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Functional Modification of Sanitary Nonwoven Fabrics by Chitosan Treatment (Part I) -Change of Surface Structure and Hand-

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키토산 처리에 의한 위생용 부직포의 기능성 개질화 (제1보) -표면구조 및 태 변화-

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Abstract

Chitosan, a natural polymer has been used to nonwoven fabrics based polypropylene for sanitary top sheets. The changes in mechanical properties relating to the surface structure of functionally improved nonwoven fabrics were investigated with respect to the molecular weight and concentration of chitosan that was used. Low molecular weight(LMW) chitosan treated fabric was found to be evenly coated on the fabrics. It was shown that the bending and shearing characteristics of chitosan treated fabrics increased, which helped to make it stronger and harder, while shape stability improved following treatment using high molecular weight(HMW) chitosan. And the surface structure of treated fabrics was smooth and the sensitivity of its bulk improved somewhat. The treated fabrics were not overly stiff because the increase in Koshi value was not considerable compared to that of the bending characteristics. In the change of hand value relating to chitosan treated fabrics, THV generally improved. In the case of a 0.5% chitosan, HMW chitosan treated fabrics produced better THV than LMW chitosan treated fabrics. However, in the case of a 1.0% chitosan, THV of LMW chitosan treated fabrics produced outstanding results.

Key words: Sanitary nonwoven fabric, Chitosan, Surface structure, Hand value; 위생용 부직포, 키토산, 표면구조, 태

I. Introduction

It is generally agreed that environmental pollution and degradation have been brought on by rapid industrialization. However, the demand of disposable and sanitary products such as diapers, hygienic bends, sanitary napkins etc. have increased following the trend to pursue a more convenient life style and sanitary environment. As the studies on diaper use for middle aged adults and seniors who suffer from incontinence have taken more focus(Jo et al., 1999). It is considered that among the many goods avail-

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able, disposable diapers are the most necessary to senior citizens. However its development has not been as active as that of diapers for babies.

Disposable diapers for seniors who suffer from chronic diseases or functional disorder consist of nonwoven fabrics, charging agents, absorbing agents and cover sheets. In the case of sanitary top sheet nonwoven fabrics for disposable diapers, problems such as skin rashes have resulted from increased levels of moisture and chemicals from urine and feces, and infections from bacteria and irritation have arisen from the prolonged friction between the skin and the sheets. As a result, it is imperative to improve surface tactile of the sanitary nonwoven fabrics and functional modification thereof. The nonwoven fabrics have been widely used for disposable goods as well as a durable element for the industry due to the development of various manufacturing technologies.

Chitosan is the second most abundant natural biopolymer, next to cellulose and is very useful in recycling, considering the current environmental problems such as lack of resources, pollution, and contamination(Xu et al. 1996). In particular, there has been a recent global trend of preference towards methods with good affinity to human beings and fiber processing methods of the natural polymer chitosan. So far, due to the lack of the durability utilization of chitosan, it has been difficult to achieve outstanding results in the market although chitosan shows excellent safety and antibiotics properties (Kim et al., 1997b). However, it is considered that the cleaning of sanitary nonwoven fabrics is not a requirement, which may lead to the maximized efficacy in processing chitosan.

Kawabata(1980) developed the KES-FB system in order to evaluate hand objectively, and established the equation of evaluation for hand based on basic mechanical characteristic values as well as subjective determinations using individual feelings. The mechanical characteristics are related to the relationship between external pressure and deformation is a result of the pressure given to the fabrics. Hand is determined by sensory characteristics there from (Winakor & Kim, 1980). It is said that hand is a means to determine the final application function of fabrics. Accordingly, it is mandatory to evaluate hand in order to effectively control touch and the function of nonwoven fabrics in compliance with consumers.

Therefore, in this study, polypropylene nonwoven fabrics commonly used for top sheets were treated with chitosan by varying its molecular weight and concentration of chitosan. The resulting changes in mechanical characteristics and hand were examined. The purpose of this study was to raise the availability of sanitary top sheet nonwoven fabrics by providing improvements in touch and function.

II. Experimental

1. Materials

100% polypropylene(0.16mm, 18.4g/m^2) provided by Korea Vilene Co., Ltd. was used. Chitosan was provided by Chembio Co., wherein chitosan with a similar deacetylated degree but different molecular weight was used. <Table 1> shows characteristics of chitosan. Other agents, Grade I or higher were used.

Table 1. Characteristics of chitosan

	Chitosan	Chitosan oligomer
Particle condition	powder	powder
Viscosity	36 cps	5.6 cps
Degree of deacetylation	95%	95%
Average molecular weight	30×10^4	1.5×10^4
Moisture content	6.0%	7.0%
Residue on ignition	0.13%	0.16%

2. Methods

1) Chitosan Treatment

Chitosan was dissolved in a 1%(v/v) acetic acid sol'n with varying chitosan concentrations and the sample was immersed in the resulting solution for 10minutes. Afterward, treatment with chitosan was completed by padding the sample to its weight pick up at 100±2%, and by heating at 100°C for 3 minutes.

2) SEM Measurement

The surface structure of the treated nonwoven fabrics was examined using the Scanning Electron Microscopy(JSM-5620, Joel) at 500X magnification following the vacuum plating of Au-Pd using Ion Sputter E-1010(Hitachi) on the surface of the chitosan treated nonwoven fabrics.

3) Add-on Ratio Measurement

To determine the add-on ratio after treatment with chitosan, the sample was dried completely at 105°C, and weighed before and after drying. Add-on ratio was calculated following the equation.

$$\text{Add-on Ratio(\%)} = \frac{(W_1 - W_0)}{W_0} \times 100$$

W_0 : dry weight of sample before chitosan treatment
W_1 : dry weight of sample after chitosan treatment

4) Whiteness Index Measurement

Whiteness index of the treated fabrics was measured using the spectrophotometer(Minolta, CM-3600d), and whiteness index was calculated following the equation by obtaining values of L*, a* and b* on the CIE color matrix system.

$$\text{Whiteness Index(W.I.)} = 100 - \sqrt{(100 - L^*)^2 + (a^{*2} + b^{*2})}$$

5) Mechanical Properties and Hand Value

In order to determine the mechanical properties of the chitosan treated nonwoven fabrics, 16 mechanical properties of the fabrics relating to tensile, bending, shearing, compression, surface characteristics, weight and thickness were measured using the KES-FB System(Kawabata Evaluation System, Kato Tech. Co. Ltd., Japan). The mean value was measured by 3 samples in standard conditions.

Primary hand value(HV) such as Koshi, Numeri and Fukurami were calculated using the KN-302-LDY equation, and total hand value(THV) was calculated using the KN-302-W-dress convert equation based on determined primary hand value.

III. Results and Discussion

1. Characteristics of Surface Structure

The touch was quantitatively expressed by measuring the mechanical characteristics of the treated fabrics while the change of surface structure was

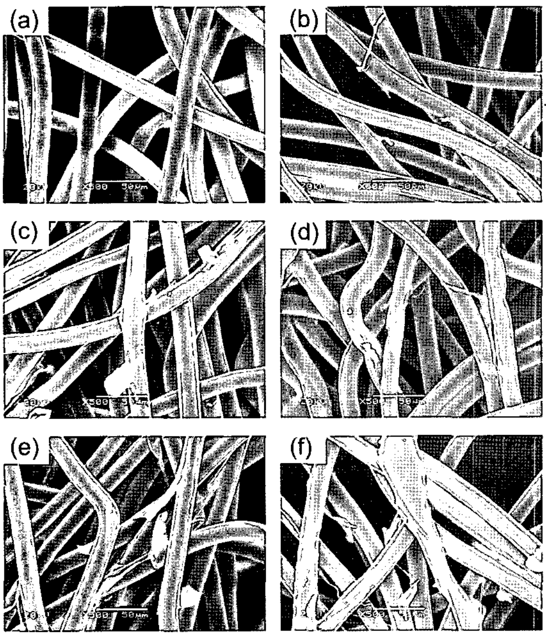

Fig. 1. Scanning electron micrographs (×500) of chitosan treated nonwoven fabrics(Mw 30×10^4)

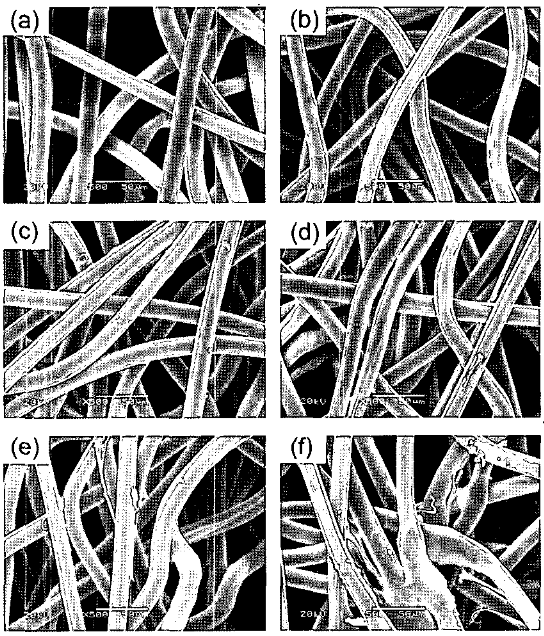

Fig. 2. Scanning electron micrographs (×500) of chitosan treated nonwoven fabrics(Mw 1.5×10^4)

(a) untreated (b) 0.1% (c) 0.3% (d) 0.5% (e) 0.7% (f) 1.0%

determined by observing the degree of attachment of chitosan onto the surface of fabrics as well as the surface state of the fabrics. <Fig. 1> shows SEM photograps of the fabrics treated with HMW chitosan (Mw=30×10^4), <Fig. 2> shows SEM photograps of the fabrics treated with LMW chitosan(Mw=1.5×10^4). When HMW chitosan was used, the at-tachment of chitosan at low concentrations on the surface of the fabrics resulted. When LMW chitosan at low concentrations were used, traces of chitosan were rarely seen but the fabrics were evenly coated with chitosan. In order to quantitatively confirm this, the add-on ratio as a function of concentration of chitosan to be used was observed. As shown in <Table 2>, HMW chitosan has a higher ratio of attachment than LMW chitosan. In the case of LMW chitosan to be used, chitosan could not be seen on the surface of the fabrics due to its evenly coated surface. It was observed that the add-on ratio highly increased with increasing concentrations of chitosan used, and that the higher molecular weight of chitosan and the larger the ratio of attachment is, the more chitosan powder was seen on the surface of the treated fabrics.

Meanwhile, the effects in finishing treatment with chitosan mainly depend on the molecular weight of chitosan(Kim et al., 1997a). The color of the nonwoven fabrics treated with chitosan is not affected because HMW chitosan is white originally. However, in order to improve the ratio of attachment and control the viscosity of chitosan(viscosity of HMW chitosan is extremely high), low concentrations of chitosan are normally used. Using low concentrations of chitosan affect the color of the surface of the sanitary top sheet nonwoven fabrics due to the color of chitosan itself, although the effects of coating are

Table 2. Add-on ratio of chitosan treated fabrics

Chitosan conc.(%)	Add-on ratio(%)	
	Mw(30×10^4)	Mw(1.5×10^4)
0.1	0.42	0.21
0.3	0.51	0.43
0.5	0.73	0.55
0.7	0.94	0.85
1.0	1.04	0.92

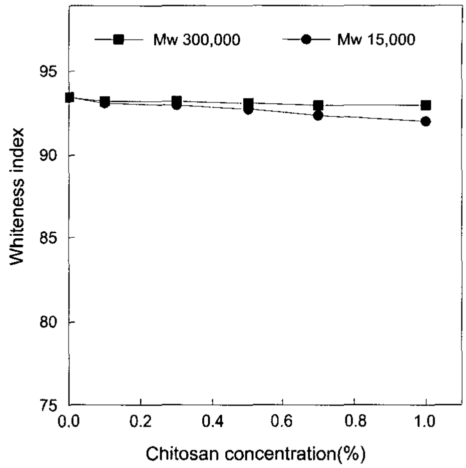

Fig. 3. Effect of chitosan concentration on whiteness index of chitosan treated nonwoven fabrics

acceptable. Therefore, degrees of whiteness of the treated fabrics were compared as a function of the concentration of chitosan to be used.

As shown in <Fig. 3>, whiteness index of the treated fabrics with increasing concentrations of chitosan decreased slightly while whiteness index of the treated fabrics decreased dramatically after treated with LMW chitosan. It is known that the color of chitosan powder darkens in the process to decrease HMW chitosan, which may result in a remarkable decrease in whiteness of the treated fabrics. In the meantime, the effects of processing and the coloration of the surface of nonwoven fabrics are important because sanitary top sheet nonwoven fabrics are almost always white.

2. Change of Mechanical Properties and Hand Value

In addition to the changes in the mechanical properties of the fabrics, appearance characteristics such as the comfort, touch, and drapability of the clothing are affected when the surface of fabrics are treated with chitosan(Kim & Jeon, 1995). The mechanical properties of the nonwoven fabrics after treatment with chitosan were determined, hand was estimated based on the determined properties and examined the efficacy in finishing of sanitary top sheet nonwoven fabrics treated with chitosan. The change in mechanical properties of the treated fabrics was measured using different molecular weights in order to clearly compare the differences in processing. As a result, two different concentrations of chitosan were chosen and used.

1) Mechanical Properties

Tensile characteristics relate to tensile behavior and resilient behaviors under given maximum loads(Fmax). Nonwoven fabrics are deformed based on a mechanism quite different from that applied to other fabrics when stress is given to the fabrics because nonwoven fabrics have less directional properties than other woven fabrics(Jeong et al., 2002). <Fig. 4> shows tensile characteristics of the chitosan treated nonwoven fabrics such as LT(linearity), WT(tensile energy), and EM(extensibility) value as a function of the chitosan concentration. The increase in LT value means that tension at the beginning stage has become difficult. Overall, it is observed that the changes of LT value are not considerable regardless of molecular weight or concentration of chitosan thereof, but LT value increase compared to those of nontreated fabrics.

WT value means the amount of work when the fabric was become tensile deformation. The higher this value, the easier tensile deformation occurs. In case of 0.5% chitosan, it is observed that the WT value of HMW chitosan treated fabrics is higher than that of LMW chitosan treated fabrics. But by increasing concentrations of chitosan to 1.0%, the WT value of HMW chitosan treated fabrics decreased below that of LMW chitosan treated fabrics. The decrease in value of WT relating to the treated fabrics is meant to make the treated fabrics stiffer in terms of the evaluation of the touch. In the light of this, LMW chitosan treated fabrics do not become stiffer by increasing the concentration of chitosan while HMW chitosan treated fabrics do become stiffer by increasing the concentration of chitosan. Therefore, it can be concluded that it is very important to choose a proper chitosan for various applications.

EM value define the ratio of deformation at tensile deformation, which relate to the availability of deformation or flexibility(Kim et al., 1997a). When a

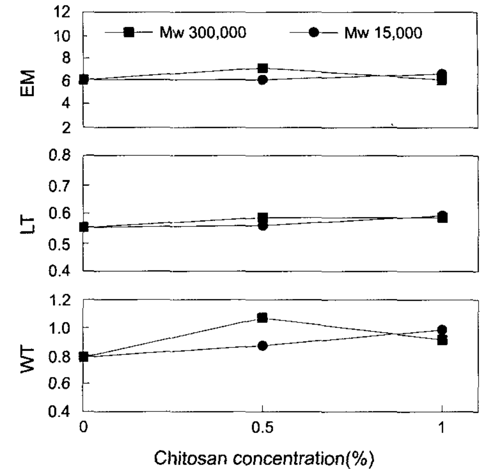

Fig. 4. Tensile properties of chitosan treated nonwoven fabrics

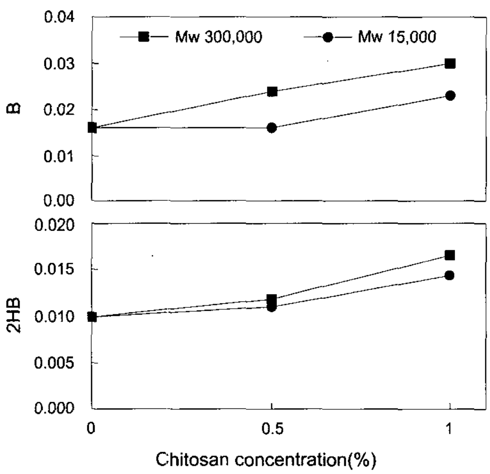

Fig. 5. Bending properties of chitosan treated nonwoven fabrics

1.0% chitosan was used, EM value of the treated fabrics was higher than that of the nontreated fabrics. It was results by increasing the resistance against tensile deformation along with increasing the viscosity of chitosan. On the contrary, EM value of LMW chitosan treated fabrics was not changed because LMW chitosan deposition occurred evenly on the surface of the fabrics, and might not occurred increase of the resistance against tensile deformation.

Bending characteristics relate to the drapability of fabrics and are influenced by constitutional factors such as mechanical characteristics of constitutional fibers, state of assembled fibers and friction between fibers(Jeon et al., 2003). As shown in <Fig. 5>, values of B(bending rigidity) and 2HB(bending hysteresis) increased. In particular, the extent of the increase was greater when HMW chitosan was used because the attachment of high viscosity chitosan leads to the stiffness of the treated fabrics. In addition, interaction between chitosan and the fibers of the fabrics at crosslinked points increased, which in turn lead to the decrease in slipperiness between the fibers as well as the increase in the bending rigidity(Park & Bae, 2005). It was said that when values of both B and 2HB decrease, the fabrics become smoother while the fabric become stiffer when the values were larger. When the fabrics are stiffer, a proper space between the skin and the fabrics is maintained. Therefore, the touch of the sanitary top sheet nonwoven fabrics is improved because the fabrics do not touch closely to the skin. If the value of bending hysteresis is high, it means that there are degrees of deformation. In other words, bending recovery is not good enough to allow the fabrics to return to their original geometry.

In order to investigate the loss of recovery energy during a process of recovery, a ratio of 2HB/B was observed. If the ratio of 2HB/B is larger, geometry of the fabrics is easily deformed, and a lot of wrinkles on the fabrics occur. On the contrary, if the ratio is smaller, the stability in geometry of the fabrics is good, producing fewer wrinkles on the surface of the fabrics(Seo & Kim, 1998).

As shown in <Fig. 6>, there was a tendency for the value of 2HB/B of HMW chitosan treated fabrics to decrease slightly in comparison to that of the non-treated while the value of LMW chitosan treated fabrics increased. From this, it was recognized that crumpling or deformation of HMW chitosan treated fabrics was suppressed, and stability of geometry thereof was improved more than those of LMW chitosan fabrics. Values in 2HB/B of HMW chitosan treated fabrics at a 0.5% chitosan were much lower, while the values in 2HB/B of the LMW chitosan treated fabrics at a 1.0% chitosan was much lower. Therefore, we can conclude that the concentration of chitosan contributing to the stability in the geometry of the fabrics varies depending on the molecular weight of chitosan to be used because of the differential attachment of chitosan.

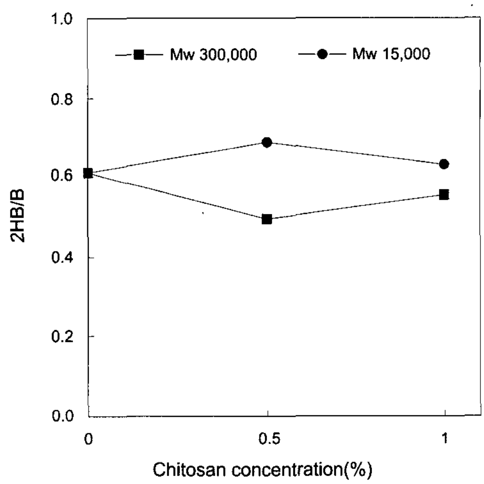

Fig. 6. 2HB/B of chitosan treated nonwoven fabrics

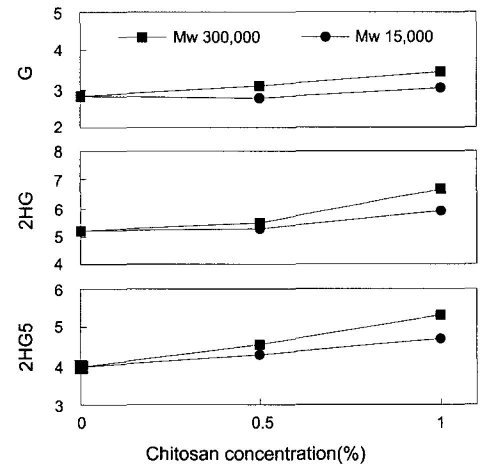

Fig. 7. Shearing properties of chitosan treated nonwoven fabrics

Shearing characteristics are deformations against the external stress when one part of the fabrics fixed under a certain load, while the other part is extended at a certain angle, which is a fabrics that influences compliance to the curved surface of the body line and drapability(Kim et al., 2000). Sanitary nonwoven fabrics should be in compliance with the three dimensional curved surface of the body, as appearance properties such as the drapability and stability of geometry considerably affect the shearing characteristics. As shown in <Fig. 7>, the values of G(shear stiffness) increased regardless of M_W or the concentration of chitosan. It was noticed that the values of G of HMW chitosan treated fabrics increased more than that of LMW chitosan treated due to attachment occurring between the fibers.

2HG(shearing hysteresis) is involved in the deformation and recovery in shearing deformation. It means that the higher the value of shearing hysteresis, the larger the energy loss is during recovery. And the recovery against shearing deformation was better when LMW chitosan is used for treatment.

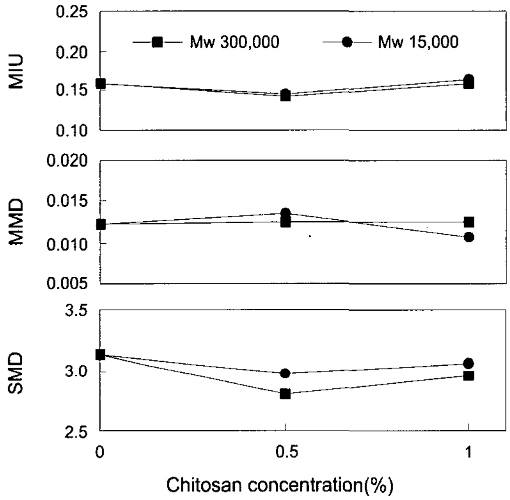

Fig. 8. Surface properties of chitosan treated nonwoven fabrics

Surface characteristics are involved in the smoothness of the fabrics, and MIU(coefficient of friction) value relates to crispness, the feeling when the surface of the fabrics is crisp and rigid(Jeon et al., 2003). As shown in <Fig. 8>, MIU decreased after treatment with chitosan, and the surface friction decreased due to coating using chitosan. MMD(mean deviation of MIU) and mean deviation of the coefficient of friction relates to touch, wherein the lower the value, the smoother the fabrics, and even friction was obtained (Nam et al., 2000).

HMW chitosan treated fabrics maintained their MIU value without any substantial changes. In the event that a high concentration of LMW chitosan is used for treatment, the MIU value decreased and chitosan was coated evenly on the surface of the fabrics, creating smoothness. SMD(geometrical roughness) representing the geometrical roughness of the surface of the fabrics, relates to flexion of the surface, and it decreased regardless of what kinds of chitosan were used. The resulting surface was smooth after a process of treatment, wherein chitosan solution were absorbed into the surface of the fabrics, and coated over the surface, dried and finally evenly attached onto the surface of the fabrics. Also the resulting sur-

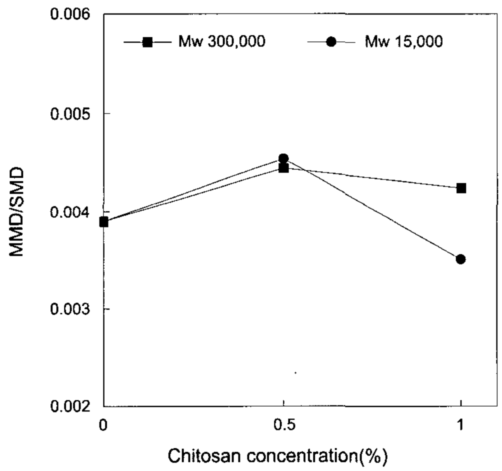

Fig. 9. MMD/SMD of chitosan treated nonwoven fabrics

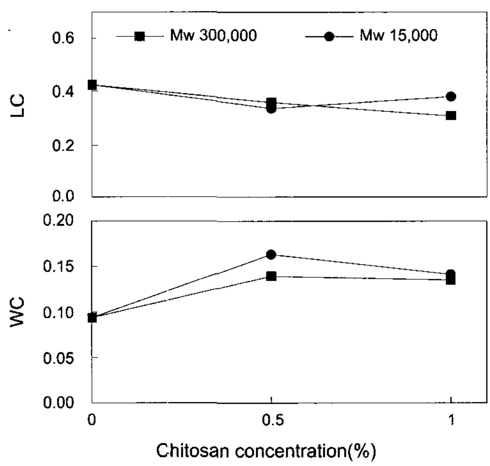

Fig. 10. Compression properties of chitosan treated nonwoven fabrics

face was received by the effect of padding. When it comes to sanitary nonwoven fabrics, the tactile of the surface is very important. The sensory test investigates the values of MMD/SMD, which are closely related to smoothness. It is well established that the smaller the value of MMD/SMD, the smoother the surface is(Kawabata et al., 1984). As shown in <Fig. 9>, MMD/SMD value noticeably decreased when LMW chitosan was used for treatment. It means that chitosan is more evenly attached onto the surface, which leads to the excellent surface smoothness of the fabrics.

Compression characteristics closely relate to the thickness and the volume of the fabrics, and in particular influence fullness, smoothness, comfort and warmth. As shown in <Fig. 10>, the value of LC (compressional linearity) of the treated fabrics decreased compared to nontreated fabrics. It resulted from passing the fabrics through a mangle during treatment, which provided a more compressed surface of the treated fabrics. Continuously decreasing LC values by increasing the concentration of the HMW chitosan was noticeable, however, it was not observed in the treatment of the fabrics with LMW chitosan. WC(compressive energy), a characteristic representing deformation in response to compression power decreased in value somewhat after increasing. As shown in <Fig. 11>, it had a similar tendency to an increase in thickness. Regardless of the molecular weight of chitosan, the resulting nonwoven fabrics became bulkier when treated with low concentrations of chitosan.

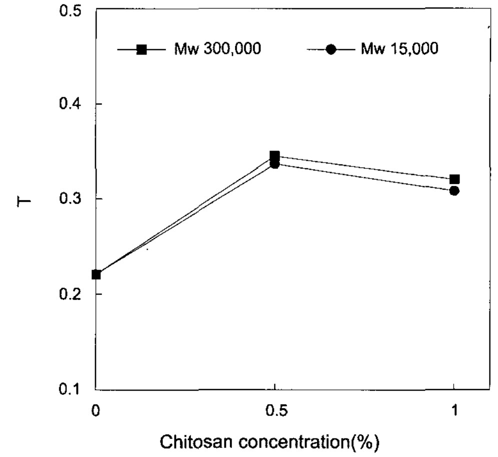

Fig. 11. Thickness of chitosan treated nonwoven fabrics

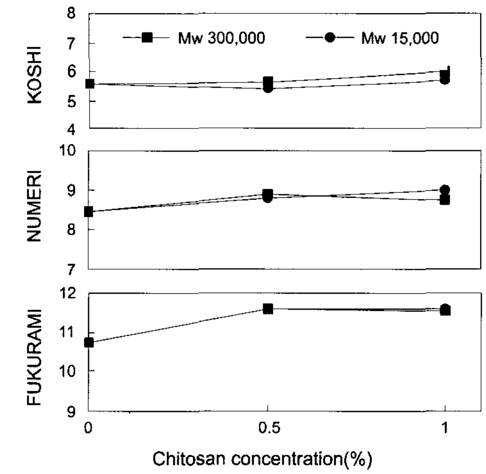

Fig. 12. Primary hand value(HV) of chitosan treated nonwoven fabrics

2) Change of Hand Value

In order to objectively observe the changes in touch of the treated fabrics following the treatment of sanitary nonwoven fabrics with chitosan, mechanical properties were determined using the KES-FB System, from which the primary hand value(HV) was obtained according to the equation KN-302-LDY. Total hand value(THV) was calculated based on the primary hand value following KN-302-W-dress and compared.

Koshi denotes a combination of repelling power, elasticity and resilience, which is influenced by the bending and shearing characteristics. As shown in <Fig. 12>, it was judged that the increase in Koshi following the treatment resulted from the increasing in the bending and shearing characteristics. However, the extent of increase in Koshi was not considerable compared to that of the bending characteristics, denoting that the treated nonwoven fabrics did not become stiffer. In light of this, it was desirable to treat nonwoven fabrics with chitosan as it does not result in sanitary nonwoven fabrics to stiffen, which touch the skin.

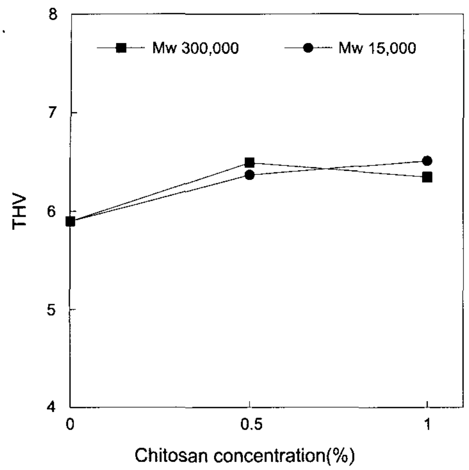

Fig. 13. Total hand value(THV) of chitosan treated nonwoven fabrics

Numeri is the smooth feeling we feels when we touch fabrics, which is influenced considerably by surface characteristics. Regardless of the kinds of chitosan, Numeri was improved and in turn the surface of the treated fabrics became smoother after its treatment with chitosan. When the fabric was treated with 1.0% chitosan, Numeri was better with LMW chitosan because the smaller MMD, the larger Numeri was, which in turn provides a smoother surface.

Fukurami is the feeling of touch, bulkness and resilience we feel when we grasp fabrics, which is mainly influenced by compression characteristics. It seemed that Fukurami of the treated fabrics increased regardless of MW and/or the concentration of chitosan that was used for treatment. We presumed that the resulting fabrics became bulky after the treatment with chitosan because there was a change in compression characteristics wherein LC remained constant, and values of WC increased.

Hand is a value added factor in the field of textile industry. In order to investigate general feelings following the treatment of sanitary nonwoven fabrics with chitosan, Total hand value was estimated based on primary hand value. The result was shown in <Fig. 13>. According to the results, THV of the treated fabrics improved more than that of nontreated fabrics. In the case of 0.5% chitosan treatment, THV of the fabrics treated with HMW chitosan improved. However, when the concentration of chitosan was increased to 1.0%, THV of the fabrics treated with LMW chitosan were better. Accordingly, in order to improve THV of sanitary nonwoven fabrics, one available method is to control the concentration of chitosan depending on its MW. For example, a high concentration of LMW chitosan and vise versa could possibly be an effective means. The suggestion coincides with Shin's findings(Shin & Son, 1998).

IV. Conclusions

The purpose of this study was to investigate about functional modification of sanitary top sheet nonwoven fabrics by chitosan treatment. Surface structure, mechanical characteristics and change of hand value were examined. Chitosan, as a natural polymer and having excellent human affinity, was treated by varying its M_W and concentration of chitosan.

The degree of attachment of the fabrics treated with HMW chitosan was larger than that of the fabrics with LMW chitosan. In addition, the higher concentration of chitosan, the more the degree of attachment increased. When LMW chitosan was used, it was confirmed that chitosan was coated evenly on the surface of the fabrics, and whiteness index decreased only slightly in comparison with HMW chitosan treatment.

The bending and shearing characteristics increased following treatment with chitosan, which led to stronger and stiffer. The shape stability of the fabrics improved more when HMW chitosan was treated compared to LMW chitosan usage. On the contrary, recovery from deformation was better with LMW chitosan usage. Regardless of MW or the concentration of chitosan, surface smoothness improved, and in particular, MMD/SMD value decreased dramatically when HMW chitosan was treated.

The increase of Koshi was not considerable and did not result in stiffer fabrics. Treatment with LMW chitosan provided better smoothness and improved the bulk of the fabrics. In the change of hand relating to sanitary nonwoven fabrics treated with chitosan, THV generally improved. In the case of a 0.5% chitosan treatment, HMW chitosan treated fabrics produced better THV than LMW chitosan treated ones. On the contrary, in the case of a 1.0% chitosan treatment, THV of LMW chitosan treated fabrics produced outstanding results.

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요 약

위생용 탑시트로 쓰이는 폴리프로필렌 부직포에 천연고분자이며, 인체친화력이 우수한 가공제인 키토산을 사용하여, 키토산의 분자량과 처리농도를 변화시켜 처리하므로써 기능성 개질화된 부직포의 표면구조와 역학적 성질 및 태의 변화를 살펴보았다. 저분자량의 키토산 처리포가 더 균일하게 코팅되었으며, 분자량과 처리농도가 클수록 부착률이 증가하였다. 키토산 처리포는 굽힘특성과 전단특성이 증가하여 다소 강경해지고, 형태안정성은 고분자량의 키토산 처리 시 더 향상되었다. 표면 촉감은 매끄러워졌으며, 부피감이 다소 향상되었다. 굽힘특성의 증가에 비해 Koshi의 증가가 크지 않으므로 지나치게 뻣뻣해지지는 않았고, 키토산 처리농도가 증가할수록 저분자량의 키토산 처리포가 더 매끄러워졌으며, 벌키성이 부여되었다. 키토산 처리에 의한 위생용 부직포의 태 변화는 미처리포에 비해 전반적으로 THV가 향상되었으며, 키토산 처리농도가 0.5%일 경우 고분자량의 키토산 처리포의 THV가 더 좋았으나, 처리농도가 1.0%일 경우는 저분자량의 키토산 처리포의 THV가 더 우수하였다.