〔보 문〕

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A Study on Physical and Mechanical Properties of Breathable Waterproof Fabrics Manufactured with PTFE Membrane-Fabric Composite

PTFE막-직물 복합체로 제조된 투습방수직물의 물성 및 역학특성에 관한 연구

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Abstract

다양한 용도로 사용되고 있는 라미네이팅 직물은 주로 별도로 제조된 고분자 필름 또는 막을 접착제, 열, 압력 등을 이용하여 기포(基布)와 결합시키는 방법으로 제조되어진다. 이축연신시킨 Poly(tetrafluoroethylene) (PTFE) sheet 는 매우 우수한 높은 투과성을 지니는 다공성 물질이며, 본 연구에서는 이 막을 나일론 직물에 라미네이팅 시킨 투습방수직물을 시료로 사용하여 라미네이팅 후의 역학특성 변화를 분석하였다.

라미네이팅에 따른 투습방수직물의 물성과 역학특성의 변화에 관하여 살펴본 결과 다음과 같은 결과를 얻었다. 3-layer 라미네이팅 직물(base fabric-PTFE membrane-knitted lining)의 인열강도는 2-layer 라미네이팅 직물(base fabric-PTFE membrane)에 비해 매우 높게 나타났으며, 가공 전 직물과 비교하여 코팅직물에서 나타난 것과 같은 인열강도의 감소는 나타나지 않았다. 직물-PTFE 막 복합체의 경우, 라미네이팅이 파단강도 및 파단신도의 증가에 기여한 것으로 나타났으며 특히 3-layer 라미네이팅 직물의 경우, 신장률이 20%를 넘어서면서 강도가 현저히 증가하였다. 의복을 착용하였을 때 가해질 수 있을 정도의 소변형(small deformation) 하에서의 역학특성에 있어서는 라미네이팅에 의해 전단특성이 가장 유의한 변화를 나타내었다. 전단강성(G)과 전단 히스테리시스(2HG, 2HG5) 모두 증가하였고, primary hand value 중에서는 stiffness가 가장 현저한 증가를 나타내었다.

Key words: Breathable waterproof fabrics, Laminating method, PTFE membrane, Mechanical properties, Fabric hand; 투습방수직물, 라미네이팅법, PTFE 막, 역학적특성, 태

I. Introduction

Waterproof fabrics allow no water to penetrate through the surface, and coating methods using rubber or synthetic plastic materials can make fabrics that are completely waterproof. However, these fabrics tend to be too warm and uncomfortable for the body as they create a barrier that traps air and sweat inside. Recent advances in fabric coating and laminating have led to the development of fabrics that are waterproof and breathable. The general principle of these fabrics is that they keep out water from rain and snow, but allow the passage of moisture vapor from perspiration. They are promoted for use in outdoor clothing and for active sports[1-5].

Polytetrafluoroethylene (PTFE) film is the basis for some unique constructions which give a fresh approach to solve the problems. Mentioned above, PTFE membranes were produced by R. W. Gore[6] with a microscopic structure in which the pores have an equivalent diameter. Biaxial orientation of film or sheet made from fine powder PTFE is used to produce microporous sheeting. Orientation at elevated temperature causes fibrillation and produces a matrix of particles bound together by the resulting fibrils: these provide good physical properties and contain a high void volume for good permeation. Sheeting produced in this manner is used in the products such as sports apparel, hospital and surgery apparel, and filter bags[7-10].

The manufacture of laminated breathable waterproof fabrics involves adhesive system by which the textile fabric or porous outer material can be combined with the PTFE membrane without losing its porous structure, to produce waterproof and water vapor permeable materials[11]. However, the behavior of the fabric-reinforced flexible composites may be different from that of pure fabric. Since the geometric displacement of the fabric is restricted by the matrix (even with a very soft one), the composite becomes much harder than pure fabric. So the ease of body motion and the level of the load generated in the fabric during that movement are thus obviously related to the fabric construction and the mechanical behavior. However, the studies on the mechanical properties of these materials have rarely been carried out, though the mechanical properties are very important factors in tactile comfort.

In this work, the breathable waterproof fabrics manufactured through laminating process were used, and some constructive properties and mechanical properties with small and large deformation were measured and analyzed according to laminating process, fabric construction and so on. Then, the alteration of the fabric performance after laminating process and deformation behavior with increase of strain in this composite system was investigated in comparison with pre-laminated fabrics. It is expected that this work may be helpful to applications of the breathable waterproof fabrics manufactured with laminating process, so more comfortable and better performing materials can be developed.

II. Experimental

1. Materials

The specimens used in this study were chosen in breathable waterproof fabrics manufactured with laminating process, and they were supplied from Gore-Tex. These were prepared through laminating process with PTFE membrane. Table 1 shows the classification and the characteristics of the materials used in this study. The fabrics were composed with base fabric, PTFE membrane, and knitted lining, and these material combined through adhesives sprayed between the base fabric and the PTFE membrane. The functional component of these laminates was a thin and microporous membrane made from solid PTFE sheet produced through novel drawing and annealing process. The unfinished fabrics were also used for comparison with the finished ones in this study.

2. Constructive properties

The weight in mass per unit area was measured before and after laminating, and the thickness was

Table 1. Characteristics of the specimens

Sample code	Finishing	Construction of base fabrics: Fiber contents	Yarn count (denier)	Fabric count (warp × filling/inch)	Thickness (mm)	Weight (g/m²)
2L1	2-layer[a]	nylon	70×70	97×94	0.23	81.1
2L2		nylon	70×144	118×68	0.36	95.5
2L3		nylon	380×150	61×59	0.37	135.3
2L4		nylon	80×240	136×55	0.47	143.2
3L1	3-layer[b]	nylon	70×70	97×94	0.28	98.0
3L2		nylon	80×84	120×97	0.24	95.9
3L3		nylon	80×200	109×70	0.29	104.0
3L4		nylon	70×140	110×78	0.28	107.2

[a] fabric substrate + PTFE membrane

[b] fabric substrate + PTFE membrane + knitted lining*

* 100% nylon, 20denier, 36×50/inch, 33g/m²

measured with KES-FB3 compression tester at 0.5gf/cm² load. Adhesive force between the base fabric and polymer membrane was measured in accordance with ASTM D 4851 using constant-rate-of elongation tester.

3. Mechanical properties with large deformation

The tearing strength was measured with tongue method according to ASTM D 2261 before and after laminating. The uniaxial tensile testing was made according to ASTM D 5035. The specimens were prepared with raveled strip method and cut strip method before and after laminating fabrics, respectively. Yield point was calculated according to Meredith' s construction[12].

4. Mechanical properties with small deformation

Tensile properties, shear properties, bending properties, compression properties, and surface properties with small deformation were measured with KES-FB system[13], which is an objective evaluation system based on standardized subjective expression of fabric hand. From this system, 16 characteristic parameters were measured, and the primary hand values were calculated with KN-101-Winter equation.

III. Results and Discussion

1. Adhesive force of laminating to fabric

It becomes necessary to use combinations of materials to improve properties because any one material alone can not do so at an acceptable rate of performance. In case of breathable waterproof fabrics manufactured with laminating process, PTFE membrane and fabric were used as the

Table 2. Adhesion properties of laminating to base fabrics

Finishing	Direction	Mean adhesive force (gf/cm)	T-values: paired t-test[a]	t-test[b]
2-layer laminating	warp	122.75	0.82	−3.66***
	filling	104.25		
3-layer laminating	warp	158.00	−3.45*	
	filling	171.75		

[a] paired t-test between warp and filling direction.

[b] t-test between 2- and 3-layered composites.

*p<0.05, **p<0.01, ***p<0.001

breathable waterproof component and substrate, respectively. Therefore, the adhesive force between base fabric and polymer layer has a very important meaning.

Table 2 shows the results of the adhesive force and the significance of them from t-test. These fabrics were made with the method of bonding the base fabric and PTFE membrane. Lower adhesive force compared to other coated breathable waterproof fabrics was obtained as the adhesive droplets were added between them in order to overcome the well-known non-sticky property. The low surface energy of this polymer makes it very difficult to bond their surfaces with other substrates, so this surface inertness thus makes fluoropolymers unsuitable for use in areas involving adhesive bonding.

Generally, the correlation coefficient of adhesive force with cover factor, fiber count and fabric density were very low compared with direct coating process. The adhesive force of warp direction was higher than that of filling direction, and the significance between them was only shown in 3-layered composites. This is due to the knitted lining component, which is an anisotropic material equal to the woven fabrics. It is certain that the adhesive forces of 3-layered ones are much higher than those of 2-layerd ones at significant level of 99%. But as the strength is somewhat insufficient as in durability, it is necessary to promote the strength by various surface modification.

2. Mechanical properties with large deformation

Since the rate of movement of motion in sports is so excessive compared with ordinary times, superior durability is needed for sportswear. But actually the breakage of sportswear have often occurred in outdoor sports. So mechanical properties at large strain of the fabrics for sportswear need to be considered.

The results of tearing strength before and after laminating are shown in Figure 1. Tearing strength of all the laminated fabrics was higher than that of pre-laminated fabrics. And the degree of increment made slight difference according to different laminating methods. It was believed that laminated lining was more responsible than PTFE membrane for increasing tearing strength. These results indicated that the laminated fabrics had some different breaking behavior compared with the other type of breathable waterproof fabrics manufactured by coating process. The tearing strength after coating decreased as coating dope penetrated into base fabric construction. In the case of laminating process, any solution that deeply penetrates into fabric construction was not added, but some adhesives were sprayed between the base fabric and the PTFE membrane. So no loss in tearing strength was found.

The influence of laminating process on the tensile behavior was investigated, and the results are shown in Table 3. It was found that lamination has a positive effect on tensile breaking force and elongation. Fabric-PTFE membrane composites

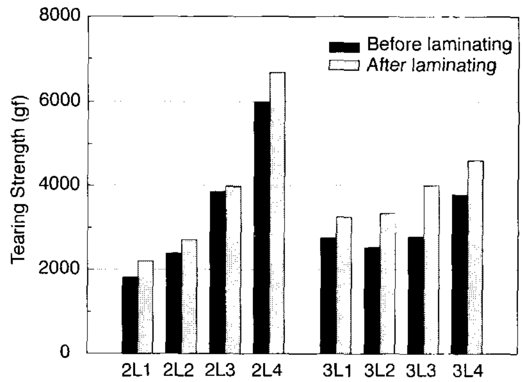

Fig. 1. Variations of tearing strength of breathable waterproof fabrics with laminating.

Table 3. Tensile strength and elongation of the fabrics before and after laminating

Finishing method	Force (kgf)				Elongation (%)			
	Yield		Breakage		Yield		Breakage	
	before	after	before	after	before	after	before	after
2-layer laminating	5.89	6.79	33.42	34.97	1.40	1.53	8.12	8.48
3-layer laminating	5.38	6.38	30.88	37.52	1.19	1.33	7.57	8.79

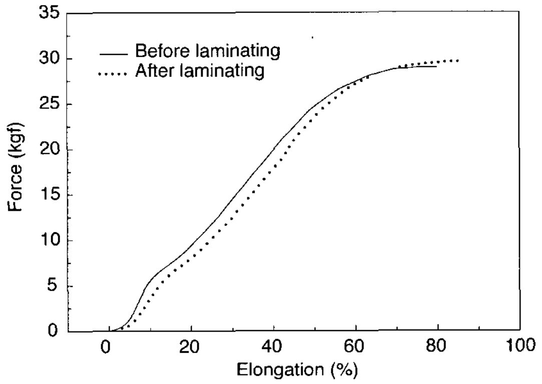

Fig. 2. Load-elongation curves of 2-layer laminated fabrics.

can undergo relatively large deformation, and they maintain good formability. Figure 2 shows the load-elongation curves with laminating. Load-elongation curve of textile fiber may be obtained by gradually extending it and measuring the tension corresponding to each increase in length. After an initial period with a steep slope, extension suddenly becomes much easier. It is the region where the yield point occurs. In the case of 2-layer laminated fabrics, the yield point of the laminated fabrics was observed more obscurely than that of pre-laminated fabrics. It meant that the initial frictional resistance to bending of the threads decreased under the influence of the laminating process. In the initial region, the elasticity decreased a little, as the incline of the curve decreased.

Figure 3 shows the load-elongation curves and changes on tensile forces of 3-layer laminated fabrics. There were little differences in initial behavior, but the load with elongation steeply

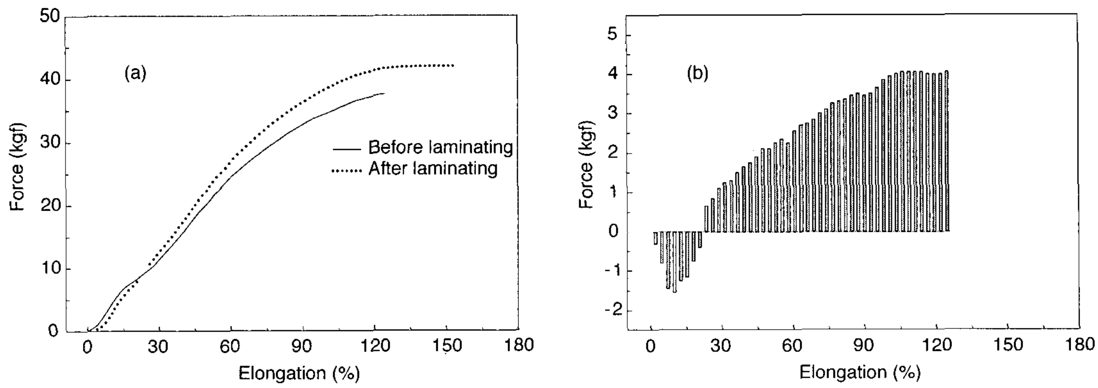

Fig. 3. (a) Load-elongation curves and (b) the difference of the force between before and after laminating in 3-layer laminated fabrics.

Table 4. The mean and t-values of significant mechanical properties of the fabrics before and after laminating

Characteristics		Finishing	Mean values: before laminating	Mean values: after laminating	T-values from paired t-test: between before and after laminating	T-values from paired t-test: between 2- and 3-layered fabrics
Tensile properties	LT (none)	2-layer	0.742	0.684	1.506	1.661
		3-layer	0.748	0.728	0.629	
	WT (gf · cm/cm²)	2-layer	7.920	7.758	0.142	1.070
		3-layer	8.753	7.305	1.404	
	RT (%)	2-layer	65.548	65.005	0.656	−0.541
		3-layer	61.878	66.998	−4.019*	
Bending properties	B (gf · cm²/cm)	2-layer	0.077	0.160	−4.888*	−1.993
		3-layer	0.074	0.442	−1.719	
	2HB (gf · cm²/cm)	2-layer	0.049	0.125	−4.165*	−2.245
		3-layer	0.049	0.264	−1.699	
Shear properties	G (gf/cm · degree)	2-layer	1.023	3.693	−20.860***	−5.033**
		3-layer	2.348	6.825	−3.345*	
	2HG (gf/cm)	2-layer	2.103	8.975	−7.182**	−6.451***
		3-layer	3.393	14.325	−4.784*	
	2HG5 (gf/cm)	2-layer	3.903	14.780	−8.330**	−3.283*
		3-layer	8.208	39.620	−2.849	
Compression properties	LC (none)	2-layer	0.366	0.365	1.506	−0.061
		3-layer	0.392	0.399	−0.280	
	WC (gf · cm/cm²)	2-layer	0.086	0.054	1.506	0.862
		3-layer	0.062	0.075	−1.354	
	RC (%)	2-layer	37.578	63.952	−4.987*	−9.025***
		3-layer	33.073	58.544	−7.898*	
Surface properties	MIU (none)	2-layer	0.154	0.154	1.506	0.106
		3-layer	0.136	0.135	1.506	
	MMD (none)	2-layer	0.020	0.017	1.506	2.729*
		3-layer	0.020	0.011	1.506	
	SMD (μm)	2-layer	3.813	4.105	−1.920	−0.085
		3-layer	2.632	2.371	1.506	
Constructive properties	W (mg/cm²)	2-layer	11.378	14.462	−4.116*	−5.737***
		3-layer	10.126	17.697	−23.038***	
	T (mm)	2-layer	0.357	0.340	1.506	−2.125
		3-layer	0.270	0.467	−10.283**	

*p<0.05, **p<0.01, ***p<0.001

increased in 3-layer laminated fabrics after 20% strain. It could be confirmed from Figure 3(b) that the different force temporarily decreased, and it was caused by the effect of the membrane and the knitted lining bonded to base fabric. Generally, laminating method forms somewhat indirect bonding with adhesive, so the supportable force to substrate fabric is more insufficient. It meant that the drop of the force at a few points resulted from destruction among the components. Breaking

Table 5. Changes on primary hand values with laminating process

Finishing		Mean primary hand values		
		Stiffness	Smoothness	Fullness & Softness
2-layer laminating	Before	3.27	3.45	2.14
	After	7.72	1.97	1.75
3-layer laminating	Before	4.09	3.13	1.60
	After	9.21	2.62	3.00

force and elongation increased with 3-layer laminating process. 3-layer laminated fabrics showed some improvement in points of the touch on the inside of fabric and comfortable feeling, but the clothing manufactured from these fabrics might generate much load and distribution to the body.

3. Mechanical Properties with small deformation

Sixteen mechanical characteristic values were evaluated and the respective results were used for analyzing paired t-test. Table 4 shows the mean and t-values of the mechanical properties. In the tensile properties, LT decreased after laminating was confirmed from load-elongation curve and the increase of RT was due to the contribution of laminated materials. It meant that the breakage between base fabric and laminated materials have not occurred yet as the force applied to the fabric in this test was very small.

In the bending properties, B and 2HB increased in both of 2- and 3-layered fabrics with laminating process. Especially 3-layer laminated fabrics showed remarkably high bending rigidity and hysteresis, and the increase in bending rigidity (B) and hysteresis (2HB) depended on the bonding construction of some layers, base fabric-adhesive-PTFE membrane-adhesive-knitted lining.

The laminating of PTFE membrane to base fabric was observed to increase shear stiffness (G) and hysteresis (2HG, 2HG5). It was significant that the increase in G, 2HG, and 2HG5 depended on the addition of adhesive and laminated membrane. The variations of the shear hysteresis of laminated fabrics with increase of shear angle were significant. Especially, those of 3-layer laminated fabrics showed relatively steep increase until ϕ=5° as compared with pre-laminated ones, and then, the magnitude of increase after that point was more remarkable than any kinds of coated or laminated fabrics. The shear stiffness in 3-layer laminated fabrics was generally higher than that of 2-layered fabrics by various factors. This was primarily due to the PTFE membrane laminated to base fabrics, which interfered with level of shear angle. But the knitted lining laminated with 2-layered fabrics acted as the secondary shear resistant as shear angle increased, so the hysteresis of shear force became higher.

In compression properties, there was no significance between before and after laminating in LC and WC, but RC increased in both of 2- and 3-layer laminated fabrics. This result indicates that the compression was easier and the recovery of compression was better after laminating. Surface properties of these fabrics were rarely changed by laminating process. Weight and thickness showed similar aspects with coated fabrics except for the case of 3-layered fabrics.

Fabric hand is an individual' s response to touch when fabrics are held in the hand. A number of separate fabric mechanical properties or constituent elements contribute to the overall evaluation of hand. The equation (1) used to derive primary hand values is assumed to be linear.

$$Y = C_0 + \sum_{i=1}^{16} C_i \frac{X_i - \overline{X}_i}{\sigma_i} \quad (1)$$

where, Y : hand value

X_i : i th characteristic value or its logarithm

$\overline{X}_i$: the mean and standard deviation of i th value

C_0, C_i : constant coefficient

The primary hand values converted by the equation before and after laminating are shown in Table 5. The laminated fabrics increased in stiffness, and the magnitude of increase was remarkable. As bending rigidity, shear rigidity, and weight were positively correlated with stiffness, the increase of them was due to the stiffness. Especially, 3-layered fabrics had significantly high stiffness. Smoothness decreased a little due to adhesive used on finishing. Fullness & softness decreased in 2-layered fabrics and increased about twice in 3-layered fabrics. A significant relation in compression and surface properties was observed in fullness & softness. Compressional energy and resistance increased with positive correlation, and coefficient of friction and geometrical roughness decreased with negative correlation.

IV. Conclusions

Breathable waterproof fabrics used in this study involve an adhesive system by which the base fabric and highly porous PTFE membrane can be combined. The correlation between adhesive force and various base fabric constructive properties was very low, and the adhesive forces of three-layered ones were much higher than those of two-layered ones at significant level of 99%.

Tearing strength of all the laminated fabrics was higher than that of pre-laminated fabrics. And the degree of increment made slight difference between the number of layers. It is believed that laminated lining is more responsible than PTFE membrane to increase tearing strength. Fabric-PTFE membrane composites can undergo relatively large deformation, and they have good formability while retaining high strength. In case of two-layer laminated fabrics, the yield point of the laminated fabrics was observed more obscurely than that of pre-laminated fabrics. And there were little differences in initial behavior in three-layer laminated fabrics, but the load with elongation steeply increased in laminated ones above 20% strain. The drop of force at the two point was observed with the result of destruction among the components.

In the mechanical properties with small deformation, shear property was the most significant characteristics with laminating process. All of G, 2HG and 2HG5 increased. Among primary hand values, stiffness remarkably increased and smoothness decreased slightly after laminating.

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