The Tailoring Performance and Mechanical Properties of Breathable Waterproof Fabrics

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Abstract: Breathable waterproof fabrics manufactured by wet coating, dry coating, PTFE-laminating, and PTFE-knitted lining laminating processes were selected to investigate the changes of mechanical properties and tailoring performances. Most of the breathable waterproof finishings are carried out on fabric substrates, so various physical properties are significantly changed not only in feeling of wearing but also in tailoring process. In this study, various characteristic values related with tailoring performance were evaluated. Shear characteristics in the coating types significantly increased with finishing except wet coating type with floating knife, and laminated fabrics also increased in G, 2HG, 2HG5, which depended on the adhesive and laminated membrane. Formability and sewability increased and decreased after finishing, respectively, and dry coated fabrics showed remarkable changes on these tailoring factors. From the examination of the penetrating behavior of the needle into the fabrics, all kinds of breathable waterproof finishing play a significant role in obstructing needle penetrating. Penetration force, frictional force, and penetration energy increased with finishing and plying numbers. The changes were different with finishing methods, and the results were partially confirmed from the broken shape of the stitch holes.

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1. Introduction

It is generally known that breathable waterproof fabrics easily transport water vapor through the fabric structure while they have resistance to the passage of water [1]. Outer garments manufactured from these materials can improve wearer comfort by reducing the buildup of perspiration inside the clothing [2-5]. The breathable waterproof fabrics are usually manufactured into sportswear, footwear, and the other outdoor equipment, etc., and in these cases, the products are composed of more than one layer. When layers are combined together by sewing, it is important to obtain the relationships between intrinsic properties of the single layers and the corresponding properties of seamed fabrics. The cutting and the other fabric handling processes are also sensitive to the fabric intrinsic properties [6].

Although the textile material is regarded as the finished product of the textile industry, it is at the same time regarded as the raw material for the garment manufacturing or tailoring industry. The mechanical properties of the raw materials are very important in the shape formation obtained by design, cutting, sewing and fusing of flat pieces of fabric into three-dimensional

garments [7,8]. So the tailoring industry also requires an objective method for production and process control based on the quantitative specification of fabric mechanical properties for each particular operation in the tailoring.

The number of problems related to tailoring efficiency increased with the higher sewing speeds. Changes to finer gauge knits and fabrics finished with different dyes and finishings, together with the widespread acceptance of synthetic fibers in both fabrics and sewing threads, created more sewability problems to join the newer textile materials [9-13].

Most of the breathable waterproof finishings are carried out on fabric substrates, so various physical properties are significantly changed not only in feeling of wearing but also in tailoring process. In this study, various characteristic values related with tailoring performance were evaluated by using the mechanical properties of the fabrics. The significant changes were analyzed and compared with different breathable waterproof finishings.

2. Experimental

2.1 Materials

In this study, twenty-two breathable waterproof fabrics which are commercially used to sportswear and foul weather garments were chosen. The specifications for these fabrics are given in Table 1. The specimens were prepared by coating and laminating processes, and classified according to the coagulation method, shape of knife, and the number of laminating layer. The coated fabrics were manufactured by direct coating with polyurethane resin. The water vapor permeability and waterproof performance of the fabrics were obtained by microporous structure through wet- or dry-coagulation process except the dry coating type with floating knife. Since microporous structure was not formed, some hydrophilic components were added to get the moisture transport ability. The laminated fabrics were prepared by 2- and 3-layer laminating with base fabric and polytetrafluoroethylene (PTFE) membrane. The functional component of these laminates was a thin and microporous membrane made from solid PTFE sheet by a novel drawing and annealing process. And the pre-finished fabrics with coating and laminating methods were also used to compare with finished.

Table 1 Specifications of the fabrics.

No.	Finishing methods and functional component		Construction of the fabric		
			Fiber contents	Thickness (mm)	Mass / unit area (g/m ²)
WA1	wet coating floating knife	PU ^{a)}	nylon	0.28	83.6
WA2		PU	nylon	0.14	66.9
WA3		PU	nylon	0.54	166.8
WB1	wet coating roll over knife	PU	nylon	0.32	119.1
WB2		PU	nylon	0.52	124.5
WB3		PU	nylon	0.41	105.8
WB4		PU	nylon	0.19	98.2
DA1	dry coating floating knife	PU	nylon	0.29	89.4
DA2		PU	nylon	0.52	124.5
DA3		PU	nylon	0.63	173.0
DB1	dry coating roll over knife	PU	nylon	0.53	108.0
DB2		PU	nylon	0.53	134.3
DB3		PU	nylon	0.25	96.9
DB4		PU	nylon	0.63	173.0
2L1	2-layer laminating	PTFE ^{b)}	nylon	0.24	111.0
2L2		PTFE	nylon	0.34	128.1
2L3		PTFE	nylon	0.37	164.3
2L4		PTFE	nylon	0.41	174.7
3L1	3-layer laminating	PTFE	nylon	0.48	170.6
3L2		PTFE	nylon	0.47	168.1
3L3		PTFE	nylon	0.51	189.6
3L4		PTFE	nylon	0.42	179.5

^{a)} PU: polyurethane

^{b)} PTFE: polytetrafluoroethylene

2.2 Mechanical properties with small deformation

Tensile properties, shear properties, and bending

properties with small deformation were measured before and after finishing by using Kawabata evaluation system (KES-FB). From this system, the various mechanical parameters can be calculated, which are recognizably related to tailoring performance.

2.3 Calculation of the values related with tailoring performance

Formability and sewability were evaluated based on fabric mechanical properties in tensile, shear, bending, and fabric weight, and the theoretical equations [14] are as follows:

$$\text{Formability} : \frac{EM_2}{LT_2 \times 500} \cdot \frac{G}{2HG5} \cdot B_2 \quad (1)$$

$$\text{Sewability} : \left(\frac{G}{2HG5} \right) / W \cdot \frac{EM_2}{LT_2 \times 500} \quad (2)$$

where, EM : tensile strain at 500 gf/cm

LT : linearity

G : shear stiffness

2HG5 : shear hysteresis at $\phi=5$ degree

B : bending rigidity

W : mass per unit area

the suffix 2 indicates the weftwise fabric property.

Formability is described as the ease with which fabrics may be shaped or molded during garment making, and sewability is defined as the ability and ease with which fabric components can be qualitatively and quantitatively seamed together, to convert a garment [15,16].

2.4 Penetrating behavior of sewing needle

Measurement of the force, which was developed when sewing needles were penetrated into and withdrawn from fabrics, were carried out on an Instron. The needle was mounted in a holder which was clamped in the top jaw, and another holder with a hole centered under the point of the needle was clamped in the lower jaw [17]. The needle used was size number 11 of surface nickel finished type. Stitch hole by the needle was observed by Cam Scope.

3. Results and discussion

3.1 Mechanical properties with small deformation

The mechanical properties of apparel fabrics are important from the point of view of stresses applied to fabrics in making a garment during its use. We could see from the precedent study that the characteristics of the breathable waterproof fabrics were more subjected to the influence of finishing methods than the construction of base fabrics [18]. So we mainly considered the results with finishing methods. Among the mechanical properties with small deformation, shear properties of the

fabrics showed very significant differences between before and after finishing. Table 2 shows the results of shear characteristics. In the results from paired t-test between before and after finishing, wet coating A type did not show significant changes with coating process, but the shear characteristics in the other coating types significantly increased. Two factors are believed to be responsible for this phenomenon. The freedom of movement between the threads in fabric was reduced and shear rigidity was very high because extension was interrupted by crosslinked structure of polyurethane. Little coating dope was used in wet coating A type compared to the other coating types, and the mechanical properties of base fabrics were not affected by coating process.

Table 2 The mean and t-values of shear properties and weight of the fabrics before and after finishing.

Shear properties	No.	Mean values		T-values	
		Before	After	from paired t-test	
G (gf/cm · degree)	WA	1.377	3.953	-6.452*	
	WB	0.778	3.913	-18.971***	-17.783***
	DA	0.947	4.213	-11.784**	
	DB	1.038	3.988	-6.375**	
	2L	1.023	3.693	-20.860***	-5.033**
	3L	2.348	6.825	-3.345*	
2HG (gf/cm)	WA	1.250	9.467	-4.068	
	WB	1.320	6.153	-6.357**	-10.665***
	DA	0.773	7.917	-8.265*	
	DB	0.940	7.575	-6.661**	
	2L	2.103	8.975	-7.182**	-6.451***
	3L	3.393	14.325	-4.784*	
2HG5 (gf/cm)	WA	6.747	14.980	-2.570	
	WB	3.180	10.418	-8.852**	-10.245***
	DA	3.837	10.997	-5.204*	
	DB	4.463	11.253	-8.371**	
	2L	3.903	14.780	-8.330**	-3.283*
	3L	8.208	39.620	-2.849	
mass per unit area (g/m ²)	WA	105.76	116.97	-2.524	
	WB	111.90	156.94	-4.699*	-7.285***
	DA	153.94	186.57	-14.680**	
	DB	128.05	166.10	-8.122**	
	2L	113.78	144.62	-4.116*	-5.737***
	3L	101.26	176.97	-23.038***	

* p < 0.05: significant at 0.05 level

** p < 0.01: significant at 0.01 level

*** p < 0.001: significant at 0.001 level

In the laminating type, it was significant that the increase in G, 2HG, and 2HG5 depended on the adhesive and laminated membrane. 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 when shear angle increased, so the hysteresis of shear force became higher.

3.2 Evaluation of formability and sewability

In order to produce good three dimensional surface by stitching, the important factors are not only the operator's technique for the overfeed operation but also the mechanical properties of the fabric. Figures 1-2 show the formability and sewability of the fabrics calculated by mechanical characteristics with small deformation before and after finishing. Mean values for groups of specimens classified according to the type of breathable waterproof finishing were taken to plot the graphs.

Fig. 1 Formability with various breathable waterproof finishings.

Fig. 2 Sewability with various breathable waterproof finishings.

Formability increased with coating and laminating processes, but sewability decreased, and especially, the change on dry coating A type was prominent. Uemura [14] defined the judging standards of the control system for buying and tailoring of fabrics. It shows excellent grade when the formability is over 5 and sewability is over 4, and poor grade when the formability is below 3 and the sewability is below 2. In the case of wet coating type, sewability did not decrease to poor grade,

but the dry coating type and laminating type showed poor grade. Formability of wet coated fabrics increased a little with finishing, and both of A and B type could not reach at excellent grade. On the other hand, all of the dry coated fabrics increased to that grade.

3.3 Penetrating behavior of needle into the fabric

In analyzing the results of sewability and formability, it is noticeable that the variation of the wet coating A type was very low, but the dry coating A type showed remarkable changes. So we examined the penetrating behavior of the needle into the fabrics in wet coating A, dry coating A, and 2-layer laminating type. Figure 3 is a typical curve showing the forces developed in an experiment of fabrics. Having compared the penetrating behavior with various finishings in Fig. 4, we could see some different aspects.

Fig. 3 Penetrating behavior of the needle for unfinished nylon fabrics: (a) maximum penetration force, (b) minimum force at scarf, (c) maximum frictional force, (d) maximum force on shoulder, (e) maximum withdrawal force, (f) maximum frictional withdrawal force, (g) withdrawal force at eye, area under the graph: penetration and withdrawal energy.

Breathable waterproof finished specimens commonly showed the followings. First, the maximum force needed to punch a hole in the fabric and the total energy required to form the simulated are high. Second, minimum force at scarf of coated fabrics is relatively high. It can be usually very low because the scarf is somewhat thin portion of needle. But in the case of coated fabrics, the stitch hole tends to close around the needle after the eye passes through the fabrics influenced by high elastic polyurethane membrane. Thirdly, the maximum frictional force and frictional withdrawal force are remarkably high in coated fabrics. Withdrawal behaviors of the coated fabrics are also caused by contraction characteristic of the stitch hole.

Table 3 lists the needle penetrating behavior during

Fig. 4 Penetrating behavior of the needle for finished fabrics: (a) Wet coating A, (b) Dry coating A, (c) 2-layer laminating type.

sewing of a fabric to which different finishes were applied. The needle-fabric force interaction would be made by dividing the total energy into two components, one associated with the energy to form a hole in the fabric and the rest of the energy which would be largely related to the friction included during penetration and withdrawal. In the case of coated fabrics, the forces from the frictional resistance of the material against the needle motion within the fabric were higher than those of untreated fabrics. Frictional force and frictional withdrawal force are relatively high and proportionally increase with the number of layers. Especially, the curves of dry coating A type revealed that the frictional

Table 3 The mean characteristic values of needle penetration with various finishing methods.

Finishing method	Number of layers	Penetrating behavior			Withdrawal behavior		
		Penetrating force (N)	Frictional force (N)	Penetrating energy (mm·N)	Withdrawal force (N)	Frictional force (N)	Withdrawal energy (mm·N)
Wet coating A	1	2.16	0.82	0.07	-0.90	-0.16	0.02
	3	8.14	3.14	0.32	-3.43	-1.00	0.07
	5	15.37	6.63	0.60	-6.49	-2.07	0.14
Dry coating A	1	3.00	0.90	0.10	-1.77	-0.63	0.06
	3	10.59	3.49	0.32	-4.55	-1.14	0.09
	5	18.57	8.06	0.70	-8.03	-4.61	0.28
2-layer laminating	1	1.50	0.63	0.07	-0.88	-0.23	0.02
	3	3.59	1.47	0.15	-1.74	-0.66	0.06
	5	5.90	2.44	0.24	-2.92	-0.72	0.10

Fig. 5 Photographs of the stitch hole broken by needle with various breathable waterproof finishings : (a) Wet coating A, (b) Dry coating A, (c) 2-layer laminating type.

force at withdrawal was somewhat higher than those of any other finishing methods. Stitch holes in the finished fabrics penetrated by needle were observed to

look into the cause of these differences with finishing methods.

Figure 5 illustrates the finished fabrics in which holes have been formed by a needle. From the observation of the holes, it is shown that the broken shapes of dry coated fabrics (Fig. 5-b) are irregular and the outwall of the hole is somewhat rough compared with wet coating and laminating type. In addition to it, the broken portion around the hole formed with penetrating of needle might increase the frictional resistance when the needle returned to the initial place. The membrane of wet coating A type was relatively thin, so remarkable changes such as dry coating A type were not detected while the shape of hole was similar with it.

As shown in Fig. 5-c, it was observed that the broken hole of laminated fabric was very smooth. Laminated membrane was attached to base fabric by dotted adhesives, so there were some differences with coating process in which coating dope penetrated into fabric interstices. Various forces including frictional withdrawal force of laminated fabrics are lower than those of coated ones, but we confirmed that the stitch hole was formed somewhat large, which might reduce water resistance of 3-dimensional garment or equipment.

4. Conclusion

Breathable waterproof fabrics which are used to construct sportswear and foul weather garments were selected and subjected to various experiments. The characteristic values related with tailoring performance were evaluated by the mechanical properties of the fabrics, and some different forces and energies were measured when a needle penetrates and withdraws from the fabrics.

Shear characteristics in the coating types significantly increased except wet coating A type, and it was due to

the reduction of the freedom between the threads and interruption of the extension by crosslinked structure of polyurethane. In the laminating type, it was also significant that the increase in G, 2HG, and 2HG5 depended on the adhesive and laminated membrane.

Formability and sewability increased and decreased after finishing, respectively. In the case of dry coating and laminating types, sewability decreased to poor grade, on the other hand, formability of the dry coated fabrics increased to excellent grade. These characteristics showed conflict concept, so it is needed to find the proper condition for high production efficiency and requirement of consumers by choosing an appropriate finishing method.

From the examination of the penetrating behavior of the needle into the fabrics, we found some different aspects in breathable waterproof finished fabrics. First, the maximum penetration and withdrawal forces and the total energy required to form the stitch hole were very high. Second, minimum force at scarf of coated fabrics was relatively high, because the stitch hole tends to close around the needle after the eye passes through the fabrics influenced by high elastic polyurethane membrane. Thirdly, the frictional forces are remarkably high in coated fabrics. And these results were confirmed from the broken shape of the stitch holes in the finished fabrics penetrated by the needle.

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