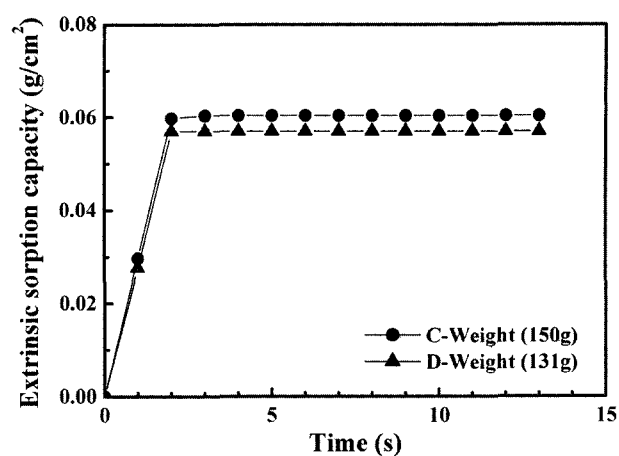


Figure 11. Effect of specific weight of the fabrics on the extrinsic sorption behavior of benzene.

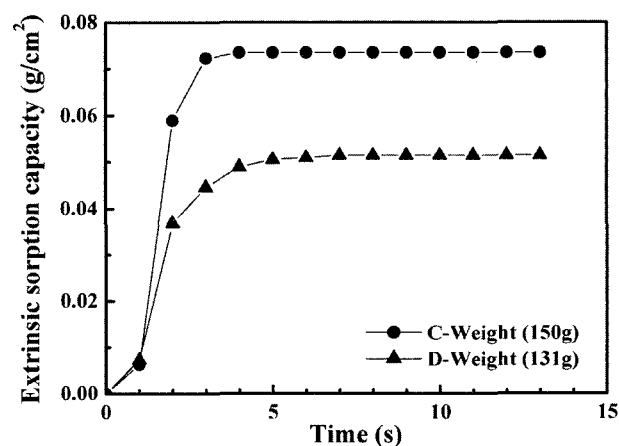


Figure 12. Effect of specific weight of the fabrics on the extrinsic sorption behavior of toluene.

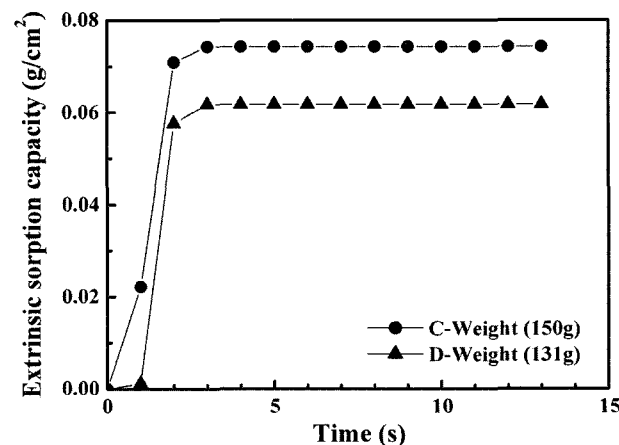


Figure 13. Effect of specific weight of the fabrics on the extrinsic sorption behavior of xylene.

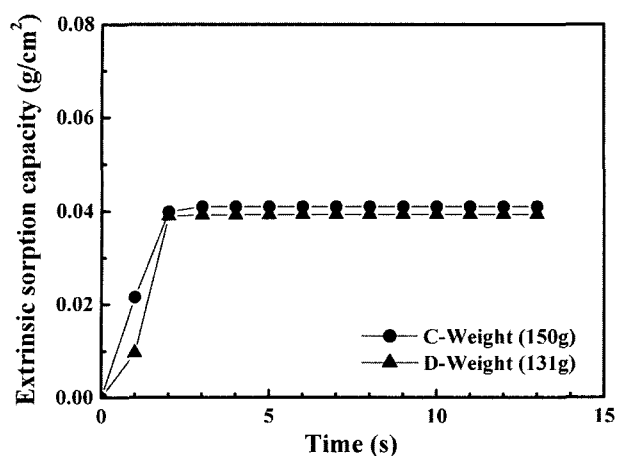


Figure 14. Effect of specific weight of the fabrics on the extrinsic sorption behavior of isopropyl alcohol.

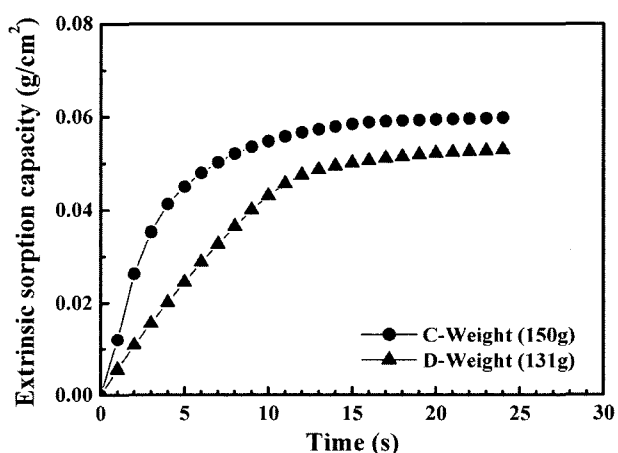


Figure 15. Effect of specific weight of the fabrics on the extrinsic sorption behavior of ethylene glycol.

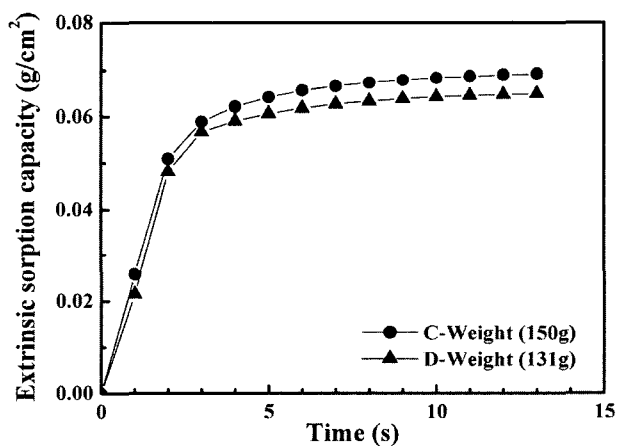


Figure 16. Effect of specific weight of the fabrics on the extrinsic sorption behavior of formamide.

the effect of the density on the sorption rates was less influenced by higher viscosity solvents.

Effect of the Structure of the Fibrous Assembly on the Sorption Curve

Knit and woven samples were selected to investigate the effect of the structure of the fibrous assembly on the sorption characteristics. Samples D and F, which were composed of the same materials, showed only small differences in their thickness and filament fineness. The difference in their densities was due to the different structure of their fibrous assembly, which was the reason for the investigation. The intrinsic sorption capacity characteristics of the samples were determined, and the results of their sorption behavior are depicted in Figures 17-22. Although the sorption characteristics and the sorption rate were similar for both Samples D and F, Sample D exhibited a higher sorption capacity than Sample F. This result suggests that there were more pores and spaces that could be filled with solvent in Sample D, due to its more aerated structure.

Similar to the effect of density variation on the sorption behavior, the sorption rates of Samples D and F with lower viscosity solvents revealed very similar tendency, irrespective of the sample structure. However, ethylene glycol exhibited a different sorption rate, because Sample D had a bulky knit structure with large pores.

Absorption Behavior of the Samples with Solvent Viscosity

To investigate the initial sorption rate more specifically, Sample E, which was the heaviest sample among the fibrous samples, was selected, because it was considered that Sample E would show the greatest distinction in its sorption behavior with different organic solvents. Sample E reached maximum sorption capacity within 2-3 s, because all the solvents selected had relatively low viscosities. To investigate the influence of the solvent viscosity, the initial sorption rate was examined

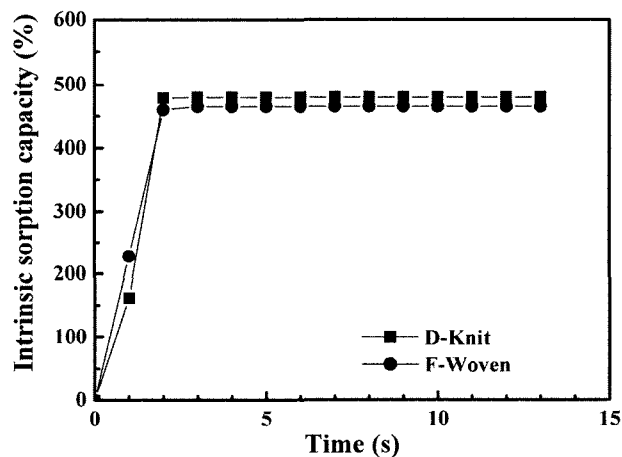


Figure 17. Effect of fabric structure on the intrinsic sorption behavior of benzene.

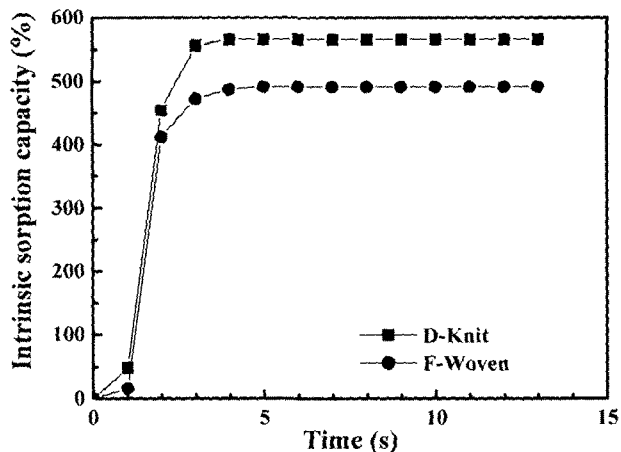


Figure 18. Effect of fabric structure on the intrinsic sorption behavior of toluene.

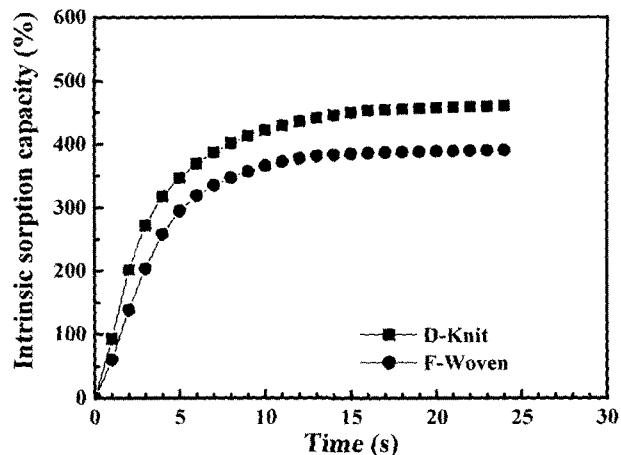


Figure 21. Effect of fabric structure on the intrinsic sorption behavior of ethylene glycol.

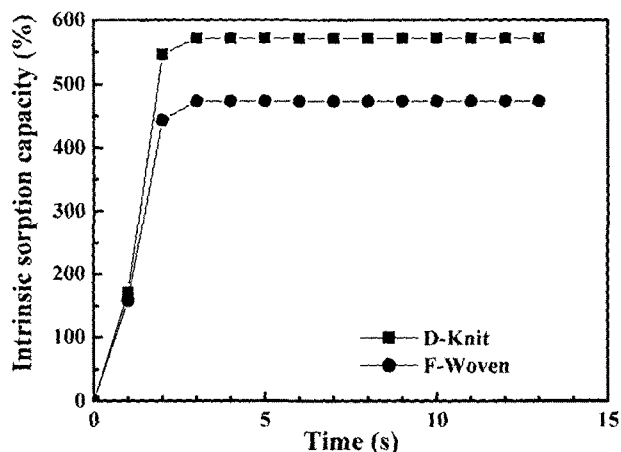


Figure 19. Effect of fabric structure on the intrinsic sorption behavior of xylene.

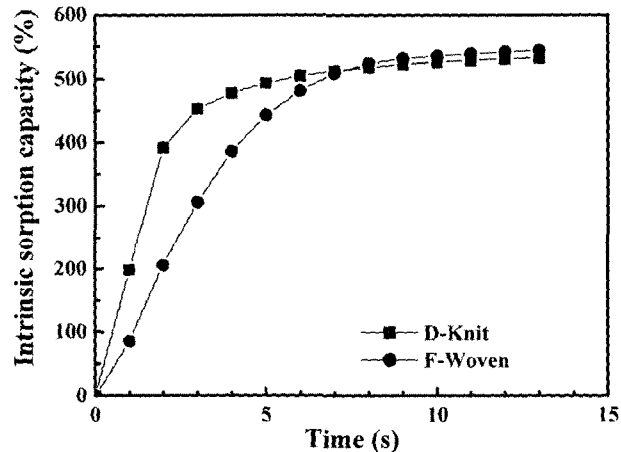


Figure 22. Effect of fabric structure on the intrinsic sorption behavior of formamide.

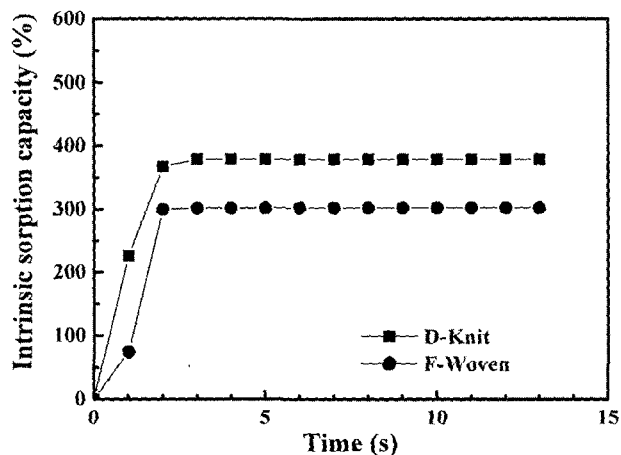


Figure 20. Effect of fabric structure on the intrinsic sorption behavior of isopropyl alcohol.

for a period of 1 s. Using Poiseuilles Law, the fluid transfer rate is [22,23],

$$v = \frac{D^2 \Delta P}{32 \eta l} \tag{4}$$

where v is the traveling rate of the liquid; D is the capillary diameter; ΔP is the effective pressure gradient; η is the viscosity of the fluid; and l is the distance traveled along the capillary. In equation (4), all the variables are constant, because the experiment was carried out under the same conditions. The results were calculated from the gradient of plots versus absorption time, as shown in Figure 23 and Table 6. When the solvents were absorbed into the fabric, the lower viscosity solvents showed a higher initial sorption rate, because they more easily penetrated into the fibrous assembly and transported into the inner spaces of the capillaries.

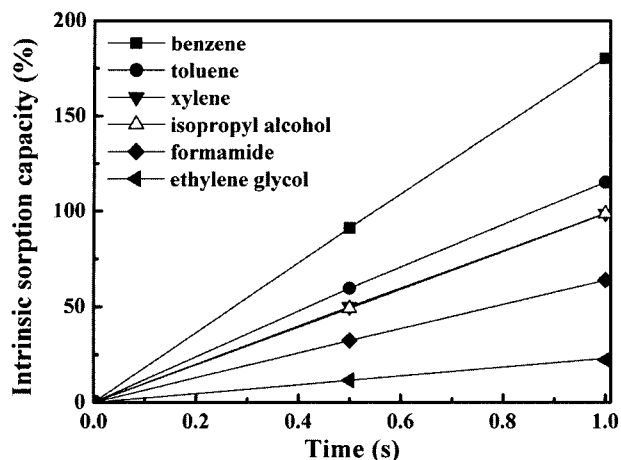


Figure 23. Initial sorption rate of various solvents for Sample E.

Table 6. Slope of the initial sorption curves of the organic solvents used

Solvents	Slope (E)
Benzene	0.9
Toluene	0.58
Xylene	0.49
Isopropyl alcohol	0.49
Formamide	0.32
Ethylene glycol	0.1

Conclusions

The absorption characteristics of split-type microfiber and polyester microfiber fabrics in various organic solvents were investigated for the application to wiping cloths for use in clean rooms. To determine the chemical affinity between the solvents and the compositional polymer fabric materials, the contact angle was measured for thermally pressed fabric films with various organic solvents that are widely used in the manufacturing processes of electronic devices.

The sorption behavior of microfiber fabrics was more influenced by the structure of the fibrous assembly than by any chemical attraction between the fibrous assembly and the organic solvents. Using this result, the influences of the fabric density, specific weight, and sample structure on the sorption capacity and rate were examined for various organic solvents.

The sorption capacity was influenced by the density and the specific weight of the fibrous assembly. However, the sorption rate was less influenced by lower viscosity solvents. In the case of the fabric structure, knitted fabrics showed a higher sorption capacity than woven fabrics.

The initial sorption rates were investigated with various viscosity solvents. When Poiseuilles Law was applied, the lower viscosity solvents showed a higher initial sorption rate, and more easily penetrated into the fibrous assembly.

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