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Mechanical Properties of Breathable Waterproof Fabrics with Seaming and Sealing Processes

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Abstract: Waterproof fabrics are seamed and sealed by waterproof sealing tape to prevent water from penetrating through the stitch holes. As this process may change the mechanical properties of breathable waterproof fabric related to its deformation with human body, the changes in mechanical properties were investigated. In both of parallel and perpendicular directions, tensile characteristics were remarkably changed with seaming and sealing processes. The increase of LT and WT means that the clothing sealed by waterproofing tape may produce somewhat discomfort feeling. On the other hand, the bridge of the sewing thread seemed to be reinforced by waterproofing tape. Shear characteristics such as G, 2HG, and 2HG5 gradually increased with seaming and sealing processes in parallel direction. However, they decreased with sealing process in perpendicular direction because the seam line would work as an axis located at the center of the testing range.

Keywords: Tensile property, Shear property, Seam, Seam sealing, Breathable waterproof fabric

Introduction

Breathable waterproof fabric transports water vapor, but prevents the passage of water through itself. The general process used to manufacture a garment from these fabric pieces is sewing, but it is possible of this fabric to leak water at stitch holes. This causes a fatal problem to the functionality of the breathable waterproof fabric. Therefore, it is necessary to seal the seam line with waterproofing tape when we make a three dimensional garment or an outdoor equipment with breathable waterproof fabric.

Wearing comfort is related to mainly fabric tensile and shearing deformations, and is also related to comfortable wear associated with less restraint of human body by fabric. The shape-retention of suit is also covered by these properties [1,2]. It has been reported that the effect of sewing on mechanical behavior depends on the nature of the seam, the seam allowance, seam direction, and the layers of the fabrics [3,4]. Moreover, it may be remarkably changed on breathable waterproof fabrics because of sealing process with waterproofing tape. So the mechanical properties of the seamed fabrics are as important as those of the finished fabrics prior to tailoring [5,6]. Therefore, the changes in the mechanical performances from sewing and sealing processes should be considered for high production efficiency with the most suitable functional quality. In this study, tensile and shear properties with small deformation with finishing, seaming and sealing processes were investigated and analyzed according to the finishing methods.

Experimental

Materials

Twenty-two breathable waterproof fabrics which are commercially used for sportswear and foul weather garments were chosen. The specimens were prepared by polyurethane direct coating and PTFE membrane laminating methods. Details of their characteristics were described in the previous research [7].

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Seaming and Sealing Condition

The seaming was performed on a standard domestic sewing machine, and the details of the sewing conditions are specified in Table 1. All seams were sewn at constant machine conditions. Each sample was sewn together in warp and weft direction, respectively. For the sample preparation the lock stitch sewing machine was modified by additional attachments such as guide rail, fabric tension controller, long plate, machine control panel, etc. [8]. Figure 1 shows the photograph of sewing machine used in this study. By using this machine the samples can be automatically sewn without human operation. Then, the seamed fabrics were sealed with waterproof sealing tape on seam sealing machine. In this case, the sealing temperature and feeding speed were controlled considering the characteristics of the specimen.

Table 1. Sewing conditions

Item	Specification
Seam type	Ssa-1
Seam allowance[a)]	10 mm
Stitch type	301
Stitch density	4.7 ± 0.5 stitches per centimeter
Needle size & finish	metric 90, nickel plated
Sewing thread	100 % polyester spun yarn 40's/2

[a)]Seam allowance: distance from the edge of a fabric to the parallel stitch line farthest from the edge.

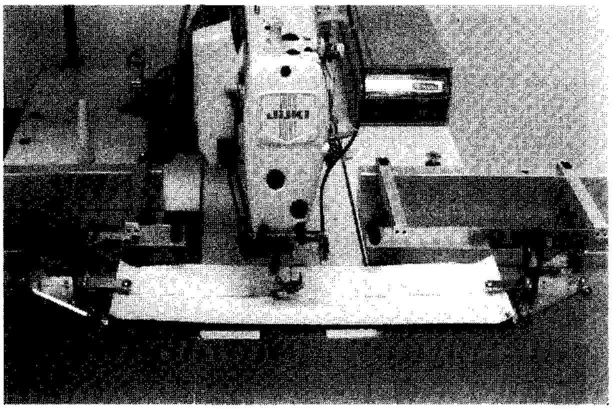

Figure 1. Photograph of sewing machine modified by additional attachments.

Mechanical Properties with Seaming and Sealing Processes

Tensile properties and shear properties with breathable waterproof finishing, seaming, and sealing were measured by using Kawabata evaluation system (KES-FB). From this system, the various mechanical parameters can be calculated in both of parallel and perpendicular direction to seam line.

Results and Discussion

Variations of Tensile Properties after Seaming and Sealing Processes

Tailors have found good fabrics through experience and have expressed the properties of these good fabrics with a combination of fabric mechanical parameters. There are no equations and particular values expressing the excellence of this property, however, they expressed the good zone directly by using the mechanical parameters of tensile and shearing properties [9]. In this quality range, fabric extensibility and shear deformation ability are important for fabric deformation with human body.

In tensile and shear test with small deformation, they were measured in both of perpendicular and parallel directions to seam. Figures 2-5 show the various tensile characteristics with wet coating A type of finishing, seaming, and sealing processes. Generally, different tendencies were remarkably appeared with seaming and sealing processes in perpendicular direction to seam. We obtained the results from previous researches that the characteristics of the breathable waterproof fabrics were more subjected to the influence of finishing method than the construction of base fabrics. So we did not consider the results with the base fabrics.

Tensile linearity (LT) significantly decreased after seaming, which was caused by the extension of sewing thread playing a role like bridge between two pieces of fabric. Stress concentration, due to the non-uniform structure and non-uniform stress distribution induced by sewing process, could result in decreased tensile linearity. And then it was somewhat increased

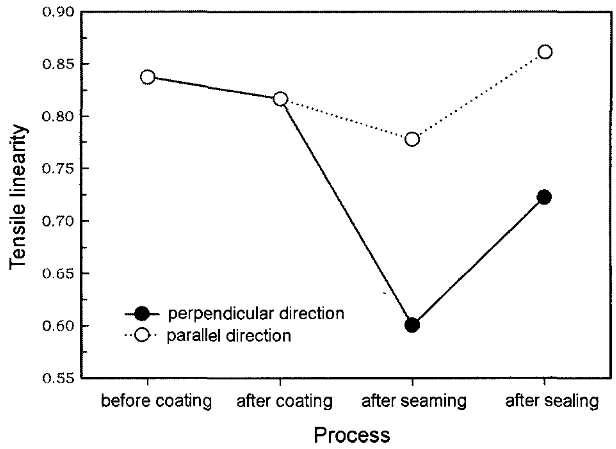

Figure 2. Tensile linearity with breathable waterproof finishing (wet coating A type), seaming, and sealing processes.

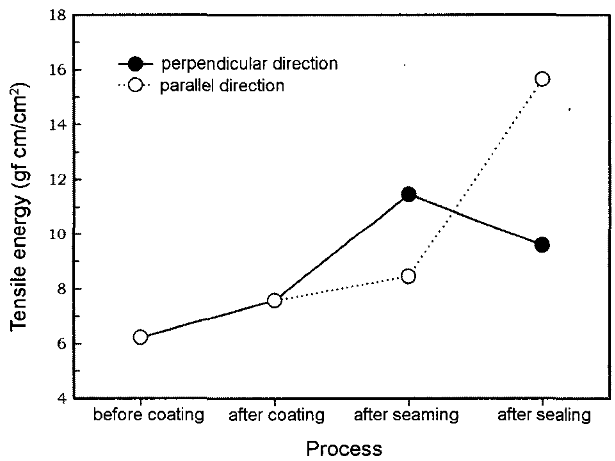

Figure 3. Tensile energy with breathable waterproof finishing (wet coating A type), seaming, and sealing processes.

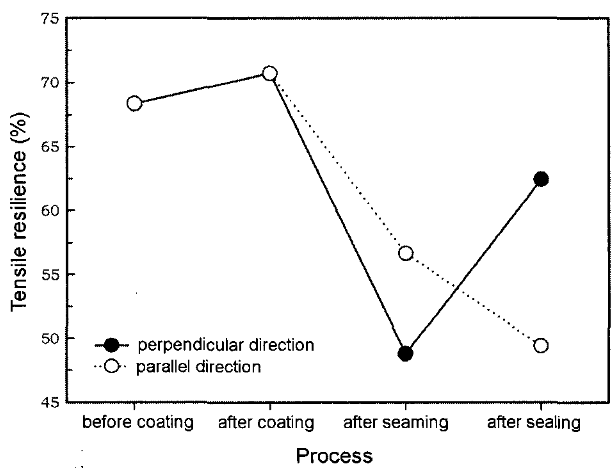

Figure 4. Tensile resilience with breathable waterproof finishing (wet coating A type), seaming, and sealing processes.

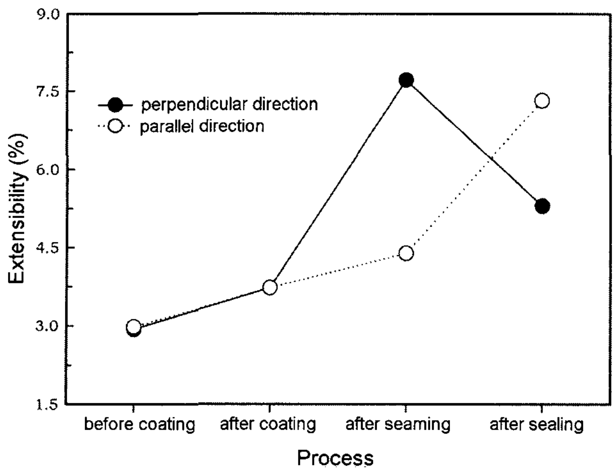

Figure 5. Extensibility with breathable waterproof finishing (wet coating A type), seaming, and sealing processes.

by sealing process. It was reported that seam breakage of breathable waterproof fabric was initiated with the breakage of sewing thread at seam line on seamed fabric [7]. However, the waterproof tape covers the bridge and restrains the thread to extend and break. This phenomenon was remarkable in the perpendicular direction.

Tensile energy (WT) generally increased with coating, seaming and sealing in parallel direction. This means that seaming and sealing on the breathable waterproof fabric exert bad influence upon formability of the fabric, and it was caused that the extension was mostly concentrated in the seam line. The decrease in WT was caused by the reduction of extensibility in the perpendicular direction.

The trend of Tensile resilience (RT) was similar to that of LT, but was different that RT in parallel direction was much smaller. Since the seam type used in this study was a SSa-1, of which seam allowance was 10 mm in both sides, the portion of fabric was partially thickened by seaming and sealing and was disturbed to recover after deforming by load.

Extensibility (EM) showed opposite aspect to RT. On the other hand, the changes of the properties in parallel direction after seaming were positively maintained to sealed fabrics. The reason was that the shrunken seam by sealing was recovered. The trends of the dry coating and the laminating type were similar to the wet coating type. Tables 2 and 3 show the mean values of them with finishing methods.

Variations of Shear Properties after Seaming and Sealing Processes

Figure 6 shows the shear characteristics with coating, seaming, and sealing processes. First of all, shear stiffness and hysteresis significantly increased after coating compared with pre-coated ones as mentioned before. In the case of parallel direction, shear stiffness (G), shear hysteresis at 0.5 ° of shear angle (2HG), and shear hysteresis at 5 ° of shear angle (2HG5) gradually increased with seaming and sealing.

Table 2. Mean values of perpendicular direction with breathable waterproof finishing, seaming, and sealing processes

Tensile characteristics	Sample	Perpendicular direction to seam				t-values[a)]
		Before finishing	After finishing	After seaming	After sealing	
LT	Wet coating	0.81	0.77	0.63	0.71	–4.90**
	Dry coating	0.78	0.71	0.65	0.74	
	2 layer laminating	0.74	0.68	0.68	0.73	
	3 layer laminating	0.75	0.73	0.63	0.78	
WT ($gf \cdot cm/cm^2$)	Wet coating	5.42	6.70	10.30	8.55	4.14**
	Dry coating	5.47	7.90	11.80	9.28	
	2 layer laminating	7.88	7.76	12.73	10.03	
	3 layer laminating	8.75	7.31	12.61	8.96	
RT (%)	Wet coating	70.57	74.45	51.92	65.34	–4.02**
	Dry coating	71.41	74.88	53.73	61.82	
	2 layer laminating	65.55	63.01	46.33	57.37	
	3 layer laminating	61.88	67.00	46.75	57.34	
EM2 (%)	Wet coating	3.08	4.11	6.88	5.22	4.40**
	Dry coating	3.10	7.02	7.86	5.44	
	2 layer laminating	4.03	4.18	6.32	4.54	
	3 layer laminating	6.24	4.88	8.61	4.80	

[a)] the values from t-test between the characteristics of seamed and sealed specimen.
**$p < 0.01$: significant at 0.01 level.

Table 3. Mean values of parallel direction with breathable waterproof finishing, seaming, and sealing processes

Tensile characteristics	Sample	Parallel direction to seam				t-values[a)]
		Before finishing	After finishing	After seaming	After sealing	
LT	Wet coating	0.81	0.77	0.78	0.85	1.35
	Dry coating	0.78	0.71	0.79	0.84	
	2 layer laminating	0.74	0.68	0.84	0.83	
	3 layer laminating	0.75	0.73	0.87	0.96	
WT ($gf \cdot cm/cm^2$)	Wet coating	5.42	6.70	7.34	11.35	−3.45*
	Dry coating	5.47	7.90	10.59	13.36	
	2 layer laminating	7.88	7.76	9.41	14.34	
	3 layer laminating	8.75	7.31	9.23	17.51	
RT (%)	Wet coating	70.57	74.45	63.02	53.67	2.50*
	Dry coating	71.41	74.88	59.06	52.03	
	2 layer laminating	65.55	63.01	53.19	46.30	
	3 layer laminating	61.88	67.00	54.03	42.07	
EM2 (%)	Wet coating	3.08	4.11	4.20	5.64	−2.53*
	Dry coating	3.10	7.02	6.18	7.81	
	2 layer laminating	4.03	4.18	3.76	5.94	
	3 layer laminating	6.24	4.88	4.91	8.41	

[a)] the values from t-test between the characteristics of seamed and sealed specimen.
*$p < 0.05$: significant at 0.05 level.

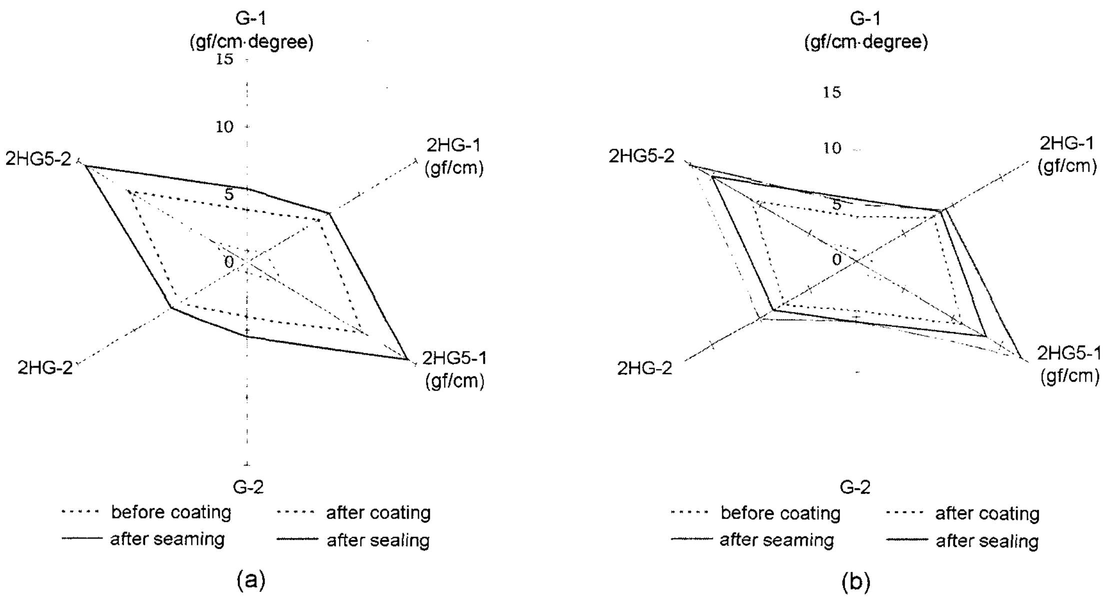

Figure 6. Shear characteristics with coating, seaming, and sealing processes: (a) parallel direction to seam, (b) perpendicular direction to seam.

While the shear load was applied in the parallel direction to seam line, sewing thread was extended and sealing tape was separated from the fabric with increasing shear angle along the seam. On the contrary, 2HG and 2HG5 decreased in perpendicular direction after sealing. If the shear load was applied in the perpendicular direction to the seam line of the fabric, the seam line would work as an axis located at the center of the testing range. Seam line is relatively thick and stiff portion because it is composed of layers and sealing tape. So it resists fabric distortion with shear deformation at the center. After unloading it, the shear recovery was rapidly occurred, and the shear hysteresis decreased.

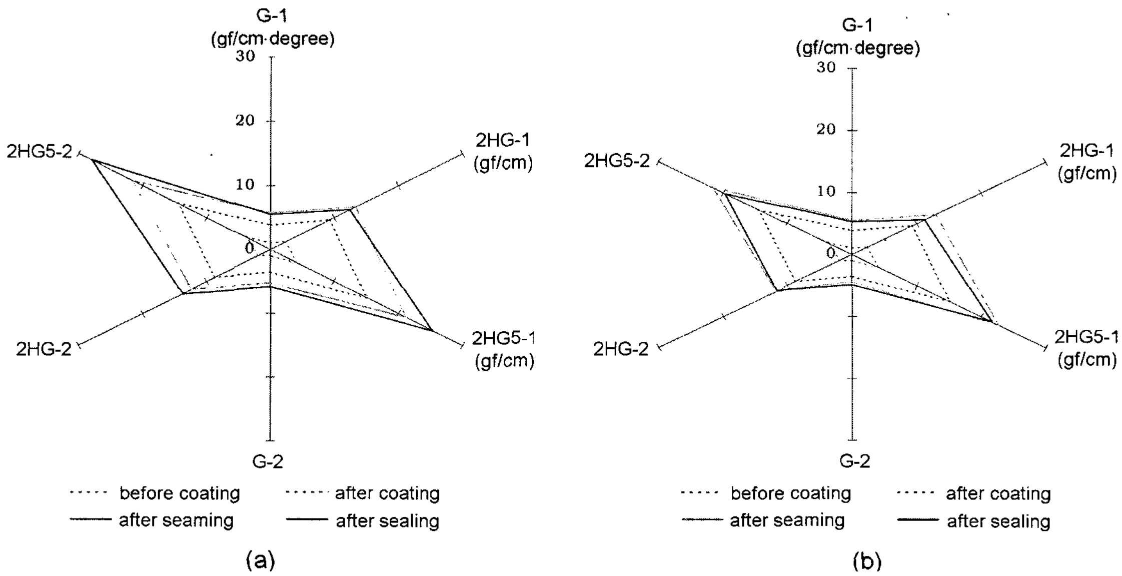

Figure 7. Shear characteristics with laminating, seaming, and sealing processes: (a) parallel direction to seam, (b) perpendicular direction to seam.

Figure 7 shows the changes of shear characteristics with laminating, seaming and sealing processes. Generally, it was similar to those of coating type, but there were some differences. Compared with G value, 2HG and 2HG5 values were very high and the shear graph slanted to the axis direction of hysteresis. 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 was resulted from destruction among the components. Shear recovery of laminating type was disturbed because of the adhesive droplets, which functional membrane was detached by shear deformation. It increased shear hysteresis of fabric.

Conclusions

The breathable waterproof fabrics are usually manufactured into sportswear, footwear, and the other outdoor equipments, etc. The seamed fabrics are sealed by waterproof sealing tape to prevent water from penetrating through the stitch holes. Most of the breathable waterproof finishing are carried out on fabric substrates, and the combination of the materials has the advanced properties. Various mechanical properties are significantly changed with finishing, seaming, and sealing processes. The changes of the mechanical properties with shape formation of breathable waterproof fabrics were investigated and the conclusions are as follows.

Tensile and shearing deformations of seamed and sealed fabric were related to clothing comfort and shape retention of suit. In both of perpendicular and parallel directions to seam line, LT and WT increased with sealing process. It means that the clothing sealed by waterproofing tape produces somewhat discomfort feeling regardless of seam direction.

In case of parallel direction, G, 2HG, and 2HG5 gradually increased with seaming and sealing. On the contrary, 2HG and 2HG5 decreased in perpendicular direction after sealing because the seam line would act as an axis located at the center of the testing range. Shear recovery in parallel direction of laminating type was disturbed, because the membrane was detached by shear deformation.

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